REPORT 811-2

BROADCASTING-SATELLITE SERVICE

Planning elements including those used in the establishment of Plans of frequency assignments and orbital positions for the broadcasting-satellite service in the 12 GHz band

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

(1978-1982-1986)

1. Introduction

The first step in establishing a plan of frequency assignments and orbital positions for the broadcasting-satellite service is to select various system characteristics in the light of their implications for planning. This Report considers the fullest possible list of such characteristics which served as bases for the Plans in the band 11.7 to 12.5 GHz in Region 1, in the band 11.7 to 12.2 GHz in Region 3, and in the band 12.2 to 12.7 GHz in Region 2.

2. Planning elements

The planning elements used in the development of plans depend to a large extent on the amount of detail desired in the plans. However, it must be remembered that, in order to establish the workability of a plan, it must be tested by computer analysis. Although there are other factors that bear significantly on the operational workability of a plan, its technical feasibility depends mainly on meeting the agreed interference criteria for all systems that are part of the plan. Therefore, the tests must include the computation of interference from all sources, and this requires the use of specific values for all parameters that are relevant to this computation. When the plan allows ranges of values for some parameters, the values leading to the generation of the greatest interference and to the greatest vulnerability to interference should be used in the tests. These values cannot always be predicted and must be determined by the tests themselves. Because of the extremely large number of parameter combinations that would have to be tested, such exhaustive tests are, in general, impractical. This limits the number of parameters for which ranges can be allowed. The RARC SAT-83 recognized this difficulty and explicitly incorporated the stipulation that parameter values different from the ones specified may be used provided that the systems using them create no more interference than they would if they used the specified values.

Table I is a summary of the planning elements used in the establishment of the broadcasting-satellite service Plans for Regions 1 and 3 at the WARC-BS-77 and for Region 2 at the RARC SAT-83. The following sections provide additional details on some of the elements contained in this table.

3. System characteristics

3.1 *Polarization*

Circular polarization was adopted for the planning of the broadcasting-satellite service down links by both the WARC-BS-77 and the RARC SAT-83. The technical factors affecting the choice of polarization are treated in Report 814, and its effect on sharing is treated in Reports 809 and 631.

3.2 *Angle of elevation*

The satellite position, and so the angle of elevation of the satellite in the service area, should be chosen such that the weight and cost of the satellite which provides an acceptable signal strength during rain conditions is minimized, subject to the constraint that the angle of elevation throughout the service area is large enough so that the shadowing due to buildings, trees and surrounding terrain is not severe, and so that tropospheric fading and multipath effects do not become a dominant factor.

In addition, consideration of eclipse protection will affect the choice of satellite orbital position. In general, satellites are located west of their service areas in order to assure that the onset of eclipse is after the local midnight of that service area.

For coverage zones located in latitudes above 60°, the angle of elevation is bound to be less than 20°. In favourable terrain conditions almost normal service might be provided with angles of elevation as low as 10°. Special measures are needed, however, if service is planned to be extended under this angle or to areas with a less favourable terrain. For mountainous areas even an angle of elevation of 20° may be insufficient. In the Alpine valleys, for example, which are deep and populated, an angle of at least 30° may be essential to provide an acceptable service.

Subject to these constraints, the choice of the angle of elevation to the satellite to minimize weight and cost of most satellites is equivalent to the choice of angle of elevation to minimize tube output powers. In this minimization the following factors should be considered:

- the rain attenuation,
- the variation in antenna gain with the solid angle subtended at the satellite by the specified coverage area,
- the variation in total system noise temperature (including the effect of rain-induced fading),
- the variation in propagation path length.

The above factors plus the gain of the receive terminal determine the carrier-to-noise temperature (C/T) achievable for a given satellite transmitter power. Therefore to minimize the required satellite power for a given receiver G/T the satellite position could be chosen to maximize C/T.

A general formulation of the problem of determining the optimum longitudinal location of a geostationary communications satellite for a specified beam coverage region is described in [Sinha, 1982].

TABLE I – *Summary of planning elements*

BSS down links	Regions 1 and 3 (1)	Region 2 (1)
Propagation model	Annex 5, § 2	Annex 5, § 2
Modulation	FM or equivalent	FM or equivalent
Polarization	Circular	Circular
C/N (dB)	14 (exceeded for 99% of worst month)	14 (exceeded for 99% of worst month)
Protection ratio (dB)	Co-channel: 31 Adjacent channel: 15	Co-channel: 28 Adjacent channel: 13.6
Channel spacing (MHz)	38.36 between second adjacent channels	29.16 between second adjacent (co-polarized) channels
Minimum receiving installation G/T (dB(K^{-1}))	Individual reception: 6 Community reception: 14	Individual reception: 10
Receiving antenna half-power beamwidth (degrees)	Individual reception: 2.0 Community reception: 1.0	Individual reception: 1.7
Receiving antenna reference pattern	Annex 5, § 3.7.2, Fig. 7	Annex 5, § 3.7.2, Fig. 8
Necessary bandwidth (MHz)	For 625-line systems: 27 For 525-line systems: 27	24 (for some administrations using 625-line systems: 27)
Guard bands	Lower: 14 Upper: 11	Lower: 12 Upper: 12
Satellite station-keeping (degrees)	± 0.1 for both N-S and E-W	± 0.1 for both N-S (2) and E-W
Minimum elevation angle (degrees)	20-40; < 20 acceptable for arid and high latitude areas	20-40; < 20 acceptable for arid and high latitude areas
Satelite transmitting beam cross-section	Elliptical or circular	Elliptical or circular
Satellite transmitting antenna reference pattern	Annex 5, § 3.13.3, Fig. 9	Annex 5, § 3.13.3, Figs. 10 and 11
Satellite antenna pointing accuracy (degrees)	0.1 from boresight ± 2 in rotation about axis	0.1 from boresight ± 1 in rotation about axis
Satellite transmitter power tolerance (dB)	0.25 above nominal	0.25 above nominal
PFD at edge of coverage area (exceeded for 99% of worst month) (dB(W/m^2))	Individual reception: −103 Community reception: −111	Individual reception: −107
Ratio of e.i.r.p. at beam centre to e.i.r.p. at edge of coverage area (dB)	⩽ 3	⩽ 3
Use of energy dispersal (dB/4 kHz)	22 (3)	22 (3)

(1) References are to Appendix 30 (ORB-85) of the Final Acts of the WARC ORB-85.

(2) Recommended but not required in the N-S direction for Region 2.

(3) Corresponds to a peak-to-peak deviation of 600 kHz.

The important conclusion from this analysis is that a broad range of elevation angles can be used with only a minor variation in C/T under *all* climatic conditions. Even though there is an "optimum" satellite location, depending upon the specific system characteristics and the shape and orientation of the service area, the actual variation in C/T with elevation angle is generally quite small, of the order of a few tenths of a dB down to elevation angles as low as 20°.

3.3 *Service quality and availability objectives*

It is considered that planning should be on the basis of achieving the following carrier-to-noise ratio objectives at the edge of the service area:

a) 14 dB exceeded for 99% of the worst month;

b) 10 dB exceeded for 99.9% of the worst month.

3.4 *Figure of merit and type of receiver*

The preferred figure of merit G/T (with T in K) depends on both economic and technical factors. The value may be considered to range from 4 dB(K^{-1}) to 12 dB(K^{-1}) for individual reception, and from 8 dB(K^{-1}) to 24 dB(K^{-1}) for community reception, the most economic value depending on the size of the service area and, in particular, on density of receivers within that service area. The WARC-BS-77 adopted values of 6 dB(K^{-1}) for individual reception and 14 dB(K^{-1}) for community reception for planning purposes. The RARC SAT-83 adopted a value of 10 dB(K^{-1}) for planning purposes.

Note. – The definition of G/T should be that given in Report 473 as "usable G/T".

3.5 *Satellite transmit antenna beams*

For planning purposes, it has been convenient to deal only with beams of elliptical or circular cross-sections. However, [CCIR, 1978-82] indicates that more efficient plans may be possible if shaped beams could be incorporated into the planning process since, in the implementation of actual systems, it may be possible to use shaped beams that conform to the actual service areas, which may be of irregular shapes, much better than simple ellipses or circles. This would tend to lower the power required to produce a given power flux-density within the service area and, at the same time, reduce the power flux-density produced outside the service area, thus reducing the interference produced. Shaped beam antennas have been used on Intelsat IV-A, the Japanese communications satellite (CS) and broadcasting satellite (BSE) and are planned for, among others, Intelsat V. The level of sidelobe protection that can be obtained with shaped beams requires further study.

A further stage of optimization, which can be used to advantage where necessary, can reduce the spread of power flux-density by reducing the constant gain contour in such a way that the minimum required signal power is met or exceeded at each vertex of the polygon defining the required service area for the given climatic conditions or elevation angles. In effect this further stage of beam optimization approximates a constant minimum pfd contour to cover the service area rather than a constant e.i.r.p. contour. It should be noted that, in general, the minimum pfd contour is not an ellipse and will exhibit discontinuities at the climatic zone boundaries.

Launch vehicle payload envelope and other technological constraints on the antenna result in a minimum beamwidth for planning purposes. At the WARC-BS-77 the value used was 0.6°. Based on more recent antenna and launch vehicle analyses, a value of 0.8° was used for planning at the RARC SAT-83.

3.6 *Antenna gain at edge of coverage area*

The difference between the satellite antenna gain value towards the centre of the coverage area and the value towards the edge of the coverage area is termed ΔG. Normally, the antenna gain is assumed to be 3 dB below the maximum at the edge of the coverage area, i.e., $\Delta G = 3$ dB.

For a given coverage area, a value for ΔG can be selected between 3 and 6 dB. The maximum antenna gain is therefore modified, but the satellite's transmission power remains more or less constant.

The theoretically optimum value of ΔG is usually about 4 dB. Some different considerations apply to the case of small service areas which would require a beam smaller than that corresponding to the maximum practicable size of the transmitting antenna. In these cases, the optimum value of ΔG is less than 4 dB.

3.7 *Minimum channel spacing and satellite output multiplexer losses*

In deriving a broadcasting-satellite plan, the required usable bandwidth of a given RF channel should be determined. Based on this value, the minimum spacing between adjacent-channel centre frequencies in a given service area should be determined. This value is determined primarily by the design of the spacecraft multiplexers and filters and the design of filters and image rejection techniques in the earth stations.

Some studies based on an orbital spacing between satellites of the order of 7.5° to 10° have indicated a preference for 20 MHz spacing between 27 MHz-wide channels. The optimum value may depend on the orbital spacing chosen between satellites. The WARC-BS-77 adopted a channel spacing of 19.18 MHz with a spacing of 6° between satellites in the Plan for Regions 1 and 3. Report 634 gives values for protection ratios for different channel spacings. The RARC SAT-83 did not adopt a regular orbital spacing scheme for Region 2.

When a number of radio-frequency channels are to be multiplexed to feed a common satellite antenna, the following constraints arise from implementation of present-day technology:

- a spacing of more than 52 MHz between any two channels assigned to a country would not cause any technical problems;
- a spacing of approximately 40 MHz would be feasible, providing power levels were not excessive;
- a spacing of less than approximately 40 MHz would not be feasible.

The spacing between the assigned frequencies of two channels being transmitted to the same service area can be smaller than 40 MHz when that area is served from multiple (clustered) satellites at the same orbital position or from a large satellite with multiple antennas. The spacing would then be limited by the receiver characteristics.

3.8 *Variations in output power*

Owing to the tolerances in the output powers of satellite travelling wave tubes, the nominal output power at the start of service may be 0.4 dB above the design value.

This output power can be expected to decrease by 0.1 dB yearly, according to the experience of the European Space Agency. Thus, there will be a loss of 0.6 dB after 6 years. Taking account of this loss, and allowing for the 0.4 dB tolerance referred to above, the travelling wave tube may give a power 1 dB higher than the planned value at the start of service. This value of 1 dB is termed the operating power margin.

The Final Acts both of the WARC-BS-77 and of the RARC SAT-83 state that the output power of a space station in the broadcasting-satellite service must not rise by more than 0.25 dB above its nominal value throughout the life of the satellite.

3.9 *Pointing accuracy of the antenna beam*

With the present state of the art for controlling pitch and roll error of a spacecraft, the boresight error circle of the transmitting antenna should be capable of being maintained within 0.2°.

With the introduction of improved systems (e.g., radio-frequency sensing: see § 4.4, Doc. [CCIR, 1974-78a]) this radius could be reduced to 0.1°.

Studies performed in the USA [CCIR, 1974-78b] and Europe [ESA/SBAG, 1976] indicate that eventually an accuracy of 0.05° can be achieved for a significant and predictable portion of the operational lifetime.

Motion around the yaw axis (the line joining the satellite and the centre of the Earth) can presently be stabilized within ± 1°, as has been demonstrated with the CTS satellite. Greater accuracy is already technically feasible, but this would require more complex design [Redisch, 1975].

Proper consideration of pointing accuracy is particularly important when irregularly shaped beams (see § 3.5) are used, because a mispointing condition greater than had been anticipated during the design of the satellite can cause a sharp drop in e.i.r.p. along virtually all of the edges of the service area. This is because a shaped beam, by definition, follows closely most of the edges of the service area. In contrast, an elliptical beam generally comes close to the edges of the service area only at a few points so that a mispointing condition beyond design value may lead to a significant drop in e.i.r.p. only at a few points near the edges of the service area.

4. Power flux-density required

The power flux-density (*PFD*) required for satisfactory television reception in a broadcasting-satellite system depends on the desired down-link carrier-to-noise ratio, C/N (dB), the receiver figure of merit, G/T (dB(K^{-1})), the frequency, f (GHz) and the receiver bandwidth, B (MHz) in the following way:

$$PFD = (C/N) - (G/T) + 20 \log f + 10 \log B - 147.1$$

where *PFD* is the power flux-density in dB(W/m^2). Table II lists the characteristics of several representative receiving systems and the resulting power flux-densities. It also lists the values adopted by the WARC-BS-77 and the RARC SAT-83 for planning purposes.

Report 473 indicates achievable noise figures of 4 to 5 dB for community reception and of 6 dB for individual reception. The values of the required power flux-density adopted by the WARC-BS-77 are generally based on the receivers with relatively poorer performance, reflecting the concern with receiver cost in systems requiring a large number of receivers. For many countries of high population density, this may, in fact, represent an economic solution which is close to the optimum with respect to total system cost, bearing in mind that the use of higher power flux-density reduces receiver cost but increases satellite cost, and vice versa. In other situations, the optimum system may require the use of receiving terminals whose size and performance is closer to the ones under heading "B". Furthermore, high power flux-densities, requiring high power emissions from the space station, lead to decreased spectrum-orbit capacity and thus reduce the total amount of services that can be provided in this frequency band. The economic value of these services (many not well defined at this time) cannot be assessed easily, and therefore some conclusions based on the economics of a particular broadcasting-satellite system of narrowly defined scope may not be valid when the total range of possible services is considered. There may be technical advantages to using higher power flux-densities in systems employing digital modulation. These trade-offs require further study.

The values listed in Table II are those required from the point of view of the broadcasting-satellite service; they do not take into account any requirements for sharing with other services operating in the band.

The requirements corresponding to a value of C/N of 14 dB are to be met for 99% of the worst month at the edge of the service area. Typically, the clear weather power flux-density values will be 1 to 2 dB greater at the service edge (no rain attenuation) and 4 to 5 dB greater at the centre of the service area.

TABLE II – *Characteristics of representative receiving systems and resulting power flux-densities*

Type of reception	Individual				Community		
	A	B	C	D	A	B	C
HP beamwidth (degrees)	2.4	1.5	2.0	1.7	1.0	0.75	1.0
Antenna diam. (m)	0.75	1.2	(0.9)	(1.0)	1.8	2.4	(1.8)
Noise figure (dB)	6.2	3.7 (1)	(5.9)	(3.9)	4.2	2.2 (1)	(4.2)
G/T (dB(K^{-1})) (2)	4	12	6	10	14	20	14
Overall C/N required (dB)	14	14	14	14	14	14	14
Frequency band (GHz)	12	12	12	12	12	12	12
Bandwidth (MHz)	18	27	27	24 (3)	18	27	27
Power flux-density, PFD (dB(W/m^2)) (4)	–103	–109	–103	–107	–112	–117	–111

(1) In these cases the losses assumed in the example were reduced by 1 dB.

(2) Computed by assuming the same losses and conditions as in the example in Annex I of Report 473-3 (1982), except that an antenna efficiency of 55% was used.

(3) For those administrations using 625-line standards with greater video bandwith than 525-line standards, the "necessary bandwith" is 27 MHz but the power flux-density limit remains at –107 dB(W/m^2).

(4) Includes an allowance of 0.5 dB for transmission of up-link noise.

A: readily achievable.
B: achievable at additional cost.
C: adopted by the WARC-BS-77 for Regions 1 and 3.
D: adopted by the RARC SAT-83 for Region 2.

Numbers in parentheses were not adopted explicitly, but are implied by adopted numbers.

REFERENCES

Document ESA/SBAG [1976] 3, Annex 3, European Space Agency.

REDISCH, W. N. [November, 1975] ATS-6 description and performance. *IEEE Trans. Aerospace Electron. Systems*, Vol. AES-11, **6**, 994-1003.

SINHA, A. K. [Fall, 1982] Optimum orbital location of a communications satellite. *COMSAT Tech. Rev.*, Vol. 12, **2**, 295-317.

CCIR Documents

[1974-78]: **a.** 2/94 (Draft revisions of Report 546); **b.** 11/129 (USA).

[1978-82]: 10-11S/33 (USA).

BIBLIOGRAPHY

SIOCOS, C. A. [December, 1973] Broadcasting-satellite coverage: geometrical considerations. *IEEE Trans. Broadcasting*, Vol. BC-19, **4**, 84-87.

SIOCOS, C. A. [March, 1975] Broadcasting-satellite service: minimum elliptical beam determination. *JSMPTE*, Vol. 84, **3**, 147-150.

CCIR Documents

[1974-78]: 11/415 (France); 11/420 (France).

[1978-82]: 10-11S/44 (Canada).

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.