

RECOMMENDATION ITU-R BO.794*,**

Techniques for minimizing the impact on the overall BSS system performance due to rain along the feeder-link path***

(Question ITU-R 86/11)

(1992)

The ITU Radiocommunication Assembly,

considering

- a) that any degradation on the feeder links will impact on the broadcasting-satellite service (BSS) performance over the whole service area;
- b) that the BSS satellite transponder should be maintained at nominal output level to minimize the impact of feeder-link fading on reducing the downlink e.i.r.p.;
- c) that while excessive use of on-board automatic gain control (AGC) can result in increasing the inter- and intra-system interference it can maintain the transponder operation at or near nominal output level noting however that the feeder link carrier-to-noise will not be improved;
- d) that while feeder link power control can potentially increase inter-system interference its application can maintain transponder operation at or near nominal output level without degrading the feeder link C/N ;
- e) that while use of site diversity can lead to complex operational considerations, it is an effective technique for reducing feeder link fading, particularly in high rain rate areas,

recommends

that the following techniques be used to the extent practicable for alleviating BSS system degradation due to rain fading on the feeder link:

- on-board satellite AGC (see Annex 1);
- uplink power control (see Annex 2);
- site diversity (see Annex 3).

* This Recommendation should be brought to the attention of Radiocommunication Study Group 4.

** Radiocommunication Study Group 6 made editorial amendments to this Recommendation in 2001 in accordance with Resolution ITU-R 44.

***Note: Report ITU-R BO.952 (§ 5.4.1, 5.4.2 and 7) was used in preparing this Recommendation.

ANNEX 1

On-board automatic gain control (AGC)

AGC on board spacecraft minimizes the effect of rain fades at the feeder-link station on the downlink 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 downlink a constant level of the wanted signal which is attenuated on the feeder link, but re-radiates on the downlink 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 downlink 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 downlink. 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 downlink.

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 downlink.

ANNEX 2

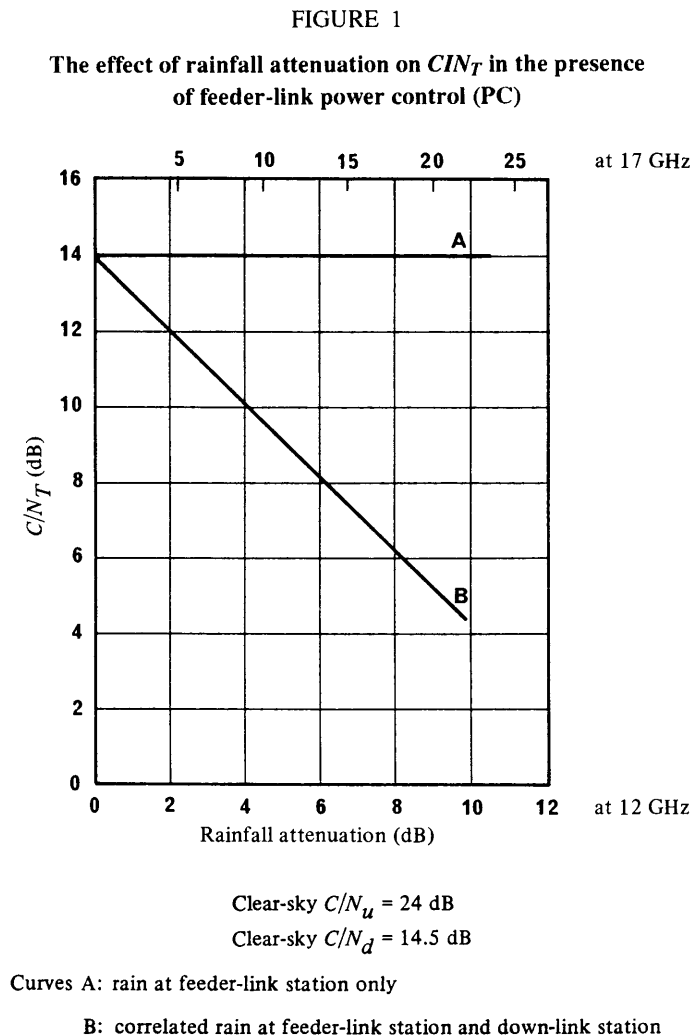
Feeder link power control

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.

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. 1.



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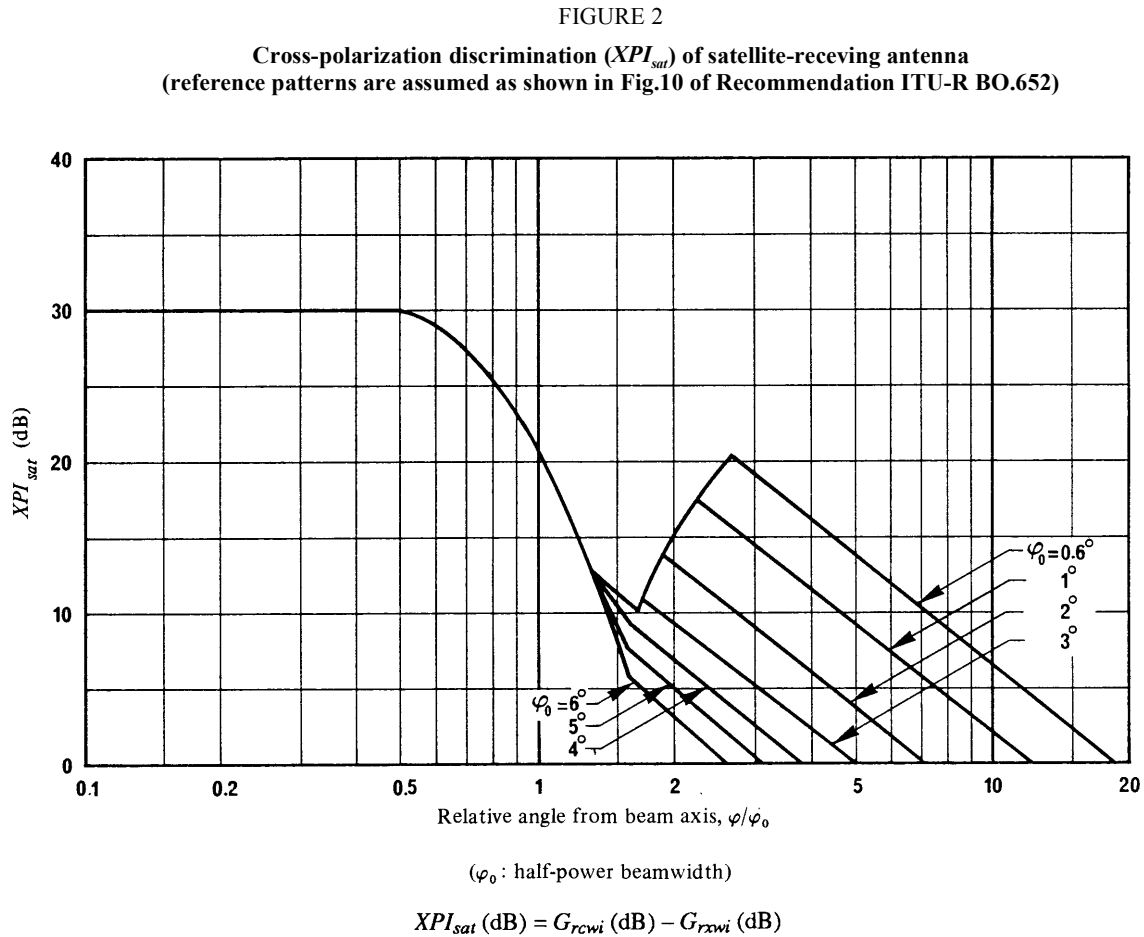
Experiments using the BSE of Japan have shown that power control is effective in maintaining a nearly constant level of desired carrier during periods of rain. In this experiment, at 14 GHz a variation of power received at the satellite of 6 dB (peak-to-peak) and 1.5 dB r.m.s. without power control,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

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 analysed in this section.

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 beamwidth φ_0 .

For the satellite-receiving antenna reference pattern in Fig. 10 of Recommendation ITU-R BO.652, the XPI_{sat} can be graphically expressed as in Fig. 2.



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In order to analyse 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 (1).

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

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 : rain polarization given by:

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

where:

$V = 20$ for below 15 GHz

$V = 23$ for above 15 GHz

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 $\theta = 60^\circ$ in the above equation.

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

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

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:

$$\Delta M = \frac{C/I_{u, \text{rain}}}{C/I_{u, \text{clear}}} = \frac{R_i}{\Delta P_i} \cdot \frac{1}{1 + \frac{A}{\frac{1}{XPI_{sat}} + \frac{1}{XPI_{es}}}} \quad (2)$$

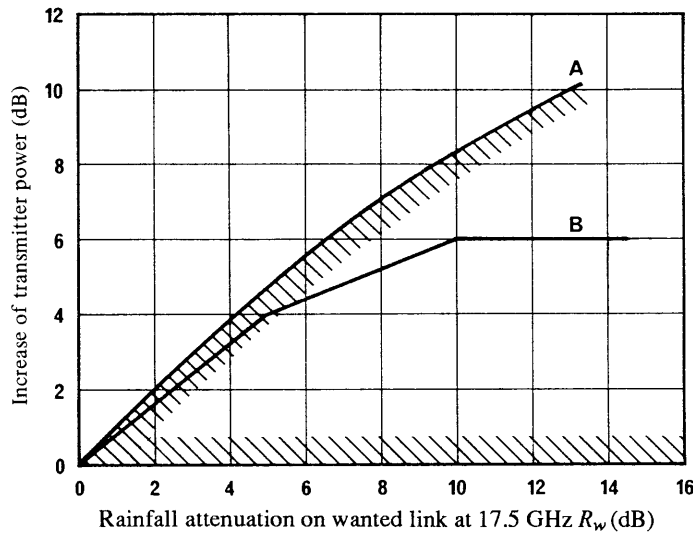
where:

- $C/I_{u, \text{rain}}$: C/I_u when rain occurs at the interfering site with resultant rainfall attenuation of R_i
- $C/I_{u, \text{clear}}$: C/I_u when the interfering site lies in clear weather ($C/I_{u, \text{clear}}$ 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. no degradation of 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. 3, 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. 3.

FIGURE 3

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 1

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

Power control as shown in Curve B of Fig. 3 results in a positive ΔM (dB) as illustrated in Curve B of Fig. 4, 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. 4 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. 3.

Table 1 summarizes other examples of feasible combinations of increased transmitter power and rain attenuation for various values of XPI_{sat} and elevation angle.

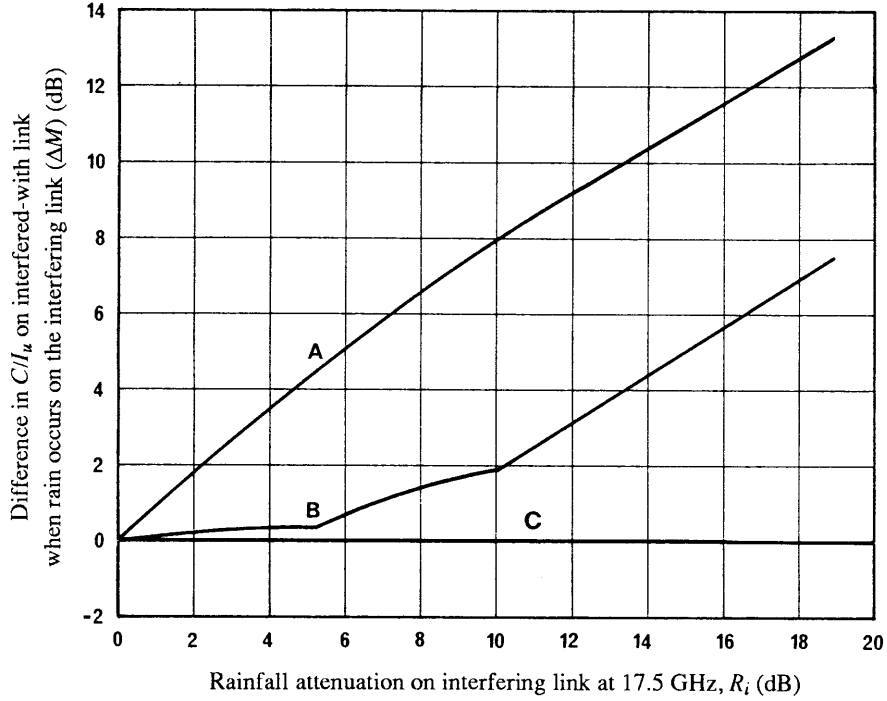
TABLE 1

**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 to 5 dB	For rainfall attenuation 5 to 10 dB and more
10 to 15	0 to 10	0	0
	10 to 30	0 to 4	4 to 7
	30 to 50	0 to 4	4 to 8
	50 to 60	0 to 5	5 to 9
	60 to 90	0 to 5	5 to 10
15 to 20	0 to 10	0	0
	10 to 30	0 to 2	2 to 4
	30 to 40	0 to 3	3 to 4
	40 to 50	0 to 3	3 to 6
	50 to 60	0 to 4	4 to 8
20 to 25	60 to 90	0 to 5	5 to 9
	0 to 30	0	0
	30 to 40	0 to 2	2
	40 to 50	0 to 3	3 to 4
	50 to 60	0 to 4	4 to 6
25 to 30	60 to 90	0 to 5	5 to 8
	0 to 40	0	0
	40 to 50	0 to 2	2
	50 to 60	0 to 3	3
	60 to 90	0 to 5	5

FIGURE 4

An example of effective power control



Curves A: without power control

B: with power control, corresponding to curve B in Fig. 3

C: upper limit for power control without degradation of C/I_u ,
on an interfered-with link, corresponding to curve A of Fig. 3

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

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3 Use of power control with potential for increased interference

Some applications of power control can worsen the interference situation. Studies have shown 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 not 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:

$$I_{pc} - I_{npc} = M_w - M_i + (CPA)_{i\ inst.} - (CPA)_{w\ inst.} \quad (3)$$

where:

I_p :	interference with power control
I_{npc} :	interference with no power control
$(CPA)_i \text{ inst.}$ and $(CPA)_w \text{ inst.}$:	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 (3)) 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, 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 analysing 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:

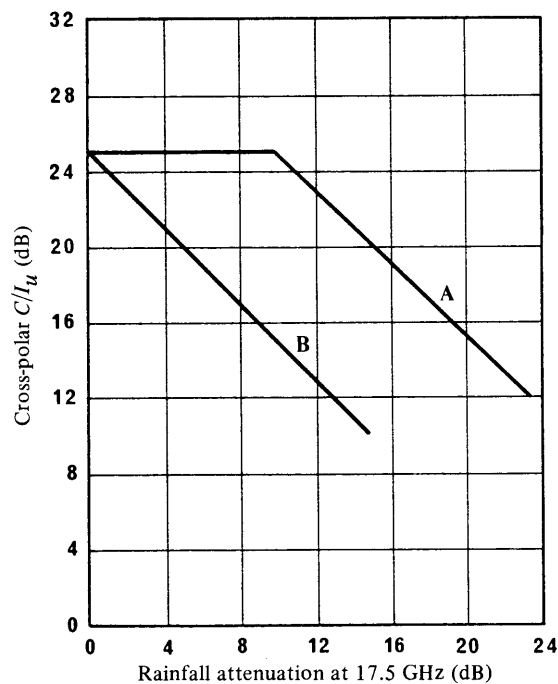
- a) it rains at the wanted site only;
- b) it rains at the wanted and interfering sites simultaneously; and
- c) it rains at the interfering site only.

Use of power control at both sites is also assumed.

The results are given in Figs. 5, 6 and 7, 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 uplink 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 uplink power control has no effect on cross-polar C/I_u when it rains simultaneously at both the wanted and interfering sites.

FIGURE 5

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))



$$XPI_{sat} = 27 \text{ dB}$$

$$XPI_{es} = 30 \text{ dB}$$

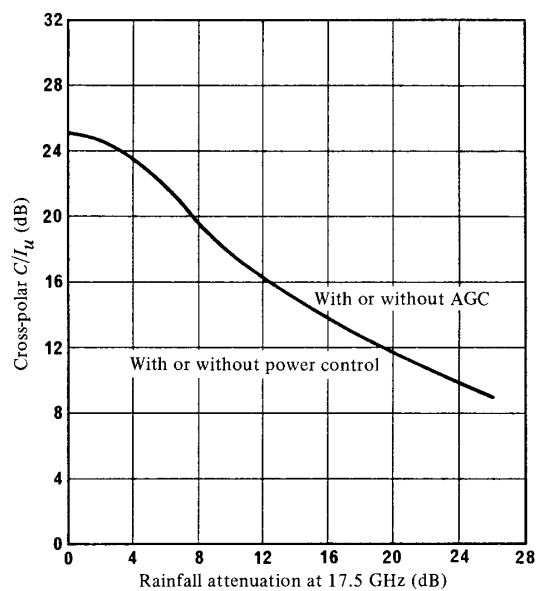
Curves A: with 10 dB power control

B: with or without AGC
without power control

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FIGURE 6

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))

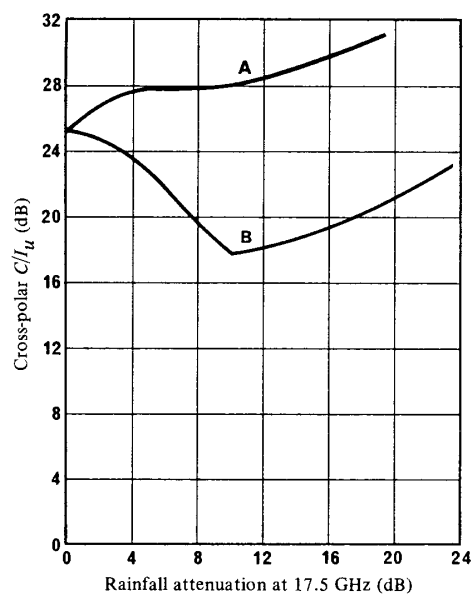


$$XPI_{sat} = 27 \text{ dB}$$

$$XPI_{es} = 30 \text{ dB}$$

FIGURE 7

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))



$$XPI_{sat} = 27 \text{ dB}$$

$$XPI_{es} = 30 \text{ dB}$$

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

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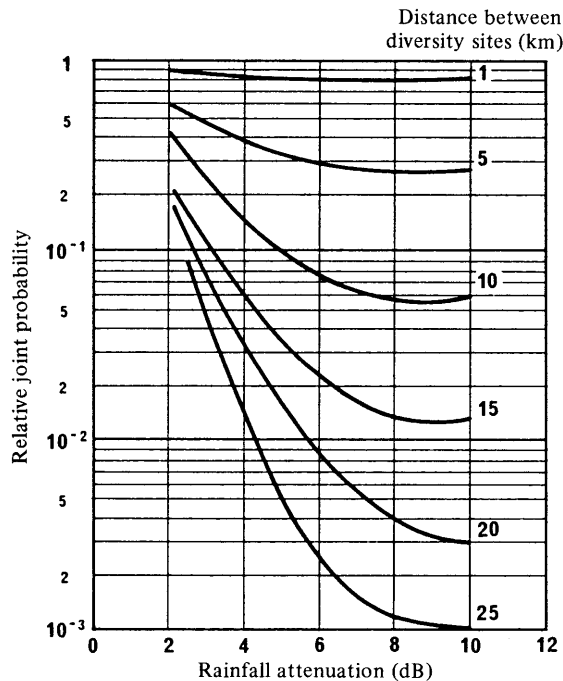
ANNEX 3

Diversity operation of feeder links

The technique of site diversity to achieve greater availability of satellite links is well documented. Recommendation ITU-R P.618 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. 8 for attenuations up to 10 dB and site separation up to 25 km on the basis of a log-normal distribution of rain cells. 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 .

FIGURE 8

Relative joint probability of site diversity as a function of rainfall attenuation and distance between diversity sites



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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 8 indicates that under these worst-case conditions, the use of site diversity with diversity stations separated by at 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.

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.
