SECTION 10/11D: PLANNING

Reports

REPORT 633-3

ORBIT AND FREQUENCY PLANNING IN THE BROADCASTING-SATELLITE SERVICE

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

(1974-1978-1982-1986)

1. Introduction

The provision of broadcasting-satellite services to countries within a Region entails careful planning of frequency allotment and satellite location to reduce interference to an acceptable level. This Report deals with the problems of planning, mainly for the 12 GHz band, and outlines the parameters involved in preparing plans, together with methods of assessing the likely success of a plan and its efficiency.

The following features of planning are mentioned initially as they are of a general nature, applying to services in all relevant bands:

- It is assumed that all broadcasting-satellite services of the same kind, to the same service area, would generally be provided from the same geostationary orbital position to permit the use of a fixed receiving antennas. Some important exceptions are: services designed for different audiences (e.g., programmes for individual reception and programmes for community reception), exceptionally large service area requirements satisfied by using more than one satellite per service area, and services provided to areas of intentional overlap between service areas within the territory of an administration (e.g., to allow the territory to be served by fewer than the authorized number of satellites during the initial phases of implementation of the Plan);
- for the purpose of calculating the wanted-to-interfering signal ratio in the case of several interfering signals, the total interfering signal may be calculated on the basis of adding the component interfering signal powers received by the antenna;
- whenever possible, the coverage area should be the minimum necessary to provide the required coverage;
- if a plan is agreed on that is based on certain technical parameters (e.g., channel bandwidth and channel spacing), an administration may nevertheless implement systems with parameters different from those adopted, provided that it does not cause more interference than it would cause, nor demand greater protection from interference than it could demand, if it adhered to the adopted parameters;
- if it is proposed initially to operate a broadcasting-satellite service for community reception, and at a later date to operate broadcasting-satellite services for individual reception in the same frequency band, both services should employ the same modulation system to facilitate compatibility. Under such circumstances, it would also be necessary to assume sharing criteria that would allow for the broadcasting services ultimately required. However, if a system is designed for community reception on a permanent basis with no plans for later use of the same frequency band for individual reception, the assumption of sharing criteria more stringent than those required for the planned system could be wasteful;
- all the signals transmitted from the same orbital position and meant for the same audience should generally be of the same polarization, however, exceptionally large service requirements may make it necessary to use both polarizations (in interleaved channels as discussed in § 2.1.2) from the same orbital position and meant for the same audience.

Sections 2 to 8 deal with planning of the 12 GHz band in general terms. Sections 9 and 10 discuss the results of 12 GHz planning in Regions 1 and 3, and Region 2 respectively. Section 11 considers the planning of broadcasting satellites in other bands, and § 12 deals with spacecraft service functions.

2. Guidelines toward efficient planning

2.1 *General principles*

All planning should make use of the following principles, consistent with the service demands of individual administrations and to the maximum extent practicable, in order to achieve a high efficiency of spectrum and orbit utilization.

2.1.1 *Orthogonal polarization*

Orthogonal polarization offers a potential for a significant decrease in mutual interference and, therefore, increased spectrum-orbit utilization. When used in conjunction with frequency interleaving, it may produce a degree of discrimination sufficient to allow re-use of the frequency band in the same satellite system. When used in adjacent satellites, the additional discrimination may allow the spacing between them to be decreased to about one half, in many cases. For some systems, maintaining the correct polarization angle at all the receiving installations may introduce underdesirable complexities which must be considered before the principle can be implemented. The use of this technique is also discussed in Reports 555 and 814.

It should be noted that the principle does not say that adjacent satellites should always use opposite polarization. Rather, it says that polarization should be used in the most effient manner. For example, if the service areas of two satellites are far enough apart, the satellites can be placed very close together even when co-polarized. A third satellite possibly serving an area much closer to the area served by the first one, may then use an opposite polarization.

2.1.2 *Frequency interleaving*

Frequency interleaving, or the technique of offsetting the carrier frequencies of one satellite (or one set of transponders in a single satellite) relative to the carrier frequencies of another, is used in order to reduce interference. The principle proposed is that this technique should be used wherever practical, in such a way as to lead to the most efficient spectrum-orbit utilization. Generally, that means that the frequencies should be interleaved in satellites relatively close to one another, but need not be interleaved in satellites serving widely separated areas. Also, an administration which is assigned a block of frequencies at a given orbital position may choose to utilize contiguous, non-interleaved channels.

The implementation of the frequency interleaving principle may be difficult when different systems use transponders with widely different bandwidths, and with multi-carrier signals. Some advantage may still be possible from the use of frequency interleaving, but the principle must be stated more generally in terms of avoiding coincident carrier frequencies.

2.1.3 *Crossed-path geometry*

Crossed-path geometry refers to the principle that considerable improvements in orbit-spectrum utilization may be achieved if adjacent satellites serve areas separated by at least one other intervening service area. If the intervening service area is relatively large, the adjacent satellites may be placed relatively close together.

2.1.4 *Clustering*

Administrations having service requirements which exceed the capacity of a single satellite may choose to locate two or more satellites in a single nominal orbital position. Such clustering of satellites may allow up to the entire available band to be utilized for a particular service area, from a single orbital position. Nominally collocated satellites may need to be separated slightly in order to avoid collisions, excessive feeder-link interference, etc.

2.1.5 *Homogeneity of systems*

The orbit efficiency would be maximized if all satellites in a portion of the orbit transmitted at the same e.i.r.p. per television signal. However, there may be reasons for some inhomogeneity between different systems because of different propagation margins being required in different service areas, because of receiving terminals with different G/T values in different systems, etc. The effect of this inhomogeneity on orbit efficiency requires further study. Report 453 provides information in this regard.

2.1.6 *Feeder link considerations*

The planning of feeder links is discussed in Report 952. When feeder links and down links are planned at the same time, advantage may be taken of the trade-offs possible by considering overall performance of the feeder link and down link together. This applies in particular to requirements of protection ratio and energy dispersal (see Report 215).

There may be cases where the feeder link and the down-link service areas are not coincident. For example, an administration whose territory spans several time zones may find it desirable to serve each time zone from a different orbital position in order 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. These matters received particular attention in the RARC SAT-83, which demonstrated the advantages of simultaneous planning of the feeder links and down links.

2.1.7 *Protection ratio*

The single entry protection ratio adopted for the WARC-BS-77 Plan for Regions 1 and 3 is 35 dB. According to the satellite transmitting antenna pattern given in Appendix 30 of the Radio Regulations, a discrimination of 35 dB occurs at a separation of service areas of 5.2 beamwidths while a discrimination of 30 dB is achieved at a separation of 1.58 beamwidths. Hence, at this lower separation the requirement of a 35 dB protection ratio would not be satisfied. However, the impact on spectrum-orbit capacity would be substantial if a 30 dB single-entry protection ratio could be acceptable as a trade-off for increased spectrum-orbit capacity or increased flexibility in positioning broadcasting satellites.

The RARC SAT-83 adopted an aggregate co-channel protection ratio of 28 dB for Region 2, corresponding to a single-entry protection ratio of about 32 dB. This is one of the reasons why the Region 2 Plan permitted smaller satellite separations, in some cases, than the Plan for Regions 1 and 3.

2.2 *Geographic considerations*

Geographic features affect the use of the geostationary orbit in two ways: they determine the usable service arcs for the given service areas, and they interact in various degrees with the three techniques employed for the re-use of the same frequencies.

2.2.1 *Service arcs*

The service arc of a given service area depends directly on the geographic features of latitude, size and shape. Additional restrictions may be imposed by special requirements of minimum angle of elevation and eclipse protection:

For example, studies on 12 medium-sized service areas have shown that the average available arc (subject to the elevation angle constraints in Appendix 30 of the Radio Regulations and eclipse protection to local midnight) is 23°, while the average available arc to meet a 20° elevation angle and assuming full battery support is 112°, a nearly five-fold resource increase.

- *Latitude:* For a single receiver and for an assumed minimum angle of elevation, the length of the service arc is a function of latitude only. Figure 1 shows the length of the service arc for such a point as a function of latitude for angles of elevation from 0° to 40°. For an area that is narrow in latitude, so that all of its points are approximately at the same latitude, this length is decreased by the distance (measured in degrees of longitude) between its easternmost and westernmost points;

- *Size and shape:* The service arc of an extended area of irregular shape is determined by the latitude and longitude of the two points in the area at which the elevation angle first falls below the given value as the satellite moves east or west, respectively. These points frequently are not obvious by inspection and must be determined by trial and error or by graphical means. In general, the larger the service area and the higher its latitude, the smaller its service arc. As far as shape is concerned, a long narrow service area has a smaller service arc than a roughly circular one of the same size. For a service area near the equator, the east-west dimension tends to be the determining one; for a service area nearer one of the poles, the east-west dimension at the highest latitude is critical.

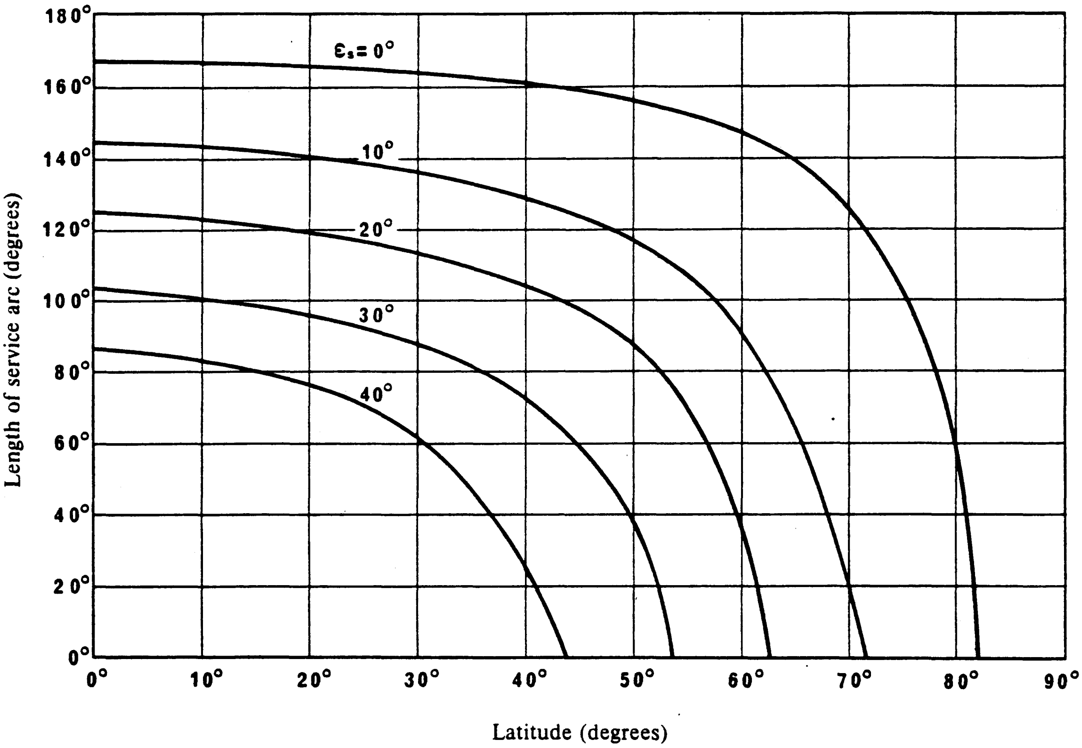


FIGURE 1 – *Service arc of single receiver*

(ε_s: angle of elevation)

2.2.2 *Frequency re-use*

Frequency re-use is possible primarily through three techniques: orthogonal polarization, earth-station antenna discrimination, and satellite antenna discrimination. Geographic features have some effects on all three.

– *Orthogonal polarization:* The discrimination obtainable between two cross-polarized beams depends on two geographic features: the climate (which determines the rain statistics) and the location, i.e. the latitude and longitude of the earth receiving station. Depolarization caused by rain is an important effect both with linear and with circular polarization. The variation of the received polarization angle with latitude and longitude, which may or may not be significant depending on several factors, will be present only with linear polarization. Both these effects are discussed in detail in Report 814.

– *Earth-station antenna discrimination:* The effect of geography on the earth-station antenna discrimination is a minor one. For a given earth-station antenna characteristic, satellite spacings must be larger when the service area is near the rim of the visible Earth (as seen from the satellite) than when the service area is near the sub-satellite point. Because the ratio of the geocentric to topocentric angles between two satellites varies between 1.18 and 0.99 over the Earth's surface, the ratio between satellite separations required in these extreme cases is 1.19 to 1.

– *Satellite antenna discrimination:* The discrimination obtainable from the satellite antenna, according to the patterns adopted by the WARC-BS-77, is at most equal to its on-axis gain which, for the smallest beam considered by that Conference (0.6°), is 48.9 dB. This value is reached when the receiver is about 18 beamwidths away from beam centre. However, substantial values of discrimination are obtained at points much closer. The adopted pattern has a plateau that gives a discrimination of 30 dB at points that are between 1.6 and 3.2 beamwidths away from beam centre. Similarly at the RARC SAT-83, a minimum beam size of 0.8° was adopted. This corresponds to a maximum discrimination of 46.4 dB which occurs at 16.5 beamwidths or 13.2° off-axis. Even larger values of discrimination may be possible when shaped beams are used. Examples of the performance obtainable with shaped-beam technology are given in Report 810. The relative location of different service areas, which determines their separation and therefore the amount of satellite antenna discrimination achievable, is the single most important geographic factor affecting spectrum-orbit utilization.

Service areas can be covered in three general ways:

– using a single circular or elliptical beam,
– using multiple circular or elliptical beams, or
– using a shaped beam,

as shown in Figs. 2, 3 and 4. Methods of fitting minimum area ellipses to service areas are addressed in Report 812. In the multiple elliptical or circular beam case, assuming the same channel and polarization assignment, there is considerable improvement in frequency re-use capability since the required separation of service areas for co-polar, co-frequency re-use will be much smaller for the smaller beams. Of course, required separations for adjacent-frequency re-use will also be reduced.

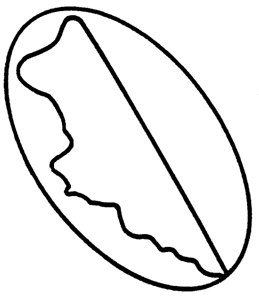


FIGURE 2 – *Single elliptical beam*

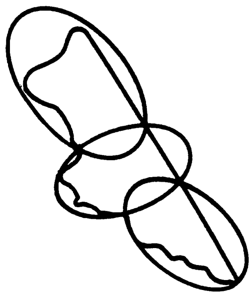


FIGURE 3 – *Multiple elliptical beam*

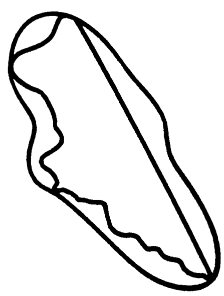


FIGURE 4 – *Shaped beam*

In the multiple beam case, the transmissions to the different positions of the service area may be at different frequencies, thus adding a degree of flexibility to the possible services. If different frequencies (or polarizations) are used, the total number of channels used is correspondingly increased. The overall capacity of the spectrum-orbit resource may be increased or decreased depending on the size of the beams and the separation of the service areas to which the same or adjacent channels are assigned or allocated. If identical transmissions are used, this case becomes equivalent to that of the shaped beam. In fact, shaped beams are often achieved by combining several elliptical beams of the proper amplitudes and phases.

It must be noted, however, that the size of service area ellipses in the multiple beam case, or that of the beam elements in the shaped beam case, may be limited by considerations similar to those which led to the adoption of a minimum ellipse size at the WARC-BS-77, e.g. spacecraft antenna size.

2.3 *Broadcasting-satellite systems for community reception*

One of the planning principles adopted by the WARC-BS-77 and by the WARC-79 (Resolution No. 701) is that all planning should be done on the basis of individual reception. This may lead to inefficient spectrum-orbit utilization for those cases in Region 2 in which there is a permanent requirement for a community broadcasting-satellite service, i.e. where there is no intention to later convert to individual reception. It may be possible, in some cases, to implement more community broadcasting satellites than individual broadcasting satellites in a given orbital arc, due to the greater discrimination of the receiving antennas of the community broadcasting-satellite system. This advantage may be limited, however, due to the differences in e.i.r.p. of the different systems (see § 2.1.5). The extent to which this implementation is possible depends on the technical characteristics of the systems involved and on the geographical separation of the various service areas affected. Spectrum-orbit efficiency might be increased if this possibility is taken into consideration during the planning stage. It will be necessary to further study this method of use of the 12 GHz band in Region 2.

2.4 *Impact on planning of multi-service (hybrid) and multi-beam satellites*

In some cases, an administration may achieve significant cost savings by sharing a single (hybrid) satellite among two or more services such as the BSS, FSS and MSS. Similarly, two or more administrations may achieve savings by sharing a single satellite having multiple fixed beams (as discussed in Report 810) or time-shared steerable beams; in these cases, the shared satellite may also provide two or more services if desired. These savings are likely to be greatest for administrations whose requirements for certain services have not yet developed sufficiently to make a dedicated satellite practical.

Multi-service satellites might use specialized transponders of two or more types, one type for each distinct service, or may use transponders capable of providing more than one service each.

Certain studies [Edelson and Morgan, 1977; Fordyce and Stamminger, 1979] have suggested that such multiple service/multiple beam systems may be particularly attractive economically given the growing capability to launch large space platforms, although more conventional space stations can also be efficiently used to provide such services where total power requirements are modest.

Total power requirements would depend on whether the concerned administrations desired to implement, at any given time, the full number of channels available to them and/or the full transponder power allowed by a plan or other regulatory limitation. For example, an interim service scheme is conceivable in which less than full capacity and/or power would be used, at the choice of the concerned administrations, for a period of time (e.g. the life of the satellite) until the full service was implemented at a later date. Several administrations, allotted different orbital positions on the basis of their ultimate requirements may, for interim or developmental service, wish to share the same space station with one or more channels assigned to each administration.

Report 665 notes that space station antenna beams can be steered or directed using arrays. Mechanically steered antennas operating over wide areas have been demonstrated on ATS-6 and CTS spacecraft. Thus, it is possible to *time share* a given satellite capacity, including individual transponders, among two or more administrations.

Where two or more administrations time share the same channel, they would be using the same frequencies, which may not be the frequencies allotted to each of them in a plan. For a single space station, separate feeder-link frequency bands, or portions of bands would be required for each down-link service. Where multiple administrations are served, different specific frequencies may be necessary for each administration or service area, depending upon such factors as antenna discrimination, beamwidth, separation of service areas, interference objectives, etc. Thus feeder-link considerations in multi-beam or multi-service satellites present important limitations.

Plans which allot specific orbital positions and frequencies for one service will not, in general, be compatible with such plans for another service. Because of differing requirements and technical characteristics in different services, orbital allotments will not, in general, be the same for the different services in the same administration or service area. Thus, unless substantial flexibility were built into those plans, or plans were carefully coordinated with each other, multi-service satellites would not be possible to implement, and the economic advantages of such satellites could not be achieved [CCIR, 1978-82a].

The difficulties imposed by specific plans on shared use of space stations by different services or different administrations, and the potential technical and economic attractiveness of such shared use, should be taken into consideration in planning the BSS in Region 2. Flexibility in the implementation of a plan or bringing into service systems affected by a plan (such as stated as a principle for planning in Region 2 by Annex 6 to the Final Acts of the WARC-BS-77) could help to resolve some of the difficulties.

Precise methods of taking multiple service/multiple beam space stations into consideration in planning have not been developed and require further study.

A discussion of multiple service (hybrid) satellites may also be found in Report 453, § 7.3.

3. Key elements

The key elements of planning for the broadcasting-satellite service are descriptions or specifications of:

- the broadcasting-satellite service requirements to be satisfied,
- the range of technical parameters and interference criteria,
- the structure of the plan and the resulting allotments, and
- the methods for subsequent modifications to accommodate changing service requirements and technology.

Each of the key elements will be discussed in turn.

3.1 *Service requirements*

Service requirements are prepared and/or coordinated by individual administrations or groups of administrations to reflect domestic or regional broadcasting-satellite requirements. The specification of these requirements could range from a statement of the total bandwidth, preferred orbital position and associated service area to a complete delineation of the types and number of broadcasting channels and their service area.

Service requirements are closely coupled to the time element dictated by the particular approach to planning. It should be appreciated that the most speculative forecasts are those made over the longest term, whereas the most accurate are those for the short-term.

3.1.1 *Examples of factors relating to the required service*

- the required number of television channels for each service area;
- the number of service areas in each country;
- the shape, dimension, and location of each service area, in the form of geographical co-ordinates of the corners of a polygon which represents the area considered, with sufficient approximation, or possibly the detailed characteristics of the planned antenna beam if available; the geographical co-ordinates of several points within each service area resulting in a sufficiently representative sampling for purposes of calculating protection margins;
- the quality of service, including the required carrier-to-noise ratio, and signal-to-noise ratio, for specified portions of time;
- the preferred location of the satellite in the geostationary orbit, including the possible preference for some service areas to share, or not to share, the same orbital position;
- the kind of service desired in each service area, e.g., individual reception or community reception, and possibly in the case of the latter, the number of receiving installations;
- possibly the locations, antenna sizes, and e.i.r.p.s of all feeder-link transmitting stations in each service area;
- possibly the frequencies to be used for the feeder-link transmissions;
- the philosophy of satellite spares;
- the expected growth and evolution of the service.

3.2 *Technical parameters and interference criteria*

Depending on the type of broadcasting-satellite application and its state of development, the technical parameters and inter-system interference criteria may vary from system to system and with time. For example, using one planning approach, each administration would have the flexibility to construct and expand its broadcasting-satellite system in accordance with its growth requirements and by its own criteria, minimum cost for example. For this planning approach, the technical parameters and inter-system interference criteria would change with time in response to changing service requirements, technology and cost.

Using a different planning approach, the parameters and criteria would be fully specified for all systems, perhaps with appropriate modification procedures.

3.2.1 *Examples of factors relating mainly to technical standards*

- the carrier frequency spacing of adjacent channels;
- the preferred carrier frequency spacing of channels allocated to the same service area;
- the overall protection ratios for all broadcasting systems included in the plan (co-channel and adjacent channel) including both feeder link and down link;
- receiver characteristics, including the figure of merit (G/T);
- the radiation patterns (co-polar and cross-polar) of the satellite transmitting antenna and the earth receiving antennas;
- the pointing tolerance of transmitting and receiving antennas;
- station-keeping accuracy;
- propagation data, including allowances for rain attenuation, clear air attenuation, and depolarization caused by rain;
- the limits of the usable arc of orbit for each area, as determined by the time of satellite eclipse and the minimum elevation angle;
- the minimum power flux-density required within the service area for the kind of service desired, e.g., individual reception or community reception.

3.3 *Structure and allotments*

Allotments might be made in various forms and for various periods of time, independent of the time period associated with the service requirements.

Using one particular planning approach, assignments are recorded in the Master Register after successful coordination with other systems. These frequency and orbit position assignments in the Master Register constitute one possible base of a plan.

Using a different approach, band segments and orbit positions would be allotted to each administration or group of administrations for a specified period.

3.3.1 *Examples of characteristics determined by the plan*

In the broadcasting satellite service, the object of a plan is to specify, for each satellite emission, the following characteristics:

- the shape, dimensions and orientation in space of the antenna beam used to cover the service area;
- the transmitted power (or the e.i.r.p.);
- the frequency (or the channel);
- the satellite position in the geostationary orbit;
- the polarization.

To present the channel, orbit position, and polarization assignments in a given plan, it is convenient to use a matrix in which each row corresponds to one channel and each column to one orbital position. The various service areas are then entered as the appropriate elements of the matrix together with a symbol indicating polarization. Table I illustrates a method of presentation of a plan.

TABLE I — *Plan for showing assignments in a plan with C channels (1, ... C), S orbit positions (at longitudes $\lambda_1, \ldots \lambda_S$), and two polarizations (1, 2). Service areas are designated A, B, . . . N*

Channel \ Longitude	λ_1	λ_2	. . .	λ_S
1	A(1)	B(2)	. . .	G(2)
2	D(2)	E(1)	. . .	H(1)
. . .	. . .	. . .	. . .	. . .
C	K(1)	L(2)	. . .	N(2)

3.4 *Modification*

The final major element of alternative planning approaches is the accommodation of changes in service requirements, technical parameters, criteria, and technology, and possibly consequential changes in allotments. The ability and the degree to which changing requirements may be accommodated within a plan depends on the planning approach adopted and the portion of the total capacity of the geostationary orbit/spectrum resource not already allotted in the plan. The capacity is a function of the technical parameters of the systems in the plan and the satellites' positions in the geostationary-satellite orbit.

4. Planning approaches

The following are possible approaches to planning. Not all these approaches are necessarily applicable to all allocated broadcasting-satellite frequency bands.

4.1 *Detailed orbital position and channel allotment plan*

In such a plan, specific values of satellite orbit location, frequencies, and service areas are specified for each administration, along with a specific satellite e.i.r.p. and sense of polarization. The orbital spacing and service area separations required for co- and adjacent-channel operation in the plan are based on specific values assumed for a number of additional system characteristics, which include:

- noise and pfd objectives;
- receiver figure of merit;
- station-keeping tolerances;
- interference objectives;
- antenna characteristics;
- modulation method and necessary bandwidth;
- eclipse protection and minimum angle of elevation requirements.

It is convenient to distinguish between three types of detailed allotment plans.

Type 1: *Long-term plan (15-20 years)*

A long-range detailed frequency/orbit plan where technical criteria, frequencies and orbital positions are fixed and changes are limited to special circumstances to the extent that they do not introduce additional interference or require additional protection. The plan would be reviewed after the specified term at a competent administrative radio conference.

Type 2: *Medium-term plan (7-15 years)*

A detailed frequency/orbit plan, with assignments of orbital positions and channels to each administration coupled with a modification procedure that would allow as much flexibility as possible while retaining the integrity of the plan. New requirements and criteria may be accommodated by agreement of affected administrations during the lifetime of the plan. A regional or world administrative radio conference would be held at the end of the period to update the plan, taking into consideration technological changes and new requirements.

Type 3: *Short-term plan (3-6 years)*

A short-term plan with orbital positions and channels assigned to each country for a period of 3-6 years. Conferences would be held before the end of the period (say every 5 years) to amend the plan to include new requirements and reflect new technology. Of course, the integrity of all systems notified or operating according to the current plan would be respected.

Typically, all plans must include orbit positions and a minimum number of channels for each administration in the plan in order that it can develop its system or concepts within a defined framework.

4.2 *Detailed orbital position and block frequency allotment plan*

In this planning approach administrations are assigned blocks of spectrum at certain orbital positions. These blocks of spectrum would be associated with certain service areas, but neither specific frequencies nor polarizations would be allotted. The channel bandwidth would be determined by the administration(s) concerned. In effect, this scheme leaves to the administrations concerned the flexibility to choose the type of microscopic planning schemes best suited to their requirements and needs. Administrations would be free to change their frequency plans, polarizations and bandwidths as their requirements change, or to increase the capacities of their allotted blocks of spectrum as permitted by advances in technology. With proper attention to selection of service areas and orbital positions, administrations would be able to share a satellite with other administrations in the initial phase of development of their requirements, while retaining the flexibility to change their use of the block of spectrum as their requirements increase. Specific channel and polarization assignments would be made at the time an administration was ready to implement a system for a particular service area. The key to accomplishing such an approach is arranging orbital locations so as to obtain the necessary isolation between the service areas concerned.

4.3 *Detailed frequency assignment and orbital arc allotment plan*

Under this scheme, individual administations would be alloted a number of specific channels per service area, but would not have specific orbital locations associated with them. However, administrations would be allotted specified geostationary orbital arcs that could be used to provide service to the concerned service areas. Specific assignments of orbital position to a service area would be made at the time an administration was ready to implement a system for that service area.

This planning approach could provide flexibility in some aspects of system design. However, in order to assure the required numbers of channels per service area, certain technical planning constrains must be assumed, including channel bandwidth.

4.4 *Guaranteed access by means of multilateral coordination*

A formal plan would not be established, but there would be procedures for guaranteed frequency/orbit access for requirements as they arise. Normally, frequency/orbit access would be coordinated in accordance with the procedures contained in the method described in § 4.5. When a new requirement could not readily be accommodated, a special meeting would be called of those administrations that might be affected and a means would be found to accommodate the new requirement, including adjustments to existing systems, in order to accommodate new systems of administrations.

4.5 *Coordination procedures and technical factors that are revised periodically*

This approach to planning is a phased revision of the existing regulatory procedures, regulations and CCIR Recommendations as well as the development of new procedures, regulations and Recommendations (simplified to the extent possible) leading to more efficient use of the geostationary-satellite orbit/spectrum resource.

5. Procedures for detailed a priori planning

The planning of the broadcasting-satellite service is constrained by two main technical factors: system noise and interference. Since, in most cases, these two factors affect different system parameters, they can be considered somewhat separately in the development of the planning procedure. This permits the partitioning of the synthesis problem into two steps.

The first step consists of optimizing the basic technical system parameters so that the thermal noise performance criteria are met. This is based on the minimization of the transmit power at the satellite, for a given figure of merit for the receiving terminals and a specified performance criteria for protection against thermal noise, i.e. minimum C/N to be met everywhere within a given service area for a specified percentage of the time. The beam parameters as described in § 7.1 can be optimized under these constraints. For this purpose, the service area boundaries are usually approximated by a polygon defined by the coordinates of its apexes.

There is a need, in the planning process, to optimize a beam for each of the possible assignments of orbital locations for the satellite serving each of the service areas so that, during the assignment stage, the relevant beam parameters are available from the list in order to compute the mutual interference between the different systems involved. Requiring the assignment process to select beams from this list according to the orbital position assignment of each satellite will ensure that all systems in the final plan will also be protected against thermal noise.

The second step of the synthesis is the assignment of orbital positions, polarizations and channel frequencies so that the interference performance criteria are met.

This section describes a possible procedure for detailed *a priori* planning. It is applicable when channel bandwidths are compatible among the systems being planned. Further study is required to relax this constraint.

5.1 *Planning with regular channel distributions*

When it is envisaged to make a complete plan at the outset, it may be useful to divide the task into two steps. First, a plan is made which permits the broadcasting of one television programme (or its equivalent) to each service area using a limited number, C_1, of channels. Then this "plan with one programme per service area" is transformed into a more general plan which assigns the required number of channels to each service area having the same position in the orbit and the same polarization for channels serving the same area. A study [CCIR, 1974-78a] describes a method by which the construction of such a general plan may be worked out on the basis of regular channel distributions. This method may be used directly when it is required to assign the same total number of channels to each service area; and can, also, be modified to fit the case when this does not hold to be true (see § 5.4).

5.2 *Definition of regular distribution*

A regular distribution is characterized by:

d: the difference between the ordinal numbers of the consecutive channels serving an area;

t: the number of channels assigned to each area (a channel may carry one television programme or many sound broadcasting programmes);

C_1: the number of channels for a single programme per area.

The total number of channels C is given by:

$$C = tC_1 \quad (1)$$

This equation also indicates that C_1 is the maximum number of service areas that can be served from one satellite position without having to resort to frequency re-use.

The carrier spacing Δ is given by:

$$\Delta = \frac{W - gb - b}{(C - 1)} \quad (2)$$

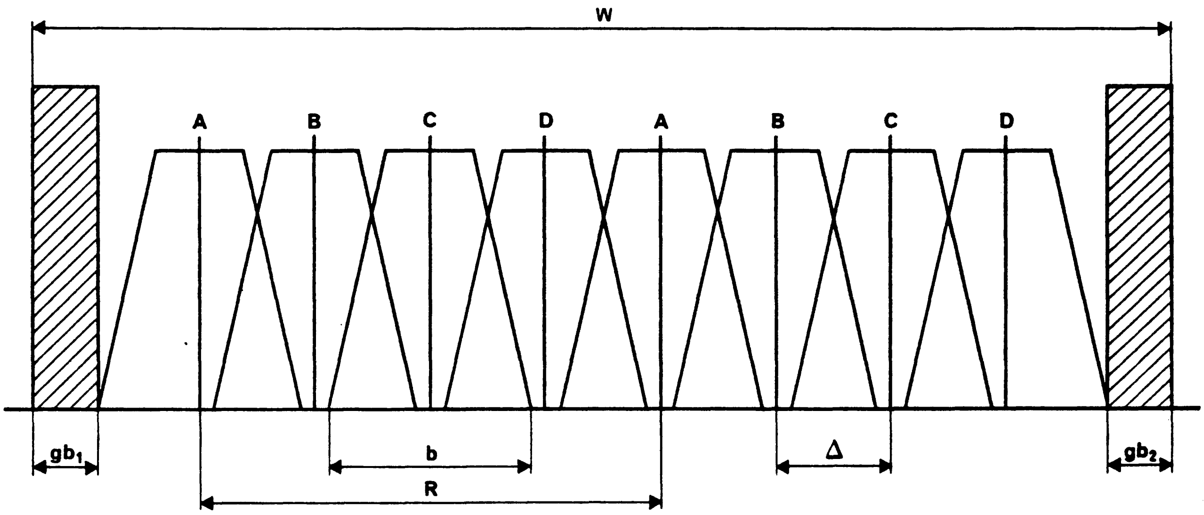
where:

W: the total bandwidth including the two guard bands;

gb: the total bandwidth occupied by the two guard bands at both ends of the allocated band;

b: necessary channel bandwidth.

This can readily be seen from Fig. 5.



CHANNELS		1	2	3	4	5	6	7	8	
AREAS		A	B	C	D	A	B	C	D	

FIGURE 5 – *Example of a regular channel distribution*

$C = 8$
$C_1 = 4$
$t = 2$
$d = 4$
$gb = gb_1 + gb_2$
$W = gb + b + (C - 1)\Delta$

5.3 *Constraints on distributions*

The principal restrictions to which the regular distributions are subject are as follows:

- the value of d must be greater than 1 to avoid the assignment of two adjacent channels to the same country, which would give rise to difficulties when multiplexing the signals for the same transmitting antenna; d must also be small, so as not to make excessive the receiver tuning range necessary to receive all the programmes intended for one service area.

  If R is the range over which the centre frequency of the receivers can be tuned, it will be necessary that:

$$d \leqslant \frac{R}{(t - 1)\Delta} \tag{3}$$

- the number of channels per service area t, should normally be chosen to be as high as possible, taking account of the available bandwidth;
- the number of channels for one programme per service area, C_1, should be a multiple of d. Moreover, it should lie between a minimum value (which corresponds to the case where it is possible to neglect adjacent-channel interference, requiring a large channel spacing), and a maximum value which is determined;
  - by the necessity to have a sufficient number of positions on the orbit to take advantage of the discrimination against interference given by the receiving antennas;
  - by the necessity to avoid a reduction of the channel spacing to such a degree that the increase in the necessary adjacent-channel protection ratio would make planning impossible.

  For values of C_1 between maximum and minimum, the carrier spacing is, in general, smaller than the channel bandwidth, and assignments must be made so as to protect both the same channel, and adjacent channels, as required by the corresponding protection ratios. The optimum value of C_1 is the one which results in approximately equal importance for co-channel and adjacent-channel interference. According to preliminary studies involving some forty service areas in the European Broadcasting Area, optimum C_1 there, would be equal to 8;
- to obtain advantage from the use of orthogonal polarizations, it is very useful to alternate polarization from one channel to the next in a given orbit station, as well as from one station to the next, in a given channel. This facilitates assignment of adjacent channels to adjacent areas from the same orbital position, and the assignment of the same channel to areas with modest geographic separation from neighbouring satellite stations. However, for all the channels serving a given area to have the same polarization, the difference d between the ordinal numbers of the successive channels of the area must be an even number. Then, as C_1, the number of channels per programme per area, is necessarily a multiple of d, it must also be even;
- it may be helpful to introduce guard bands, on the one hand at the ends of the band allocated to satellite broadcasting in order to reduce adjacent-band interference (see Report 809) and on the other, between the groupings of channels within the band in order to reduce the cases of adjacent-channel interference. The latter guard bands should be eliminated if it is intended to standardize the channel spacing for more than one Region.

The Final Acts of the WARC-BS-77 (see § 3.5.3 of Annex 5 to Appendix 30 (ORB-85) to the Radio Regulations) specify that the spacing between the assigned frequencies of two channels being transmitted by the same satellite antenna must be greater than 40 MHz for Regions 1 and 3 (see also Report 811). However, the spacing between the assigned frequencies of two channels being transmitted to the same service area can be smaller than 40 MHz (and therefore the value of $d\Delta$ 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. More study is required to evaluate the trade-off between the complexity and cost of such arrangements and the increased flexibility resulting from relaxation of the 40 MHz restriction. The spacing would then be limited by the receiver characteristics.

All the above constraints severely limit the number of regular channel distributions of practical interest to planning.

Figure 6 gives two examples of channel utilization at a given orbital position. In the first, the parameters chosen for a total bandwidth of 800 MHz are $d = 4$, $t = 5$, $C_1 = 8$. In the second, the parameters chosen for a total bandwidth of 500 MHz are $d = 6$, $t = 5$, $C_1 = 6$. In accordance with the channel order, the service areas follow the sequence A, B, C, D; or A, B, C, D, E, F.

5.4 *Non-regular distributions*

When it is required to assign a number of channels varying from one service area to another, the preceding considerations still apply under the condition that t of the regular distribution is taken to be equal to the greatest common divisor of the different channel totals for the various service areas; the limiting case being $t = 1$. Moreover, it is necessary to make each area appear as many times as the number of groups of t channels assigned to it. In some particular cases, another method may consist of distributing a group of t channels amongst several service areas. The inconvenience of these non-regular distributions consists in increasing the difficulty of the problem of adjacent-channel interference. However, such situations may be unavoidable in practice.

CHANNEL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
AREAS	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	E	F	G	H	E	F	G	H	E	F	G	H	E	F	G	H	E	F	G	H

CHANNEL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
AREAS	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F

FIGURE 6 – *Examples of regular channel distributions occupying a total bandwidth of 800 and 500 MHz. In both examples, the number of channels, t, assigned to each service area is 5. In the first example,* C_l*, the number of channels for one programme per service area, is 8 and the difference, d, between channel numbers assigned to the same service area is 4. The corresponding numbers in the second example are 6 and 6. The 800 MHz bandwidth is then divided into 40 channels with carrier separation of 19.18 MHz and the 500 MHz bandwidth is divided into 30 channels with nominal carrier separation of 16.7 MHz. Channel assignments to service areas A, B, C, D,... could be repeated (to other service areas) for other positions on the orbit*

5.5 *Standardization of carrier position and spacing*

Standardization of the channel spacing and position of each channel in the whole allocated band may be desirable with a view to utilizing the frequency/orbit more effectively and simplifying interference calculations. The exact value of channel spacing and exact location of the channel may be determined, taking into account the relevant technical characteristics, and a detailed regular channel distribution may then be constructed.

6. Calculation of the total interference

When evaluating the power produced at a given point by a single satellite (down link) or at a given satellite location by an earth-station transmitter (feeder link) the concept of an equivalent gain for each partial link may be employed.

There are two antennas involved in each partial link, and these have both co-polar and cross-polar transmission and reception characteristics. In addition, atmospheric propagation effects, represented principally by co-polar attenuation and cross-polar discrimination, influence the net signal level.

The equivalent gain (as a power ratio) for one partial link can be represented by the following approximation:

$$G = G_1 \cdot \cos^2 \beta + G_2 \cdot \sin^2 \beta \tag{4}$$

$$G_1 = G_{tp} \cdot G_{rp} \cdot A + G_{tc} \cdot G_{rc} \cdot A + G_{tp} \cdot G_{rc} \cdot A \cdot X + G_{tc} \cdot G_{rp} \cdot A \cdot X$$

$$G_2 = (\sqrt{G_{tp} \cdot G_{rc} \cdot A} + \sqrt{G_{tc} \cdot G_{rp} \cdot A})^2 + G_{tp} \cdot G_{rp} \cdot A \cdot X + G_{tc} \cdot G_{rc} \cdot A \cdot X$$

where:

- β : for linear polarization, is the relative alignment angle between the received signal polarization plane and the plane of polarization of the receive antenna, and, for circular polarization, $\beta = 0°$ is assumed to correspond to co-polar transmission and reception and $\beta = 90°$ is assumed to correspond to mutually cross-polarized transmission and reception;
- G : gain (power ratio > 1);
- A : co-polar attenuation on the interfering partial link (as a power ratio $\leqslant 1$);
- X : cross-polar discrimination on the interfering partial link (as a power ratio $\ll 1$);

$$X = 10^{-0.1[30 \log f - 40 \log(\cos \varepsilon_s) - 20 \log(-10 \log A)]}$$

for $5° \leqslant \varepsilon_s \leqslant 60°$

where:

- f: frequency (GHz); and
- ε_s : satellite elevation angle as seen from the earth station (degrees).

For $\varepsilon_s > 60°$, use $\varepsilon_s = 60°$ in calculating the value of X.

Using the equivalent gain concept, the wanted carrier power (in dBW), or the single-entry interfering power, on each partial link is simply given by:

$$P_R = P_T - L_{FS} - L_{CA} + 10 \log G \qquad \text{dBW} \tag{5}$$

where:

P_R : power received (dBW),

P_T : transmitting antenna power (dBW),

L_{FS} : spreading ("free-space") loss (dB),

L_{CA} : clear-air absorption (dB).

In the expression for G_1, power summation of the terms is assumed throughout. Near the main axis of the wanted transmission, a voltage addition of the first two terms may be more appropriate due to phase alignment whilst away from this axis random effects dictate power addition. However, since the second term is insignificant near this axis the assumption of power addition does not compromise the approximation. Atmospheric depolarization is a random effect thus the last two terms are power summed.

In the expression for G_2, voltage addition of the first two terms is assumed since, near axis, either term could be dominant and phase alignment of these terms would dictate voltage addition. Away from this main axis the third and fourth terms become the dominant contribution: thus, although a power addition of the first two terms is warranted, in this region as for the G_1 discussion, the validity of the assumed model is not unduly compromised by maintaining voltage addition in all regions. Since the transition from voltage addition near axis to power addition off-axis is nebulous, the above expressions, in view of the arguments presented, would appear to be a reasonable compromise between accuracy and simplicity.

If the ratio of the wanted carrier power to the power of an interfering signal, where both powers are calculated using equation (5) above, is to be evaluated for the worst case, such parameters as satellite station-keeping tolerances, satellite antenna pointing errors, and propagation conditions must be taken into account.

The expression for G_2 above can be used to investigate the overall discrimination sensitivity to both transmit and receive antenna cross-polar discrimination near the axis. For example, using the WARC-BS-77 antenna patterns as a reference and relaxing first the satellite cross-polar pattern by 7 dB to −33 dB, a reduction in the net discrimination of 0.5 dB is obtained, whereas in relaxing the receive antenna cross-polar pattern by 5 dB to −20 dB, the reduction in net discrimination is 3 dB.

Equations (4) and (5), in the form shown, apply to circular polarization; they are also valid for linear polarization provided that the polarizations of the wanted and unwanted signals are the same or orthogonal. (If the angle between the polarizations of the two signals has any other value, additional interference components appear.)

The aggregate interference power is obtained by adding the powers so calculated for all interferers. The ratio of the desired signal power to the aggregate interference power is the down-link aggregate carrier-to-interference ratio (C/I). The feeder-link aggregate interference power and C/I are obtained in a similar way, and the two aggregate values of C/I are then combined to obtain the total aggregate C/I.

The station-keeping and satellite transmit-antenna beam errors which should be included are those which result in the lowest receive level of the wanted signal and the highest receive level of the interfering satellite signal. When the interfering satellite is at a lower elevation angle than the wanted satellite, worst-case interference conditions usually occur during clear-sky operation. Conversely, if the interfering satellite is at a higher elevation angle, worst-case interference usually occurs during heavy rain conditions. If sufficient data are not available to evaluate faded conditions, a possible alternative is to use the following formula:

$$A = S_a(R, f)\; l(\theta, R) \qquad \text{dB} \tag{6}$$

where:

A : foul weather signal attenuation (dB);

S_a : specific attenuation (dB/km) which depends on the rain rate R (mm/h) and carrier frequency f. Values of R are given in Report 563 for the various climatic zones and percentage of the average year. The value of S_a can be determined from Report 721 (Fig. 1 or Fig. 2) given values for R and f;

l : effective path length (km) through the rain which is a function of the angle of elevation θ and the rain rate R (see Report 564).

Factors affecting rainfall attenuation are examined further in [CCIR, 1974-78b].

7. Principal planning steps

The object of this section is to give some indication of the successive planning steps.

7.1 *Calculation of transmitting antenna beam and e.i.r.p.*

For planning purposes, it has in the past proved convenient to assume that all the beams of various service areas have circular or elliptical cross sections. Some actual systems will probably employ shaped beams to suit the desired coverage and an alternative approach is to assume shaped beams in assessing the protection margin. In the shaped beam approach, modifications to some of the following planning steps may be required. This requires further study.

The parameters to be determined for circular or elliptical beams are:

- the co-ordinates of the centre of the service area, defined as the point at which the beam axis touches the surface of the Earth;
- the dimension of the major axis and the minor axis of the elliptical section of the beam. These dimensions should preferably be specified in such a way that the envelope of the elliptical section corresponds to the envelope of the transmitting antenna radiation pattern at the -3 dB points;
- ΔG, the reduction of the transmitting-antenna gain between the centre and the nominal limit of the service area (see Report 810);
- the orientation of the major axis of the elliptical section, preferably in the form of the azimuth of the projection of the major axis on the surface of the Earth with respect to the meridian passing through the centre of the service area;
- the orientation of the major axis of the elliptical cross-section, determined as follows: in a plane normal to the beam, the direction of the major axis of the ellipse is specified as the angle measured anti-clockwise from a line parallel to the equatorial plane, to the major axis of the ellipse.

In the calculation of these parameters, it is necessary to take account of the allowable pointing and rotation errors of the transmitting antenna so that the country being considered is still covered in all cases, and also of an eventual limitation of the dimensions of the transmitting antenna; (a limitation which corresponds to a minimum size of realizable beamwidth).

These parameters can be optimized according to specified criteria. EBU studies, described in Report 809, have been based on the following criteria:

- the representation of the country boundaries is approximated by a polygon which should be completely covered by the beam;
- the optimization is carried out so that the ratio between the areas (measured on a projection plane perpendicular to the beam axis) of the cross-section of the beam ellipse, and the projection of the polygon corresponding to a country, is as close as possible to unity.

In Canadian studies [CCIR, 1974-78c], boundaries of countries are represented in the same manner as above, but optimization (through minimizing the beam cross-section) is made possible by using projection on a sphere which is centred on the satellite.

As the optimal beam for a service area depends on the position in orbit, it could be advantageous to carry out the calculations for a large number of positions on the orbit, spaced, for example, every 2.5° within the usable arcs ahead of time. In this way, a file of optimum beams for the various service areas would be established.

Once the beams have been determined, the necessary radiated powers can be calculated by the usual link-budget method (see Report 215). In practice the actual powers may differ from the nominal powers specified by the plan, by an amount designated as the operating power margin (see Report 810).

7.2 *Calculation of co-polar and cross-polar emission discrimination matrices*

These matrices give, for the least-favourable point in each country, for the co-polar and cross-polar components respectively, the ratio:

$$\frac{\text{wanted co-polar power flux-density}}{\text{interfering co-polar (or cross-polar) power flux-density}}$$

The terms in these matrices apply to all the possible pairs of interfered-with and interfering countries. The calculations should take account of the least-favourable conditions of transmitting-antenna pointing. To a first approximation, these matrices are not affected by any change in the positions on the orbit, provided that the optimum beam is always used at each position. The matrices can, therefore, be calculated with an arbitrary choice of provisional positions on the orbit.

These matrices can be used:

- to indicate, independently of the position on the orbit, and thus independently of the receiving-antenna discrimination, the relative intensity of the potential interference between service areas;
- to calculate the actual level of interference between two service areas when the positions on the orbit are known. It is then necessary to add the receiving-antenna discrimination to the transmitting-antenna descrimination and to take account of the relative polarizations.

7.3 *Interference matrix for reception*

When the positions on the orbit are provisionally assigned in advance, it is also possible to calculate an interference matrix which gives, for each pair of countries, the ratio of wanted power/interfering power at the receiving antenna output.

The main advantage of the interference matrix is that it permits the transmission causing the predominant interference to be identified for each interfered-with service area. If a critical case of interference arises and it is decided to adjust the plan being considered, the interference matrix acts as a guide to the assignments which it is necessary to modify to improve the plan.

Furthermore, the interference matrix gives a preliminary idea of the real distribution of interference since, to a first approximation, the effect of multiple interference can be included by using a correction factor estimated, for example, at 3 dB, which is applied for a given interfered-with country, to the term in the matrix corresponding to the predominant interference.

7.4 *Algorithms for the assignment of channels, positions on orbit and polarizations*

The number of plans which are theoretically possible is so vast that there is no hope of evaluating them all. One valuable method can take the form of algorithms programmed on a computer which will enable a certain number of more-or-less satisfactory draft plans to be obtained. The aim of these algorithms should be to select assignments where the interference is weak. In other methods similar draft plans can be prepared manually without the use of computers.

Several computer programs have been written in several countries (see Report 812). Some of these make it possible to produce plans in which either all the protection margins are positive with the minimum number of channels, or in which the lowest protection margin is maximized for a given number of channels. The plans thus obtained can be modified manually, in cases where the impact of the modification is minor – for example, beam orientation, e.i.r.p. etc. However, some parameters cannot be modified without a destructive effect on the optimized plan.

Even when a computer is used, some of the planning steps may be done manually, in particular the assignment of polarization can be done systematically with the aid of certain simple rules. For example, in accordance with § 5.3, one can assign orthogonal polarizations to satellites using adjacent channels from the same orbital position, or using the same channel from adjacent orbit positions. However, such manual rules are less flexible than the use of operational research algorithms on computers.

In the case where the feeder links are planned at the same time as the down links (as in the case of RARC SAT-83 for Region 2), it is well recognized that there is a significant advantage in allowing the individual adjustment of feeder-link and down-link contributions of noise and interference. However, the complexity of the planning process is then increased considerably. Computer tools then become even more necessary.

If it is assumed that the down link will dominate the noise and interference budgets then the general approach to planning the feeder links and the down links will be to consider an initial planning stage to allocate spectrum and orbit resources to the down link. This entails first a synthesis process and an analysis process linked together in an optimization loop. The second stage would allocate corresponding spectrum resources to the feeder link (the orbit having already been allocated, or at least constrained in the first stage). This stage will also consist of a synthesis process and an analysis process linked together in an optimization loop (this second loop can, however, be made much simpler than in the case of the down link). This two-stage planning process can then be connected to an overall analysis process and iterated until an acceptable assignment is achieved. The whole process is illustrated in Fig. 7a.

A second approach, much more simplified, permits the simultaneous optimization of both feeder-link and down-link assignments and consists of a synthesis process and an analysis process connected together in an optimization loop as shown in Fig. 7b [CCIR, 1978-82b]. This approach will, however, generate the same relative assignments of the feeder links as for the down links. This results in a common translation frequency for all systems under consideration. It is assumed in this approach that a completely transparent transponder is used, i.e. no additional adjacent-channel filtering, no small signal suppression or enhancement due to operation at, or near, saturation of the non-linear travelling-wave tube. In the case where this common translation is too constraining, the resulting plan could be readjusted using the first approach described above in order to meet some specific requirements that the exact frequency translation of the down-link plan would not allow and to optimize the plan even further.

This second approach is only one way to simplifying the problem of planning the feeder links and down links. Further study is needed to identify other means.

8. Criteria for planning approach selection and plan assessment

8.1 *Criteria for selection of a planning approach*

General criteria could be used in determining which of the various possible methods of planning the use of orbit and spectrum will be most satisfactory in any specific set of circumstances. The following criteria are suggested, based on the studies of Interim Working Party 4/1.

These criteria have been presented in an arbitrary order, recognizing that the relative importance of each will differ between individual administrations. However, the important step is to first determine the objectives, and their relative importance, and then to evaluate the ability of each planning method to meet those objectives. The duration of the plan also has a bearing on the evaluation of the objectives.

Not all of these criteria are applicable to all cases of planning, depending upon the frequency band under consideration.

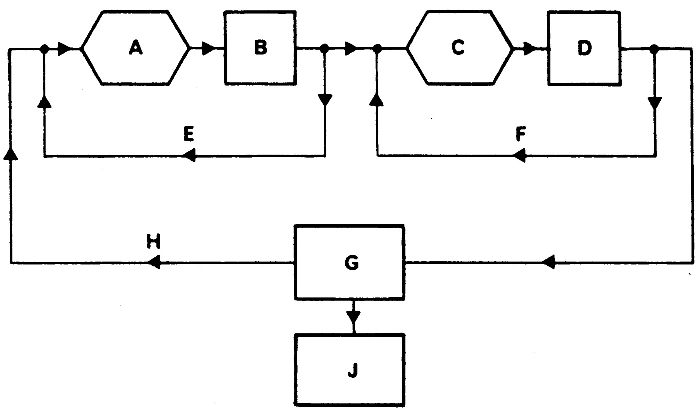


FIGURE 7a – *Process for planning the feeder links and down links in the broadcasting-satellite service*

A: *down-link synthesis*
Assign – down-link channels,
– down-link polarization,
– orbital location
B: *down-link analysis*
C: *feeder-link synthesis*
Assign – feeder-link channels,
– feeder-link polarization
D: *feeder-link analysis*
E: unacceptable down-link plan iteration
F: unacceptable feeder-link plan iteration
G: *full analysis*
H: unacceptable overall plan iteration
J: *acceptable overall plan documentation*

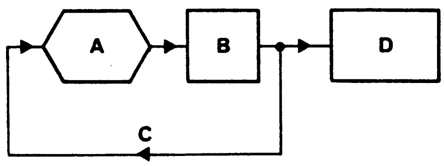


FIGURE 7b – *Simplified process for the simultaneous planning of the feeder links and the down links*

A: *plan synthesis*
Assign – feeder- and down-link channels,
– polarization and orbital position
B: *plan analysis*
C: unacceptable plan iteration
D: *acceptable plan documentation*

8.1.1 *Equitable access*

Does the method guarantee in practice for all countries equitable access to the geostationary-satellite orbit and the frequency bands being planned?

8.1.2 *Service requirements*

8.1.2.1 Is it possible to establish realistic forecasts of broadcasting-satellite service requirements to be used as the basis for allotments in the plan?

8.1.2.2 Can allotments be defined in the plan that will accommodate the likely variety of requirements, including multi-administration satellite systems?

8.1.3 *Accommodation of unforeseen new systems or changes in requirements*

Is there an effective procedure for accommodating unforeseen new systems or increasing or decreasing (e.g., when services are transferred to new satellites in other frequency bands) broadcasting-satellite service requirements?

8.1.4 *Accommodation of existing systems*

Does the method ensure protection to existing operational systems during the implementation and operation of the method?

8.1.5 *Establishment and modifications of technical parameters and interference criteria*

8.1.5.1 Can technical parameters and interference criteria be established and maintained for the life of the plan that will accommodate changing technology and service requirements?

8.1.5.2 Is there a provision for modifying the technical parameters and interference criteria of the plan to take advantage of the technical developments that are more efficient and/or less costly?

8.1.6 *Restrictions due to sharing with other services*

Does the method impose any additional sharing constrains either on planned or unplanned terrestrial or space services due to sharing the same frequency allocation?

8.1.7 *Efficient use of the orbit-spectrum*

8.1.7.1 Does the method make efficient use of the orbit-spectrum resource?

8.1.7.2 Is there incentive to use optimum technical standards?

8.1.8 *Impact on satellite system costs*

Are there features of the plan that, over the life of the plan, are likely to force administrations to utilize progressively more costly satellite systems? Does the plan allow administrations to take advantage of cost savings made possible by future developments in technology?

8.1.9 *Administrative costs*

Does the administrative implementation and operation of the plan involve substantial work for administrative and technical staff, taking into account the relative magnitude of system and administrative costs?

8.2 *Plan assessment*

8.2.1 *Introduction*

It is desirable to have available precise and, if possible, standardized methods to evaluate the performance which would be attained in adopting a given planning scheme, in order to be able to analyse a certain number of plans and to choose the one offering the greatest advantages. The quality of a plan may be judged from several aspects, some of which may not necessarily be calculable.

8.2.2 *Efficient use of the orbit-spectrum resource*

A fundamental criterion is the efficiency of use of the orbit-spectrum resource available to users of the plan. Orbit-spectrum efficiency would be measured by the maximum number of programmes or channels which could be carried by a number of satellites using a limited orbital arc and a limited spectrum bandwidth. Several studies have been made on this subject [CCIR, 1974-78d].

8.2.3 *Protection margins*

Another factor to be considered is the protection margin as described below.

8.2.3.1 *Overall co-channel protection margin*

The overall co-channel protection margin is defined in § 4.7 of Recommendation 566. This margin defines the quality of the plan under consideration, in the sense that if the value is never negative, the co-channel interference is always acceptable. Unlike the interference matrix, the overall protection margin takes account of the interference caused by all the transmissions using the same channel. Its value must be calculated for all the receiving points being considered and, in order to give an idea of its statistical distribution within each interfered-with country, it is possible to note the values of the overall protection margin which are exceeded at 100%, 90%, 50% and 0% of the receiving points.

8.2.3.2 *Overall adjacent-channel protection margins*

The overall adjacent-channel protection margin and the second adjacent-channel protection margin are defined in § 4.8 and § 4.9, respectively, of Recommendation 566.

8.2.3.3 *Overall equivalent protection margin*

Although it is important for planning purposes to consider the overall co-channel and adjacent-channel protection margins separately when evaluating a plan, it is often useful to adopt an overall equivalent protection margin, as defined in § 4.10 of Recommendation 566.

All computations of protection margins are based on power addition of contributions from different interferers. Recent measurements conducted in Canada [CCIR, 1982-86a] and the United States [CCIR, 1982-86b] have shown that this is an approximation, and may be slightly pessimistic for co-channel interferers and optimistic for adjacent-channel interferers. Measurements indicate that multiple adjacent-channel interferers combine to produce an effect which is 2-6 dB worse than power addition. However, for the combination of co-channel and adjacent-channel interferers, the effect more nearly approaches a power addition of the individual interference effects over the entire C/I range. At high C/I the subjective effects are dominated by the co-channel interference, while at low C/I, the adjacent channel is dominant. Details of the measurements can be found in Report 634.

A plan might be considered acceptable, in every service area, if the overall equivalent protection margins are positive or near zero.

8.2.4 *Worst-case scenario testing*

In testing scenarios in any planning approach, it is usual practice to test for the simultaneous occurrence of worst-case conditions of the many variables involved, e.g.:

- protection ratio,
- antenna discrimination characteristics,
- antenna mispointing tolerances,
- station-keeping tolerances,
- differential rain attenuation,
- transmit power tolerances,
- receive gain tolerances, etc.

Ideally, what is needed is a statistical approach to maintaining an adequate protection ratio where a certain target C/I is maintained for a certain percentage of the time in analogy with the handling of precipitation attenuation and with the subjective perception of picture quality (which is, after all, the final critical criterion).

However, it is virtually impossible to determine the statistical nature of a set of interrelated parameter tolerances since in some cases the statistics are not known, in some cases the statistics are time-dependent (e.g. weather or ageing), and in other cases the statistics are under the control of the various operating agencies (e.g. station-keeping and beam mispointing) which may adopt different control strategies. Thus, under these conditions, a fully implemented plan should be assumed under a worst-case combination of the above parameters and tolerances.

9. Results of Plan for Regions 1 and 3 and of other studies

The Plan that was adopted by the WARC-BS-77 for Regions 1 and 3 shows that generally five programmes per service area can be obtained with channel spacings of 19.18 MHz and nominal satellite spacings of 6°. The Plan includes a few negative equivalent protection margins (of the order of -1 to -3 dB with respect to 31 dB protection ratio), but is generally considered satisfactory.

A study [CCIR, 1974-78e] provides information on the required discrimination when two broadcasting satellites serve adjacent overlapping areas, using the same frequencies. Figure 8 shows the protection ratio versus antenna discrimination angle for frequency sharing between broadcasting satellites. The studies undertaken by the EBU are summarized in [Mertens *et al.*, 1976].

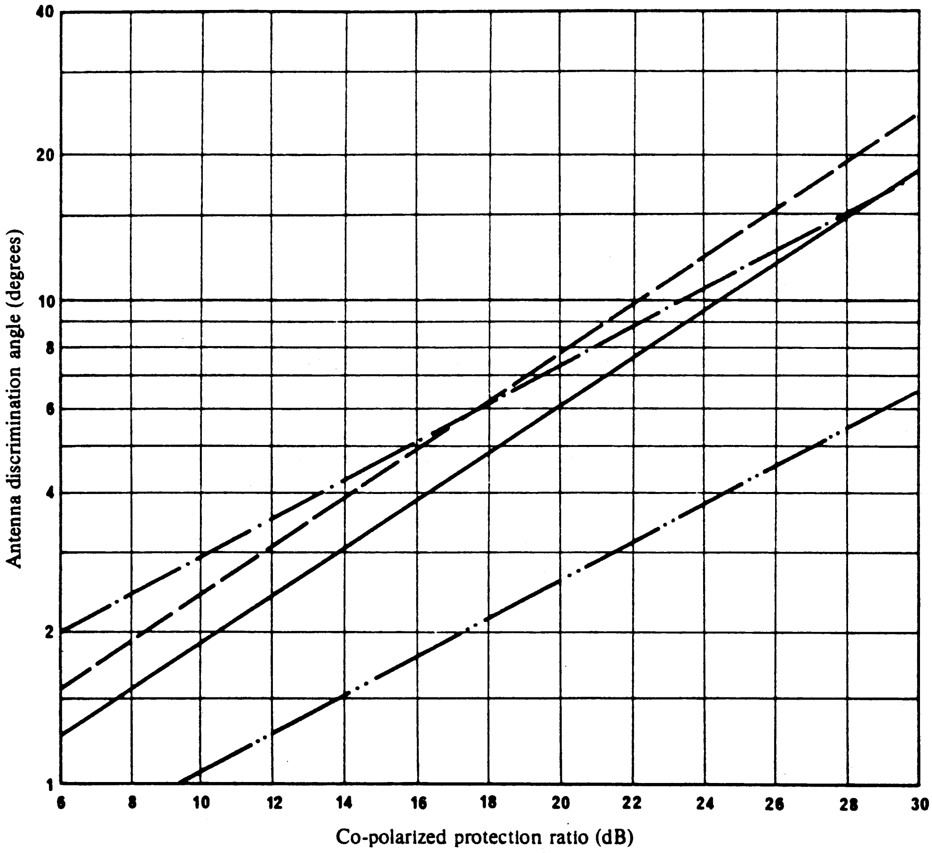


FIGURE 8 – *Protection ratio as a function of antenna discrimination angle for frequency sharing between broadcasting satellites*

————	Protection between broadcasting satellites for individual reception (antenna diameter 1 m, beamwidth 1.7°, gain 39.2 dB)
— — — —	Protection between broadcasting satellites for individual reception (antenna diameter 0.75 m, beamwidth 2.2°, gain 36.7 dB)
—··—··—	Protection between broadcasting satellites for community reception (antenna diameter 1.5 m, beamwidth 1.1°, gain 42.7 dB)
—·—·—	Protection of community reception from individual reception broadcasting satellites

10. Results of the Plan for Region 2

10.1 *The Plan*

The Plan adopted by the RARC SAT-83 was able to accommodate almost all requirements for broadcasting-satellite services submitted before the Conference. This included multiple satellite positions, each with the full bandwidth (12.2-12.7 GHz), for the countries with the largest requirements, no less than four channels for any country, and several regional beams for countries that had requested them.

The evaluation of the Plan by computer analysis showed several negative overall equivalent protection margins but these margins were generally considered acceptable by all administrations participating in the RARC SAT-83.

The average capacity per service area of this Plan is significantly greater than that of the Plan for Regions 1 and 3. The principal reasons for this are:

- the lower protection ratio adopted (28 dB as compared to 31 dB);
- the use of non-regular satellite spacings;
- the adoption of technical parameters reflecting improved technology, particularly with respect to reference antenna patterns;
- the use of multiple orbital positions and both senses of polarization for some service areas;
- the systematic exploitation of the special geographic features of Region 2; and
- that there are fewer service areas per degree of longitude in Region 2 than in Regions 1 and 3. These features are discussed further below.

10.2 *Special geographical features of Region 2*

10.2.1 *Boundaries*

Region 2 differs from the other two Regions in that its boundaries both on the east and on the west are almost entirely adjacent to water. And, with two exceptions – Iceland and eastern Siberia – there are no significant inhabited land masses outside the boundaries and close to them. Furthermore, both the eastern and the western boundaries generally run in a north-south direction. As a result, the interaction between the broadcasting-satellite service of Region 2 and the services operating in the same frequency bands in Regions 1 and 3 are comparatively weak. These interactions are discussed in greater detail in Report 809.

10.2.2 *Division into sub-regions*

It may be possible for orbit-planning purposes to think of Region 2 as consisting of three sub-regions: South, Central and North America. Greenland, which is part of Region 2, is not formally a part of North America, but geographically it is an appendage thereof.

One feature of this division is the relatively weak interaction between North and South America. Their exact separation in terms of beamwidths depends, of course, on the size of the service areas chosen, particularly in the larger countries that are likely to be covered by more than one service area. But for most of the likely choices, the only service areas of North and South America that are not separated from each other by at least 1.6 beamwidths are Mexico in the north and Colombia and Venezuela in the south.

There are, however, strong interactions between Central America (which is taken here to include the Carribbean Islands) and North America, and between Central America and South America. One important fact is that although the sizes of the service areas in Central America are small, their number is relatively large. This had to be taken into account during planning.

10.2.3 *Consequences*

The above geographical characteristics can be used to advantage in increasing the spectrum-orbit utilization of the 12 GHz broadcasting-satellite Plan for Region 2. In particular, two co-channel satellites serving areas of North and South America respectively can be placed quite close in the geostationary-satellite orbit. In the limit, when the satellites serve areas at least five to eight beamwidths apart (possibly less if shaped beams are used), with the larger service area used as a basis, they can be collocated. When the satellites serve areas less widely separated, such as the case when one satellite serves Central America and the other serves either North America or South America, somewhat larger separations are required, but still less than would be required for adjacent service areas.

A discussion of geographic factors relevant to planning may also be found in Report 453, § 10.4.

11. Planning considerations for other bands in which the broadcasting-satellite service has an allocation

11.1 *Introduction*

The other bands in which the broadcasting-satellite service has an allocation are from 620 to 790 MHz, from 2500 to 2690 MHz, from 22.5 to 23 GHz, from 40.5 to 42.5 GHz, and from 84 to 86 GHz. Very little is known about planning for the 23, 42 and 85 GHz bands except that phenomena associated with propagation through the atmosphere will be of major importance.

11.2 *2.6 GHz systems**

Under the provisions of the Radio Regulations, the use of the 2.6 GHz band for satellite broadcasting is limited to national and regional systems for community reception (see No. 757 of the Radio Regulations).

In this Report, the results of a study [CCIR, 1970-74a] for community reception are included in Table II.

TABLE II

System	Frequency (GHz)	Bandwidth (MHz)	Protection ratio (dB)	Satellite spacing (degrees)	Receiving pattern
1	2.6	22	30	4	A
2	2.6	22	33	2.8	B

Pattern A: $\Delta G = 10.5 + 25 \log (\varphi/\varphi_0)$ dB

Pattern B: ΔG = the smaller of: $10 \log [1 + (2\varphi/\varphi_0)^{6N-9}]$ or

$3 + 10 \log [80N + (2\varphi/\varphi_0)^N]$ dB

where: ΔG is the on-axis gain minus the gain at angle φ.

$\Delta G \leqslant 40$ dB for both patterns,

and N is the exponential rate of decay as a function of the angle of the envelope of the side lobe; for example $N = 2$ for individual reception and $N = 2.5$ for community reception.

11.3 *700 MHz systems**

With regard to the efficient utilization of the geostationary-satellite orbit, studies indicate that for the broadcasting-satellite television service operating at frequencies around 700 MHz, the following criteria are appropriate for frequency modulation, assuming a peak-to-peak deviation of 8 to 16 MHz:

11.3.1 For frequency sharing between areas which do not overlap and which are served from the same geostationary orbital position, the total discrimination necessary to provide the required protection ratio must be achieved by side-lobe reduction of the transmitting antennas. In general, this would require a minimum separation of the service areas approximately as great as that corresponding to the first minimum of the transmitting antenna pattern. The use of orthogonal circular polarizations could help in the case of more closely spaced service areas.

11.3.2 For transmitters which share the same frequency channel and are located at different orbital positions, a useful minimum separation may be approximately that which corresponds to the angle between the axis of the main beam and the first minimum of the receiving antenna pattern; assumed to be the same for all receiving installations. The transmitting and receiving antennas must together provide sufficient discrimination to achieve the required protection ratio.

11.3.3 To keep propagation effects small and to conserve the geostationary orbital positions available, a broadcasting-satellite longitude should be within about 45° of the mid-longitude of its service area. Consideration should also be given to the sharing conditions with terrestrial television broadcasting services when determining the actual satellite position relative to the service area mid-longitude.

A study of the number of frequency channels required to provide services to each of about thirty countries has been made [CCIR, 1970-74b] and the results are shown in Fig. 9. A receiving antenna for community reception was assumed. These are provisional results for a single example and further study is required.

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* As this band is shared with other services, many of which are already implemented in the countries of some administrations, attempts to plan these bands may encounter substantial practical difficulty involving sharing, in the case of existing equipment operating in accordance with the relevant assignments.

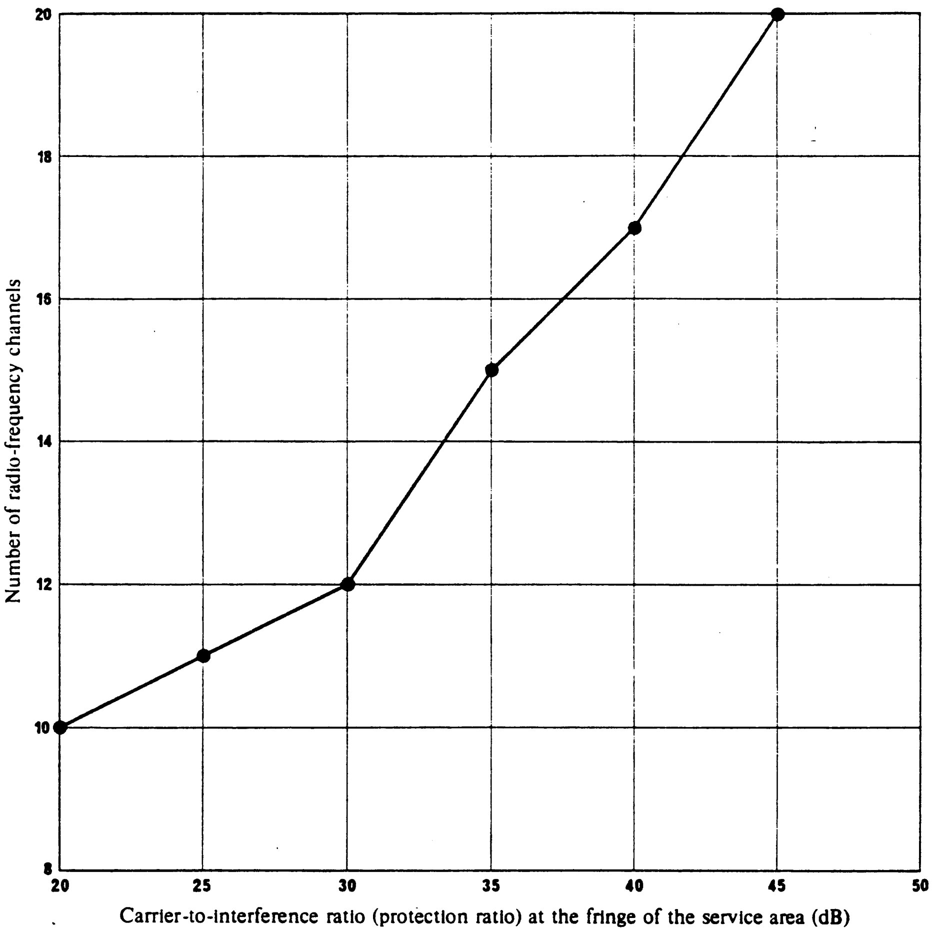

FIGURE 9 – *Number of radio-frequency channels required to provide one national programme to about thirty countries of a continent as a function of the carrier-to-interference ratio*

(Example for a region typical of the East Asian area)

Frequency: 700 MHz, community reception
Diameter of ground receiving antenna: approx. 3.5 m (beamwidth, 8°)
Satellite at longitude of target area
Beamwidth of satellite antenna φ: $7° > \varphi \geqslant 3°$

12. Spacecraft service functions

According to the Radio Regulations, spacecraft service functions such as telemetry, tracking and command (TTC) should be accommodated within the frequency bands of the service in which the space station is operating. These functions can be summarized for the space-to-Earth direction as follows:

– telemetry: continuous low data rate transmission;
– ranging: non-continuous tone or code ranging;
– earth-station antenna tracking: continuous, on residual telemetry carrier or swept carrier.

In addition to the down-link spacecraft service function signals summarized above, up-link service functions should also be accommodated. These include:

– telecommand,
– tracking (ranging),
– execute commands (after verification),
– possible cooperative ground beacon for beam pointing.

Telecommand and ranging are obvious requirements. Most command systems require a two-step process for command execution; the telecommand is transmitted back to the ground equipment for verification via the telemetry channel, and then executed by means of a separate execute command from the ground. The beacon could be received by an RF sensor on the spacecraft, and used to improve the pointing accuracy of the spacecraft down-link antenna.

When collocated satellites are clustered in a single orbital location, it is often necessary that they be commanded by different users or administrations. In such cases, interference with video signals may be produced due to multiple command signals occupying a single non-linear satellite channel. A study [CCIR, 1978-82c] shows that channel non-linearities, due primarily to TWTAs, create intermodulation products from multiple telecommand signals which cause interference in channels adjacent to the guard bands. This study is summarized briefly in § 6 of the Annex to Report 634.

Further discussion of TTC functions may be found in Report 1076.

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[1978-82]: **a.** 10-11S/32 (USA); **b.** 10-11S/111 (Canada); **c.** 10-11S/153 (France).

[1982-86]: **a.** 10-11S/55 (Canada); **b.** 10-11S/49 (USA).

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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.