

REPORT 814-2

**FACTORS TO BE CONSIDERED IN THE CHOICE OF POLARIZATION
FOR PLANNING THE BROADCASTING-SATELLITE SERVICE**

(Question 1/10 and 11, Study Programme 1A/10 and 11)

(1978-1982-1986)

1. Introduction

For purposes of planning the broadcasting-satellite service in the band 11.7-12.5 GHz in Region 1 and 11.7-12.2 GHz in Region 3, right- and left-hand circular polarization was adopted. Similarly, in Region 2, right- and left-hand circular polarization was selected for the Plan for the broadcasting-satellite service in the band 12.2-12.7 GHz as well as for the associated feeder-link Plan in the band 17.3-17.8 GHz. Furthermore, at the WARC ORB-85 the frequency bands 14.5-14.8 GHz (for countries outside Europe and for Malta) and 17.3-18.1 GHz were selected for the planning of feeder links for the broadcasting-satellite service in Regions 1 and 3. It was assumed that circular polarization will be used for planning. Alternatively linear polarization could be used, subject to the agreement of all administrations sharing the given orbital position.

This Report presents a summary of the factors that were considered in making this choice, both for the record, and for the planning of future systems in other bands that are, or may be, allocated to the broadcasting-satellite service. It is also suggested that the data in this Report be periodically updated.

2. Comparison between linear and circular polarization

The comparative advantages and disadvantages of linear and circular polarization for use in the broadcasting-satellite service are summarized in Table I. The symbols in the last two columns of the Table indicate for each factor which type of polarization, linear (L) or circular (C), is considered to have the advantage. In evaluating these comparative advantages and disadvantages, it must of course be recognized that the different factors are not all of equal practical importance and that their relative importance is also a matter of engineering judgement.

To aid in evaluating the importance of satellite antenna orientation on the choice of polarization (item 3 in Table I), a short, quantitative discussion of the effects of system geometry on linear polarization is given in Annex I.

The choice between linear and circular polarization for planning the BSS is governed by two major factors:

- the effect of rain attenuation and depolarization on C/N and C/I ;
- the effect on interference of the misalignment between the reference linear polarization vectors and of the misalignment of earth station and satellite polarizers.

Rain affects both the C/N and C/I of linearly and circularly polarized waves for small percentages of time. On the other hand, the misalignment between linearly polarized signals of interfering networks and the misalignment between transmitters and receivers has:

- no effect on C/N of linearly and circularly polarized networks,
- no effect on C/I of circularly polarized networks,
- little effect on co-polar C/I of linearly polarized networks, but
- has a strong effect on the cross-polar C/I of linearly polarized networks.

This is significant since linear polarization is normally used to improve C/I during rain but, as a consequence of the misalignment, it may decrease C/I far below the maximum possible discrimination capability of the satellite and earth-station antennas.

It was found that even for high rainfall zones, the effect of rain on co-polar and cross-polar C/I is small for all but 1% of the worst month. For smaller percentages of time, the effect of rain becomes more important and its effect on cross-polar C/I depends on the type of polarization and on the reference vectors for linear polarization.

There are two main reference systems that can be used to define linear polarization:

- *canted linear polarization*: *Vertical polarization* is defined so that the polarization vector is perpendicular to the satellite antenna beam axis and lies in the plane defined by the satellite antenna beam axis and the local vertical. *Horizontal polarization* is defined so that the polarization vector is perpendicular to the satellite antenna beam axis and is contained in the local horizontal plane. These vectors will be in the direction closest to the local horizontal or local vertical at the boresight of the satellite antenna;
- *equatorial linear polarization*: *Polar polarization* is defined so that the polarization vector is perpendicular to the satellite antenna beam axis and lies in the plane defined by the satellite antenna beam axis and a line parallel to the Earth's polar axis. *Equatorial polarization* is defined so that the polarization vector is perpendicular to the satellite antenna beam axis and parallel to the equatorial plane.

In general, the better performance that would be available from linear polarization requires two conditions which are, in most cases, incompatible. On the one hand, the best performance of linear polarization is obtained when the signal is received vertically polarized. On the other hand, the orthogonally-polarized interfering signals must be received exactly at 90° from the wanted signal. Because of the geometry of the problem these two conditions cannot be met simultaneously.

A slightly better performance can be obtained with linear polarization when the reference vector is defined perpendicular to the equatorial plane, and if the receiver misalignment does not exceed 3° for all co-polar systems. This implies that the polarization is not received vertically, and therefore does not meet the first condition. Since this improvement is considered marginal considering the additional constraint imposed on the receiver polarizer alignment, circular polarization is therefore suggested for planning of the broadcasting-satellite service.

Information on depolarization due to rain is given in Reports 722 and 564.

3. Experimental results

A study was performed in Canada on the choice between linear and circular polarization for the BSS down links. The cross-polar discrimination capability of the earth-station antenna XPI_{ES} is assumed to be in the range of 20 to 25 dB and the XPI_{SAT} of the satellite antenna in the range of 27 to 33 dB for both linear and circular polarization.

The effect of rain attenuation and depolarization on the down link C/I has been studied for rain climatic zones E, K and N using the rain model of Report 564. The results have shown that for all but 1% of the worst month, the effect of rain attenuation and depolarization on co-polar and cross-polar C/I is very small. For smaller percentages of time, the effect of rain attenuation and depolarization on cross-polar C/I depends on the type of polarization and on the reference vectors for linear polarization. Figure 1 gives the results of the availability of cross-polar C/I between homogeneous satellite down-link beams (2° diameter) using canted linear or equatorial linear or circular polarization.

TABLE I — Some aspects of linear as compared with circular polarization

Factor	Remarks	Advantage ⁽¹⁾
1. Alignment of receiving antenna	Alignment of the polarization direction is not necessary for circular polarization	C
2. Effect of misalignment on cross-polarization	Misalignment of polarization direction of both transmitting and receiving antennae required with linear polarization, 2 to 4 dB extra cross-polar protection margins in comparison with circular polarization	C
3. Orientation of satellite antenna	With linear polarization, the plane of polarization will not in general correspond to the major or minor axes of a beam with elliptical cross-section; therefore:	C
	(a) it may be difficult to produce a good cross-polar response with linear polarization (in particular for elliptical beams)	C
	(b) transfer to a spare satellite at a different orbital position would probably be more difficult with linear polarization because of the need to realign the polarization plane	C
4. Sharing with other services	(a) If circular polarization is chosen for the broadcasting-satellite service and other services use linear polarization, 3 dB protection between these services and the broadcasting-satellite service is assured	C
	(b) If both the broadcasting-satellite and other services, e.g., fixed-satellite and terrestrial services, use linear polarization, then in isolated cases, where the dominant interference arrives near the main beam of a receiving antenna, it may be possible to increase the isolation by the use of orthogonal polarization	L
5. Propagation effects	Circular polarization is more affected by atmospheric conditions than linear polarization for high rainfall rates (greater than 12.5 mm/hour) and low angles of arrival	L
	For example, the cross-polar attenuation may be 20 dB for 1% of the time with circular polarization according to some measurements in Switzerland [CCIR, 1974-78]. This disadvantage of circular polarization may not be significant if compared with linear polarization transmission on or near a 45° plane [Shkarofski and Moody, 1976]	

(1) C: circular

L: linear

The elevation angle to the satellite is 25° and the earth-station antenna is assumed to be perfectly pointed to the satellite and aligned to the wanted polarization. However, when the polarization misalignment, B_R , is 0.1° for equatorial linear polarization and 10.3° for canted linear polarization, the corresponding tilt angles for the wanted and interfering beams are around 5° and 10° respectively for canted linear polarization and for equatorial linear polarization.

The figure shows that for 1 dB attenuation, the cross-polar C/I is 19.5 dB for circular polarization and for equatorial linear polarization. However, for canted linear polarization, the 10.3° misalignment, B_R , decreases the cross-polar C/I to 13.5 dB for 1 dB rain attenuation.

For larger values of rain attenuation, the C/I is governed by the differential attenuation between linear horizontal and vertical polarization and by depolarization. Canted vertical polarization is the least attenuated and therefore can surpass the C/I performance of horizontal equatorial, circular and even vertical equatorial polarization. However, these change-overs in cross-polar C/I performance generally occur for very small percentages of time when the signal attenuation is excessive (greater than 10 dB).

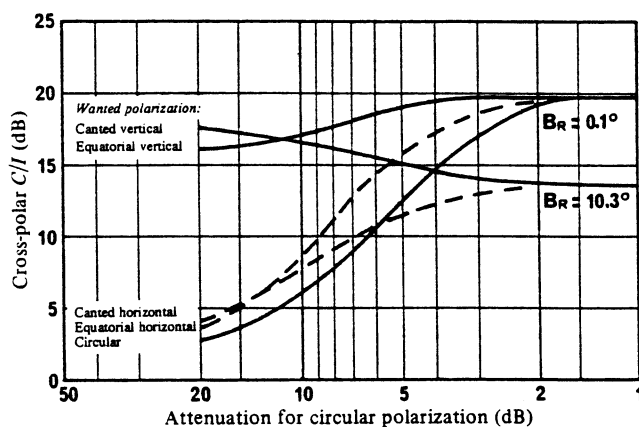


FIGURE 1 – Availability of cross-polar C/I at edge of coverage area between co-located satellites serving adjacent beam areas. (The antennas are assumed to be perfectly aligned.)

12 GHz down links
 Co-located satellites
 Satellite antenna beam size: 2°
 Elevation angle: 25°
 $XPI_{ES} = +20$ dB
 $XPI_{SAT} = +33$ dB

If we then ignore the effect of rain at 12 GHz on C/I , the effect of the total misalignment between linearly polarized networks, B_T , on the clear-sky C/I is illustrated in Fig. 2 and is compared to the performance of circular polarization. The figure shows the rapid decrease of the clear sky cross-polar C/I with the misalignment between linear polarizations. Circularly polarized receive antennas with 20 and 25 dB XPI give higher cross-polar C/I than linearly polarized antennas for any misalignment greater than 5° and 2° respectively. The figure also shows some typical values of total misalignment, B_T , assuming a satellite antenna rotation error $B_S = \pm 1^\circ$ and an earth-station alignment error $B_{ES} = \pm 5^\circ$ for both equatorial and canted linear polarization. It would appear difficult to align and maintain the polarizers of millions of low-cost receive antennas to better than $\pm 5^\circ$ of the wanted polarization.

The maximum 5° total misalignment may give a higher cross-polar C/I with linear polarization than with circular polarization depending on the discrimination capabilities of the antenna. A maximum of 5° misalignment can only be achieved with equatorial linear polarization when it is possible to align and maintain the polarizer of the receiver to within about 3° of the wanted polarization. The use of canted linear polarization with typical minimum value of misalignment, B_R , of 4° would, in the majority of cases, give worse C/I than circular polarization.

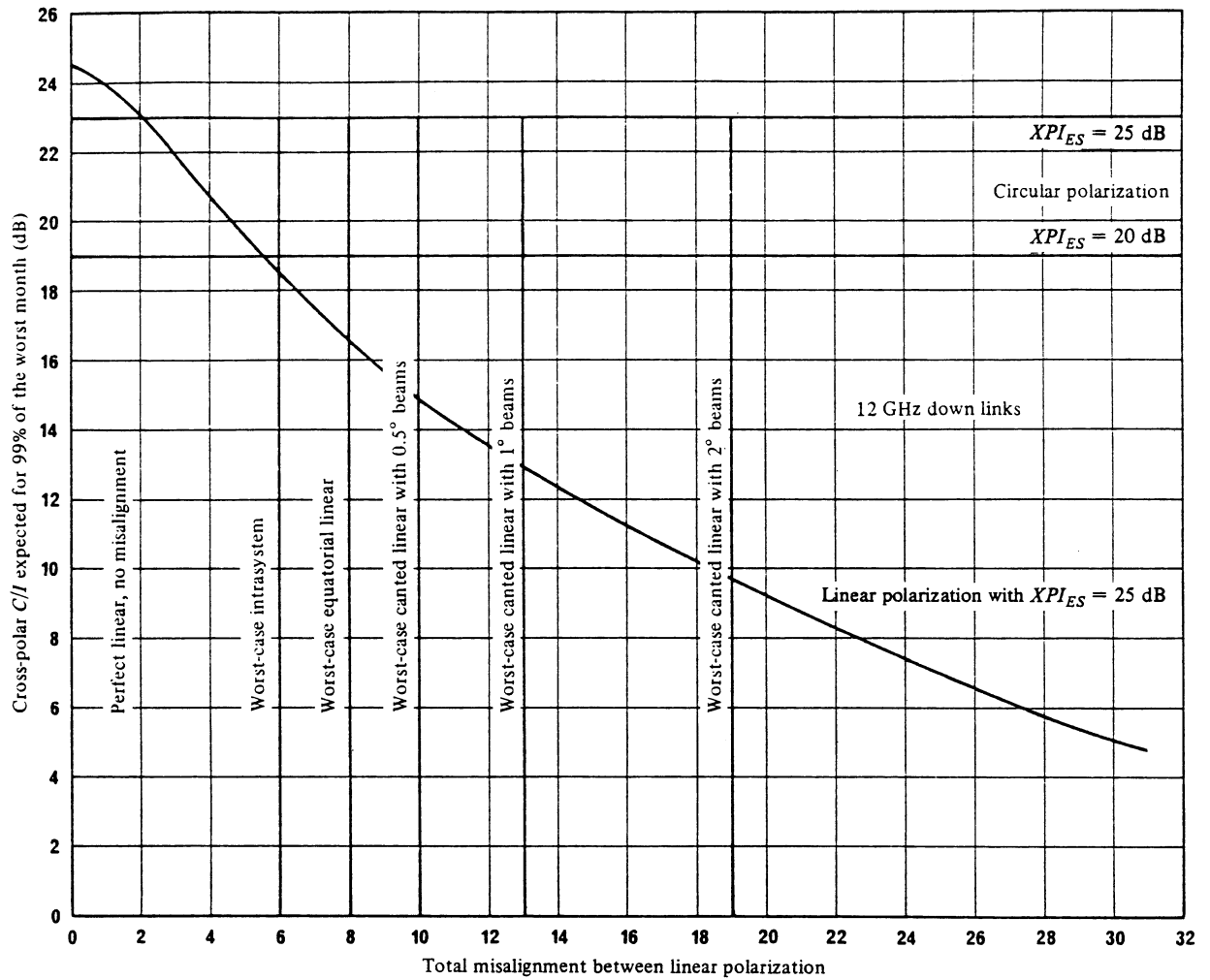


FIGURE 2 – Clear sky cross-polar C/I between adjacent satellite beams transmitted from a satellite to an earth station located at the common point of the -3 dB contours (The best case of equatorial linear and circular polarization and the worst case of canted linear polarization are illustrated)

REFERENCES

SHKAROFSKI, I. P. and MOODY, H. J. [September, 1976] Performance characteristics of antennas for direct broadcasting satellite systems including effects of rain depolarization. *RCA Rev.*, Vol. 37, 3, 279-319.

CCIR Documents

[1974-78]: 9/248 (Switzerland).

ANNEX I

EFFECTS OF SYSTEM GEOMETRY ON LINEAR POLARIZATION

For linear polarization, the received angle of polarization will vary as a function of the latitude and longitude of the ground receiving terminal relative to the sub-satellite longitude. The reason for this is the variation in orientation of the reference system (the local horizontal and vertical) with relative geographic location.

The angle of polarization of the incident linearly polarized wave, assuming the polarization vector of the transmitted wave is parallel to the equatorial plane, is given by (ignoring Faraday rotation which is negligible at 12 GHz):

$$\theta_p = \arctan \left\{ (\sin \Delta\lambda / \tan \phi) \sqrt{1 + [\sin \theta / (\beta - \cos \theta)]^2} \right\}$$

where:

θ_p : angle of polarization of the incident wave measured from the line of intersection of the local horizontal plane and the plane perpendicular to the line of sight to the satellite at the ground receiving terminal.

$\Delta\lambda$: relative longitude of the receiving ground terminal.

θ : earth central angle between the sub-satellite point and the receiving ground terminal ($\theta = \arccos [\cos \Delta\lambda \cos \phi]$), and

β : 6.62 (the radius of the geostationary orbit divided by the radius of the earth).

This variation of the polarization angle is illustrated in Fig. 3 for various latitudes and relative longitudes. The angle, θ_p , is given by the angle that the small vector makes with the $\Delta\lambda$ axis. Contours for angles of elevation of 0° and 20° are also shown.

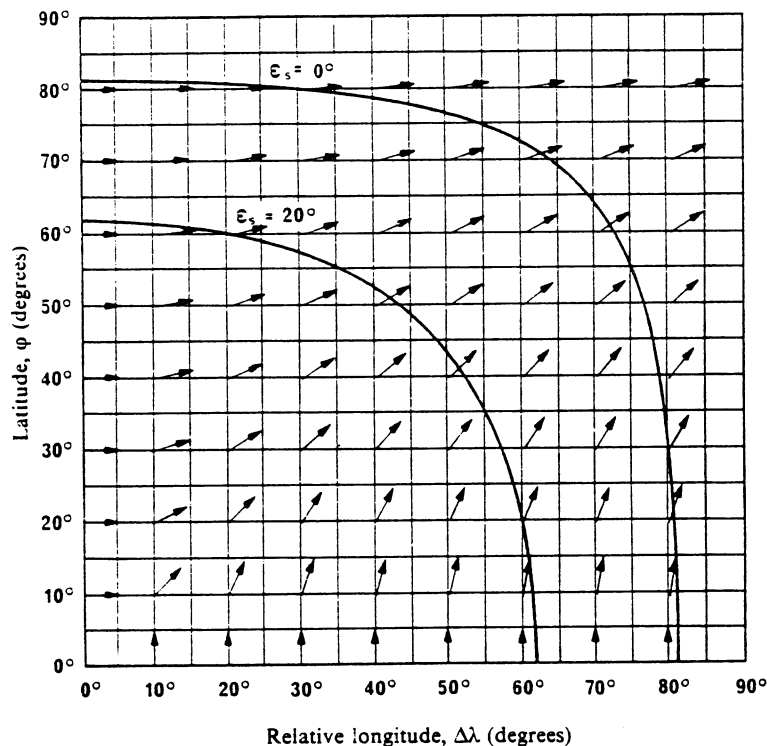


FIGURE 3 - Variation of received angle of polarization on the Earth

ϵ_s : angle of elevation

The angle of polarization is seen to vary over a large range with geographical location. Consequently, it seems to be impractical to adjust the polarization of the transmitted wave to insure that it would be received horizontally at all points in the service area.

Because of this variation in the angle of polarization with latitude and relative longitude, the simple choice of horizontal polarization (the polarization vector parallel to the equatorial plane) for the space station in the broadcasting-satellite service will not insure that it will be received orthogonally to the desired polarization vector (usually vertical) in terrestrial systems.