REPORT 952-2*

TECHNICAL CHARACTERISTICS OF FEEDER LINKS TO BROADCASTING SATELLITES

Elements required for the establishment of plans of frequency assignments and orbital positions for the broadcasting-satellite service and the associated feeder links – Sharing in the feeder-link bands

(Question 1/10 and 11, Study Programmes 1B/10 and 11, 2J/10 and 11)

(1982-1986-1990)

1. Introduction

The purpose of this report is to deal with the technical characteristics and operational constraints for the feeder links to broadcasting satellites.

This report examines exclusively the feeder links for 12 GHz broadcasting satellites, since feeder link Plans for the 12 GHz broadcasting satellite are established (see § 2) and very little is known about the problem related to feeder links for broadcasting satellites operating at frequencies other than 12 GHz.

2. Frequency-band allocations

The WARC-79 considered the problem of frequency-band allocations for the feeder links to the broadcasting satellites operating in the 12 GHz band. Certain frequency bands were allocated for this purpose to the fixed-satellite service (Earth-to-space), but limited for the feeder links to the broadcasting satellites. These are:

10.7-11.7 GHz : in Region 1 only, shared with the fixed service, the fixed-satellite service (space-to-Earth) and the mobile service (except aeronautical);

14.5-14.8 GHz : shared with the fixed and mobile services. This use is reserved for countries outside Europe and for Malta;

17.3-18.1 GHz : the upper half of this band is shared by the fixed and mobile services and the fixed-satellite service (space-to-Earth).

The WARC ORB-85 selected the frequency bands 17.3-18.1 GHz and 14.5-14.8 GHz (for countries outside Europe and for Malta) for feeder-link assignment planning in Regions 1 and 3. It decided not to use the frequency band 10.7-11.7 GHz for the feeder-link assignment Plan.

A Plan for feeder links to Region 2 broadcasting satellites was developed for the 17.3-17.8 GHz band at the RARC SAT-83.

A Plan for feeder links to Regions 1 and 3 broadcasting satellites was developed in the frequency bands 14.5 - 14.8 GHz and 17.3 - 18.1 GHz at the WARC ORB(88) Conference. The 14.5 - 14.8 GHz band was used for certain countries outside Europe.

* This Report should be brought to the attention of Study Groups 4 and 9.

3. System design and technical characteristics

3.1 *General*

A feeder link for broadcasting satellites comprises the following elements:

- the earth transmitting station characterized by the radiation characteristics of the antenna and the transmit power;
- the link from the earth station to the satellite mainly characterized by the propagation conditions through the atmosphere;
- the satellite receiving antenna with a certain radiation characteristic and the satellite receiver of a certain sensitivity (noise figure).

The characteristics of these elements and particular constraints, where relevant, are discussed in § 5 to 9, while further general system considerations are summarized below.

In some cases, broadcasting satellites will have a single, primary feeder-link earth station for each set of down links within a single service area. In other cases, it may be desirable to allow for the location of feeder-link earth stations anywhere within a predetermined feeder-link service area. Such feeder links will normally employ a primary earth station with a comparatively large antenna and high transmit power. This specificity as to the "primary earth station" was not considered in the planning of the feeder links in Region 2. Small fixed and transportable earth stations providing a direct connection to an experimental satellite have already been used and their number can be expected to increase as the broadcasting-satellite service develops [CCIR, 1978-82a].

Recognizing that the service quality objectives of these small earth stations could be less than those of the primary stations, their use should be taken into account to the maximum extent possible.

Feeder links may affect the planning of the broadcasting-satellite service for several reasons:

- the noise and interference present in the feeder link will be retransmitted on the down link and may constitute a non-negligible part of the total down-link noise and interference; in this context, it may be desirable to plan both the feeder-link and the down-link channel assignments at the same time so as to meet the required protection ratio for a desired service quality. This may be done in two ways, by planning the feeder links and the down links sequentially or simultaneously, as described in Report 633;
- the feeder link may require coordination with satellite systems operating in the feeder-link frequency band and may, therefore, impose additional restrictions on the orbital positions of the broadcasting satellites;
- feeder links may require coordination with terrestrial systems;
- the feeder-link and the down-link service areas may not be coincident in some cases. For example, an administration whose territory spans several time zones may find it desirable to serve each time zone from a different orbital location to obtain better eclipse protection, and at the same time to be able to access each satellite from any point within its territory that has an adequate elevation angle;
- it may be desirable that feeder links operate from a considerable number of small or fixed transportable earth stations located at any point within the service area or, even in some cases, outside the service area.

The total bandwidth requirements for feeder links could be reduced by exploiting the greater directivity of the earth station transmitting antenna by using polarization discrimination and possibly by employing more advantageous methods of modulation. However, small fixed or transportable feeder-link earth stations have limited antenna directivity.

For maximum flexibility in the positioning of satellites, the same or a greater bandwidth may be required for feeder links than for down links. Consequently, since bandwidth is limited, maximum flexibility may not be realizable.

For the period during which broadcasting satellites will be introduced, the viability of the broadcasting-satellite service is particularly vulnerable to high costs. Thus, any method for reducing feeder-link bandwidth or saving orbit must not entail such high cost as potentially to make the broadcasting-satellite service not viable. Cost should be acceptable and, accordingly, it forms another constraint. The bandwidth-reduction techniques listed in Report 561 should be looked at under this light.

3.2 *Partitioning of noise between feeder links and down links*

The WARC-BS-77 adopted for the purposes of planning a maximum reduction of 0.5 dB of the overall carrier-to-noise ratio, to represent the contribution of the feeder link to that ratio for 99% of the worst month. That corresponds to a difference of about 10 dB (see Report 215) between the carrier-to-noise ratios of the down links and feeder links.

According to an EBU study [CCIR, 1978-82b], the contribution of the noise resulting from the feeder link may be rendered negligible by adopting a relatively small margin in the carrier-to-noise ratio of the down link, This study considered the case of automatic gain control in the satellite and was based on a statistical analysis of the attenuations on the feeder link and down link. The probability of having an overall carrier-to-noise ratio less than a given value is expressed by a general formula given in [CCIR, 1978-82b].

Numerical applications have been made assuming that the attenuations (in dB) follow a log-normal relationship for which the parameters fit measurements made in Europe. It is seen, first, that the results obtained assuming either total correlation or total independence between feeder-link and down-link fadings, are more or less identical. The influence of a margin of 0.5 dB on the down link, however, is crucial. The improvement due to this margin is better than that obtained by dimensioning the C/N ratio of the feeder link for 99.9% of the worst month instead of for 99%. Hence, if we take a down-link C/N ratio of 14 dB for 99% of the worst month, the noise contribution from the feeder link to the overall circuit makes the overall link C/N drop below 14 dB 50% to 10% more often (depending on whether the feeder link is dimensioned to give a C/N ratio of 24 dB for 99% or 99.9% of the worst month). If account is taken of the 0.5 dB margin on the down link, the percentage of the time during which the overall C/N drops below 14 dB, including the noise contribution of the feeder link, is still smaller than the specified 1% of the worst month in both cases.

This result confirms the suitability of the choice, made by the WARC-BS-77, to take account of the feeder link by means of such a margin, even at frequencies of the order of 18 GHz.

Similar studies were conducted in Canada on the effects of rain attenuation and satellite transponder characteristics as related to the partitioning of the noise contributions on the feeder links and down links in a broadcasting-satellite service [CCIR, 1978-82c].

Some of the results can be found in Fig. 1, where the same assumptions as in the above-mentioned study were made. The curves in this figure represent the degradation of the down-link C/N due to the noise contribution from the feeder link, $(C/N_d - C/N_t)$ as a function of the difference between the C/N of the feeder link and the C/N of the down link $(C/N_u - C/N_d)$. Full correlation and independence of the fadings on both links are illustrated. All C/N values are specified for 99% of the worst month.

Partitioning of noise need not be specified as a planning element for Region 2 because the overall carrier-to-noise ratio is the applicable criterion when planning feeder links and down links at the same time. However, some assumption of noise partitioning is required in order to determine feeder-link characteristics, such as e.i.r.p. needed to satisfy broadcasting-satellite service requirements.

As a guidance to the development of the Plans for Region 2 and Regions 1 and 3, the noise contribution of the feeder link to the overall link was assumed not to exceed 0.5 dB for 99% of the worst month.

3.3 *Feeder-link carrier-to-noise ratio*

Assuming that there is no transponder output back-off, a 0.5 dB noise contribution of the feeder link to the overall link requires that:

$$(C/N)_u = (C/N)_d + 10 \quad \text{dB} \tag{1}$$

is exceeded for 99% of the worst month. Under clear-sky conditions, the $(C/N)_u$ is then:

$$(C/N)_u = (C/N)_d + 10 + L_{Att} \quad \text{dB} \tag{2}$$

where:

$(C/N)_u$: feeder-link carrier-to-noise ratio,

$(C/N)_d$: down-link carrier-to-noise ratio, and

L_{4u}: feeder-link rain attenuation exceeded for 1% of the worst month.

A margin of 1 dB is also needed for planning purposes for possible mispointing of the earth-station transmitting antenna.

Furthermore, the high-power, non-linear amplifier of the repeater introduces, on account of its AM/PM conversion factor, a degradation by the thermal noise in the demodulated signal. The impairment caused to the frequency demodulated signal by the AM/PM phenomenon is given by:

$$D = \frac{\alpha + I}{1 + I} \tag{3}$$

where:

D: decrease in post detection signal-to-noise ratio (S/N) (see Fig. 2) due to increase in post-detection noise in the presence of AM/PM conversion.

$I = (C/N)_u/(C/N)_d$

$\alpha = 1 + \left(\frac{K}{6.6}\right)^2$ (for frequency modulation).

K: AM/PM conversion factor.

K is of the order of 5 to 6 degrees/dB with present-day amplifier technology. This gives a value for α in the region of 2.0-2.6 dB, which has been demonstrated theoretically and experimentally [CCIR, 1982-86a].

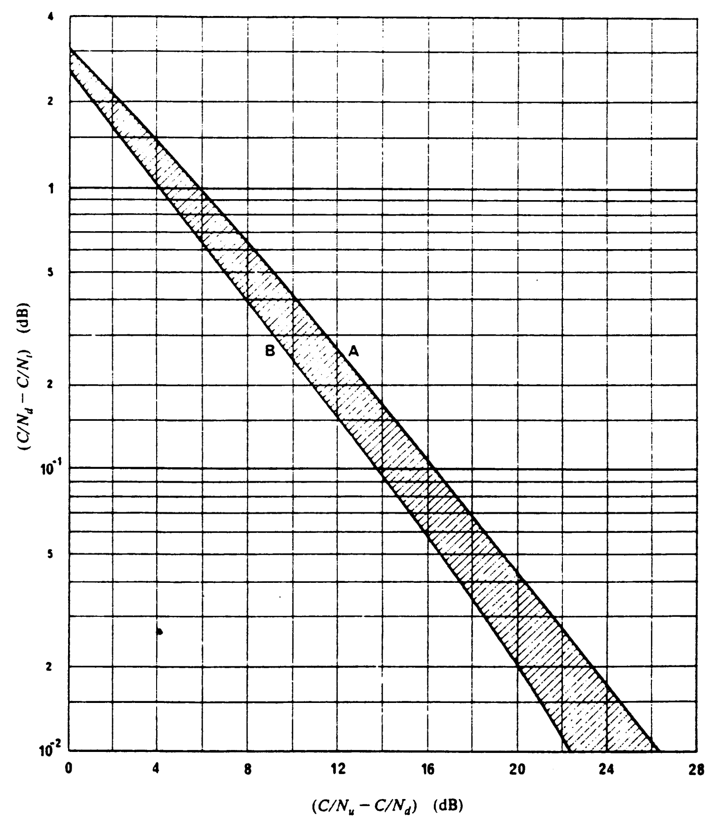

FIGURE 1 – *Noise contribution of the feeder link*

A: correlated
B: uncorrelated

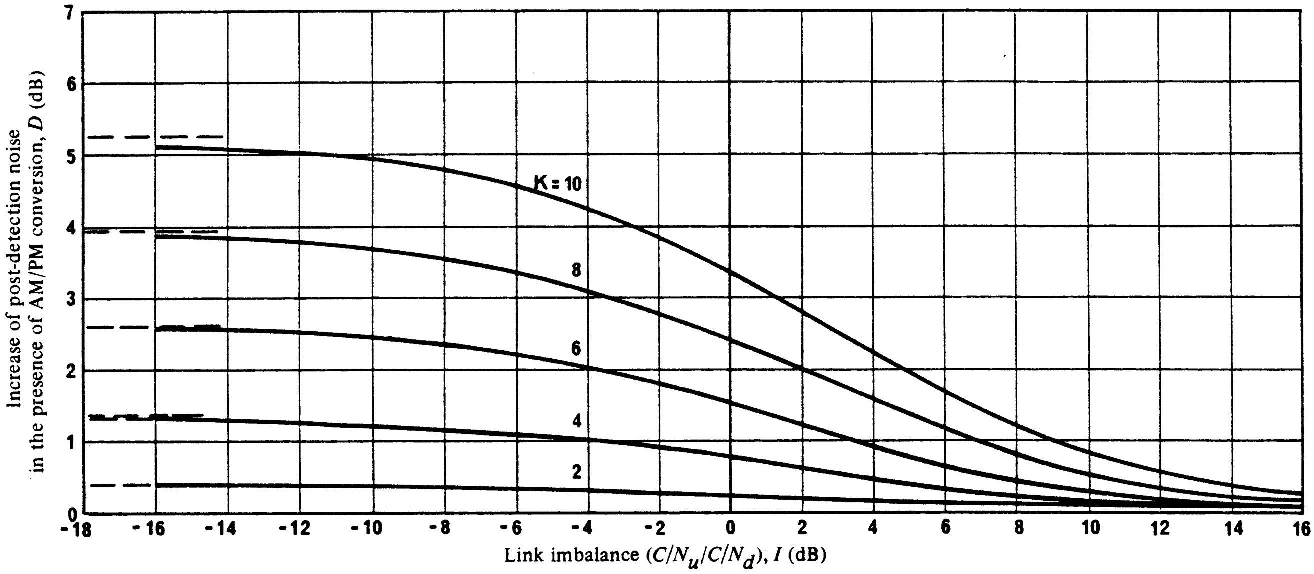

FIGURE 2 – *Effect of AM/PM conversion on the post-detection noise power*

K : AM/PM conversion factor (degrees/dB)

— — —: I → – ∞ dB

The degradation caused by AM/PM conversion cannot be observed by means of direct radio-frequency carrier-to-noise ratio (C/N) measurements. However, this degradation can be measured by other means. It must be taken into account when calculating feeder-link budgets and can be compensated for by an increase in C/N_u of 10 log α dB. AM/PM conversion was not taken into account in the development of the Region 2 Plan.

In a plan based on homogeneous characteristics of feeder-link stations which in turn leads to homogeneous nominal (clear sky) power flux-densities at the satellites, the C/N_u varies with satellite receive antenna gain. In Region 2, the range of interest of the satellite receive antenna gain at the −3 dB edge of coverage area varies from about 28 dB for a large country-wide feeder-link beam of 3° × 8° to 46 dB for a small spot beam of 0.6°. With a system noise temperature at the satellite of 1500 K, which is readily achievable for satellite receivers at 18 GHz, the range of interest of G/T varies from −4 dB(K^{-1}) to 14 dB(K^{-1}) at the edge of coverage area. The choice of feeder-link power into the transmitting antenna may be in the range of 500 to 1000 W. The Region 2 feeder-link Plan is based on a maximum radio-frequency power of 1000 W delivered at the input of the feeder-link antenna. Table I gives a range of C/N_u at 17.5 GHz assuming an antenna efficiency of 65%, a filter bandwidth of 24 MHz and 1 dB gain loss due to mispointing of the earth-station antenna for 500 and 1000 W transmitted power. In Region 2, the Plan is based on a 5 m antenna diameter but larger and/or smaller antennas can be used.

For example, in the case of a 14.5 dB C/N_d on the down link and a possible 1 dB mispointing of the earth-station transmitter antenna, a very small number of cases in Table I would give a noise contribution of the feeder link greater than 0.5 dB to the overall noise of the communication channels. These few cases are italicized in the Table. In Regions 1 and 3, the Plan is based on 5 and 6 m antenna diameters for frequency bands 17 and 14 GHz respectively and 500 W transmitter power. These values correspond to an e.i.r.p. of 84 and 82 dBW respectively and aim to achieve a carrier-to-noise ratio (C/N) of 24 dB exceeded for 99% of the worst month.

TABLE I – *Range of carrier-to-noise ratio calculated for earth-station antenna mispointed by 1 dB and transmitting 500 or 1000 W of power* (Region 2)(1)

Earth-station antenna diameter (m)	Minimum G/T of satellite receive antenna (edge of coverage area) (dB(K^{-1}))	Carrier-to-noise ratio C/N_u (dB)					
		Clear sky		With 5 dB rainfall attenuation		With 10 dB rainfall attenuation	
		Transmitted power (W)					
		500	1000	500	1000	500	1000
2.5	– 4	*19.2*	*22.2*	*14.2*	*17.2*	*9.2*	*12.2*
	+ 2	25.2	28.2	*20.2*	*23.2*	*15.2*	*18.2*
	+ 8	31.2	34.2	26.2	29.2	*21.2*	*24.2*
	+14	37.2	40.2	32.2	35.2	27.2	30.2
5	– 4	25.2	28.2	*20.2*	*23.2*	*15.2*	*18.2*
	+ 2	31.2	34.2	26.2	29.2	*21.2*	*24.2*
	+ 8	37.2	40.2	32.2	35.2	27.2	30.2
	+14	43.2	46.2	38.2	41.2	33.2	36.2
8	– 4	29.3	32.3	24.3	27.3	*19.3*	*22.3*
	+ 2	35.3	38.3	30.3	33.3	25.3	28.3
	+ 8	41.3	44.3	36.3	39.3	31.3	34.3
	+14	47.3	50.3	42.3	45.3	37.3	40.3
11	– 4	32.1	35.1	27.1	30.1	*22.1*	25.1
	+ 2	38.1	41.1	33.1	36.1	28.1	31.1
	+ 8	44.1	47.1	39.1	42.1	34.1	37.1
	+14	50.1	53.1	45.1	48.1	40.1	43.1

Note 1 - In case of the feeder link Plan for Regions 1 and 3, the figures in Table I should be reduced by 0.5 dB with a reference bandwidth of 27 MHz.

3.4 *Influence of the atmosphere*

3.4.1 *Rainfall attenuation*

The feeder-link signal will suffer attenuation when passing through the atmosphere. These effects are of statistical nature and will also strongly depend on the feeder-link frequency and the location of the feeder station.

Rainfall attenuation will result in decreased values for C/N and C/I on the feeder link. In addition, C/N on the down link will decrease unless automatic gain control is used on the satellite to maintain the satellite transponder at or near saturation.

The propagation model for feeder links in Regions 1 and 3 using circularly polarized signals is based on the value of rain attenuation for 1% of the worst month.

WARC-ORB(88) adopted the method for calculation of the rainfall attenuation as follows:

The mean zero-degree isotherm height h_F is:

$$h_F = 5.1 - 2.15 \log \left[1 + 10^{\frac{(|\zeta| - 27)}{25}}\right] \quad \text{(km)}$$

where ζ is the latitude of the earth station (degrees).

The rain height h_R is:

$$h_R = C \cdot h_F$$

where $C = 0.6$ for $0° \leq |\zeta| < 20°$

$C = 0.6 + 0.02\ (|\zeta| - 20)$ for $20° \leq |\zeta| < 40°$

$C = 1$ for $|\zeta| \geq 40°$

The slant-path length, L_s, below the rain height is:

$$L_s = \frac{2(h_R - h_o)}{\left[\sin^2 \theta + 2 \dfrac{(h_R - h_o)}{R_e}\right]^{1/2} + \sin \theta} \quad \text{(km)}$$

where h_o = the height above mean sea level of the earth station (km)

θ = the elevation angle (degrees)

R_e = the effective radius of the Earth (i.e. 8,500 km).

The horizontal projection, L_G, of the slant path is:

$$L_G = L_s \cos \theta \text{ (km)}$$

The rain path reduction factor $r_{0.01}$ for 0.01% of the time is:

$$r_{0.01} = \frac{90}{90 + 4\ L_G}$$

The specific attenuation γ_R, is determined from:

$$\gamma_R = k\,(R_{0.01})^{\alpha} \quad \text{(dB/km)}$$

where $R_{0.01}$ is given in Table II for each rain climatic zone. The frequency dependent coefficients k and α are given in Table III. The rain climatic zones are given in Report 563.

Table II - Rainfall intensity $R_{0.01}$ for the rain climatic zones (exceeded for 0.01% of an average year)

Rain climatic zone	A	B	C	D	E	F	G	H	J	K	L	M	N	P
Rainfall intensity $R_{0.01}$ (mm/h)	8	12	15	19	22	28	30	32	35	42	60	63	95	145

Table III - Frequency dependent coefficients

Frequency* (GHz)	k	α	
14.65	0.0327	1.149	For Regions 1 and 3
17.5	0.0521	1.114	For Region 2
17.7	0.0531	1.110	For Regions 1 and 3

* Mean frequencies of the feeder-link bands.

The rainfall attenuation exceeded for 1% of the worst month is:

$A_{1\%} = 0.223\,\gamma_R L_s\, r_{0.01}$ (dB) for Regions 1 and 3

$A_{1\%} = 0.21\,\gamma_R L_s\, r_{0.01}$ (dB) for Region 2.

For the calculation of power control described in Section 5.4.4, the rainfall attenuation for 0.1% of the worst month is used. It can be calculated as follows:

$$A_{0.1\%} = 3.3\,A_{1\%}$$

3.4.2 *Depolarization*

Both rain and ice can cause depolarization of signals and thereby reduce the carrier-to-interference ratio, C/I, at co-located and adjacent satellites. When ice is in the transmission path, particularly when it is melting, its depolarization effect is particularly strong (the "bright band" phenomenon), although there is little attenuation at such times.

The CCIR rain model (see Report 564) predicts that rain depolarization, *XPD*, varies with attenuation and elevation angle as illustrated in Fig. 3 for circular polarization. For any given value of rainfall attenuation, A_p, the *XPD* value decreases with decreasing elevation angle.

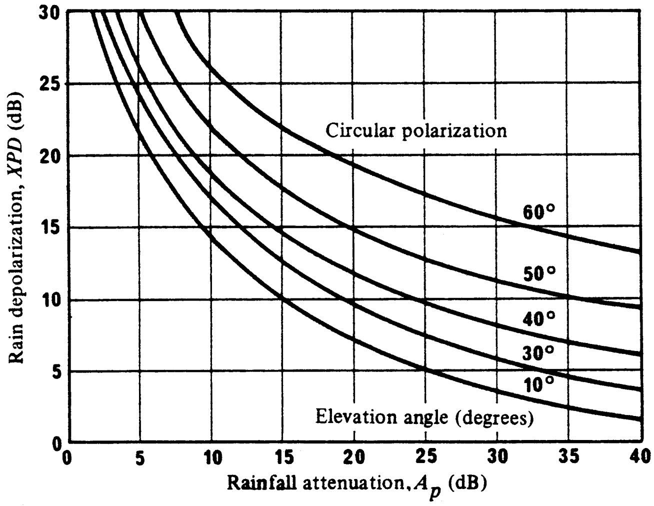

FIGURE 3 – *Rain depolarization and attenuation predicted for circularly polarized signals (14 GHz)*

The WARC-ORB(88) Conference adopted the following method for the calculation of depolarization (XPD), not exceeded for 1% of the worst month:

$$XPD = 30 \log f - 40 \log (\cos \theta) - V \log A_p \text{ (dB) for } 5° \leq \theta \leq 60°$$

where $V = 20$ **for 14.5 - 14.8 GHz**

and $V = 23$ **for 17.3 - 18.1 GHz**

where A_p**: co-polar rain attenuation exceeded for 1% of the worst month**

f **: frequency (GHz)**

θ **: elevation angle (degrees).**

For values of θ **greater than 60°, use** $\theta = 60°$ **in the above equation.**

3.4.3 *Rain scatter*

Rain scatter, as a potentially important short-term interference mechanism at 17 GHz, is analyzed [CCIR, 1982-86b] for sharing between feeder links. Further study is required since several simplifying assumptions have been made and the rain scatter model that was used is specifically applicable to terrestrial scatter paths. The provisional analysis shows that:

- rain scatter interference contributions should not be a problem at 17 GHz but, however, can greatly exceed the interference on the direct earth station (side-lobe)-to-victim satellite path;
- rain scatter interference is highest, relative to the direct earth station (side-lobe)-to-victim satellite interference, at large angular separations between the victim and intended satellites;

- in some cases, the net interference during rain might exceed that which is present during clear-sky conditions. However, all such cases are associated with situations where this interference is negligibly small;
- further study is needed to assess the magnitude of precipitation scatter interference from around and above the 0°C isotherm. 10 GHz radar reflections from the melting layer at this altitude are typically substantially greater than those from somewhat lower altitudes.

3.5 *Propagation margin*

The propagation margin at 17 GHz (L_{Att} in equation (2)) depends primarily on the rain climatic zone and the elevation angle. Rainfall attenuation not exceeding 10 dB is predicted for 1% of the worst month in many rain climatic zones with little or no restriction on elevation angle. In rain climatic zones *M*, *N* and *P*, it might be desirable to locate the satellites so as to limit the minimum elevation angle and thus minimize the cases where rainfall attenuation could exceed 10 dB for 1% of the worst month. The minimum elevation angles in rain climatic zones *M*, *N* and *P* are approximately 12°, 35° and 60°, respectively, for 10 dB of rainfall attenuation exceeded for 1% of the worst month.

Possible techniques to compensate for rainfall attenuation include site diversity and power control. These subjects are discussed in § 5.6 and 5.4, respectively.

3.6 *Practical feeder-link earth stations*

It is useful to obtain information on the technical characteristics and operation of operating feeder links, in particular, based on overcoming the problems of heavy rain attenuation, and on increasing the effectiveness of transportable earth stations.

According to the experience with the feeder-link operations of the Japanese broadcasting satellite (BS-2), Annex II to this report gives information on the following two aspects of the actual feeder link [CCIR 1986-90a]:

- feeder-link operation in rainy conditions (section 1 of Annex II);
- systems of transportable earth stations (section 2 of Annex II).

4. Interference

Since the sources of interference in the satellite-to-Earth path, namely, the broadcasting satellites, are numerous and since this type of interference is liable to reduce the number of programmes broadcast to each country, the WARC-BS-77 decided for Regions 1 and 3 that, for planning purposes, the interference due to the satellite-to-Earth path should be 90% of the total interference.

The WARC-BS-77 approach requires that the feeder links have protection ratios about 10 dB greater than those of the down link. However, it must not be forgotten that the WARC-BS-77 specified more stringent conditions for the protection against interference than for that against noise. It may be expected that, under clear-sky conditions, a C/N ratio in the vicinity of 30 dB could be obtained on the feeder link. Even under those conditions, the received noise power would still be ten times greater than the interference power, assuming a protection ratio of 40 dB.

The feeder-link C/I ratio need not be specified as a planning element when feeder links and down links are planned at the same time because the overall carrier-to-interference ratio is the applicable criterion.

4.1 *Co-channel, co-polar interference*

A single entry protection ratio (C/I_u) of 40 dB between co-polarized feeder links transmitted from adjacent service areas is readily achievable for 99% of the worst month. Under clear-sky conditions a C/I_u of 40 dB requires satellite separation of about 3° for feeder-link antennas having 5 m diameters. When considering the worst case of aggregate interference and a 10 dB rain fade at the wanted transmitting earth station, the required minimum orbital separation between satellites serving adjacent services areas is about 10°. Orbital separations of less than about 10° would require some separation of feeder-link service areas, just as some separation is required for down-link service areas when orbital separations are less than 15°. Satellite separations will normally be determined by down-link interference considerations. However, feeder-link interference might be the determining factor when the feeder-link service area is larger than, or outside, the down-link service area. A value of 40 dB for C/I_u appears suitable as guidance in development of feeder-link plans.

Experiments conducted with the OTS satellite were used to measure the perceptibility threshold of an interferer for a total link [CCIR, 1978-82d]. The tests show that for a 625-line television signal in conformity with the WARC-BS-77 Plan, the value of 30 dB is confirmed for co-channel protection ratio.

Measurements were carried out in Canada on the effect of the non-linearity of the satellite TWTA on the co-channel interference. It would seem that the commonly known "small signal suppression" phenomenon does not take place in this case and that no decrease in the interference level was observed at the output of a saturated TWTA. The satellite should therefore be considered as transparent in the calculation of the overall co-channel carrier-to-interference ratio.

A value of 40 dB for the feeder link co-channel protection ratio was used in establishing the Regions 1 and 3 Plan.

4.2 *Adjacent-channel interference*

For other than co-polar, co-channel interference, the required C/I is much reduced from 40 dB and satellite and/or service area separations can be much smaller. For common or adjacent service areas the satellites can be nearly co-located and still protect the adjacent and second adjacent channels.

Experiments conducted with the OTS satellite were used to measure the perceptibility threshold of an interferer (co-channel or adjacent channel) for a total link [CCIR, 1978-82d]. The tests show that for a 625-line television signal in conformity with the WARC-BS-77 Plan, a lower value (7 dB instead of 14 dB) may be acceptable for the adjacent-channel protection ratio in Regions 1 and 3. A very likely explanation for this qualitative reduction may be found in the improved channel selectivity due to filtering at the transmitting station. However, a reduction of adjacent-channel interference due to the filtering on the feeder links is somewhat limited by the requirement for a rather low-selectivity filter in order to transmit signals with minimum impairment. If, as it seems, the value adopted by the WARC-BS-77 for the adjacent channel in the down link is a little too high, it would be interesting to continue experiments to see whether, for the adjacent channel, a lower corresponding value (for example 17 dB) could be adopted for feeder-link planning.

Laboratory experiments in France in which feeder-link interference was simulated using 625-line television signals in conformity with the WARC-BS-77 Plan have indicated that, in addition to confirming the protection ratio of 30 dB for co-channel interference, for adjacent-channel interference, transmission filtering at the feeder-link station and the operation of the satellite amplifier tube at saturation lead to a subjectively apparent decrease of 4 dB in the adjacent-channel interference.

For the 525-line NTSC system, studies of the adjacent-channel protection ratio have been carried out in Japan, in particular taking into account the effects of the AM/PM conversion factor of satellite transponders. Results of subjective measurements of signals passed through a 12 GHz TWTA and computer simulation of saturated amplification, including AM/PM conversion, agree and indicate that the adjacent channel protection ratio required for just perceptible interference can be reduced to 11 dB, after taking into account an AM/PM conversion factor of 6 degrees/dB (see § 3.3 of this Report).

Considering the differing experimental results presented, it appears that a unified planning value of the order of 21 dB would be appropriate for the feeder link adjacent-channel protection ratio irrespective of the television system used.

A value of 21 dB for the feeder link adjacent channel protection ratio was used in establishing the Regions 1 and 3 Plan.

4.3 *Second adjacent-channel interference*

Because of the relatively limited out-of-band rejections of the receiver filters expected to be used in practice, the second adjacent channel interference can become a non-negligible contributor to the interference level. The protection ratio is found to be in the neighbourhood of −10 dB for frequency modulated NTSC signals with two sound sub-carriers and with simple lumped-element 4-pole filters.

Some measurements with C-MAC signals indicate a protection ratio in the range 0 to −8 dB to be appropriate with the same type of filter [Shelswell, 1984].

The major contributors to this second adjacent channel interference are the feeder links. The contribution of the down link is negligible since the e.i.r.p. differential towards a given point in the service area due to beam overlap is limited to a few decibels. The contribution from the feeder links is found to be more important and the worst case occurs when the feeder links for the two channels, wanted and second adjacent interfering channels, are from the same service area towards the same orbital location. A difference in antenna gain towards the two wanted and interfering stations as well as a rain fade at the wanted transmission site where clear-air conditions are found at the interfering site can produce a relatively large differential in the levels received at the satellite.

In the case of the Region 2 planning at the RARC SAT-83, this feeder-link level differential could be found to be as high as 16 dB giving a second adjacent channel margin of −6 dB for a corresponding protection ratio of −10 dB, becoming in many cases the predominant interference mechanism. A 10 dB reduction of the feeder-link second adjacent channel interference was assumed due to satellite channel filtering in order to avoid this predominance.

Further problems which can result are significant transmission of strong second adjacent channel signals through the satellite transponder and also intermodulation with the wanted signal in the transponder non-linear amplifier. These result in further interference components being radiated within and outside the nominal channel bandwidth on the down link. In the Regions 1 and 3 down-link Plan, neighbouring or overlapping coverage areas occur with channels at frequency spacings of two channels, having the same sense of polarization at the same orbit position. Thus there is some possibility of creating additional down-link interference on wanted channel n due to:

- the channel n feeder-link signal passing through co-located transponders operating on channel $n \pm 2$;
- intermodulation in the same transponders on channels $n \pm 2$ resulting from signals on channels $n \pm 4$.

Hence, adequate rejection of second adjacent channel signals must be provided by filtering in a satellite transponder to minimize this possible interference mechanism.

A study in the United Kingdom concluded that the need to take into account second adjacent channel interference should be avoidable in feeder-link planning in Regions 1 and 3, assuming direct frequency translation, provided that a second adjacent channel rejection of at least 40 dB through the satellite transponder can be provided [Shelswell, 1984]. The second study carried out in Japan showed that, assuming severe rain fading (about 18 dB) on the second adjacent channel, the required second adjacent channel rejection of the input and output channel filter in combination is approximately 50 dB.

Rejection by 55 dB of signals in the second adjacent channel can be obtained in practice from the combined effect of transponder input and output filters [CCIR 1986-90b]. Therefore, it is confirmed that it would not be necessary to take second adjacent channel interference into account when evaluating the feeder-link Plan for Regions 1 and 3.

For planning in Regions 1 and 3, the second adjacent-channel interference was not taken into account.

4.4 Calculation of the equivalent protection margin for Regions 1 and 3*

The feeder-link equivalent protection margin (M_u) is given by the formula:

$$M_u = -10 \log \left(10^{-M_1/10} + 10^{-M_2/10} + 10^{-M_3/10} \right) \text{(dB)}$$

where M_1 is the value in dB of the protection margin for the same channel, i.e.:

$$M_1 = \left[\frac{\text{wanted power}}{\text{sum of the co-channel interfering powers}} \right] \text{(dB)} - \text{co-channel protection ratio (dB)}$$

M_2 and M_3 are the value in dB of the protection margin for the upper and lower adjacent channels respectively, i.e.:

$$M_2 = \left[\frac{\text{wanted power}}{\text{sum of the upper adjacent channel interfering powers}} \right] \text{(dB)} - \text{adjacent channel protection ratio (dB)}$$

$$M_3 = \left[\frac{\text{wanted power}}{\text{sum of the lower adjacent channel interfering powers}} \right] \text{(dB)} - \text{adjacent channel protection ratio (dB)}$$

All powers are evaluated at the receiver input.

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* The definition of the equivalent protection margin for Regions 1 and 3 is included in § 4.11 of Recommendation 566.

4.5 Calculation of the overall equivalent* protection margin for Regions 1 and 3**

The overall equivalent protection margin M is given in dB by the expression [Brajan, 1986]:

$$M = -10 \log \left[10^{-(M_u + R_{cu})/10} + 10^{-(M_d + R_{cd})/10}\right] - R_{co}$$

where M_u = equivalent protection margin for the feeder link (as defined in Section 4.4)

M_d = equivalent protection margin for the down link

R_{cu} = co-channel feeder-link protection ratio

R_{cd} = co-channel down-link protection ratio

R_{co} = co-channel overall protection ratio.

The values of the protection ratios used for planning are as follows:

R_{cu} = 40 dB
R_{cd} = 31 dB
R_{co} = 30 dB.

4.6 *Interference between co-located satellites*

The most critical cases of feeder-link interference are for cross-polar channels transmitted to co-located satellites.

For the case where co-located satellites use a common cross-polarized channel, a protection ratio of 40 dB is needed. Discrimination of more than about 30 dB from the satellite receiving antenna pattern requires geographical separation of feeder-link service areas. The discrimination is the difference in co-polar gain towards points within the wanted service area and the cross-polar gain towards the closest point in the interfering service area. Satellite antenna patterns are typically given as functions of φ/φ_0 where φ is the exocentric angle between the on-axis direction and the direction of interest, and φ_0 is the 3 dB beamwidth of the satellite antenna. The discrimination between wanted and interfering signals is then the difference between the gain towards the wanted feeder-link station and the gain at angle φ. If the maximum discrimination is taken to be the opposite of the on-axis gain, 40 dB discrimination at the edge of service area would require an on-axis gain of 43 dB and values of φ/φ_0 greater than 2. Satellite antenna gains of 43 dB are not consistent with country-wide feeder-link service areas for many countries. Provisions for inhomogeneities in received signals due to rain attenuation and unequal transmit power levels would require even higher antenna gains. An on-axis gain of 49 dB (0.6° beamwidth) would provide, at best, a 6 dB margin for rain attenuation.

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* The adjective 'equivalent' indicates that the protection margins for all interference sources from the adjacent channels as well as co-channel interference sources have been included.

** These definitions are included in Recommendation 566.

Consider also the case where co-located satellites operating on cross-polarized adjacent channels have common feeder-link service areas. Assume that the discrimination capabilities are 25 dB for the satellite receiving antenna and 30 dB for the earth-station transmitting antenna. Since the two interference components may be in phase, voltage addition must be used to determine the interference level. In clear skies, the feeder-link C/I for an adjacent channel would be 21.1 dB. When the wanted feeder-link path is subjected to 10 dB rain attenuation, the feeder-link C/I drops to 11.1 dB. The protection ratio of 24 dB implied by the WARC-BS-77 cannot be achieved for this example, even under clear-sky conditions.

One possible solution to the problem of adjacent channel interference is to provide a slight separation between co-located satellites. A study performed in Canada showed that an improvement in isolation can be obtained in the case of two satellites transmitting cross-polarized adjacent channels by separating these satellites by a fraction of a degree such that they are seen as two distinct orbital locations by the feeder-link transmitting antennas but as co-located by the smaller receiving antennas. This removes almost completely the susceptibility of overall link adjacent channel C/I to rain fades on the feeder links at the cost of a small gain loss at the receiving terminal.

Figure 4 shows the results of the parametric study giving the overall adjacent channel C/I as a function of orbital separation and for different transmitting antenna sizes. The technical parameters adopted at the RARC SAT-83 including the transmit and receive antenna mispointings were used in this analysis. The figure also gives the variation in receiving antenna gain as a function of the orbital separation. It should be noted that 1 dB receiving gain loss due to mispointing is already taken into account in the earth-station G/T calculation.

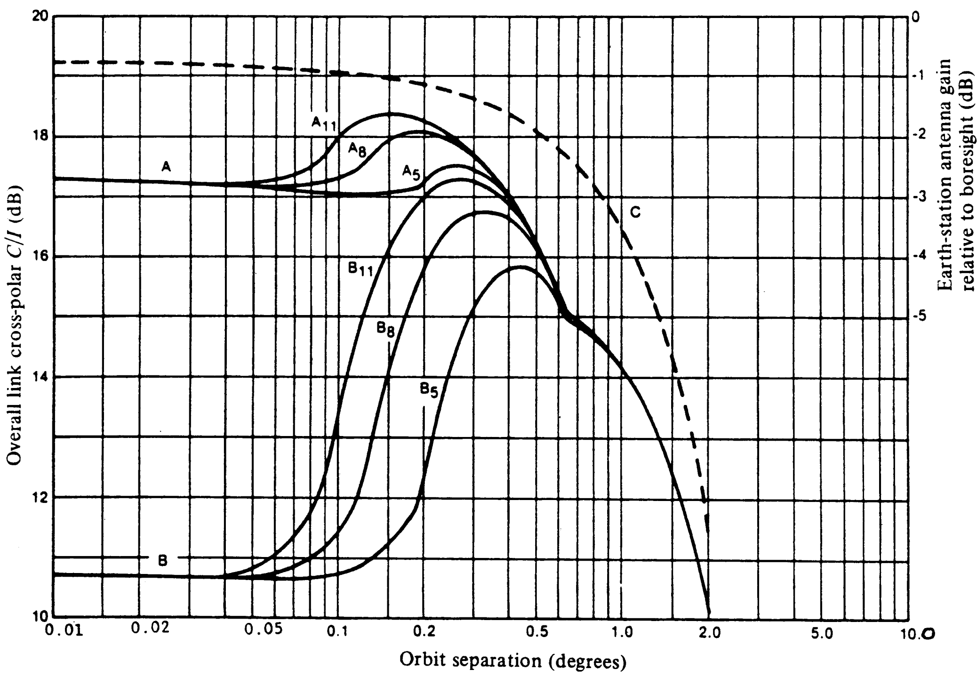

FIGURE 4 – *Cross-polar C/I improvement through orbital separation*

Curves A : clear-air conditions on feeder links and down link

B : 10 dB rainfall attenuation on the wanted feeder link

C : degradation of the earth-station receive co-polar gain

A_5 : overall link cross-polar C/I for 5 m antennas at the feeder-link sites (clear-air situation)

A_8 : overall link cross-polar C/I for 8 m antennas at the feeder-link sites (clear-air situation)

A_{11} : overall link cross-polar C/I for 11 m antennas at the feeder-link sites (clear-air situation)

B_5 : overall link cross-polar C/I for 5 m antennas at the feeder-link sites (10 dB fade situation)

B_8 : overall link cross-polar C/I for 8 m antennas at the feeder-link sites (10 dB fade situation)

B_{11} : overall link cross-polar C/I for 11 m antennas at the feeder-link sites (10 dB fade situation)

The optimum orbital separation is the point of best polarization discrimination for faded condition on the feeder link. This represents the best trade-off between feeder-link polarization discrimination and down-link loss in gain. This optimum is found to be 0.4° for 5 m feeder-link transmitting antennas. This separation was used in the development of the plan for Region 2 at the RARC SAT-83. The use of larger transmitting antennas will shift this optimum to smaller orbital separation (e.g., 0.3° for 8 m antennas and 0.27° for 11 m antennas).

The WARC ORB(88) Conference decided that administrations could place the satellites of a same "group" of satellites (i.e. sharing the same nominal position in the Plan) at any position no further than 0.2° away from the nominal position, provided that the agreement of the other administrations on that orbital position is obtained. The advantage of this arrangement is that it permits additional discrimination between feeder links (large transmitting antennas) whilst for the purposes of reception of the down link (small antennas) these satellites can still be considered as being at the same position.

4.7 *Effect of AM/PM conversion*

Section 3.3 above discusses the degradation in effective feeder-link C/N caused by AM/PM conversion in the satellite transponder. A similar effect may be expected to occur with effective feeder-link C/I ratios, although there is presently insufficient experimental evidence to confirm this. Indeed, tests in the United Kingdom indicate that with low AM/PM conversion ($< 2°/\text{dB}$), the effect of mutual interference on the feeder link is very similar to its effect on the down link [Shelswell, 1984]. Further study is required with higher values of AM/PM conversion currently found with the high-power travelling-wave tube amplifiers that are required for satellite broadcasting.

The decrease in overall link C/I ratios will depend upon the relative C/I ratios in the feeder link and down link in a similar way to that in which link imbalance affects the overall C/N ratio as discussed in § 3.3.

4.8 *Techniques for alleviating mutual interference between feeder links*

To alleviate mutual interference between feeder links, the following methods can be adopted (see the Report of WARC ORB-85):

— Use of a common set of technical parameters for all feeder links in planning is desirable but preliminary studies by a number of administrations have indicated that there may be a difficulty in obtaining the required carrier-to-interference ratios on a small number of feeder links, particularly when certain administrations have special requirements to be met.

In order to overcome this difficulty, a degree of flexibility in the values of planning parameters used is proposed. Employment of one or more of the following techniques may be used, where necessary, in the planning process to attain the target values for interference protection.

— Adjustments of the maximum level of e.i.r.p. of potential interfering feeder links or feeder links subject to excessive interference, provided that adequate carrier-to-noise and carrier-to-interference ratios on the adjusted feeder links are maintained.

— Where independent planning of orbit positions is adversely affected, the off-axis co- and cross-polar side-lobe reference patterns of the earth-station transmitting antenna may be limited to $29 - 25 \log \varphi$ (dBi), for values of off-axis angle, φ, in the regions of the adjacent and next-but-one adjacent orbital positions in the plane of the geostationary-satellite orbit.

— Where insufficient cross-polar isolation is achieved, the off-axis cross-polar side-lobe reference pattern of the earth-station transmitting antenna may be limited to $24 - 25 \log \varphi$ (dBi) for $0.76° \leq \varphi \leq 22.9°$ and -10 (dBi) for $\varphi > 22.9°$.

— Adjustment of the feeder-link channel assignments, retaining the same translation frequency for all assignments associated with a given down-link beam.

— Modifying the satellite receiving antenna beam pattern shape, size, and/or side-lobe response (for example, a multiple beam or shaped beam antenna).

— Off-setting the beam-pointing direction of the satellite receiving antenna subject to maintaining the target carrier-to-noise ratio.

— Improving the beam-pointing accuracy of the satellite receiving antenna to 0.1°.

— Setting an upper limit to the rain attenuation margin included in the feeder-link power budget.

— Separating satellite orbital positions by ± 0.2° from the nominal position and specifying the off-axis e.i.r.p. of the relevant earth station in the range 0° to 1° off-axis beam angles.

For such cases, where e.i.r.p. (dBW) is the earth station on-axis e.i.r.p., the off-axis e.i.r.p. of the earth-station transmitting antenna for angles $0° \leq \varphi < 1°$ should not be greater than:

e.i.r.p. (dBW)	for $0° \leq \varphi \leq 0.1°$
e.i.r.p. $- 21 - 20 \log \varphi$ (dBW)	for $0.1° < \varphi \leq 0.32°$
e.i.r.p. $- 5.7 - 53.2\, \varphi^2$ (dBW)	for $0.32° < \varphi \leq 0.44°$
e.i.r.p. $- 25 - 25 \log \varphi$ (dBW)	for $0.44° < \varphi < 1°$

5. Feeder-link earth station characteristics

5.1 *E.i.r.p.*

Once the frequency band and satellite G/T are specified, the earth station e.i.r.p. required to meet the C/N condition is largely determined by the statistics of precipitation-induced attenuation at the earth station sites. If L designates the net path loss in dB that is not exceeded during a certain percentage of the worst month, for example, 99%, then the required earth station e.i.r.p. per channel is given by the equation:

$$e.i.r.p. = P_E + G_E = C/N + 10 \log (kB) - G/T + L \qquad \text{dBW} \tag{4}$$

where:

- P_E: earth-station transmitter power per channel (dBW),
- G_E: on-axis gain of earth-station antenna (dBi),
- C/N: carrier-to-noise ratio at the input to the satellite receiver exceeded for, e.g. 99%, of the worst month (dB),
- k: Boltzmann's constant (1.38×10^{-23} J/K),
- B: IF bandwidth of satellite receiver (Hz),
- G/T: figure of merit of satellite (including receiver, antenna and feed) (dB(K^{-1})).

The considerations set forth in § 3.3 suggest that a satellite input C/N ratio of the order of 26 dB should be chosen. To illustrate the use of this equation, take C/N = 26 dB, B = 27 MHz (as specified in the Plan for Regions 1 and 3), G/T = 5 dB(K^{-1}) (corresponding to T = 2000 K and G = 38 dB at the edge of a 1.5° beam) and L = 212 dB (209 dB free-space loss at 18 GHz plus 3 dB rain attenuation corresponding to 1% of the worst national average of projected worst month statistics for Europe (see Report 565)). The result of the calculation for the earth-station e.i.r.p. in this case is 78.7 dBW. This is well within the capability of e.i.r.p. from an 18 GHz earth station having a transmitter power of about 200 W and an antenna diameter of about 5 m with an efficiency of 55%.

In practice, when considerations other than C/N are taken into account, the e.i.r.p. values required for feeder links will be in the range of 78-87 dBW depending on the characteristics of each system. As an example, for Region 2 planning a nominal e.i.r.p. of 87 dBW has been used.

Another practical example, based on the use of several feeder-link earth stations with a satellite having a narrow-beam receiving antenna to mitigate the problems of mutual feeder-link interference, leads to a required e.i.r.p. of 81.5 dBW. For that example the following parameter values have been chosen: C/N = 26 dB, B = 27 MHz (see Regions 1 and 3 Plan), G/T = 8.5 dB(K^{-1}) (corresponding to T = 2500 K, G = 46.5 dB at the boundary of a 0.6° beam, a margin of 4 dB for a receiving antenna pointing offset to account for feeder links located near the edge of coverage area) and L = 218.3 dB (209.3 dB of free-space loss at 18 GHz, plus 9 dB as an example of rain attenuation). The minimum e.i.r.p. required is then 81.5 dBW. In order to take into account station margin (tracking, measurement, etc.), an additional 3 dB may be added to reach the maximum necessary e.i.r.p. of 84.5 dBW.

Antennas and transmitters are readily available which can satisfy the e.i.r.p. requirement, taking into account feed and multiplexer losses. Antennas (both Cassegrain and centre fed) are available with 8 m and greater diameters and 18 GHz transmitter tubes with an output power of 1 kW are currently being developed.

5.2 *Transmitting antenna reference pattern*

A co-polar reference radiation pattern for transmitting earth-station antennas in the FSS is proposed in Recommendation 465 for antennas with $D/\lambda \geq 100$:

$$G = 32 - 25 \log \varphi \quad \text{dBi} \qquad 1° < \varphi \leq 48°$$
$$= -10 \quad \text{dBi} \qquad \varphi > 48° \tag{5}$$

Report 391 discusses this radiation pattern and gives supportive data. Report 390 discusses the factors influencing the side-lobe levels. Report 453-3 (1982), however, suggests a more stringent pattern to increase the spectrum-orbit resource utilization:

$$G = 28 - 25 \log \varphi \quad \text{dBi} \tag{6}$$

to a minimum of -20 dBi.

Based on the opinions of antenna manufacturers in France, and on tests conducted in Canada on recent high-performance antennas (see Annex I) it may be possible that antennas can be manufactured that will have no more than 10% of their side-lobe peaks above this envelope.

Among the factors indicating that these levels are achievable in practical antennas is that the design of feeds (including any sub-reflectors) can be optimized for only the transmit frequency bandwidth employed (500 or 800 MHz, depending on the Region).

The XVIth Plenary Assembly of the CCIR adopted Recommendation 580-1, which states that new earth-station antennas having a D/λ exceeding 150, installed after 1988 and operating with a geostationary-satellite should have a design objective such that the gain of 90% of the side-lobe peaks does not exceed:

$$G = 29 - 25 \log \varphi \quad \text{dBi} \qquad 1° \leq \varphi \leq 20° \tag{7}$$

Report 391 also suggests radiation patterns for small antennas ($D/\lambda < 100$), but this is equivalent to antennas smaller than 1.7 m at 17 GHz and it is unlikely that such small antennas will be used to feed broadcasting satellites.

It would also be possible to optimize antenna side-lobe performance to correspond to specific satellite separations for a plan using a fixed orbital separation. In this case, it might be desirable to use one reference pattern for planning of the broadcasting-satellite service and a separate reference pattern for coordination with other services.

Appendices 28 and 29 to the Radio Regulations extend co-polar radiation patterns to angles smaller than 1°, assuming a Gaussian main lobe and a plateau at the first side-lobe level.

5.2.1 *Reference patterns in Region 2*

The new radiation patterns described below and shown in Fig. 5 were adopted by the RARC SAT-83 for planning the feeder links to the BSS. The background information is given in Annex I to this Report.

5.2.1.1 *Co-polar component*

The co-polar component of the feeder-link antenna is based on a side-lobe envelope of $29 - 25 \log \varphi$ down to -10 dB relative to the isotropic source for the back-lobe region as indicated in Fig. 5. The main lobe of the antenna is constrained by the segment $36 - 20 \log \varphi$ to which the Gaussian main lobes of antennas of any size, assuming an antenna efficiency of 65%, are tangent. This segment extends to an angle of 0.32° beyond which a portion of the Gaussian main lobe of the 2.5 m antenna (the smallest antenna size allowed in the Plan) joins it to the side-lobe envelope $29 - 25 \log \varphi$. This is to allow for the broadening of the main lobe in the case of small antennas.

5.2.1.2 *Cross-polar component*

The cross-polar component of the feeder-link antenna is based on a plateau near on-axis with a discrimination of 30 dB relative to co-polar on-axis gain. For large off-axis angles, the cross-polar side lobes have to meet the sloped segment ($9 - 20 \log \varphi$) down to -10 dB relative to the isotropic source. The slope of this segment is such that the junction with the near on-axis plateau will always be where the worst cross-polar side lobe occurs, which happens to be at the -3 dB point on the co-polar component.

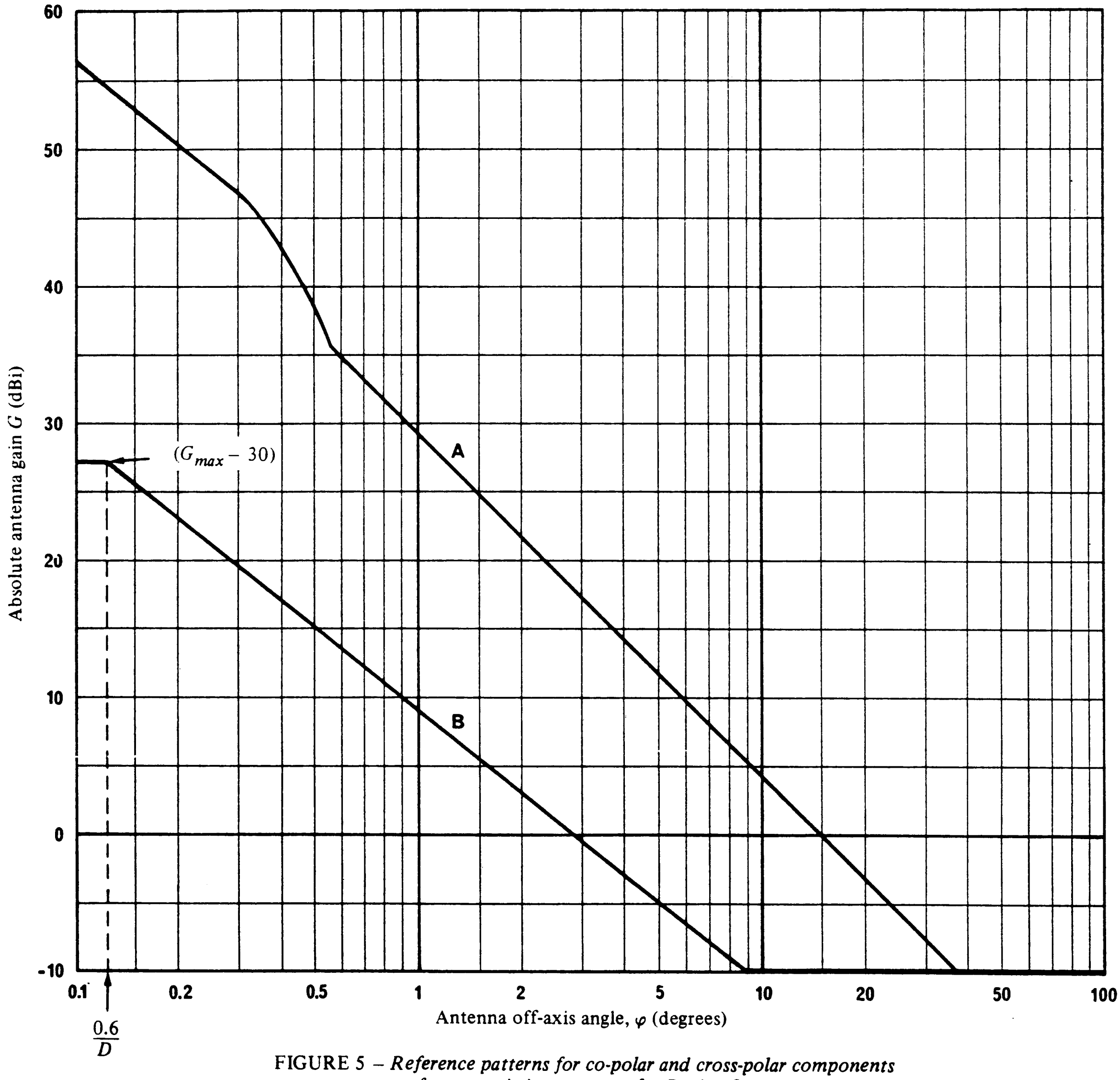

FIGURE 5 – *Reference patterns for co-polar and cross-polar components for transmitting antennas for Region 2*

Curves A: co-polar component (dBi relative to isotropic source)

$36 - 20 \log \varphi$	for $0.1° \leq \varphi < 0.32°$
$51.3 - 53.2 \varphi^2$	for $0.32° \leq \varphi < 0.54°$
$29 - 25 \log \varphi$	for $0.54 \leq \varphi < 36°$
-10	for $\varphi \geq 36°$

B: cross-polar component (dBi relative to isotropic source)

$G_{max} - 30$	for $\varphi < \left(\frac{0.6}{D}\right)^{\circ}$
$9 - 20 \log \varphi$	for $\left(\frac{0.6}{D}\right)^{\circ} \leq \varphi < 8.7°$
-10	for $\varphi \geq 8.7°$

where:

φ: off-axis angle referred to the main-lobe axis;

G_{max} : on-axis co-polar gain of the antenna;

D: diameter of the antenna (m) ($D \geq 2.5$)

5.2.1.3 *Method of analysis for meeting the reference patterns*

The evaluation of the measured antenna patterns as to whether they meet the reference patterns or not is made as follows:

- for the co-polar component, the reference pattern must not be exceeded in the angular range between 0.1° and 0.54°;
- for the cross-polar component, the reference pattern must not be exceeded in the angular range between 0° and $(0.6/D)°$; and
- at larger off-axis angles, the reference pattern can be exceeded by no more than 10% of the side lobes contained in each reference angular window. These windows are 0.54° to 1°, 1° to 2°, 2° to 4°, 4° to 7°, 7° to 10°, 10° to 20°, 20° to 40°, 40° to 70°, 70° to 100° and 100° to 180°. The first reference angular window for evaluating the cross-polar component should be $(0.6/D)°$ to 1.0°.

5.2.2 *Reference patterns in Regions 1 and 3*

For planning feeder links in Regions 1 and 3 the WARC ORB-88 adopted off-axis e.i.r.p. values which should not be exceeded. These values were based on the use of earth-station transmitting antennas having a nominal gain of 57 dBi and having the characteristics described below.

5.2.2.1 *Antenna diameter*

For a given value of on-axis e.i.r.p. and a given relative antenna pattern, the off-axis e.i.r.p. depends on the diameter of the antenna. The larger the diameter of the antenna, the smaller is the off-axis e.i.r.p. which is a potential source of interference between adjacent orbital positions.

Hence, for planning of feeder links it is necessary to define a reference antenna diameter. For the band 17.3-18.1 GHz the value adopted is 5 m, and 6 m for the band 14.5 to 14.8 GHz.

Smaller antennas of, for example, 2.5 m diameter, can also be used provided that there is no degradation of the interference situation. In practice, this means that the power might need to be reduced or the antenna pattern improved so that there is no increase in the off-axis e.i.r.p., and hence no unacceptable interference to the adjacent orbital position or to other services.

5.2.2.2 *On-axis gain*

The on-axis gain for the 5 m antenna at 17.3-18.1 GHz and for the 6 m antenna at 14.5 to 14.8 GHz is taken as 57 dBi.

5.2.2.3 ***Off-axis e.i.r.p. of transmitting antennas***

The co-polar and cross-polar off-axis e.i.r.p. for planning in Regions 1 and 3 are given in Figure 6.

5.2.2.4 *Cross-polar off-axis gain*

Studies have indicated that, for planning purposes, there is no necessity to maintain high cross-polar rejection at angles appreciably off-axis. Thus cross-polar characteristics identical to the co-polar may be used at angles corresponding to the orbital separations used in Regions 1 and 3.

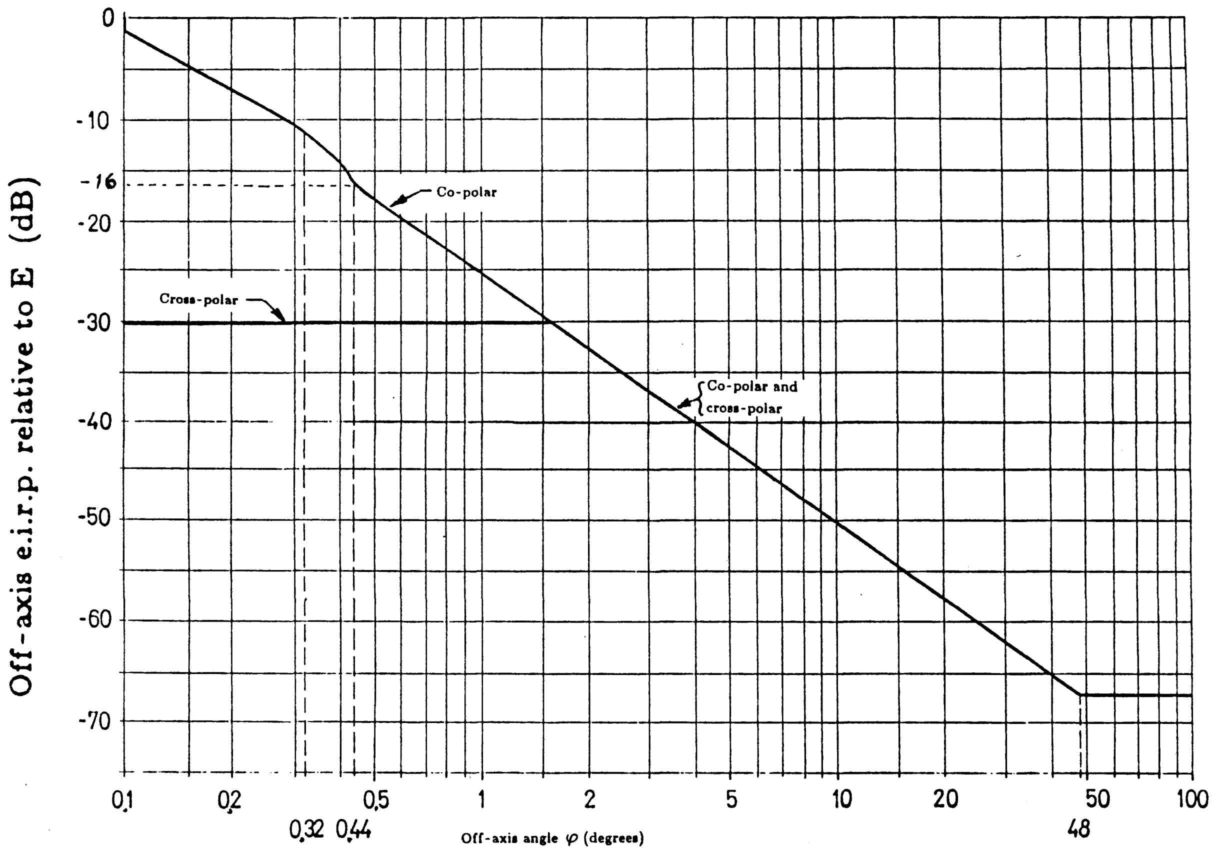

FIGURE 6 - *Earth station e.i.r.p. at angles off the antenna axis*

Co-polar component (dBW):

E (dBW) for $0° < \theta \leq 0.1°$
$E - 21 - 20 \log \theta$ (dBW) for $0.1° < \theta \leq 0.32°$
$E - 5.7 - 53.2\ \theta^2$ (dBW) for $0.32° < \theta \leq 0.44°$
$E - 25 - 25 \log \theta$ (dBW) for $0.44° < \theta \leq 48°$
$E - 67$ (dBW) for $\theta > 48°$

Cross-polar component (dBW):

$E - 30$ (dBW) for $0° \leq \theta \leq 1.6°$
$E - 25 - 25 \log \theta$ (dBW) for $1.6° < \theta \leq 48°$
$E - 67$ (dBW) for $\theta > 48°$

where:

E (dBW) is the earth station e.i.r.p. on the antenna axis.

and

θ = off-axis angle referred to the main lobe axis (degrees).

5.3 *Use of small transmitting antennas*

The minimum diameter earth-station antenna considered by the RARC SAT-83 using the feeder-link transmitting pattern described in § 5.2.1 is 2.5 m. The main beam broadening of a 2.5 m antenna (D/λ = 150) has been incorporated into the co-polar reference pattern. Such transportable terminals would not create more interference than that calculated in a plan provided that their side-lobe radiation patterns do not exceed the side-lobe envelopes proposed for planning purposes and provided that a maximum limit on transmitter power is adopted for planning.

For Regions 1 and 3, the use of an antenna with a diameter smaller than 5 m can be taken into account provided it is compatible with the interference conditions in the feeder-link Plan based on a diameter of at least 5 m. A preliminary study carried out in Japan showed that under certain circumstances in Region 3, there would be no difference in the C/I values for co-located satellites regardless of the use of transmitting antennas having a diameter of, for example, 2.5 m or even 1 m when the systems are homogeneous in e.i.r.p. Little interference would occur to adjacent satellites, even when using feeder-link transmitting antennas which have a diameter of 2.5 m and the characteristics of Recommendation 465, under the same e.i.r.p. conditions, if a 17 GHz feeder-link Plan is developed by a direct translation of the WARC-BS-77 down-link Plan. WARC-ORB(88) adopted a minimum antenna diameter of 2.5 m and compliance with the off-axis characteristics given in Figure 6 appropriate to the nominal on-axis antenna gain of 57 dBi.

The C/N_u and C/I_u achievable with these transportable earth terminals may not meet the values planned for 99% of the worst month using a larger antenna but would in most cases be adequate under clear-sky conditions as indicated in Table I for C/N_u. The C/N_u of the transportable terminals depends primarily on the transmitted power and on the satellite G/T.

The antenna systems of such transportable terminals will need to be as simple as possible and should be of practical dimensions to be carried on roads. A tracking system should not be required in all cases. Present practice in the fixed-satellite service seems to indicate that 4.5 m folding antennas and 2.5 m non-folding antennas would meet the road clearance standards in most of the cases. For a satellite station-keeping allowance of ± 0.1°, the use of antennas larger than 3 m would result in a variation of PFD at the satellite of more than 3 dB in the absence of automatic tracking.

However, when one considers the very slow drift rate of the satellite and that use of such small transportable antennas will usually be temporary, the assumption of 0.1° drift instead of 0.28° as the worst case seems reasonable. Thus, assuming a 3 dB variation in PFD at the satellite, only antennas larger than 5 m would require automatic tracking.

5.4 *Power control*

Power control of feeder links is the rapid, automatic adjustment of earth-station transmitter power to compensate for rain-induced attenuation in the path of the desired signal to a satellite.

5.4.1 *Application of power control*

In the presence of feeder-link power control (PC), the input level of the signal at the satellite transponder is maintained approximately constant and rain attenuation along the feeder-link path is effectively compensated.

As a consequence, during rain at the feeder-link station only, the use of feeder-link power control maintains a constant value of C/N_T as illustrated in Fig. 7.

Experiments using the BSE of Japan have shown that power control is effective in maintaining a nearly constant level of desired carrier during periods of rain [CCIR, 1978-82e; Shimoseko *et al.*, 1981]. In this experiment, at 14 GHz a variation of power received at the satellite of 6 dB (peak-to-peak) and 1.5 dB r.m.s. without power control, was reduced through the use of power control to 1.5 dB (peak-to-peak) and 0.5 dB r.m.s., respectively.

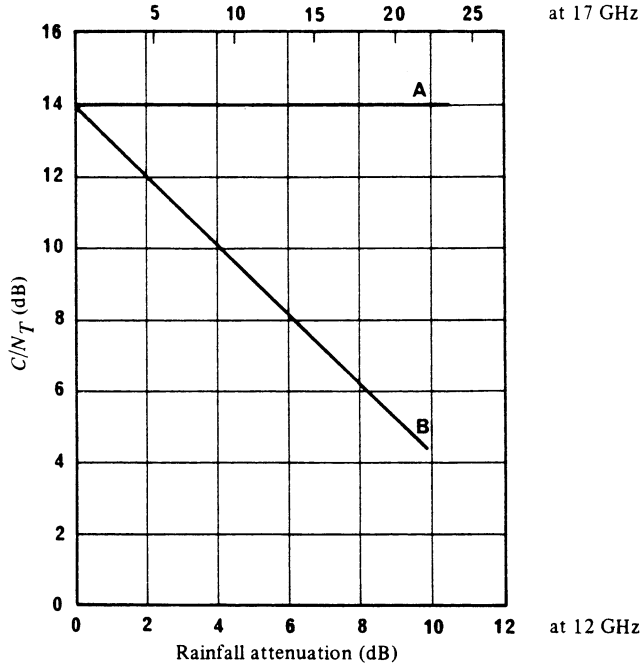

FIGURE 7 – *The effect of rainfall attenuation on C/N_T in the presence of feeder-link power control (PC)*

Clear-sky C/N_u = 24 dB

Clear-sky C/N_d = 14.5 dB

Curves A: rain at feeder-link station only

B: correlated rain at feeder-link station and down-link station

5.4.2 *Conditions for use of power control without increased interference*

Use of power control to increase the availability of feeder links beyond the values used for planning is analyzed in this section.

In [CCIR, 1982-1986c; OHMI, 1985] the conditions are determined that allow use of power control on an interfering feeder link without degradation of the C/I of an interfered-with link below the value obtained when the interfering feeder link is in clear sky.

In studying feeder-link interference problems, the geographical locations of interfering earth stations and wanted feeder-link beam areas are important factors affecting the feeder-link carrier-to-interference ratio. These factors affect the cross-polarization discrimination (XPI_{sat}) of the wanted-satellite antenna because XPI_{sat} is a function of the ratio of the off-axis angle (φ) to the half-power beam-width (φ_0).

For the satellite-receiving antenna reference pattern shown in Fig. 16, the XPI_{sat} can be graphically expressed as in Fig. 8.

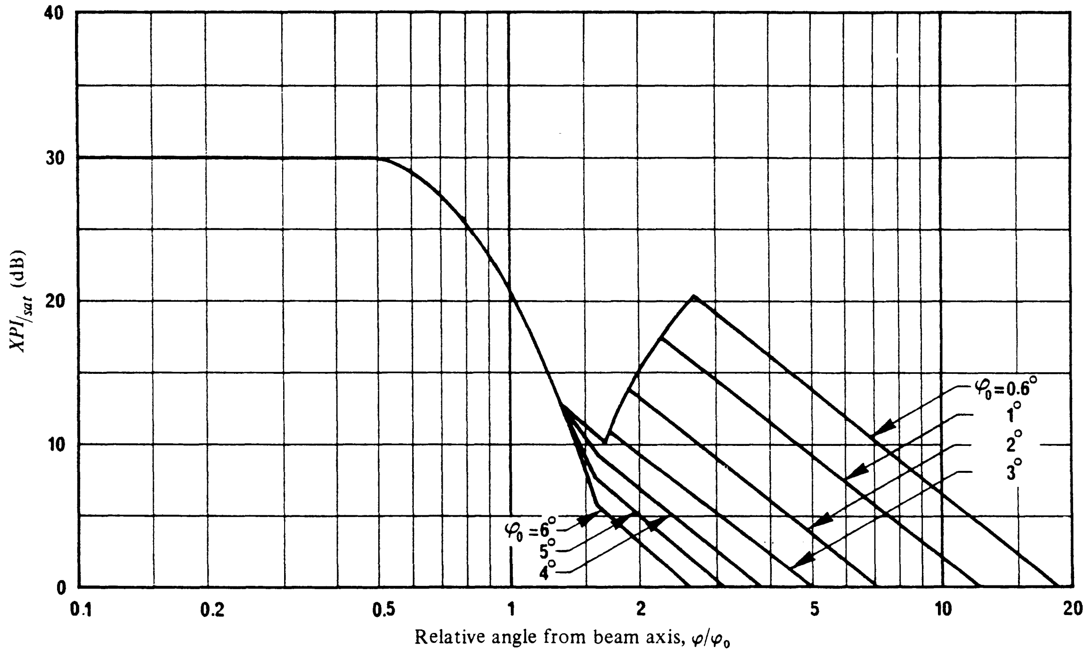

FIGURE 8 – *Cross-polarization discrimination (XPI_{sat}) of satellite-receiving antenna (reference patterns are assumed as shown in Fig. 16)*

(φ_0 : half-power beamwidth)

XPI_{sat} (dB) = G_{rcwi} (dB) – G_{rxwi} (dB)

In order to analyze the effect of the XPI_{sat} on C/I_u, the equation of C/I_u which includes the parameter XPI_{sat} explicitly, is given in equation (8).

$$\frac{C}{I_u} = \frac{P_w}{P_i} \cdot \frac{L_i}{L_w} \cdot \frac{R_i}{R_w} \cdot \frac{G_{rcww}}{G_{rcwi}} \cdot \frac{1}{A + \dfrac{1}{XPI_{sat}} + \dfrac{1}{XPI_{es}}} \tag{8}$$

where:

P_w : transmitter power at the wanted earth station;

P_i : transmitter power at the interfering earth station;

L_w : spreading ("free space") loss on the wanted path;

L_i : spreading ("free space") loss on the interfering path;

R_w : rain attenuation on the wanted path;

R_i : rain attenuation on the interfering path;

G_{rcww} : co-polar gain of the wanted-satellite receiving antenna in the direction of the wanted earth station;

G_{rcwi} : co-polar gain of the wanted-satellite receiving antenna in the direction of the interfering earth station;

A : coefficient of depolarization due to rain as expressed in the following equation:

$A = 10^{-(XPD/10)}$, where XPD is the rain depolarization given in § 3.4.2, in dB, as a function of rain attenuation and elevation angle;

XPI_{sat} : ratio of co-polar gain (G_{rcwi}) to cross-polar gain (G_{rxwi}) of the wanted-satellite receiving antenna in the direction of the interfering earth station as expressed in the following equation:

$XPI_{sat} = G_{rcwi}/G_{rxwi}$

XPI_{es} : ratio of co-polar (G_{tci}) to cross-polar (G_{txi}) of the interfering earth-station transmitting antenna in the direction of the wanted-satellite as expressed in the following equation:

$XPI_{es} = G_{tci}/G_{txi}$.

Thus, XPI_{sat} and XPI_{es} indicate the cross-polarization discrimination capability of the satellite antenna and the earth-station transmitting antenna, respectively.

The change in the C/I_u, on an interfered-with link, ΔM, can be expressed as follows when power control is used on an interfering link:

$$\Delta M = \frac{C/I_{u,\,rain}}{C/I_{u,\,clear}} = \frac{R_i}{\Delta P_i} \cdot \frac{1}{1 + \frac{A}{\frac{1}{XPI_{sat}} + \frac{1}{XPI_{es}}}} \tag{9}$$

where:

$C/I_{u,\,rain}$: C/I_u when rain occurs at the interfering site with resultant rainfall attenuation of R_i;

$C/I_{u,\,clear}$: C/I_u when the interfering site lies in clear weather ($C/I_{u,\,clear}$ is regarded as a reference C/I_u):

ΔP_i: power increase of earth transmitter by power control.

The limits on increased earth-station transmitter power which keep ΔM (dB) non-negative, i.e., not degrade the C/I on the interfered-with path from the value of C/I when the interfering site is in clear weather, are shown as a function of rain attenuation in Fig. 9, Curve (A) for the case where XPI_{sat} = 20 dB and XPI_{es} = 30 dB. Within the hatched area the transmitter power can be increased in any desired manner. An example of one possible algorithm for raising transmitter power as rain attenuation increases is shown in Curve (B) of Fig. 9.

Power control as shown in Curve (B) of Fig. 9 results in a positive ΔM (dB) as illustrated in Curve (B) of Fig. 10, i.e., the C/I_u on the interfered-with link is higher in rain than in clear skies by the amount shown. Curve (A) of Fig. 10 plots ΔM for the case where power control is not used and Curve (C) plots ΔM for power control as shown in Curve (A) of Fig. 9.

Table IV summarizes other examples of feasible combinations of increased transmitter power and rain attenuation for various values of XPI_{sat} and elevation angle.

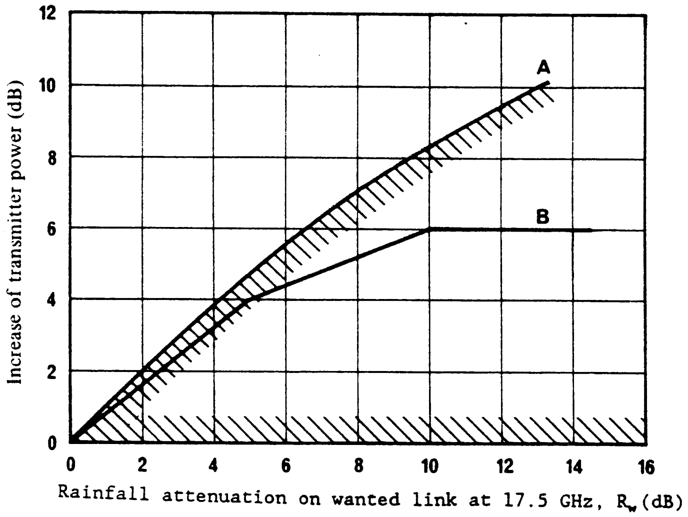

FIGURE 9 – *The possible increase of transmitter power for power control*

Curves A: upper limit for power control

B: an example of power control as illustrated in Table IV

XPI_{sat} = 20 dB
XPI_{es} = 30 dB
elevation angle: 50°

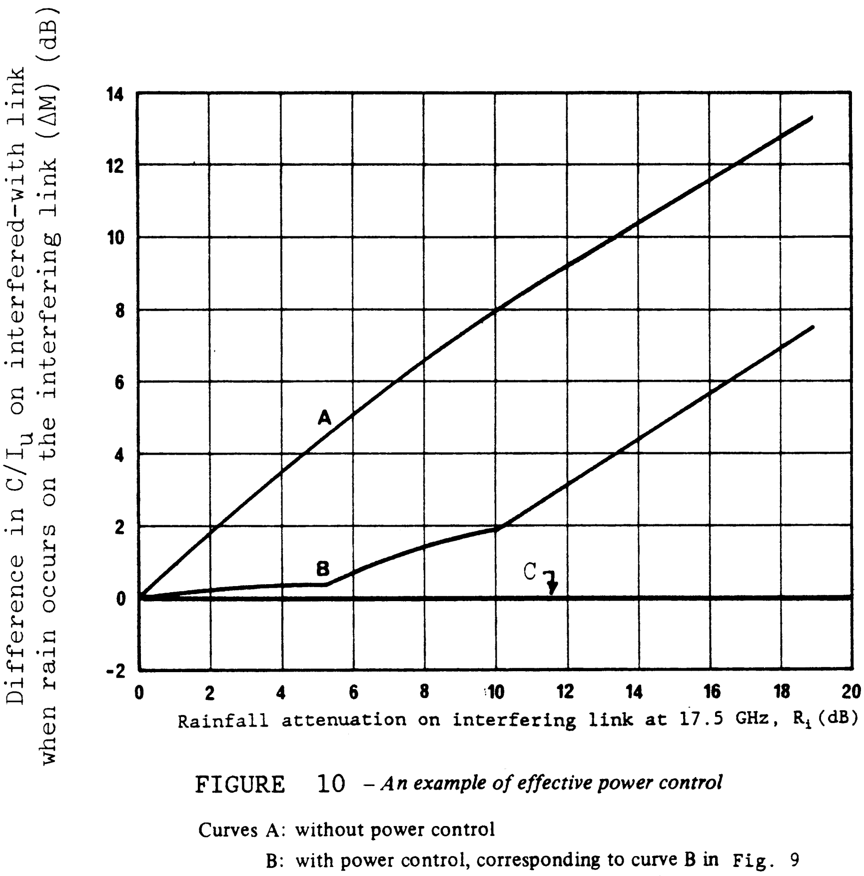

FIGURE 10 – *An example of effective power control*

Curves A: without power control

B: with power control, corresponding to curve B in Fig. 9

C: Upper limit for power control without degradation of C/I_u on an interfered-with link, corresponding to Curve A of Fig. 9

XPI_{sat} = 20 dB
XPI_{es} = 30 dB
elevation angle: 50°

TABLE IV – *Possible increase of earth-station transmitter power for power control for various values of XPI_{sat} and satellite elevation angle*

XPI_{sat} (dB)	Satellite elevation angle (degrees)	Increase of earth-station transmitter power (dB)	
		For rainfall attenuation 0 dB to 5 dB	For rainfall attenuation 5 dB to 10 dB and more
10 to 15	0 to 10 10 to 30 30 to 50 50 to 60 60 to 90	0 0 to 4 0 to 4 0 to 5 0 to 5	0 4 to 7 4 to 8 5 to 9 5 to 10
15 to 20	0 to 10 10 to 30 30 to 40 40 to 50 50 to 60 60 to 90	0 0 to 2 0 to 3 0 to 3 0 to 4 0 to 5	0 2 to 4 3 to 4 3 to 6 4 to 8 5 to 9
20 to 25	0 to 30 30 to 40 40 to 50 50 to 60 60 to 90	0 0 to 2 0 to 3 0 to 4 0 to 5	0 2 3 to 4 4 to 6 5 to 8
25 to 30	0 to 40 40 to 50 50 to 60 60 to 90	0 0 to 2 0 to 3 0 to 5	0 2 3 5

5.4.3 Use of power control with potential for increased interference

Some applications of power control can worsen the interference situation. Studies have shown [CCIR, 1978-82f], that the difference between interference levels in the case where power control is used at all stations to maintain C/N at the minimum required value, and where it is n ot used and, instead, all stations employ a margin, M, sufficiently high to take account of the attenuation experienced for all but a very small percentage of time, is given by:

$$I_{pc} - I_{npc} = M_w - M_i + (CPA)_{i\ inst.} - (CPA)_{w\ inst.} \quad (10)$$

where:

I_{pc} : interference with power control,

I_{npc} : interference with no power control,

$(CPA)_{i\ inst.}$ and $(CPA)_{w\ inst.}$: instantaneous co-polar attenuations on the interfering and wanted links, respectively,

M_w and M_i : margins on the wanted and interfering links, respectively.

The difference in the interference level (equation(10)) does not depend on the instantaneous value of the depolarization of the interfering path.

For most of the interference situations and for most of the time, the effects of interference on C/I_u will be the same with and without power control if the climatic conditions are statistically similar on the wanted and unwanted paths. There is a distinct difference, however, depending on the use or non-use of power control, whether a feeder link is affected by interference during rain on its own path or during rain on the path of the interfering feeder link.

For co-polarized, co-channel interference, which will only be important for large orbital separation and/or large feeder-link service area separation, power control would appear to offer certain potential advantages. It would permit a significant reduction in transmitting power for large percentages of time, potentially resulting in long-term savings of earth-station prime power and improved transmitter reliability. For the cases examined [CCIR, 1982-86d], use of power control increased the percentages of time that design levels of C/I could be maintained.

In the case of co-located satellites having common or adjacent feeder-link service areas and operating on adjacent cross-polarized channels, de-polarization must be taken into account in analyzing the effects of power control on C/I.

The effect of power control in the cross-polar C/I is calculated using two identical earth-station transmitters both located near the -3 dB edge of the feeder-link coverage area and directed towards co-located satellites. Cross-polar discrimination capabilities of 27 dB and 30 dB for circularly polarized satellite receiving antenna and earth-station transmitting antenna, respectively, are assumed. This gives a single entry cross-polar C/I_u of 21.2 dB under clear-sky conditions when voltage addition is assumed. An elevation angle of 40° is assumed and the cross-polar C/I_u is calculated as a function of rainfall attenuation on the feeder link for three scenarios:

(a) it rains at the wanted site only;

(b) it rains at the wanted and interfering sites simultaneously; and

(c) it rains at the interfering site only.

Use of power control at both sites is assumed.

The results are given in Figs. 11, 12 and 13, respectively for scenarios (a), (b) and (c). Although the RARC SAT-83 adopted voltage addition for C/I calculations, these figures have been drawn on the basis of power addition. The figures indicate that the use of up-link power control increases the C/I_u when it rains at the wanted site but decreases the C/I_u when it rains at the interfering site. The use of up-link power control has no effect on cross-polar C/I_u when it rains simultaneously at both the wanted and interfering sites.

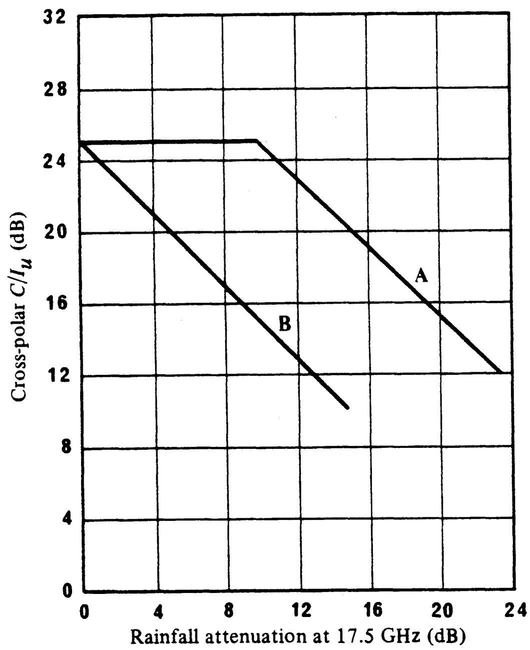

FIGURE 11 – *The effect of automatic gain control (AGC), or 10 dB of power control (PC), on the cross-polar C/I_u between circularly polarized feeder links at 17.5 GHz when it rains at the wanted site only (scenario (a))*

XPI_{sat} = 27 dB
XPI_{es} = 30 dB

Curves A: with 10 dB power control
B: with or without AGC without power control

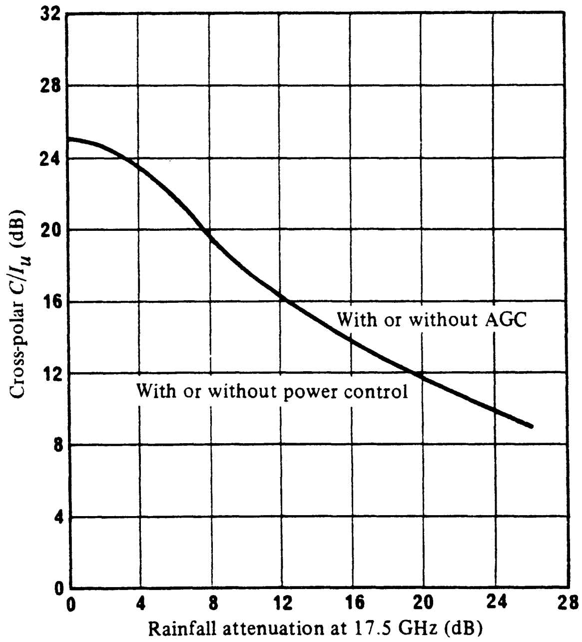

FIGURE 12 – *The effect of automatic gain control or power control on the cross-polar C/I_u between circularly polarized feeder links at 17.5 GHz when it rains simultaneously at the wanted and the interfering transmitter sites (scenario (b))*

XPI_{sat} = 27 dB
XPI_{es} = 30 dB

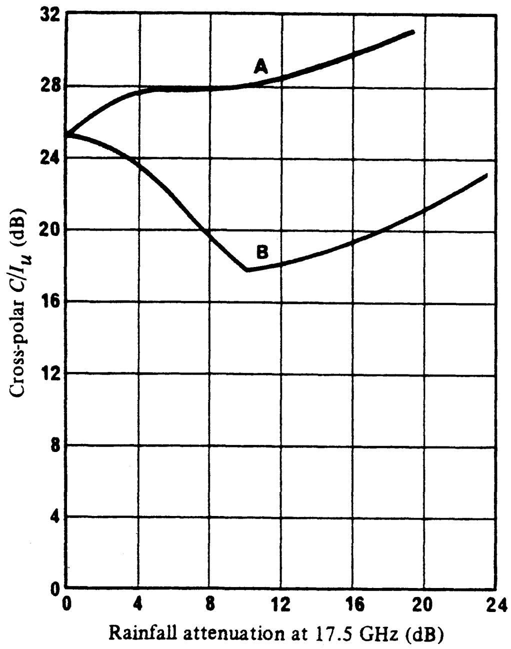

FIGURE 13 – *The effect of power control (PC) on the cross-polar C/I_u between circularly polarized feeder links at 17.5 GHz when it rains at the interfering site only (scenario (c))*

XPI_{sat} = 27 dB
XPI_{es} = 30 dB

Curves A: Without power control
B: With 10 dB power control

5.4.4 WARC-ORB(88) method for the calculation of power control in Regions 1 and 3

5.4.4.1 Conditions to be observed

In the Regions 1 and 3 Plan, power control is permitted according to the characteristics given in Figure 14 provided that the amount of interference generated to any other feeder link in the Plan does not degrade its overall free space C/I by more than 0.5 dB and that the power increase does not exceed the rainfall attenuation exceeded for 1% of the worst month or 10 dB.

5.4.4.2 Calculation method

a) Compile a list of all assignments of other administrations (A, B, C, ..) in the same orbital position and the two adjacent positions (i.e. in total, three orbital positions) liable to suffer interference from the assignment studied.

b) Calculate the feeder link equivalent protection margin of assignment A in free space conditions, taking account of all interference sources affecting A in the visible arc at the worst test points, namely:

- for assignment A: the point corresponding to the minimum C/N ratio
- for each interference source affecting A: the point corresponding to the maximum interference power affecting A.

c) Calculate for the assignment studied the rain attenuation for 0.1% of the worst month and the corresponding rain depolarization value at all test points (see Sections 3.4.1 and 3.4.2, respectively).

d) Recalculate the feeder link equivalent protection margin of assignment A taking into account the rain effects at the assignment studied at the worst test points, namely:

- for assignment A: the test point used in b) above
- for the assignment studied: the worst test point corresponding to the maximum interference power affecting A.*

At this stage, the e.i.r.p. of the assignment studied is of the nominal value.

e) Increase the e.i.r.p. of the assignment studied by 0.1 dB and recalculate the equivalent up-link margin of A as in d) above.

f) Repeat the operation of e) above until the equivalent up-link margin of assignment A is impaired by more than 0.5 dB in relation to the value found under b) above, or until the e.i.r.p. increase exceeds 10 dB or the rain attenuation calculated the assignment studied at the worst test point (see step c)). Adopt the e.i.r.p. increase in the preceding iteration step.

g) Repeat the operations in steps b) to f) above (inclusive), considering the assignments B, C,...

h) Adopt the smallest of the increases in e.i.r.p. found under f) above for the various assignments A, B, C...

* This test point may in general not be the same as that calculated under b).

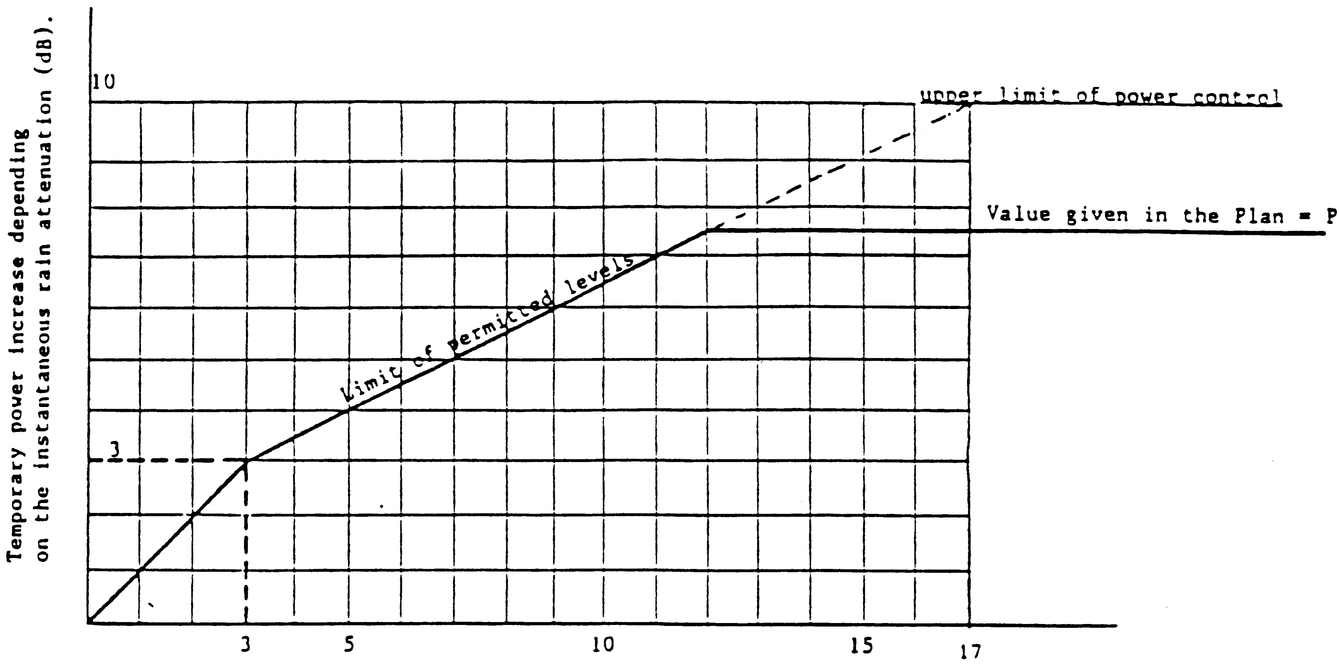

FIGURE 14

Characteristic for up-link power control

Note:

P: The value of permitted increase given in the feeder-link Plan for Regions 1 and 3 countries, which varies for each assignment. The upper limit of this value is 10 dB.

5.4.5 *Conclusions*

One application of power control would be to increase the feeder link availability above that used for planning. In this application, the increase in power would be limited to that amount which, assuming perfect implementation, would result in no increase in interference to other feeder links.

Another use of power control would be to minimize the transmitted power required except for small percentages of time. Power control, rather than a fixed margin, would be used to compensate for rain attenuation. Interference to other feeder links could increase above the clear sky value.

Use of power control in the latter application to maintain a desired C/N and C/I in the presence of rainfall attenuation clearly has benefits and disadvantages in the case of co-located cross-polarized satellites. On the one hand, C/I is improved when rain occurs on the desired path while on the other hand C/I is degraded when rain occurs on the intefering path. The decrease in C/I due to rain on the wanted path is equal to the rainfall attenuation in the absence of power control. Figures 11 to 13 show that the decrease in C/I due to rain on the interfering path is less than the rainfall attenuation when power control is used. Studies in [CCIR, 1982-86d] verify this result and calculate the difference in degradation of C/I as 4.3 dB in the presence of a 10 dB rain fade, depolarization corresponding to a 10 dB rain fade, and a feeder-link elevation angle of 30°.

The above result offers the possibility that power control might alleviate the adjacent, cross-polarized channel interference problem, associated with co-located satellites. When combined with depolarization control (§ 5.5), power control could further minimize the variation of C/I in the presence of rain.

There are possible disadvantages of the use of power control to minimize degradation of C/I due to atmospheric effects. All feeder-link stations must use power control for the benefits to be realized. Furthermore, control of the interference environment passes from the feeder link on the victim path to the feeder link on the interfering path.

Optimal use of uplink power control requires accurate measurement of the rain attenuation. This is essential to maintain the optimum power flux density at the satellite, thus ensuring optimum operation at the required input. Four methods are possible, each having some inherent difficulties. When uplink power control is to be applied, the method most suited to the particular system requirements should be adopted.

Methods of implementing uplink rain compensation are described in Annex III.

5.5 *Compensation for depolarization*

Compensation for depolarization is the rapid, automatic adjustment of the polarization of feeder-link signals from earth stations to maintain the desired polarization at the satellite receiving antenna under varying atmospheric conditions. Theoretical studies indicate that the cross-polarized component of a circularly-polarized 18 GHz signal might be held 25 dB below the co-polarized component [CCIR, 1978-82g; Fromm and McEwan, 1981; Bradford University, 1981], during both clear-sky and rain (or ice) conditions. This technique could be realized with little additional hardware in the transmitting station.

Depolarization compensation would appear to be of value for feeder links to broadcasting satellites only if power control were employed and then only for co-located satellites. In the event that power control is not used, an increase in interference would only occur for ice depolarization in the absence of rain attenuation on the interfering path. The increase in interference would have to occur at the same time the desired signal is faded to its value at 1% of the worst month for an unsatisfactory C/I to result. The joint probability for the occurrence of both events is smaller than 1% of the worst month.

Only the combined application of feeder-link power control and compensation for depolarization would provide major improvements in C/I for interference-critical feeder links. Studies have shown that such techniques can be introduced at any time with the provision of a suitable earth transmitting station only. There are no implications for the satellite design [CCIR, 1978-82g, Fromm and McEwan, 1981; Bradford University, 1981]. Obviously, earth-station e.i.r.p. levels then need to be raised during adverse propagation conditions above the maximum level used during clear-sky conditions. Another study has demonstrated the compatibility of such a technique with a feeder-link plan which is based on the principle of maximum e.i.r.p. levels for feeder-link transmitting earth stations [CCIR, 1982-86e].

5.6 *Diversity operation of feeder links*

The technique of site diversity to achieve greater availability of satellite links is well documented. Report 564 indicates that the probability of attenuation being exceeded simultaneously at two sites is less than the probability of the same attenuation being exceeded at one of the sites by a factor which decreases with increasing distance between the sites and with increasing attenuation. The relative joint probability is defined as the ratio of the former probability to the latter probability and is plotted in Fig. 15 for attenuations up to 10 dB and site separation up to 25 km on the basis of a log-normal distribution of rain cells [Strickland, 1974]. It is noted that for any given distance between diversity sites, the relative joint probability decreases rapidly with attenuation and remains almost constant for attenuation greater than about 10 dB. This joint probability data is used to illustrate the effect of site diversity on C/N_u and cross-polar C/I_u.

The availability of high values of C/N_u and C/I_u during rain is mainly governed by rain attenuation in the case where it rains at the wanted feeder-link site only. This rain scenario is considered the worst case since both the C/N_u and C/I_u decrease on a dB-per-dB basis during rain. Figure 15 indicates that under these worst-case conditions, the use of site diversity with diversity stations separated by a least 10 km would provide at least a factor of 10 improvement in the availability of high values of C/N_u and C/I_u for attenuation values greater than about 5 dB. In other words, the C/N_u and/or the C/I_u ratios exceeded for 99% of the worst month without site diversity (assuming an attenuation of at least 5 dB) could be made to correspond to an availability exceeded for 99.9% of the worst month by using site diversity with diversity stations separated by at least 10 km. A further improvement in availability by an additional factor of 10 is possible with diversity stations separated by at least 20 km. Clearly, the use of site diversity is most advantageous where the combination of rain rate and elevation angle gives high values of signal attenuation because the relative joint probability decreases to a minimum with increasing attenuation for any given separation distance between diversity stations.

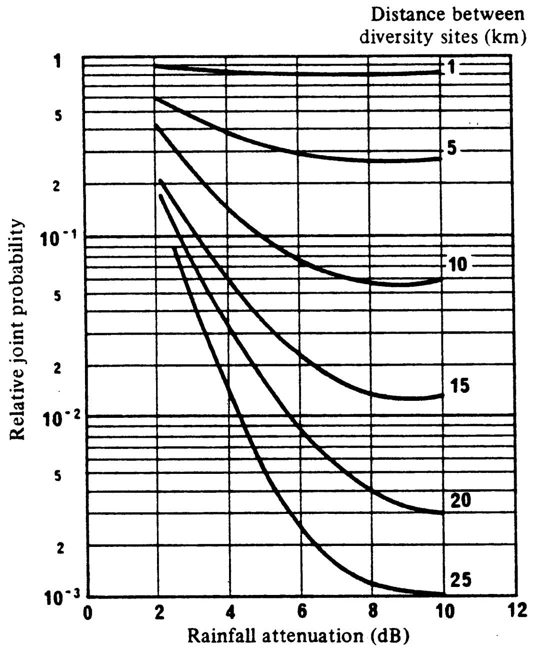

FIGURE 15 – *Relative joint probability of site diversity as a function of rainfall attenuation and distance between diversity sites*

The use of site diversity can only increase the availability of high values of C/N_u and C/I_u relative to the values calculated in a plan which is based on a single feeder-link station. Therefore, the Region 2 Plan permits the use of site diversity in the implementation of feeder links.

Even though the use of site diversity can effectively compensate for the effects of rain and depolarization, the cost and complexity of diversity stations may be significant. The use of diversity for transportable stations is particularly problematic from the standpoint of cost and operational complexity.

6. Satellite receiving antenna characteristics

The characteristics of the satellite receiving antenna are, to a large extent, governed by the type of service envisaged in the BSS. The receiving antenna may be implemented in a number of different ways depending on its system use. They include: separate fixed aperture, separate pointable aperture, common aperture separate feeds and common aperture shared feeds.

Design considerations of satellite antennas are given in Report 558 and, for the aspect of polarization, greater details are given in Report 555.

Report 558 discusses beam shaping methods and Report 810 discusses advances in antenna technology to enable reduction of radiation levels outside the desired service area.

6.1 *Use of the same antenna for feeder link and down link*

From the standpoint of spacecraft cost, complexity and weight, a common transmit/receive antenna would be advantageous. In this case, the cross-polar gain, beamwidth, pointing accuracy and the radiation pattern would be tied to the down-link antenna characteristics. In the case where feeder-link and down-link service areas do not overlap, the WARC-BS-77 reference patterns in Report 810 are applicable for non-shaped beams with circular or elliptical cross section except for degraded cross-polar performance. For shaped beams, the possible new pattern would apply.

When shaped beams are used for overlapping feeder-link and down-link service areas, the feeder link receiver feeds coincide geometrically with the down-link feed clusters and the feeds must be shared. There is a paucity of data for antenna performance across a wide frequency range such as between 12 and 18 GHz. The main problems will be cross-polar performance and side-lobe control. Feeder-link performance is critically dependent on a high value for cross-polarization discrimination. Care will be required in the design of the satellite antenna to avoid a degradation of 3 to 5 dB in cross-polar performance.

In accordance with Reports 558 and 810, consideration should be given to the fact that a particular antenna configuration can be more readily optimized when only one frequency band is involved. When the feeder links and down links are serviced by a common antenna and the frequency bands have a ratio of 1.5 : 1, the resulting minimum gain is about 0.5 dB lower than the optimum value achievable within the service area if separate antennas are used.

6.2 *Use of separate antennas for feeder link and down link*

Separate receiving antennas would offer greater flexibility in terms of independence of the feeder-link frequency, polarization and service area.

A separate, fixed aperture feeder-link antenna is the exact parallel of the down-link antenna, and hence its performance should be identical and the same patterns would apply if the same design care is exercised.

It may be desirable that considerable numbers of small fixed or transportable feeder-link stations operate from a feeder-link service area that is smaller, equal to or even larger than the down-link service area. A separate, pointable satellite receiving antenna would be useful in this case. As an example, for design simplicity, the antenna could be small, say 1.5 m in diameter, and mechanically steerable. However, side-lobe and cross-polar performance could be degraded because of interference caused by the feeds and supporting strut, if a prime focus feed is used. Because of required feeder-link isolation, it is important to use off-set feeds to avoid degradation of side lobes and cross-polarization discrimination to around 25 dB.

6.3 *Antenna size and beamwidth*

The beamwidth of the satellite receiving antenna is determined primarily by the locations of the feeder-link earth stations. At one extreme, there may be only a single fixed earth station, located most often near the centre of the service area but, in some cases, outside the service area. At the other extreme, there may be considerable numbers of small fixed or transportable feeder-link stations operating from any point within the broadcasting-satellite service area or, even in some cases, outside the down-link service area.

Where there is only a single earth station or when earth station locations are confined to a small geographical region, a general study carried out in France for Region 1 [CCIR, 1978-82h] has shown it would be highly advantageous from an interference point of view to use narrow beam satellite antennas, as for example 0.6° beam. Use of such antennas would also tend to reduce earth-station e.i.r.p. by increasing the satellite figure-of-merit G/T. Narrow beam steerable antennas can also be advantageous in improving interference and increasing the satellite G/T.

When there are a number of feeder-link earth stations providing simultaneous feeds from locations throughout, or even outside the down-link service area, as may be the case in multibeam satellite systems for the broadcasting of national programmes from locations inside a country, two cases may be identified:

- if access is to be provided from only one or few known locations, a small service area served by a small spot beam satellite receiver antenna can be planned;
- if the locations of the national transmitters are not known prior to the plan or if access from anywhere within the country is desired, e.g., for transportable terminals, a country-wide feeder-link service area needs to be planned.

The range of interest of the satellite receiving antenna gain at the -3 dB edge of coverage area varies from about 28 dBi for a large country-wide feeder-link beam of $3° \times 8°$ to 45 dBi for a small spot beam of 0.6° diameter.

6.4 *Antenna pointing accuracy*

Under the Final Acts of the WARC-BS-77, the pointing accuracy of the satellite transmitting antenna must be within 0.1°. Pointing accuracy is also important for receiving antennas, particularly those with narrow beams.

A quantitative indication of the effect of relaxing the pointing accuracy requirement on the satellite receiving antenna from 0.1° to 0.2° is provided by a French study [CCIR, 1978-82h]. This study shows that, at least for the WARC-BS-77 Plan, assuming that the position of each feeder-link earth station is at the centre of the corresponding beam in the WARC-BS-77 Plan, an increase in the receiving antenna pointing error from 0.1° to 0.2° does not appreciably worsen the interference situation.

Should only one antenna be used for transmission and reception, the pointing accuracy of 0.1° for the receiving antenna is governed by the Radio Regulations. Where two separate reflectors are used for transmission and reception, one solution is to attach the reflector to the body of the satellite in a manner such that the transmitting antenna can be steered using an automatic pointing mechanism operating by detection of a land radio-frequency beacon. With this precise antenna pointing system, a transmit reflector can be stabilized to within 0.1°.

The pointing accuracy of 0.2° mentioned above can be achieved by using signals from the control system for the transmitting antenna described above [CCIR, 1978-82i].

As the pointing error tolerances are increased, however, antennas with smaller diameters (i.e. larger beam size) become necessary in order to assure service area coverage and this has a deleterious effect on frequency re-use.

Report 558 discusses the effect of pointing accuracy upon variation of gain within a given service area.

It is believed that pointing accuracies of $\pm$ 0.1° in direction and $\pm$ 1° in rotation about the beam axis are readily achievable and may be used for planning purposes. These tolerances would be consistent with the tolerances suggested for the satellite transmitting antenna on the down link.

6.5 *Antenna reference pattern*

If both the transmitting and receiving satellite antennas are based on the same technology, it is desirable that both antennas should have the same reference patterns. With regard to purity of polarization and the side lobes, however, a greater tolerance can be allowed for the receiving antenna. This was shown by several studies carried out by ESA and EBU [CCIR, 1978-82j], by France [CCIR, 1978-82i] and by Japan [CCIR, 1978-82k], which considered interference in a feeder-link plan directly translated from the WARC-BS-77 Plan, assuming the following receiving antenna characteristics:

- the same antenna patterns as established by the WARC-BS-77, both for the co-polar and cross-polar components;
- higher first side-lobe of the co-polar component;
- higher cross-polar component near the beam axis.

These studies show that in the WARC-BS-77 Plan there may not be significant increase in interference resulting from relaxation of the cross-polar component near the beam axis to -33 dB or even -30 dB below on-axis antenna gain. This conclusion is not applicable to Region 2.

As for the co-polar component, a relaxation of up to 10 dB in the region of the first side-lobe may not significantly increase the interference between feeder links in Region 1 and in most feeder links in Region 3, except that at certain orbital positions in Region 3, the worst value of adjacent channel carrier-to-interference ratios may be degraded by 4.2 dB. Even this degradation may not be significant.

In the case of co-located satellites serving common or adjacent service areas on adjacent cross-polarized channels, the purity of polarization may be critical to achieving necessary C/I ratios.

When a fast roll-off or shaped beam antenna has been used for transmitting in order to promote frequency re-use, a fast roll-off or shaped beam antenna may also be needed for receiving. The side-lobe roll-off of the receiving antenna must be rapid to avoid impacting on service area separations needed for frequency re-use.

In the case of the Region 2 planning, done at the RARC SAT-83, the same antenna reference patterns were used for the receiving and the transmitting satellite antennas. These co-polar and cross-polar patterns are described in Report 810.

For Regions 1 and 3, the WARC ORB-88 adopted the characteristics detailed in the following:

6.5.1 *Satellite receiving antenna*

If a common transmitting/receiving antenna is used, the cross-polar gain, beamwidth, pointing accuracy and radiation pattern would be dependent upon the down-link antenna characteristics.

Where separate antennas are used for transmitting and receiving, the parameters of the receiving antenna are given in the following sub-sections. Separate receiving antennas offer greater flexibility in terms of independence of the feeder-link frequency, polarization and service area.

6.5.2 *Cross-section of receiving antenna beam*

Initial planning is to be based on beams of elliptical or circular cross-section. If the cross-section of the receiving antenna beam is elliptical, the effective beamwidth φ_0 is a function of the angle of rotation between the plane containing the satellite and the major axis of the beam cross-section and the plane in which the beamwidth is required.

The relationship between the maximum gain of an antenna and the half-power beamwidth can be derived from the espression:

$$G_m = 27843/ab$$

or:

$$G_m(\text{dB}) = 44.44 - \log a - \log b$$

where:

a and b are the angles (in degrees) subtended at the satellite by the major and minor axes of the elliptical cross-section of the beam.

A minimum value of 0.6° for the half-power beamwidth is adopted for planning, except where an administration requests a lower value for its own beams.

6.5.3 *Co-polar reference pattern*

The co-polar reference pattern is given by the formula:

Co-polar relative gain (dB) (see Fig. 16, curve A)

$$G = -12(\varphi/\varphi_0)^2 \qquad \text{for } 0 \leqslant \varphi/\varphi_0 \leqslant 1.30$$

$$G = -17.5 - 25\log(\varphi/\varphi_0) \qquad \text{for } \varphi/\varphi_0 > 1.30$$

After intersection with Curve C: as curve C (curve C equals minus the on-axis gain).

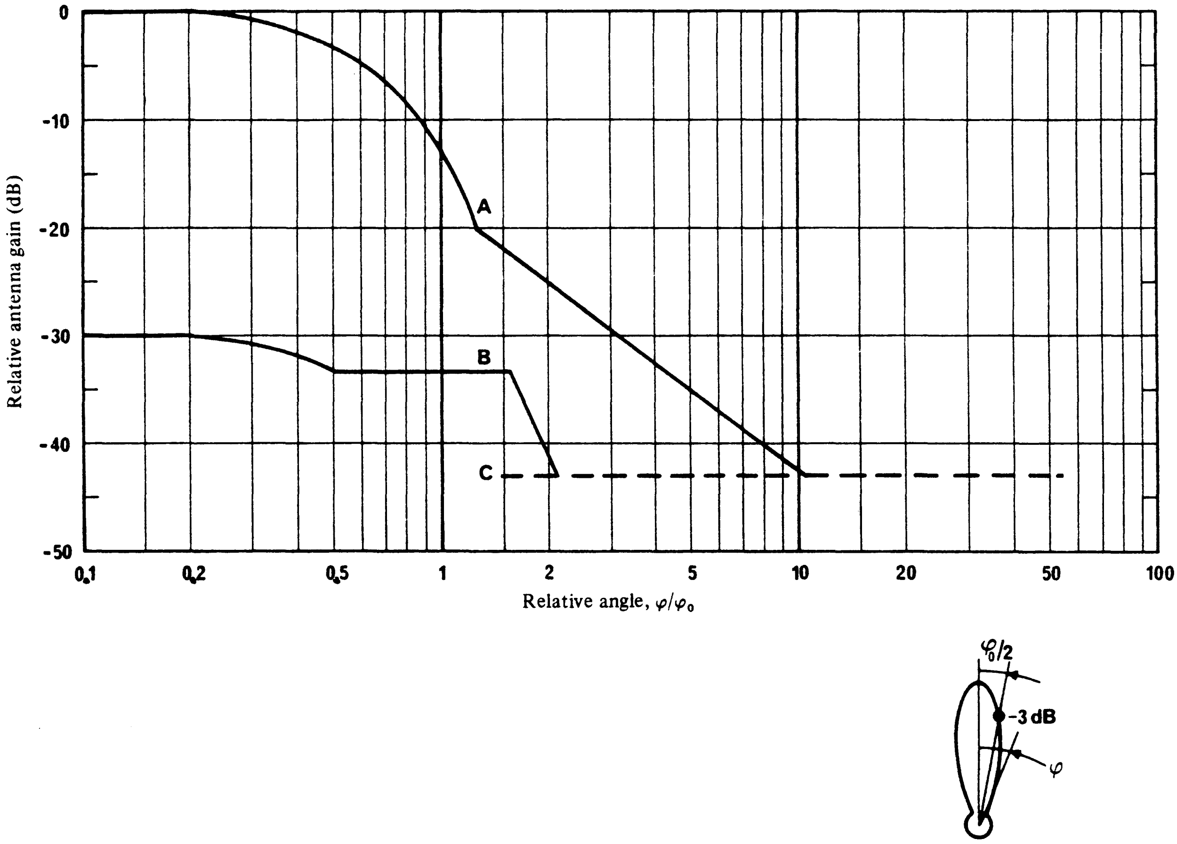

FIGURE 16 – *Satellite receiving antenna reference pattern for Regions 1 and 3 adopted by the WARC ORB-88*

Curves A: co-polar component (see § 6.5.3)
B: cross-polar component (see § 6.5.4)
C: minus the on-axis gain (curve C in this figure illustrates the particular case of an antenna with an on-axis gain of 43 dBi)

Note. – This receiving antenna reference pattern differs from that of the WARC-BS-77 transmitting antenna pattern.

6.5.4 *Cross-polar reference pattern*

The cross-polar reference pattern is given by the formula:

Cross-polar relative gain (dB) (see Fig. 16, curve B)

$$G = -30 - 12(\varphi/\varphi_0)^2 \qquad \text{for } 0 \leqslant \varphi/\varphi_0 \leqslant 0.5$$

$$G = -33 \qquad \text{for } 0.5 < \varphi/\varphi_0 \leqslant 1.67$$

$$G = -\left[40 + 40 \log \left|\varphi/\varphi_0 - 1\right|\right] \qquad \text{for } \varphi/\varphi_0 > 1.67$$

After intersection with curve C: as curve C (curve C equals minus the on-axis gain).

6.5.5 *Use of fast roll-off antennas*

In order to reduce co-polar interference, the pattern shown in Figure 17 has been used for some assignments. This pattern is derived from an antenna producing an elliptical beam with fast roll-off in the main lobe. Three curves for different values of φ_o are shown as examples.

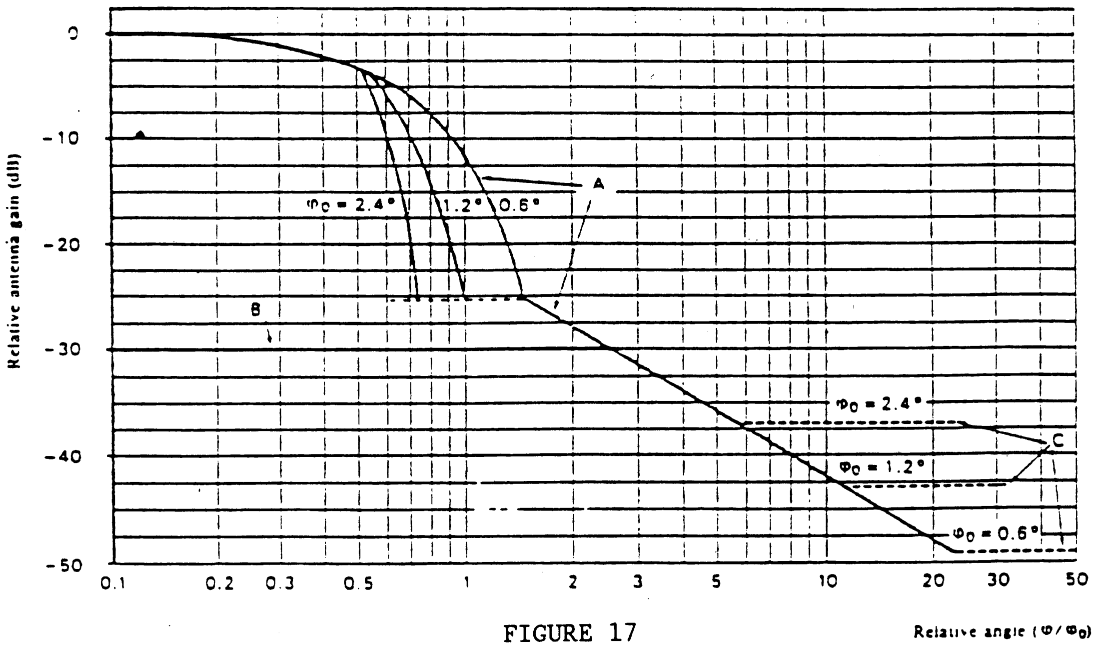

FIGURE 17

<u>Reference patterns for co-polar and cross-polar components for satellite receiving antennas with fast roll-off in the main beam for Regions 1 and 3</u>

Curve A: Co-polar component (dB relative to main beam gain)

$-12\ (\varphi/\varphi_o)^2$ for $0 \leq \varphi/\varphi_o \leq 0.5$

$-33.33\ \varphi_o^2\ (\varphi/\varphi_o - x)^2$ for $0.5 < \varphi/\varphi_o \leq 0.87/\varphi_o + x$

-25.23 for $0.87/\varphi_o + x < \varphi/\varphi_o \leq 1.413$

$-(22 + 20 \log (\varphi/\varphi_o))$ for $\varphi/\varphi_o > 1.413$

after intersection with curve C: as curve C

Curve B: Cross-polar component (dB relative to main beam gain)

-30 for $0 \leq \varphi/\varphi_o < 2.51$

after intersection with curve A: as curve A

Curve C: Minus the on-axis gain (Curves A and C represent examples for three antennas having different values of φ_o as labelled in Figure 17 . The on-axis gains of these antennas are 37, 43 and 49 dBi, respectively).

where φ = off-axis angle (degrees)

φ_o = dimension of the minimum ellipse fitted around the feeder-link service area in the direction of interest (degrees)

$$x = 0.5 \left(1 - \frac{0.6}{\varphi_o} \right)$$

7. Automatic gain control (AGC)

AGC on board spacecraft minimizes the effect of rain fades at the feeder-link station on the down-link *C/N* ratio by keeping the TWTA at saturation. The AGC operates on individual channels and increases the transponder gain of the wanted signal and of any portion of an interfering signal which falls within the filter bandwidth of the wanted channel. Therefore, during rain at the feeder-link station(s) the use of AGC permits the operation of the transponder close to saturation but the ratio of the wanted carrier to the portion of the interfering adjacent cross-polarized carrier which falls into the filter bandwidth of the wanted channel remains constant. Therefore, the use of AGC has no effect on the cross-polar C/I_u of the two feeder links under consideration.

However, the satellite using AGC radiates on the down link a constant level of the wanted signal which is attenuated on the feeder link, but re-radiates on the down link a higher level of the interfering cross-polar signal on the adjacent channel, which is not attenuated when there is no rain on the interfering feeder link. This situation may cause an increase in down-link interference to other systems receiving this re-radiation as co-channel interference. This problem could be significant only for co-located satellites serving common or adjacent service areas.

A limit on the range of AGC, in co-located satellites with cross-polarized channels, to less than 10 to 15 dB may be needed to guard against this problem of re-radiation on the down link. This problem can be reduced if satellites with cross-polarized channels serving the same service area or adjacent service areas are separated by at least 0.3° on the geostationary orbit. Non-co-located satellites with cross-polarized channels need not be subject to this limit of AGC range. A 10 dB limit on AGC range could be insufficient to maintain a constant TWTA output in some rain climates for certain elevation angles. The use of some other mechanism (power control, site diversity) might be required in these circumstances to maintain a constant signal level on the down link.

The Region 2 feeder-link Plan is based on a limit of 15 dB on the dynamic range of AGC on board some cross-polarized spacecraft to guard against this problem of re-radiation on the down link.

8. Choice of polarization for feeder links

The choice of feeder-link polarization affects:

- the possible interference into feeder links operating on the same channel or adjacent channels due to atmospheric depolarization;
- the sharing with other services operating in the same frequency band;
- the design of the satellite antennas and transponder systems.

There are two factors to be determined:

- the type of polarization (i.e., circular or linear);
- the sense of polarization (i.e., same or opposite to that of the down link).

The choice of feeder-link polarization will have to take into account the down-link polarization. The same *type* of polarization for both feeder and down link will normally benefit the satellite antenna design, permitting a less complex and lighter construction.

If the same type of polarization is used for both links, then the relative merits of the sense of polarization depend on the design of the satellite antenna. The use of the same sense of polarization is beneficial to the design of satellite antennas with specially shaped beams, using a multiple feed into a single reflector, and has been adopted in the Region 2 Plan. However, it relies totally on frequency selectivity to provide isolation between the transponder input and output. On the other hand, use of the opposite sense of polarization permits the use of a simple single feed into a common reflector for circular or elliptical beam shapes, and is being assumed in certain proposals for feeder-link plans for Regions 1 and 3. For circular polarization the feed is connected through a polarizer to an orthogonal mode coupler to separate transmitting and receiving paths, giving additional isolation of typically 30 dB, thus easing filtering requirements in the transponder. The latter approach has generally been taken in planning studies conducted in Region 1.

Regarding the effect on sharing with other services, it will be the relatively wide angle side-lobes of co-polar and cross-polar radiation patterns of the earth-station antenna which are important. These will be at about the same level regardless of the type of polarization. Hence, the choice of polarization will make little difference in the interference into terrestrial services and the fixed-satellite service in the space-to-Earth direction.

When satellites are separated by more than about 10°, the type and/or sense of polarization need not be specified for planning purposes.

Feeder-link interference is most critical between co-located or neighbouring satellites serving the same or adjacent coverage areas, thus making the value of the cross-polar discrimination a key parameter value for feeder-link planning. Linearly polarized antennas have better cross-polar discrimination than circularly polarized antennas. Table V gives typical *XPD* values.

TABLE V – *Cross-polar discrimination characteristics, XPD (dB) of feeder-link antennas*

Type of polarization	Antenna	
	Earth-station transmit	Satellite receive
Linear	35	33
Circular	30	27

The CCIR rain model (see Report 564) predicts a very small differential in attenuation between vertical and horizontal polarization for small values of attenuation and increasing to about 1.5 dB differential at 15 dB attenuation. The model also predicts that the attenuation of circularly polarized waves is the median between the attenuation of the vertical and horizontal polarization and that the cross-polar depolarization of true vertical and true horizontal polarization can be up to 15 dB better than that of circular polarization (see Report 814).

8.1 *Rain at one site*

The effect of misalignment β_T on the cross-polar C/I of feeder links is illustrated in Fig. 18 for the case when it rains at the wanted site only. The cross-polar channels are used by the same satellite or another co-located satellite serving an adjacent coverage area. If the coverage areas overlap significantly, the cross-polar channels could suffer up to 3 dB more interference than indicated in Fig. 18. The figure shows that under clear-sky conditions and under rain conditions, circular polarization offers better C/I for any misalignment greater than about 3°. This is illustrated for values of attenuation up to 15 dB. The effect of tilt angle on linear polarization C/I degradation during rain is small as indicated by the similar performance of the vertical and horizontal polarization. This is because the interfering signal is not attenuated or depolarized.

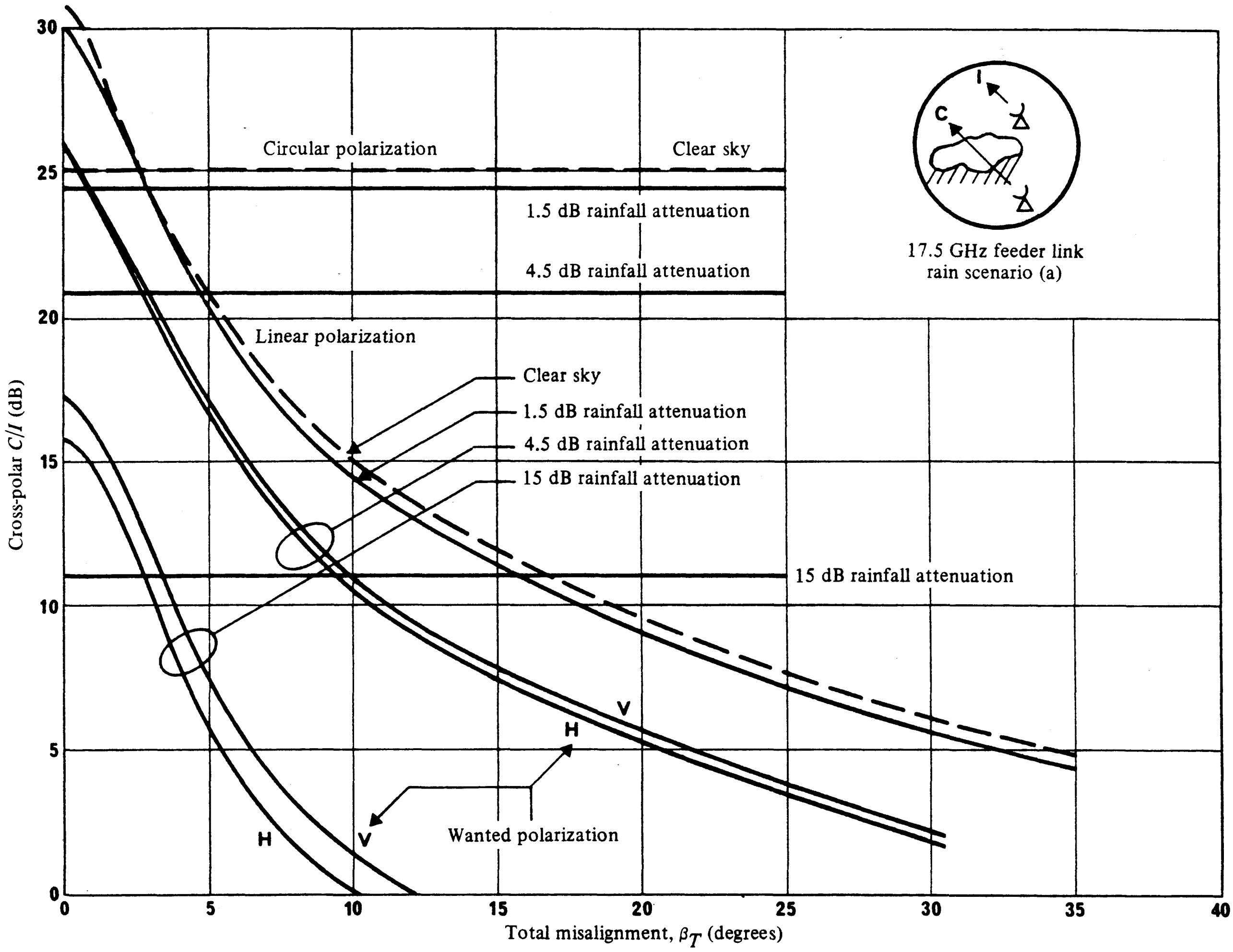

FIGURE 18 – *Cross-polar C/I of feeder links in the presence of rain at the wanted site only*

8.2 *Rain at both sites*

When it rains at both the wanted and the interfering transmitter sites, the combined effects of rain and misalignment on C/I are complicated by the contribution of the depolarization of the interfering signal. This rain scenario is applicable to two nearby feeder-link earth stations transmitting cross-polarized channels to the same satellite or to co-located satellites. The effect of misalignment and tilt angles on linear polarization is illustrated in Fig. 19 for a 4.5 dB attenuation and in Fig. 20 for a 15 dB attenuation (see also Annex I to Report 814).

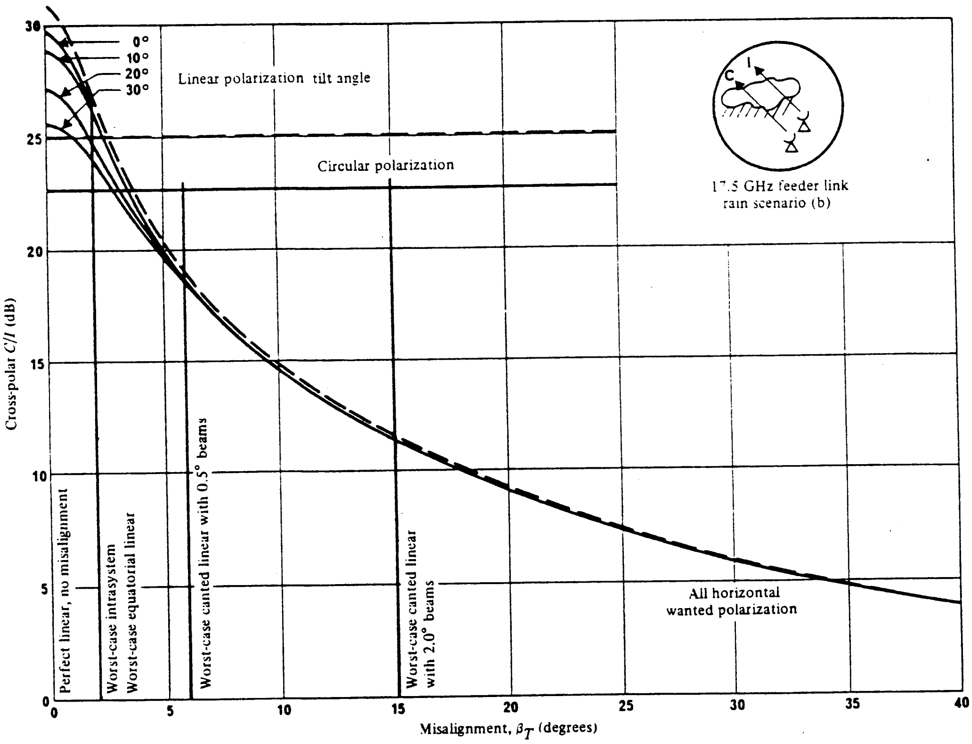

FIGURE 19 – *Cross-polar C/I of feeder links in the presence of 4.5 dB of rainfall attenuation at the wanted and interfering nearby sites*

— — — clear sky
——— 4.5 dB of rainfall attenuation

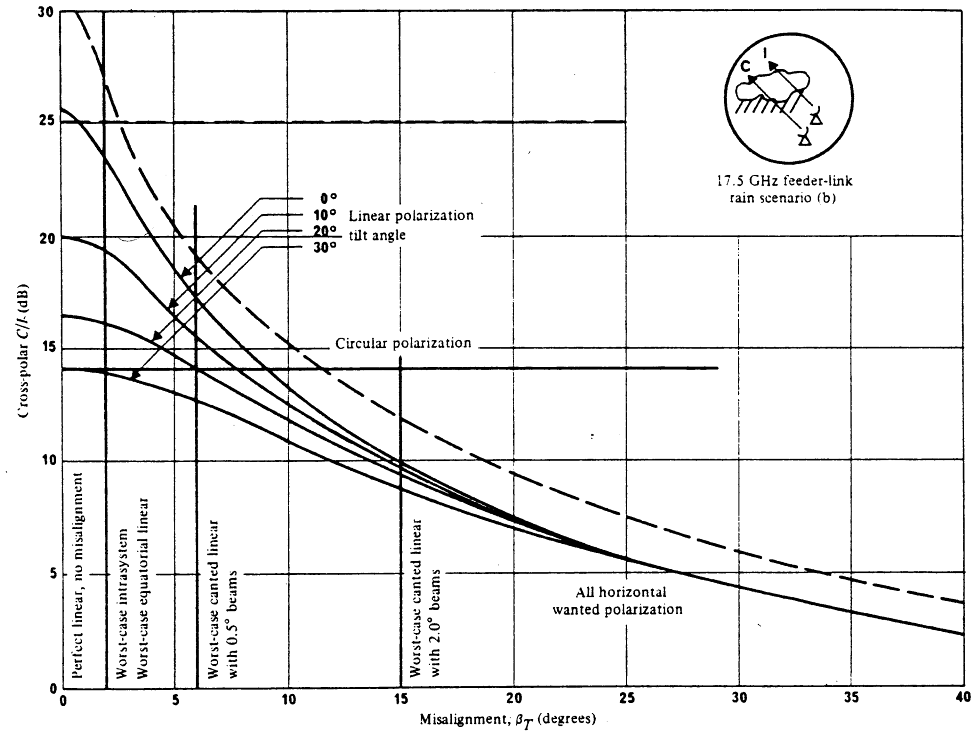

FIGURE 20 – *Cross-polar C/I of feeder links in the presence of 15 dB of rainfall attenuation at the wanted and interfering nearby sites*

— — — clear sky
——— 15 dB of rainfall attenuation

8.3 *Misalignment*

Circular polarization (CP) cross-polar discrimination (*XPD*) is independent of both the rotational alignment of the transmitting and receiving antenna polarizers and the orientation of the local horizontal and vertical vectors. Linear polarization (LP) is capable of better *XPD* than is CP, but only if the rotational alignment of the LP transmitting and receiving antennas is maintained within 2° and the transmitting antenna polarization tilt angle is less than 20°.

For feeder-link service areas up to several hundred kilometres in diameter and satellite elevation angles less than 60° (late eclipse slots and/or non-equatorial service areas), the variation of the tilt angle across each such service area is no more than approximately 20°. For such service areas, the local vertical (or horizontal) LP vector could be defined at the area's centre, or could be off-set somewhat towards a sub-area of heavier precipitation. The rotational alignment of each feeder-link transmitting antenna polarization within the service area could be adjusted, according to the equation in Annex I to Report 814 so that co-linearity with the BSS receiving antenna is achieved. This alignment could be maintained to ± 0.5° on the ground. The satellite antenna rotation tolerance is ± 1.0°. This tolerance could be reduced further, if necessary, by polarization tracking techniques on the satellite.

For larger service areas (for example the contiguous United States), within which the tilt angle varies by many tens of degrees, the 20° tilt angle could be exceeded. The concept of "progressive" linear polarization [Ohm, 1981] provides the theoretical basis for a BSS feeder-link satellite receiving antenna which is not subject to this tilt angle limitation; but until a satellite antenna based on this concept has been successfully demonstrated, this concept should not be used for BSS planning. The same system advantage could be obtained mechanically by using a steerable satellite receiving antenna of very narrow beamwidth (for example 0.5°) which when pointed towards any location visible from the satellite has its polarization vector rotated to be co-linear with local horizontal (or vertical) feeder-link transmitting antennas.

Either the progressive LP method or the polarization method of Annex I to Report 814 would provide adequate *XPD* within a service area served by its satellite cluster. For contiguous or overlapping service areas, only the progressive LP satellite antenna (either mechanical or electrical) would permit a feeder-link transmitter antenna located at the common service area border to be properly aligned as seen from both satellite clusters. However, as discussed in § 4.1, for 5 m feeder-link transmitter antennas, adequate isolation (cross- or co-polar) already exists between satellite clusters at least 10° apart.

9. General planning considerations

Planning of the feeder links can be done simultaneously with planning of the down links or it can take place separately at a later time. Simultaneous planning is discussed in Report 633. This section discusses some features of feeder-link planning that must be considered in either case.

9.1 *Feeder-link frequency*

In general, for a given size of antenna, the higher the frequency the more directional is the satellite receiving antenna and the more the interference decreases. However, propagation effects including depolarization will be more severe the higher the frequencies. According to studies carried out in Japan [CCIR, 1978-82l], in practice, as far as the worst carrier-to-interference ratios are concerned, there is little difference between the two feeder-link systems using the frequency bands 14 GHz and 17 GHz.

9.2 *Antenna location and size*

In planning the feeder links to broadcasting satellites, the operational requirements of the broadcasting-satellite service should be taken into account. The capability of feeding a television programme directly to a broadcasting satellite from locations where there is no practical means to transmit the signal to the permanent transmitting earth station is of major importance, particularly in the case of large or mountainous service areas. The use of relatively small and transportable earth stations for feeder links to broadcasting satellites should be considered under this light.

The broadcasting-satellite systems of small countries may have a single feeder- and down-link beam. Access to the satellite system may be derived from one or a few locations or from anywhere within the country. If the locations are known in advance of the plan, feeder-link service areas smaller than the down-link service area may be planned and the satellite may be equipped with a spot beam receiving antenna. If the locations of the earth stations are not known in advance of the plan, or if access from anywhere within the down-link service area using small transportable terminals is desirable, a country-wide feeder-link service area needs to be planned.

Geographical considerations (e.g., time zones) in a country and/or cultural diversity of its population may dictate the requirement of multiple down-link beams. In this case, the feeder-link antenna for each beam may be either located inside each respective down-link service area, located at specific locations inside the country, or located anywhere inside the country. If it is desired to locate the earth station only inside each respective down-link service area, coincidental feeder-link and down-link service areas may be planned. However, programmes originating from outside the down-link service area for broadcasting inside the down-link service area may need to be distributed via terrestrial systems or via fixed satellites.

If it is desired to locate the earth station anywhere inside a country served by several beams, direct access to the broadcasting satellite may be achieved with the planning of a country-wide feeder-link service area. Programmes originating from outside the down-link service area would directly access the broadcasting satellite using the planned feeder-link frequency bands.

Planning of feeder links based on one size of earth station and a maximum transmitting power value would result in greater homogeneity between feeder links. For a given antenna size and a given co-channel protection ratio, there is an orbital separation beyond which the interference from unwanted feeder-link stations becomes negligible and need not be considered in the planning of feeder links. As an example, for a 5 m antenna diameter and a side-lobe envelope meeting the $29 - 25 \log \varphi$ (dBi) reference pattern, the satellites have to be separated by at least 7.5° to attain an isolation of 40 dB in the presence of 10 dB differential rain attenuation to permit frequency re-use. In this example, co-polar transmissions are assumed, no satellite receiving antenna discrimination is considered, and the feeder-link stations are located in the same service area.

In the case where the two co-channel transmissions are cross-polar, a smaller orbital separation is required since part of the 40 dB isolation is provided by the polarization discrimination of the transmitting earth-station antenna and the satellite receiving antenna. Similarly, if the feeder-link service areas are not adjacent, the satellite receiving antenna can provide for a portion of the 40 dB protection ratio because of the angular separation. The required orbital separation can consequently be reduced to the point where the satellites are almost co-located.

In the case of interference from the adjacent channel, the required orbital separation is further reduced compared to the respective cases mentioned above since there is typically 16 dB less isolation required in this case. A particular case is dealt with in § 9.4 where it is found that the required orbital separation for cross-polar adjacent channels transmitted from the same service area under a 10 dB rain fade differential is only a fraction of a degree. This concept was extensively used in the planning of the feeder links in Region 2.

Because of the relatively larger size of the earth-station transmitting antenna, the required isolation will, in normal conditions, be reached on the feeder links for smaller orbital and/or service area separation than that required for the down links except when the feeder-link service area is larger or outside the corresponding down-link service area.

In the feeder-link Plans for Regions 1 and 3 and for Region 2, a nominal 5 m antenna diameter was found to be attractive and was used for planning. In addition to completely decoupling feeder links for satellites separated by about 10°, 5 m was found to be within the range of sizes that can be considered for transportable applications. Further, the required transmitted power for a viable feeder link was found to be readily achievable. Smaller antennas to a minimum of 2.5 m diameter were allowed in the Plans and were considered in the development of the antenna reference pattern (see § 5.2) such that their use will not increase the level of interference to other feeder links as calculated in the Plans. In satellites separated by more than 0.55°, no additional interference can result from use of 2.5 m antennas. It is understood, however, that with the use of these smaller antennas, lower C/N and C/I values will be realized than with the antenna size used as the basis for planning.

9.3 *Transmitted power*

In order to avoid excessive interference into adjacent satellites and into terrestrial services and because of the fact that off-axis feeder-link antenna side-lobe envelopes are defined in terms of absolute gain relative to an isotropic source and in order to simplify feeder-link planning, a maximum allowable power into the antenna of a broadcasting-satellite feeder link is found to be the most appropriate way of specifying the interference characteristics of the feeder-link transmitting station along with the antenna reference pattern. This maximum power limit would apply for all conditions and all antenna sizes.

Another benefit of setting a limit on the feeder-link transmitted power is that, if the planning is done with a nominal antenna size, the principle of homogeneous PFD at the orbit applies, giving the best utilization of the spectrum orbit resource. It should be noted however, that inhomogeneity of e.i.r.p. is dependent only on the difference in transmitted power, not on antenna gain, when satellites are separated by more than a fraction of a degree.

9.4 *Co-located satellites*

The most critical cases of feeder-link interference occur when satellites are co-located. As discussed in § 4.6, two situations are found in practice:

– the co-located satellites use the same channel but are cross-polarized to each other and their service areas are separated; and

– the co-located satellites have common or adjacent service areas and operate on cross-polarized adjacent channels.

Several methods for coping with low C/I ratios are available but all have an associated penalty. Site diversity combined with uniform feeder-link e.i.r.p. could be used at high cost and operational inflexibility. Degraded interference performance could be accepted for the small percentages of time associated with high precipitation losses. Power control combined with depolarization compensation is a potential solution but these techniques have not yet reached an adequate level of development.

When the channels are adjacent, there are several additional methods which might be used. Channel spacing could be increased at the cost of fewer total TV channels. Bandwidths of each channel could be reduced but with adverse impact on applications, such as high definition TV, requiring wide bandwidths.

Another solution to reduce interference would be to separate co-located satellites by a small orbital arc. This approach was adopted to develop the Region 2 feeder-link Plan and is described below.

Other factors that need to be considered when satellites are co-located are the probability of collision and potential interference on the spacecraft service function links.

9.4.1 *Satellite clusters and reduction of interference*

A satellite cluster as defined by the RARC SAT-83 in the Region 2 Plan is formed by satellites at two orbital positions which are separated by 0.4° in the Plan and which are assigned cross-polarized adjacent channels at each of the two orbital positions. Because of the other methods available to combat feeder-link interference between cross-polarized first adjacent channels, it was felt that significant flexibility in the orbital positioning of satellites was needed at the time of implementation. In the Region 2 Plan, satellites sharing the same cluster can be located at any position within the 0.4°-wide cluster with the agreement of the other administrations sharing the same cluster of satellites. Under these conditions, the optimum orbital separation between satellites can be chosen at the time of implementation and depends on:

– rain climatic zone,
– elevation angle,
– earth-station antenna diameter, and
– site diversity.

The RARC SAT-83 adopted a minimum separation of 0.9° between the centres of satellite clusters in the Plan.

9.4.2 *Collision probability*

Still another advantage to separating "co-located" satellites derives from a reduction in the probability of collision. Using the method of caculation given in [Hechler and Van der Ha, 1980], the probability of collision increases from 9×10^{-7} per year to 5×10^{-5} per year as the number of satellites, each with 100 m^2 cross-section and sharing the same 0.1° arc, increases from 2 to 12. While there would still be a 99% probability of no collision in about 200 years, the probability of any collision on the geostationary orbit would increase significantly if satellites were exactly co-located at many positions on the orbit. Once a collision occurs, secondary debris significantly increases the probability of additional collisions. It may, therefore, be preferable to minimize the risk of collision by slightly separating "co-located" satellites.

9.4.3 *Interference on spacecraft service function links*

A small orbital separation between satellites may also be used to maintain interference levels into satellite TTC channels at an acceptably low level.

The frequency separation between the limit of the television channel at the band edge and the nearest TTC channel will be of the order of 2 MHz and the television channel satellite emission roll-off is assumed to be 2 dB per MHz with typical filtering.

Isolation between the television channel at the band edge and TTC channels due to the television channel filter can be as low as 4 dB and as great as about 23 dB in the case of 12 MHz wide guard bands. Transmission of TTC channels in opposite polarization to the television channel at the band edge would increase the isolation to the 25-44 dB range under clear-sky conditions and to the 15-34 dB range in the presence of 10 dB rain attenuation on the wanted path. Nominal separation of "co-located" satellites would increase the isolation and provide flexibility in the choice of polarization for TTC channels.

9.4.4 *Method to resolve incompatibilities in the feeder link Plans*

After planning of feeder links, some cases of incompatibility may remain. The concerned administrations, after coordination, could use the following means to settle these situations. The interfering station could transmit at a lower power than the nominal value under clear sky conditions while keeping sufficient quality and an acceptable interference level. In the presence of rain attenuation, the interfering station would be allowed to increase its e.i.r.p., which could decrease the *C/I* ratio on the link subject to interference, but not below the limit given in the plan.

9.5 *Frequency translation*

For Region 2, the feeder-link Plan has been based on the use of a single frequency translation between the 17 GHz feeder-link channels and the 12 GHz down-link channels.

WARC-ORB(88) generally accepted for Regions 1 and 3 (in the 17.3 to 18.1 GHz band) the principle of a single translation frequency (5.6 GHz) except for the cases where it was necessary to resolve incompatibilities in the Plan.

As the maximum available bandwidth for the feeder-link band 14.5-14.8 GHz is only 300 MHz as against 800 and 500 MHz in the down-link Plan for Regions 1 and 3, respecitvely, several translation frequencies where selected allow any channel in the Plan to be used. Consequently, a particular feeder-link channel was assigned to several BSS Plan channels simultaneously.

For the feeder-link band 14.5-14.8 GHz, 14 channels and 2 appropriate guard bands should be assumed.

Selection of translation frequencies for this purpose and for this band is a complex task due to two domains within the possible range of translation frequencies which would create spurious mixing products within certain channels. Therefore, it is necessary to optimize the translation frequencies. Ratios of translation frequency to any frequency within the necessary bandwidth of a feeder-link channel to be avoided are 1/6 and 2/11.

The following parameters shall be used for planning feeder links in the frequency band 14.5-14.8 GHz:

Necessary bandwidth of a channel:	27 MHz
Channel separation:	19.18 MHz
Number of channels:	14
Centre frequency of the lowest channel (1):	14 525.30 MHz
Centre frequency of the highest channel (14):	14 774.64 MHz
Lower guard band:	11.80 MHz
Upper guard band:	11.86 MHz

Translation frequencies:

a) for BSS channels 1 to 14	2 797.82 MHz
b) for BSS channels 15 to 28	2 529.30 MHz
c) for BSS channels 29 to 40	2 260.78 MHz

Table VI indicates the correspondence between the channel numbers, the frequencies assigned to the feeder links and the frequencies assigned in the WARC-BS-77 Regions 1 and 3 Plan, for the three translation frequencies.

TABLE VI – *Table showing correspondence between channel numbers and assigned frequencies for the feeder links in the frequency band 14.5-14.8 GHz and the relationship to the BSS Regions 1 and 3 Plan assignments*

Feeder-link assignments		Translation frequencies (MHz)					
		2 797.82		2 529.30		2 260.78	
		BSS Regions 1 and 3 Plan assignments					
Channel No.	Frequency (MHz)	Channel No.	Frequency (MHz)	Channel No.	Frequency (MHz)	Channel No.	Frequency (MHz)
1	14 525.30	1	11 727.48	15	11 996.00	29	12 264.52
2	14 544.48	2	11 746.66	16	12 015.18	30	12 283.70
3	14 563.66	3	11 765.84	17	12 034.36	31	12 302.88
4	14 582.84	4	11 785.02	18	12 053.54	32	12 322.06
5	14 602.02	5	11 804.20	19	12 072.72	33	12 341.24
6	14 621.20	6	11 823.38	20	12 091.90	34	12 360.42
7	14 640.38	7	11 842.56	21	12 111.08	35	12 379.60
8	14 659.56	8	11 861.74	22	12 130.26	36	12 398.78
9	14 678.74	9	11 880.92	23	12 149.44	37	12 417.96
10	14 697.92	10	11 900.10	24	12 168.62	38	12 437.14
11	14 717.10	11	11 919.28	25	12 187.80	39	12 456.32
12	14 736.28	12	11 938.46	26	12 206.98	40	12 475.50
13	14 755.46	13	11 957.64	27	12 226.16	–	–
14	14 774.64	14	11 976.82	28	12 245.34	–	–

9.6 *Total needed bandwidth for feeder links*

Values derived from studies for the feeder-link/down-link bandwidth ratio vary from 1:1 to 1.5:1 depending on the assumed feeder-link characteristics [CCIR, 1978-82m]. Values below 1:1 are not reasonable, mainly because they imply signal processing repeaters in the satellite, making it more complex, costly and more prone to failure.

9.7 *Independence between orbital locations in the Regions 1 and 3 Plan*

Studies in France [CCIR, 1978-82n, o] showed that, for the 6° spacing of Regions 1 and 3 it is possible to plan independently for each orbital position with alternate polarization from one orbital position to the next, and from one channel to the next under the following hypotheses:

- diameter of earth station antennas: at least 3 m;
- antenna pattern and beamwidth for receiving and transmitting satellite antenna the same as in the WARC-BS-77 Plan;
- protection ratios: co-channel 40 dB, adjacent channel 24 dB;
- translation of the WARC-BS-77 Plan;
- essentially the same power flux-density at the satellites;
- polarization discrimination of 30 dB in the side lobes;
- the various earth stations are each situated in the centre of the corresponding down-link beam;
- rain-induced depolarization is taken as −20 dB.

Further study is required with respect to other planning hypotheses for Regions 1 and 3.

9.8 *Service area considerations, impact on frequency re-use*

As indicated above there are several reasons why it may be advantageous to consider a feeder-link service area that may be different from the corresponding down-link service area(s). From an interference point of view there are advantages to narrow feeder-link beams located near the respective centres of the corresponding down links [CCIR, 1978-82h]. Such a scenario might, however, constrain operational flexibility. In some situations operational requirements may dictate simultaneous access to several satellites at various locations or to several down-link beams from the same orbital location. Feeder-link transmissions could emanate from a single location which may or may not be in one of the down-link areas, or from anywhere within a number of down-link areas [Bouchard, 1982]. This would apply for example to a large country or to a grouping of administrations which of necessity must be fed by multiple down-link beams. In these latter situations the ability to re-use a frequency allotment need not be constrained by the feeder-link plan if technical criteria are developed to guard against feeder-link interference.

Frequency re-use capability can be expressed in terms of the required orbital separation between the satellites of the interfering systems as a function of the separation between the respective service areas for the four combinations of co- and adjacent channel and co- and cross-polarity. In the case of large countries which are served by several adjacent down-link beams and where there are requirements for country-wide access to each of these beams, frequency re-use may be constrained when the dimension of the feeder-link service area is significantly greater than the dimension of any of the down-link beams under certain combinations of:

- orbital separation,
- feeder-link earth station antenna diameter,
- inhomogeneities between feeder links, and
- feeder-link protection ratio [CCIR, 1978-82p].

However, appropriate values of these parameters can always be chosen to ensure that the frequency re-use capability of the feeder links is at least equal to or greater than that of the down link.

An integrated planning approach for the feeder links and the down links is therefore necessary to support the planning of a feeder-link service area different from the down-link service area. The simultaneous planning of both feeder links and the down-links at the RARC SAT-83 make this approach possible. A study was performed in Canada assuming the following technical parameters:

- side-lobe reference pattern of the feeder-link transmitting antenna: $32 - 25 \log \varphi$, dB;
- radiation pattern of the satellite receiving antennas: the same as that given in the Final Acts of WARC-BS-77 for the satellite transmitting antenna;
- feeder-link protection ratios: in the range of 35 to 45 dB;
- down-link protection ratio: 35 dB single entry;
- channel bandwidth: 18 MHz;
- channel spacing: in the range of 13 to 17 MHz.

Assuming a transmitting antenna diameter of 8 m for feeder links having inter-system inhomogeneities of 8 dB, co-channel protection ratio of 40 dB and adjacent channel protection ratio of 20 dB, the study has shown that the planning of country-wide feeder-link service areas is possible provided that the multi-beam satellites of large countries and the satellites of their neighbouring countries are:

- spaced more than 6° apart when co-channel co-polar allotments are intended for feeder links from anywhere within the countries;
- spaced more than 1° apart when adjacent channel co-polar or co-channel cross-polar allotments are intended for feeder links from anywhere within the countries.

These conclusions apply for both country-wide satellite receiving antennas and steerable spot beam satellite receiving antennas.

10. Sharing in the feeder-link bands

10.1 *General*

As a result of allocation actions taken by the WARC-79, the use of the frequency bands shown in § 2 of this Report by the fixed-satellite service (Earth-to-space) is limited to broadcasting-satellite feeder links (RR footnote Nos. 835, 863, 869).

The subject of frequency sharing between feeder links to broadcasting satellites and other services is discussed in Report 561.

The band 17.3-18.1 GHz is one of the bands chosen by the WARC ORB-85 for planning feeder links in Regions 1 and 3. The lower part of that band, 17.3-17.8 GHz, has been planned for feeder links in Region 2 (RARC SAT-83). This section provides information regarding the several sharing situations that will exist in the 17.7-18.1 GHz portion of this band. Sharing situations with the attendant possibility of interference will involve feeder links to broadcasting satellites, the fixed service and the fixed-satellite service in all Regions [CCIR, 1982-86f].

Some cases of sharing are under consideration in Study Groups 4 and 9.

10.2 *Sharing situations in the band 17.7-18.1 GHz*

The sharing situations that will exist in the band segment 17.7-18.1 GHz are shown in Fig. 21. Since the allocations to the three services are world-wide, interference is possible between BSS feeder links and the fixed and fixed-satellite services in all Regions. The severity of interference and interference reduction techniques for each of the cases indicated in Fig. 21 will be outlined in the sections that follow.

10.2.1 *Interference from FSS space-station transmitters to BSS space-station receivers*

Interference from FSS space-station transmitters can reach BSS space-station receivers in two ways (cases 1A and 1B, Fig. 21). One way is from the side lobes of the FSS space station transmitting antenna into the side lobes of the receiving antenna of a nearby BSS space station. The second way is from the main beam of an FSS space-station transmitting antenna into the main beam of the receiving antenna of a nearly antipodal BSS space station.

10.2.1.1 *Nearly co-located FSS and BSS space stations (case 1A)*

Interference from an FSS space station to a nearby BSS space station will be negligible unless the satellites are extremely close to each other due to the fact that the interference is transmitted and received in the far side lobes of both antennas. Small satellite separations of the order of 0.1°, i.e., separations of about 74 km, provide sufficient signal attenuation (space loss) to reduce interference to negligible levels.

10.2.1.2 *Nearly antipodal FSS and BSS space stations (case 1B)*

If an FSS and BSS space station are nearly antipodal, interference could occur in rare cases. Typically, the existence of planned BSS satellites should have a negligible constraint on the location of FSS satellites. However, some care may be required when the inter-satellite separation is in the range of 160° to 162.5°.

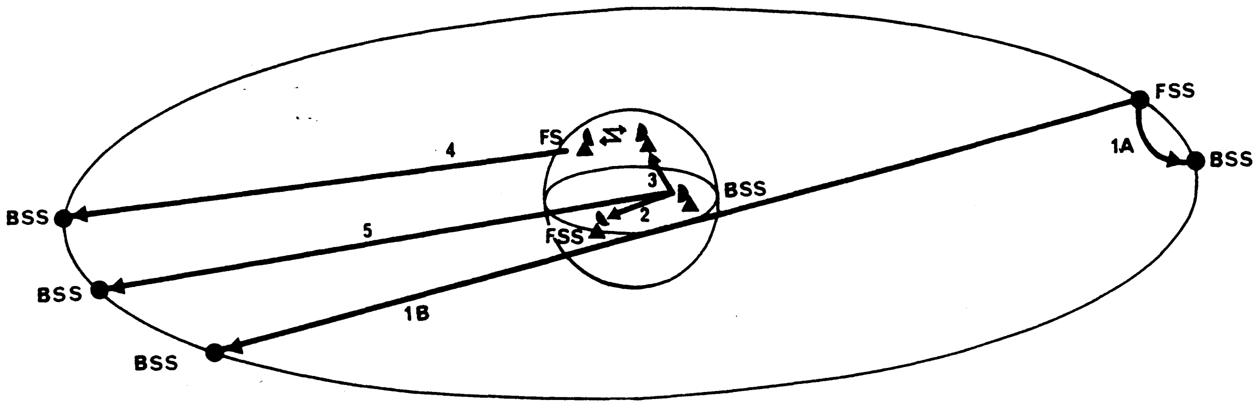

FIGURE 21

Case	*From*	*To*	*Comments*
1A	FSS (S-E)	BSS, nearby satellite	Small satellite separations will reduce interference to acceptable levels
1B	FSS (S-E)	BSS, antipodal satellite	Rare situation; Appendix 29 (increase of ΔT of 10% in Region 2)
2	BSS feeder link	FSS, receiving earth station	Appendix 28 type coordination procedure should apply
3	BSS feeder link	FS, receiver	Appendix 28 type coordination procedure should apply
4	FS transmitter	BSS, satellite receiver	Rare situation, but see Recommendation No. 4 (RARC SAT-83)
5	BSS feeder link in one Region	BSS, satellite receiver in another Region	Appendix 29 type coordination (increase of ΔT of 10% in Region 2)

10.2.1.3 *Cases 1A and 1B in Region 2*

The RARC SAT-83 (Part II, Annex 4, Section 1 of the Final Acts) applied Appendix 29 to this situation, but changed the criterion that triggers coordination to a 10% increase in ΔT. In the case of nearly antipodal satellites, Appendix 29 coordination is required only when the PFD at the limb of the Earth exceeds -123 dB(W/(m^2 · 24 MHz)), and geocentric satellite separation is more than 150°.

10.2.2 *Interference from a BSS feeder-link transmitter to an FSS receiving earth station*

Interference can be caused from a BSS feeder-link transmitter (the Earth-to-space direction of transmission) to the receiver of an FSS earth station (employing the same frequency band segment in the space-to-Earth direction of transmission) (case 2, Fig. 21). The extent of potential interference can be determined employing an adaptation of the interference calculation procedures described in Reports 557, 382, 388 and 448. Separating the two stations or siting them so that there is sufficient shielding due to terrain or artificial barriers can reduce the likelihood and level of interference to permissible values.

The RARC SAT-83 applied Appendix 28 coordination to this situation (Final Acts, Part II, Annex 4, Section 3), modified to take account of earth-station characteristics and propagation conditions in this band segment.

10.2.3 *Interference from a BSS feeder-link transmitter to a fixed-service receiver*

Interference can be caused by BSS feeder-link transmissions into the receiver of a fixed-service terrestrial station (case 3, Fig. 21).

Determination of the coordination area around the feeder-link transmitting earth station and fixed-service receivers, where these contours are in different countries, should be based on Appendix 28 to the Radio Regulations. Report 382 provides a related, although not identical, procedure reflecting the most recent, albeit in some instances at present, provisional propagation data of Reports 724, 563 and 569. More detailed interference calculation methods of Reports 448 and 388, mentioned above, can also be used in this interference situation to estimate the level of interference expected. Adequate physical separation of the stations, or the use of natural or artificial shielding can reduce interference to permissible levels as in the previous interference situation. Part II, Annex 1, Section 3 of the RARC SAT-83 Final Acts reaffirms Appendix 28 to the Radio Regulations as the way to determine if a terrestrial station could be affected.

10.2.4 *Interference from a fixed-service transmitter to a BSS space-station receiver*

Interference can be caused in certain rare cases by transmissions from a terrestrial station in the fixed service into the receiver of a BSS space station (case 4, Fig. 21). As in the interference situation described in §10.2.1.2, the BSS space-station receiving antenna must have significant gain in the direction of the limb of the Earth. There may be many terrestrial stations in the 17.7-18.1 GHz band segment eventually, and their antennas are typically pointed within a degree or so of the horizon. More potential interference situations may exist, therefore, than for the antipodal satellite case described in § 10.2.1.2. However, interference can be caused only if the fixed-service station employs the maximum permissible e.i.r.p. of 55 dBW towards the geostationary orbit and uses transmission bandwidths not significantly greater than those used by the BSS feeder link. Given the typical channelization plans for the fixed service in this band, and the e.i.r.p.s now in use, it is considered that this interference situation will be rare. However, the RARC SAT-83 adopted Recommendation No. 4 which asks the CCIR to continue its study of this situation on an urgent basis in time for consideration by the WARC ORB-85.

10.2.5 *Interference from BSS feeder-link stations in one Region to BSS satellite receivers in another Region*

Interference can be caused to broadcasting-satellite space-station receivers of one Region from feeder-link transmissions of another Region (case 5, Fig. 21). Interference within a Region is limited or prevented by the development of the respective regional plans, and by the modification procedures incorporated in each. Part II, Annex 4, Section 2 of the RARC SAT-83 Final Acts applied Appendix 29 to limit interference from Regions 1 and 3 feeder links (to be planned at the WARC ORB) to Region 2 BSS satellite receivers using an increase in ΔT of 10% as a coordination trigger.

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[1978-82]: **a.** 10-11S/43 (Canada); **b.** 10-11S/159 (EBU); **c.** 10-11S/175 (Canada); **d.** 10-11S/151 (France); **e.** 10-11S/118 (Japan); **f.** 10-11S/158 (EBU); **g.** IWP 10-11/1-25; **h.** 10-11S/127 (France); **i.** 10-11S/152 (France); **j.** 10-11S/9 (EBU); **k.** 10-11S/129 (Japan); **l.** 10-11S/21 (Japan); **m.** 10-11S/120 (IWP 10-11/1); **n.** 10-11S/67 (France); **o.** 10-11S/128 (France); **p.** 10-11S/148 (Canada).

[1982-86]: **a.** 10-11S/12 (France); **b.** 10-11S/24 (USA); **c.** 10-11S/134 (Japan); **d.** 10-11S/27 (USA); **e.** 10-11S/36 (ESA); **f.** 10-11S/25 (USA).

[1986-90]: **a.** 10-11S/105 (Japan), **b.** 10-11S/22 (Japan)

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ANNEX I

FEEDER-LINK TRANSMITTING ANTENNA SIDE-LOBE CHARACTERISTICS

RESULTS OF MEASUREMENTS

This Annex gives the results of some measurements on antennas of a type suitable for the feeder-link transmission to broadcasting satellites.

An 8 m Gregorian type antenna built in 1979 was measured in Canada. The measurement data are shown in Fig. 22. This linearly polarized antenna was optimized for high performance for transmit/receive operation at 14/12 GHz. The efficiency was found to be 78%. The results are given for three frequencies in each band (edges and centre of the band) and two azimuthal profiles (E and H planes). This antenna which is understood to be representative of the new generation of antennas meets the 29 – 25 log φ side-lobe envelope. It is likely that the feeder-link antennas which will need to be optimized for only one frequency band will also meet this envelope at 17 GHz.

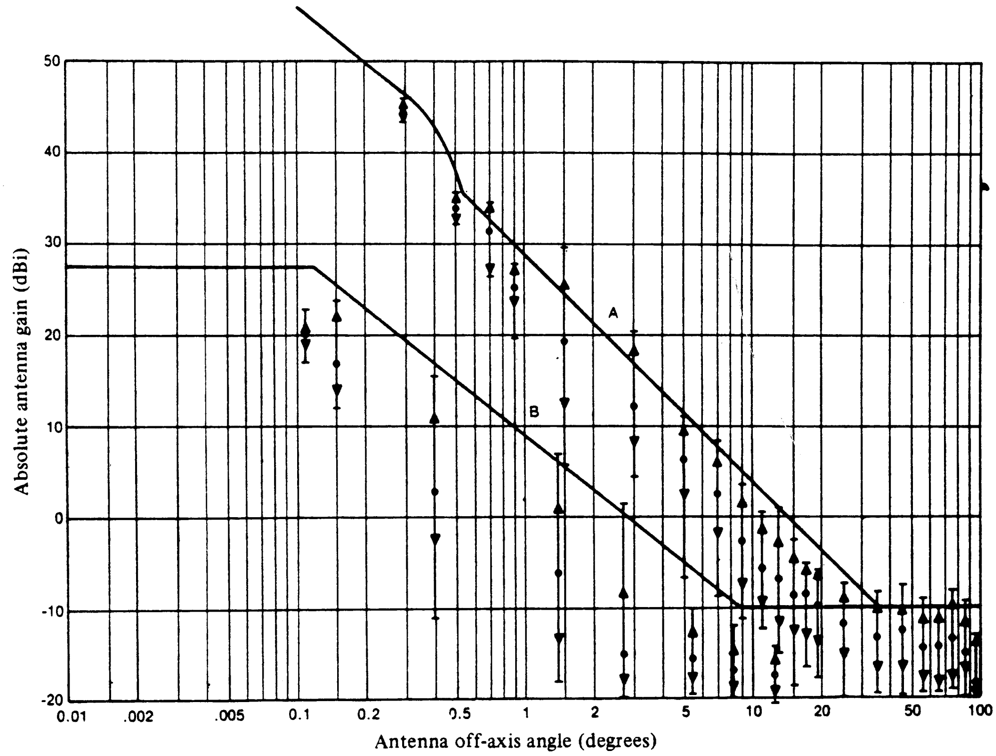

FIGURE 22 – *Measured co-polar and cross-polar patterns of an 8 m Gregorian antenna at 14/12 GHz*

Curves A: co-polar component

B: cross-polar component

: Upper limit
: Upper 10% point
: Median point
: Lower 10% point
: Lower limit

ANNEX II

OPERATIONAL AND TECHNICAL CHARACTERISTICS
OF FEEDER LINKS

1. Introduction

The feeder link Plan and the associated provisions for the 12 GHz BSS were established for Regions 1 and 3 at WARC-ORB(2) in 1988. When further studying the technical characteristics of the feeder links for optimal operation, additional information, based on actual operating conditions is required, particularly in overcoming the problems of heavy rain attenuation, and in increasing the effectiveness of transportable earth stations.

2. Feeder link operation in rainy conditions

The feeder link for the Japanese broadcasting satellite (BS-2), in use since 1984, operates in the band 14.0 - 14.5 GHz. Almost all of the TV programmes are transmitted from the main earth station, but transportable and secondary earth stations are occasionally used for various other purposes.

Table VII shows the technical characteristics, purposes and uses of the NHK earth stations in the BS-2 satellite broadcasting system.

The main earth station uses an 8 m antenna with a nominal e.i.r.p. of 80 dBW under clear sky conditions to obtain a feeder link C/N of about 30 dB. When rain attenuation on the feeder link is within the range of 3 dB to 6 dB, the e.i.r.p. is increased by 3 dB (Step 1), and when it exceeds 6 dB, the e.i.r.p. is increased by 6 dB (Step 2).

The main earth station makes it a practice to be ready at all times to switch to back-up operation, making effective use of meteorological data and other information from a wide variety of sources,such as near and long range radars, lightning detectors, local rainfall data and weather information, also data from direct observation of the sky.

At present, the secondary earth stations are located several hundred kilometres away from the main earth station. However, in order to ensure secure back-up operation, another earth station for site-diversity use is scheduled to be built about 50 km away from the main earth station, which will be linked by a terrestrial link suitable for carrying television programme transmissions.

Figure 23 shows an example of comparatively small rainfall attenuation, which can be compensated for by the Step 1 and Step 2 operations.

Figure 25 gives an example in which a thick thundercloud, of sufficient size to darken the area even at mid-day, approaches the area around the main earth station and produces a downpour with a measured value of more than 50 mm/hr. In this case the attenuation reaches 20-30 dB.

3. Systems of transportable earth stations

For the BS-2 satellite broadcasting system, there is a growing need to use small earth stations, each with a small antenna and low power consumption for the sake of economy and ease of operation.

As for the antenna, technological progress has enabled development of lower side-lobe antennas. Transportable earth stations with a 2.5 m antenna and 74-77 dBW of e.i.r.p. are being used effectively for transmission of various kinds of television programmes. The transportable earth stations do not use power control.

As for the future use of transportable earth stations, it is expected that as the broadcasting satellite service comes into wider use, transportable earth stations will increase in number for the versatility of television programme productions.

TABLE VII - *Technical characteristics and purposes of use of feeder link earth stations in the BS-2 satellite broadcasting system*

	Main earth station	Sub-earth station	Transportable earth stations	
			Type B	Type C
Antenna diameter (m)	8	8	2.5	2.5
E.i.r.p.*1 (dBW)	86	84 or 81	77	74
Location	Tokyo	Osaka, Fukuoka*2 and Sapporo*3	Tokyo	Main cities
Examples of transmission objective*4	A, F	B, D	C, F, E	B, C, E

Notes

*1 The e.i.r.p of a transportable earth station do not exceed the respective e.i.r.p. s of a reference earth station(5 m dia.,1 kW) at antenna-off-axis angles of 6, 12 and 18 degrees.

*2 A major city, 1000 km west of Tokyo.

*3 A major city, 1000 km north of Tokyo.

*4 Notation in this row is as follows;

A : Transmission of regular programs(2 channels, all day)

B : Transmission of regular programs originating from NHK's main local stations

C : Transmission from the sites of special events

D : Back-up operation.

E : Emergency news reporting

F : Experimental transmission of Hi-Vision (MUSE), and other signals.

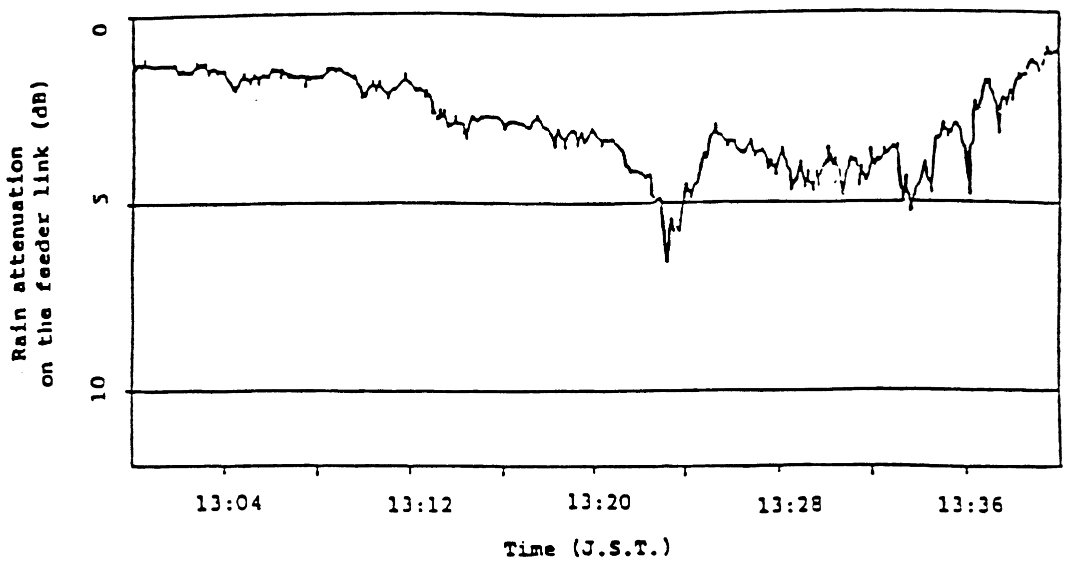

FIGURE 23 - *Moderate rain attenuation on the feeder link to the BS-2 satellite*

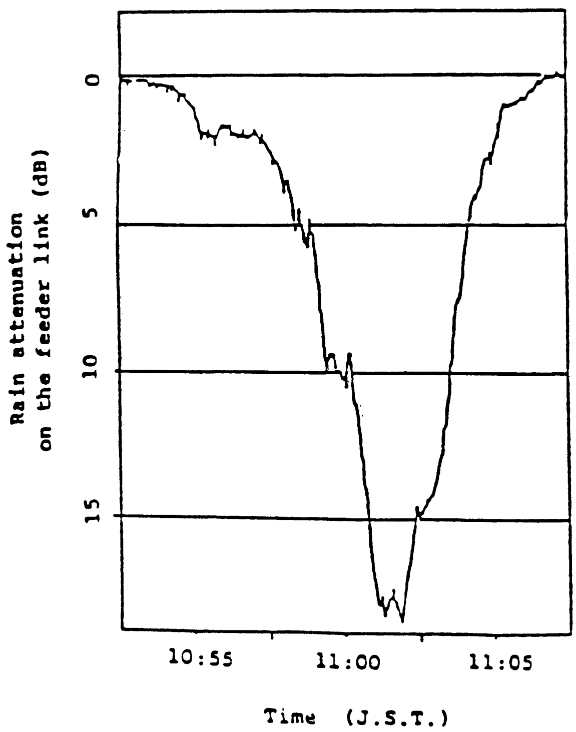

FIGURE 24

Heavy rain attenuation on the the feeder link to the BS-2 satellite

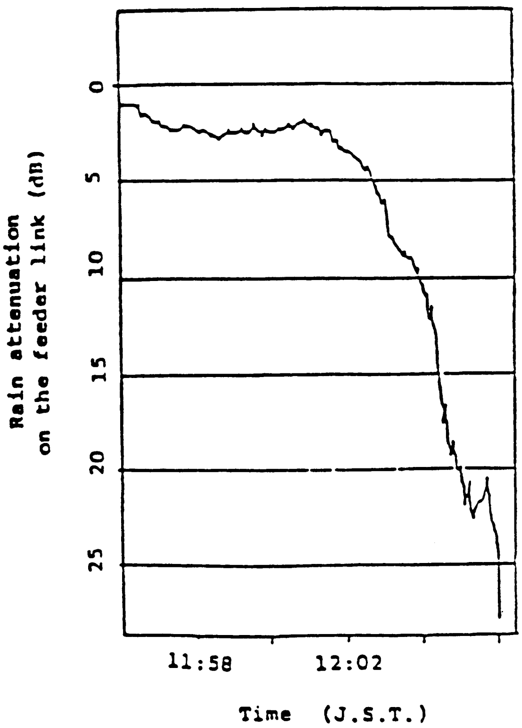

FIGURE 25

Extremely heavy rain attenuation attenuation on the feeder link to the BS-2 satellite

ANNEX III

METHODS OF CONTROLLING UPLINK RAIN COMPENSATION

1. **Monitoring of satellite beacon**

Power control may be adjusted in accordance with measured attenuation of a satellite beacon signal. These signals are normally of lower power in order to conserve satellite primary power. A tracking narrow band receiver with a reasonable fade margin is used for beacon reception.

Typical beacon transmitters vary in output due to temperature change. Normally, stability is maintained within a ±1 dB range. However, this variation can add further to the errors inherent in beacon level measurement.

2. **In-satellite processing**

Measurements of the power level received at the satellite or, where used, the AGC control voltage could be encoded and transmitted back to the originating earth station via a low rate data circuit. This would be received on a narrow band tracking receiver.

Two potential problems are inherent in this method:

- the reliability of the measurement equipment in the space segment needs to be of a very high order, and individual measurements would be necessary for each of the feeder links received. This adds complexity and weight to the space segment which should be avoided if possible;
- account would need to be taken of uplink losses due to mispointing rather than rain attenuation.

3. **Measurement of downlink power**

This method is potentially very simple but suffers from several problems:

- the downlink beam is not necessarily receivable at the uplink point;
- because of the non-linear characteristics of a transponder near saturation a small error in measurement could give rise to a large error in uplink power with consequent interference problems;
- the use of AGC in the satellite would be inhibited.

4. **Radiometer**

A simple relationship is assumed to exist between attenuation on a path through the medium and the thermal noise generated along the path.

There are shortcomings in the accuracy of the radiometer caused by:

- antenna feed losses and antenna feed pattern not being ideal;
- thermodynamic equilibrium does not exist everywhere so the medium is not a pure absorber, hence the physical temperature of the atmosphere is not constant.

When the sky noise is subsequently integrated over the antenna pattern, errors of up to 1 dB can occur.