INTERNATIONAL TELECOMMUNICATION UNION

CCIR

INTERNATIONAL
RADIO CONSULTATIVE
COMMITTEE

BROADCASTING-SATELLITE SYSTEMS

Geneva, 1983

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INTRODUCTION BY THE CHAIRMAN

1. Background

1.1 The CCIR Interim Working Party (IWP) PLEN/3 was established as successor to IWP PLEN/2 in accordance with Resolution No. 70 of the XIVth CCIR Plenary Assembly, Kyoto, 1978 (Annex to the Introduction). The IWP PLEN/3 was required to update and revise the IWP PLEN/2 special report on "Possible broadcasting-satellite systems and their relative acceptability", taking into account the experience of administrations, developments in the field and conclusions of the concerned Study Groups of CCIR, particularly Study Group 11.

1.2 The first series of meetings of IWP PLEN/3 were held in Geneva from 16 to 23 October 1980. Representatives of 17 administrations and of the CCIR and General Secretariat of ITU participated. The meetings considered the direct inputs to the IWP from administrations and also the documents referred to it by the Interim Meetings, October 1980, of Study Groups 10 and 11 and established guidelines and a programme of work for dealing with its tasks. An important decision of the meetings was that the updating of the IWP PLEN/2 report and its addendum should be in the form of fully integrated and revised texts for the various chapters. The meetings also agreed that the work of preparing the draft revised texts of the various individual chapters, as per the guidelines, should be assigned to representatives of designated, participating administrations. The draft texts were circulated for comments and considered further by IWP PLEN/3 at its final meeting.

1.3 At the final series of meetings held in Geneva from 7 to 16 October 1981, the draft revised chapter texts and comments thereon were considered by IWP PLEN/3 along with the documents referred to it by the Final Meetings (September-October 1981) of Study Groups 10 and 11. The texts as finalized and adopted by IWP PLEN/3 are presented in this report.

2. Some significant features of the report

2.1 The decisions of the WARC-BS-77 and WARC-79 have necessitated substantial revision of, and additions to, all the chapters of the IWP PLEN/2 report. The position regarding frequency allocations to the BSS (broadcasting-satellite service) as per decisions of the WARC-79 including the designation of specific frequency bands for feeder links, is presented in a consolidated manner. Reference has been made also to the decisions of that Conference concerning the BSS (sound). Chapter 5 of the IWP PLEN/2 report covering operational requirements of administrations has been deleted in its entirety since the plan (12 GHz band) adopted for Regions 1 and 3 by the WARC-BS-77 and the plan expected to be adopted for Region 2 at the Regional Administrative Radio Conference 1983 would fully reflect the requirements.

2.2 Chapters 1 and 2 of this report reflect the very considerable progress made in the technology of both the space and ground segments for the BSS, particularly in the 12 GHz band. Chapter 5 gives similar relevant information concerning the fixed-satellite service (FSS). A summary of the various planned and operational systems for the BSS and FSS has also been presented in Chapters 1 and 5 to assist the reader in getting a quick overview of the approaches adopted by the different administrations and organizations. Chapter 3 takes full note of the conclusions of the CCIR Study Groups, particularly Study Groups 10 and 11, as also the decisions of the WARC-79 in regard to compatibility of BSS with other systems. Chapter 4 gives, in essence, a methodology for system synthesis and cost estimation of broadcasting-satellite systems including a step-by-step sequence of actions to be followed. The trade-offs involved and the constraints that may operate, in practice, in adopting unified cost optimization of the space and ground segments when there is need to procure hardware from different sources have been brought out.

2.3 Appendix I summarizes the developments relevant to the BSS in the UN Committee on Peaceful Uses of Outer Space and UNESCO. Essential information concerning radio regulatory aspects has been added. Attention has also been drawn to the importance of the development of human resources through an adequate programme of training. The roles of the ITU and UNESCO in this regard have been brought out.

3. Appendix II is reproduced from the report of IWP PLEN/2.

Chairman of the IWP PLEN/3

T. V. SRIRANGAN

Note from the CCIR Secretariat. – All references within this report to CCIR Recommendations and Reports refer to the 1982 edition, unless otherwise noted, i.e. only the basic number is shown.

ANNEX TO CHAIRMAN'S INTRODUCTION

RESOLUTION 70

UPDATING OF THE TEXTS OF THE SPECIAL REPORT ON POSSIBLE BROADCASTING-SATELLITE SYSTEMS AND THEIR RELATIVE ACCEPTABILITY

(1978)

The CCIR,

CONSIDERING

(a) that various aspects of broadcasting-satellite systems (BSS) are being studied by the ITU and other institutions of the United Nations, each within the limits of its own field of competence;

(b) that technical and economic factors influence the choice of systems;

(c) that these considerations continue to be of importance for all countries;

(d) that the outcome of the WARC-BS-77 provided a firm technical basis for the planning of BSS in the 12 GHz band;

(e) that countries are already engaged actively in the planning and implementation of BSS for regular, operational service for which, in some cases, the General Secretariat through the Technical Cooperation Department is providing advisory services;

(f) that the IWP/PLEN/2, established by the XIIth CCIR Plenary Assembly submitted the Special Report on "Possible Broadcasting Satellite Systems and their Relative Acceptability" to the XIVth Plenary Assembly;

(g) that various CCIR Study Groups, particularly Study Group 11, will be conducting studies relating to broadcasting-satellite systems during the next Study Period, which will have a considerable impact on the technical material in the Special Report;

(h) that there is need for the material contained in the Special Report to be kept up to date,

UNANIMOUSLY DECIDES

1. that a new Interim Working Party (IWP) PLEN/3 be established for updating the texts of the Special Report taking into account the experience of Administrations, developments in the field and conclusions of the Study Groups of CCIR, particularly Study Group 11;

2. that the Interim Working Party should be composed of Representatives appointed by the Administrations of Germany (Federal Republic of), Brazil, Canada, Spain, United States of America, France, India, Iran, Italy, Japan, Panama, United Kingdom, U.S.S.R., together with the chairmen of the Study Groups concerned as well as an observer each from the General Secretariat and the IFRB;

3. that the Chairman of the IWP shall be a representative of the Administration of India;

4. that the IWP shall conduct its work essentially by correspondence with the assistance of the CCIR Secretariat;

5. that Administrations are urged to make available to the chairman of the IWP information which will assist in the task of the IWP;

6. that the Chairman of the IWP should submit to the XVth CCIR Plenary Assembly, the updated texts of the Special Report;

7. that this Resolution be brought to the attention of the interested organizations in the United Nations.

CHAPTER 1

BROADCASTING-SATELLITE SYSTEMS (TELEVISION AND SOUND)

1. Introduction

To achieve economic and technological growth, developing nations must face numerous problems in many fields; education, agriculture, communications, family planning, etc. To tackle these problems speedily, there is a prime need to improve methods of communicating the information to those who need it most. Of the various media, such as films, newspapers, radio, etc., television has been found to be the most effective, as it substantially enhances the impact as well as the capacity to comprehend and retain the subject material. In most developing nations television networks are under-developed and in some cases, non-existent. Recent technological advances, however, indicate a new possibility of making television available over vast areas by means of broadcasting satellites.

When planning the introduction of broadcasting-satellite systems, it is also important to evaluate alternatives of implementing broadcasting networks, namely, systems comprising broadcasting satellites, combined systems of broadcasting satellites and terrestrial broadcasting networks, and so on. It is also essential to compare the above alternatives, and the terrestrial network, from the viewpoint of technical feasibility, economics and acceptability.

2. Features of a broadcasting-satellite service

The main features which make satellite broadcasting attractive are:

2.1 *Rapid introduction of the service*

A national terrestrial broadcasting system is a complex undertaking and, depending on the extent of the area to be covered, involves a large number of transmitters, antennas and antenna towers, numerous studios and miles of intercommunication radio-relay systems. Even in the most industrially advanced areas of the world, a considerable time was required before the service approached nation-wide coverage. It is difficult to believe that the developing countries can attain in the near future a rate of growth comparable with that in developed areas. Limitations of productive capacity, availability of trained personnel, the large investment involved and the necessity for simultaneous development of both the broadcasting and the communication industries tend to impede the growth. In such parts of the world, using terrestrial means, a period of 10 to 20 years to attain a nation-wide service appears most probable.

In contrast, satellite broadcasting offers a method for quickly covering all parts of the country. Some four to five years would be needed to produce the first operational satellite unit, if adequate resources and other facilities were available. Thereafter, additional service areas could be provided at a rate determined solely by the scheduled production of receivers, suitable for reception of programmes from the satellite. Nation-wide coverage of such countries as Brazil, Indonesia, India and Nigeria would thus be possible in a relatively short time.

2.2 *Potentially low cost of covering large areas*

Terrestrial television service is usually introduced first in the larger cities. Frequently, the establishment of a television service in an urban area may cover a substantial proportion of the population. The service usually expands progressively to cover the rest of the country. After several years, when most of the populated areas have been covered, a stage is reached when the installation of an additional transmitter would only increase the coverage to a very low degree in respect of the number of population served. It is therefore clear that the cost of providing a service per receiver would continue to increase exponentially as coverages of say, 90% and over are approached. While this may be typical of most situations, individual and specific needs would, in practice, require a more detailed appraisal.

The cost considerations for satellite coverage differ considerably from the above. After the initial large capital outlay, the satellite service would reach all receivers within its footprints, provided they were equipped with suitable antennas and adapters.

Variations in signal strength also have cost implications. Weaker signals may be acceptable in suburban and rural areas where man-made noise and building absorption are lower and where mounting an antenna outdoors does not present any problem. For such types of service a satellite may prove to be less expensive.

2.3 *Potentially more efficient use of frequency*

The strength of a radio signal decreases with distance from the terrestrial transmitter and eventually becomes so low as to be unusable. In a practical sense, for terrestrial television services in bands 8 and 9, this distance is about 80 km, assuming an average antenna height of 150 m and an e.i.r.p. of 50 kW in the lower part of band 8, 100 kW in the higher part of band 8 and 1000 kW in band 9. However, even at that distance, the signal can cause interference to stations operating in the same channel. The geographical separation between stations operating in the same channel must be larger. To cite an example, it is reported that, in the United States, the current allocation plan for band 9 allows 30 to 40 stations per channel. This number takes into account co-channel and adjacent channel interference, the location of cities, the need of neighbouring countries and variations in propagation. Each station has an effective coverage of about 25 000 km^2 so that each channel covers approximately 770 000 km^2. To provide such a programme to the entire United States, a minimum of ten television channels in band 9 are required, if a terrestrial system is used. In contrast to this, a single broadcasting-satellite system could provide the same coverage at a saving in frequency occupancy of 10/1 if the same type of modulation is used. It is of course true that satellite and the terrestrial services are not exactly comparable. The ten-channel terrestrial service can carry any number of independent programmes or a single programme or any other combination, but the single frequency available from a satellite would be limited to a single programme channel. However, if national coverage is desired, it is clear that the satellite has an advantage in the use of frequencies.

3. The pattern along which a broadcasting-satellite service may be planned

The lines along which the pattern of broadcasting should be planned in any developing country cannot be evaluated without reference to the national setting, the contours of social, cultural and economic life, linguistic groups, levels of receptivity and emotional outlook, viewing habits and time. The production of programmes on equitable bases to meet the diverse needs of various segments of society is indeed a complex task.

The audience pattern in each country may be different. This is dependent on such considerations as living conditions, vocations, socio-economic factors, religious and personal philosophies and lastly, but most important of all, different linguistic groups. Therefore, each country must evolve the system best suited to its needs in the context of its cultural and national life. The following aspects must be taken into account:

- existing television services,
- size of audience,
- coverage area,
- languages,
- number of alternative programmes,
- number of video and sound channels,
- facilities for programme generation,
- location of centres,
- links to earth stations,
- hours of viewing,
- differences in time zones.

As can be foreseen today, satellite broadcasting should complement terrestrial broadcasting. In programme services, most countries must meet the needs of a wide cross-section of the population. If the pattern of such services is examined, it will be found that it must be adjusted to satisfy differences in social and economic conditions, social structure, level of receptivity, languages, educational infra-structure, including curricula, agro-crop patterns, etc. Hence, both from the psychological and the practical points of view, if a television programme is to be effective, it must evolve directly from its environment. The programmes should be based on regional needs. In geographically very small countries, a unified programme may suffice, but in general most countries have to think in terms of several programmes, for which originating centres for local programmes are necessary. The satellite system might not wholly respond to this need, but it could:

- be responsible for broadcasting a common national programme,
- make television signals available in areas where coverage by a terrestrial transmitter is precluded.

Hence, taking into account the programme needs of a country, a combination of terrestrial and satellite broadcasting must be evolved. Economic cross-over points will have to be studied to see the degree of development necessary in either direction. Some of the important aspects mentioned above, which are unique to each country, are discussed in the following:

3.1 *Languages*

In many countries, more than one language, in addition to several dialects, is spoken. Even if a single language is taken to be the national one, others may be prevalent with their own script and literature. India is one of the extreme cases with 15 languages and numerous dialects recognized by the Constitution. In India, radio programmes are broadcast in 20 languages.

3.2 *Number of alternative programmes*

The purpose of television programming in general is to inform, educate and entertain. The informative and educational parts might, however, be expanded into social and educational influences covering several aspects, such as:

- dissemination of news and information concerning local, national and international affairs;
- focusing attention on national issues, social and economic problems and those of national development;
- aiding national campaigns in problem areas such as agricultural productivity, family planning, health and hygiene, etc.;
- promotion of functional literacy and vocational skills;
- supplementation of institutionalized education and contributions to school and adult education, if necessary by expanding the existing curricula;
- training of teachers and provision of refresher courses.

The list could be lengthened further, taking account of the separate needs of urban and rural viewers, factory workers, cultivated persons, etc. In a large network, a national programme would be required, in addition to the local regional programmes. All these would call for numerous programme channels and each country could then "cut its coat according to the cloth". This could be achieved, either on a time-sharing basis, or with a separate transponder in the satellite.

3.3 *Size of audience*

In planning a television service it is important to identify the audience in terms of key considerations such as who is to be served, where and when, to make precise programme patterns. Urban communities may be expected to possess a large number of individual receivers, from which revenue can be derived from receiver licences. However, in most of the developing countries a large majority of the rural population cannot afford to own television receivers, and this emphasizes the role of television as a social service. Hence, it is necessary to treat such an audience as a special case and to provide a rural emphasis to as many television programmes as possible; community viewing may have to be arranged.

It does not, however, follow that the entire rural community must be served immediately. In many countries, there are village communities so far behind in overall development that other avenues of progress cannot be supplanted by television: here infra-structure investments and services such as roads, communications, medical and social services and education have priority. It must be evaluated practically whether television would make a difference if it were to take priority over other essential developments. As a guideline, indices such as the number of post offices and the number and quality of schools should be considered in order to make this evaluation in rural areas. Such an assessment is essential, particularly in areas where resources are limited.

3.4 *Location of programme centres*

The location of programme centres must be determined, taking linguistic, cultural, social and economic considerations into account. Each distinct group should be provided with a programming centre. Only then could a proper variety of programmes be available for dissemination to a large area by the satellite.

3.5 *Linkages*

The provision of suitable links between the programme originating centres and the earth station transmitting the programme to the satellite will require careful planning. These links would normally be provided by coaxial cables or radio-relay systems. In most countries, such links are provided by the public telecommunication system. However, where the distance between the programme originating centre and the earth station is small (say up to 50 km) which can be spanned by a single radio-relay system without the need for intermediate repeaters, the broadcasting organization could consider the establishment of its own radio-relay system.

3.6 *Hours of viewing*

The viewing hours for urban and rural populations must be considered separately. Since an urban population has widely different social and educational needs, as well as environment, programme planners, given adequate resources, are presented with endless possibilities. In the initial stage of development, most of the urban requirements will nevertheless have to be accommodated in a single channel service.

On the other hand, the hours of viewing of a rural audience are limited, since the majority of the rural population is engaged in agricultural activities from very early in the morning to late in the evening. It may be assumed that rural community viewing would be possible between 1800 and 2100 h. A later hour may not be tolerated, as the agricultural community prefers to retire early to prepare for the next day's early start.

3.7 *Differences in time zones*

Since satellite broadcasting can encompass very wide areas, the programme planner must be well aware of the possible differences in time zone between the programme originating centre and parts of the target area.

Some regions are so wide that several time zones are involved, as in the case of the USA, Canada, the U.S.S.R., and China. In these cases, the actual time prevalent in the zone of reception must be taken into consideration when planning programmes. Similarly, for educational broadcasts, it must be ensured that programmes reach the zone of reception during the appropriate school hours.

4. Basic definitions in the broadcasting-satellite service

4.1 *Broadcasting-satellite space station*

A space station in the broadcasting-satellite service.

4.2 *Broadcasting-satellite service* (see No. 37 of the Radio Regulations)

A *radiocommunication service* in which signals transmitted or retransmitted by *space stations* are intended for direct reception by the general public.

In the broadcasting-satellite service, the term "direct reception" shall encompass both *individual reception* and *community reception.*

Individual reception (in the broadcasting-satellite service) (See No. 123 of the Radio Regulations)

The reception of *emissions* from a *space station* in the *broadcasting-satellite service* by simple domestic installations and in particular those possessing small antennae.

Community reception (in the broadcasting-satellite service) (See No. 124 of the Radio Regulations)

The reception of *emissions* from a *space station* in the *broadcasting-satellite service* by receiving equipment, which in some cases may be complex and have antennae larger than those used for *individual reception*, and intended for use:

- by a group of the general public at one location; or
- through a distribution system covering a limited area.

4.3 *Reception quality*

4.3.1 *Primary grade of reception quality* (in the broadcasting-satellite service)

A quality of reception of emissions from a broadcasting-satellite space station which is subjectively comparable to that provided by a terrestrial broadcasting station in its coverage area *.

4.3.2 *Secondary grade of reception quality* (in the broadcasting-satellite service)

A quality of reception of emissions from a broadcasting-satellite space station which is subjectively inferior to the primary grade of reception quality but is still acceptable (see Report 409).

4.4 *Power flux-densities*

To permit individual or community reception with either grade of reception quality, broadcasting-satellite space stations may provide a high, medium or low power flux-density at the receiving site (see Table 1-XV).

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* The coverage area of a terrestrial sound broadcasting station is defined in Recommendation 499 for bands 5 (LF), 6 (MF), 7 (HF) and 8 (VHF). The coverage area of a terrestrial television broadcasting station is not defined but corresponds to a field strength somewhat higher than the minimum values quoted in Recommendation 417.

4.4.1 *High power flux-density* (in the broadcasting-satellite service)

A power flux-density which enables signals radiated by broadcasting-satellite space stations to be received by simple receiving installations with a primary grade of reception quality.

4.4.2 *Medium power flux-density* (in the broadcasting-satellite service)

A power flux-density which enables signals radiated by broadcasting-satellite space stations to be received either by simple receiving installations with a secondary grade of reception quality or by more sensitive receiving arrangements with a primary grade of reception quality.

4.4.3 *Low power flux-density* (in the broadcasting-satellite service)

A power flux-density lower than the medium power flux-density, which enables the necessary grade of reception quality to be obtained using more specialized transmission and reception techniques than those required under §§ 4.4.1 and 4.4.2.

4.5 *Definitions of service area and coverage area* (Annex 8 to Appendix 30 of the Radio Regulations)

4.5.1 *Service area*

The area on the surface of the Earth in which the administration responsible for the service has the right to demand that the agreed protection conditions be provided.

Note. – In the definition of service area, it is made clear that within the service area the agreed protection conditions can be demanded. This is the area where there should be at least the wanted power flux-density and protection against interference based on the agreed protection ratio for the agreed percentage of time.

4.5.2 *Coverage area*

The area on the surface of the Earth delineated by a contour of a constant given value of power flux-density which would permit the wanted quality of reception in the absence of interference.

Note 1. – In accordance with the provisions of No. 2674 of the Radio Regulations, the coverage area must be the smallest area which encompasses the service area.

Note 2. – The coverage area, which will normally encompass the entire service area, will result from the intersection of the antenna beam (generally elliptical or circular) with the surface of the Earth, and will be defined by a given value of power flux-density. For example, in the case of a Region 1 or 3 country with a service planned for individual reception at 12 GHz, it would be the area delineated by the contour corresponding to a level of -103 dB(W/m^2) for 99% of the worst month. There will usually be an area outside the service area but within the coverage area in which the power flux-density will be at least equivalent to the minimum specified value; however, protection against interference will not be provided in this area.

5. Orbits for broadcasting-satellite systems

5.1 *Factors affecting choice of orbit*

Among the factors to be considered in the selection of preferred orbits for satellite broadcasting are coverage, number of daily broadcast hours desired and antenna characteristics.

The satellite orbit for a broadcast service must provide coverage of selected regions of the Earth during desired viewing or listening hours, which may vary from several to twenty-four hours per day. For non-continuous broadcast periods, it is desirable to have these intervals occur at the same local time each day. Regardless of the duration of the broadcast period, it is desirable to have an orbit that does not require antenna tracking equipment of broadcast receiving installations.

A geostationary satellite (altitude 35 786 km above the equator) would permit a continuous broadcast service to areas as small as individual countries or as large as continents, up to about one-third of the surface of the Earth. The limitation imposed by the minimum usable angle of elevation can be determined from Fig. 1 of Report 206. A geostationary satellite also permits the use, if required, of a fixed receiving antenna of very high gain (and hence directivity).

A satellite in a sub-synchronous circular equatorial orbit can provide coverage at the same local time each day. The number of uninterrupted broadcast hours possible from such a satellite to a given area on the surface of the Earth is a function of the satellite altitude and the latitude of the receiving point. Representative visibility times are shown in Table 1-I.

Because the sub-synchronous satellites in circular orbits have a lower altitude than a geostationary satellite, a stronger signal is available for a given transmitter e.i.r.p. Such satellites may therefore have an advantage when the maximum transmitting antenna gain is limited by size restrictions and when the receiving antenna can be nearly omnidirectional.

In band 8 (VHF), or at higher frequencies, a satisfactory signal-to-noise ratio can be achieved using frequency modulation with a geostationary satellite or other high-altitude satellite, so that the lower altitude satellites do not appear to present any advantage.

A satellite with a period of 12 hours, in an elliptical orbit having a plane inclined at about 63° to the equatorial plane and an apogee of 40 000 km well north of the equator, can provide a larger area of coverage in the northern hemisphere than a geostationary satellite. The use of several satellites in such orbits can provide an uninterrupted service. The times of visibility of one satellite are given in Table 1-II for a particular latitude (60° N) of the receiving point, and a particular minimum angle of elevation (20°). In theory, because of the non-spherical shape of the Earth, an inclination of the orbit of 63.4° would ensure that the major axis does not drift in the plane of the orbit, and, therefore, that successive apogees will occur at the same terrestrial latitude.

In the example of Table 1-II, the minor axis of the orbital ellipse is assumed to be parallel to the equatorial plane. The maximum period of visibility from a given point on the Earth at latitude 60° (10.6 hours) is then obtained when the apogee is at the same longitude as the point.

In selecting highly elliptical orbits, it is preferable to avoid passage through the van Allen belt, or to ensure that satellites pass rapidly through the radiation region in order to avoid damage to components.

For the various orbits, uninterrupted reception is possible only when the satellite remains within the beam of the receiving antenna. Therefore, assuming the antenna is fixed, it must have a sufficiently large beamwidth to ensure the desired service.

If a sub-synchronous circular orbit is used, it would not be possible to employ most of the available period of visibility, using a fixed receiving antenna, unless the antenna is of low gain (e.g. a half-power beamwidth of 110° corresponding to a maximum gain of 6 dB).

If a sub-synchronous highly elliptical orbit is used, a fixed antenna of higher gain could be used (e.g. a half-power beamwidth of about 30° corresponding to a maximum gain of 15 dB).

If a geostationary satellite is used, the earth station antenna gain can be higher than in the examples above, but the maximum antenna gain might be limited (because of the consequent small beamwidth) either by practical considerations of the receiving installation or by the lack of stability of the position of the satellite.

TABLE 1-I – *Visibility times for satellites in stationary and sub-synchronous circular equatorial (non-retrograde) orbits*

Approximate period (h)	Altitude (km)	Passes per day over a given point	Approximate periods of visibility above the horizon per pass (h)			
			At equator	At ± 15° lat.	At ± 30° lat.	At ± 45° lat.
24(1)	35 786	Stationary	Continuous	Continuous	Continuous	Continuous
12	20 240(2)	1	10.1	10.0	9.9	9.3
8	13 940(2)	2	4.8	4.7	4.6	4.2
6	10 390(2)	3	3.0	2.9	2.8	2.5
3	4 190(2)	7	1.0	1.0	0.9	0.6

(1) Exactly: 23 h 56 min 4 s.
(2) Approximate values.

TABLE 1-II — *Visibility times of a satellite in a typical elliptical orbit inclined at about 63.4°*

Approximate period (h)	Approximate apogee (km)	Approximate perigee (km)	Approximate periods of visibility per pass (h) over a reception point at 60° latitude, with an angle of elevation of the receiving antenna greater than 20°	
			Maximum	Minimum
12	40 000	500	10.6	4.5

5.2 *Coverage area*

The satellite orbit is an important factor in determining coverage. A geostationary satellite (altitude 35 786 km above the equator) allows a continuous broadcasting service, both to areas as small as an individual country or as large as a continent, up to about one-third of the surface of the Earth. Such satellites permit the use of fixed receiving antennas with very high gain (and hence directivity).

Assuming that the necessary e.i.r.p. to produce the requisite power flux-density on the surface of the Earth will be provided by the satellite, the coverage area is a function of the beamwidth of the satellite antenna. The coverage area is usually referred to as that which is limited by the power contour which results in a flux density that is 3 dB below that at the beam centre, although about −6 dB might also be considered as the limit of coverage area in certain circumstances.

The diameter of the coverage circle is about 650 km per degree of the beam at the sub-satellite point. Figure 1-1 shows the relationship between the beamwidth of the satellite antenna, normal coverage circle and the e.i.r.p. of the satellite transmitter. Figure 1-2 gives the curves relating beamwidth, antenna gain and antenna diameter. An antenna efficiency of 55% and a conical beam pattern are assumed. The coverage area is circular at the sub-satellite point and the ground distance is that measured along the arc intersecting the circle and the sub-satellite point. Figure 1-3 also shows, in km^2, the coverage area at the sub-satellite point. If the beam is positioned off the sub-satellite point to some chosen longitude and latitude, the angle of elevation differs from 90° and the coverage area is elliptical. Knowing the angle of elevation (Fig. 1-4) and the circle diameter (ground distance) at the sub-satellite point as obtained from Fig. 1-3, the width and length of the elliptical area can be found in Fig. 1-5. Also Fig. 1-5 gives the relationship between the tilt angle and the elevation angle.

A satellite in an elliptical orbit could provide a larger area of coverage than a geostationary satellite, but the service would not be available continuously for 24 hours, but only for periods up to 12 hours. However, an antenna with a comparatively lower gain and a wider beamwidth would have to be used.

A satellite covering several countries in one Region offers a very economical solution for the provision of a broadcasting-satellite service, as the cost of the space segment can be shared by two or more countries.

A detailed discussion of some economic aspects of broadcasting satellite systems will be found in Chapter 4.

5.3 *Coverage area, frequency and size of the satellite antenna*

A satellite antenna is required to illuminate a given area which will depend upon the antenna beamwidth. The procedures for determining the coverage area and related factors have already been discussed in § 5.2. For the same coverage area and hence the same beamwidth, the size of the satellite antenna is inversely proportional to the frequency; this will be reflected in the size of the satellite and the cost of launching.

5.4 *Orbital spacing considerations*

Orbit planning is treated in more detail in § 7, while technology that can improve orbit utilization is discussed in Chapter 2.

6. Allocation of frequency bands

6.1 *Frequency bands for the broadcasting-satellite service*

The WARC-79 revised the Radio Regulations and opened up the following frequency bands (Table 1-III) for use by the broadcasting-satellite service:

TABLE 1-III – *Frequency bands for BSS*

Frequency band	Shared with	Power flux-density (pfd) and other constraints
620-790 MHz	Fixed, mobile and terrestrial broadcasting services (and radionavigation service in Region 3, for part of the band)	From − 129 to − 113 dB(W/m²) depending upon the angle of arrival. (See Rec. No. 705 to the RR)
2.5 GHz		
Region 1		
2500-2655 MHz	Fixed and mobile*, services	
2655-2690 MHz	Fixed, mobile*, earth exploration satellite (passive), radioastronomy and space research (passive) services	
Region 2		
2500-2655 MHz	Fixed, mobile* and FSS (down link) services	
2655-2690 MHz	Fixed, mobile*, FSS (up link and down link) earth exploration satellite (passive), space research (passive) and radioastronomy services	Limited to national and regional systems for community reception pfd limits as per RR 2561 through 2564 (− 152 to − 137 dB(W/(m² · 4 kHz)) depending upon the angle of arrival)
Region 3		
2500-2535 MHz	Fixed, mobile* and FSS (down link) services	
2535-2655 MHz	Fixed and mobile* services	
2655-2690 MHz	Fixed, mobile*, FSS (up link), earth exploration satellite (passive), radioastronomy and space research (passive) services	
12 GHz		
Region 1		
11.7-12.5 GHz	Fixed, mobile* and terrestrial broadcasting services	Frequency/orbit assignment plan and pfd constraints as per App. 30 to the RR
Region 2		
11.7-12.2 GHz	Fixed, mobile* and FSS (down link) services	1. Principally allocated for FSS, may be used additionally for BSS with max. e.i.r.p. not to exceed 53 dBW per TV channel (RR 836) 2. Limited to national and sub-regional systems
12.2-12.7 GHz	Fixed, mobile* and terrestrial broadcasting services	Limited to national and sub-regional systems
Region 3		
11.7-12.2 GHz	Fixed, mobile* and terrestrial broadcasting services	Frequency/orbit assignment plan and pfd constraints as per App. 30 to the RR
12.5-12.75 GHz	Fixed, mobile* and FSS (down link) services	Limited to community reception; pfd not to exceed − 111 dB(W/m²) as per Annex 8 of APP. 30 (RR 847)
22 GHz		
Region 1	No Allocation	—
Regions 2 and 3		
22.5-22.55 GHz	Fixed, mobile services	—
22.55-23 GHz	Fixed, mobile and inter-satellite services	—
40.5-42.5 GHz	Fixed, mobile and terrestrial broadcasting services	—
84-86 GHz	Fixed, mobile and terrestrial broadcasting services	—

* Allocated to mobile services except aeronautical mobile services.

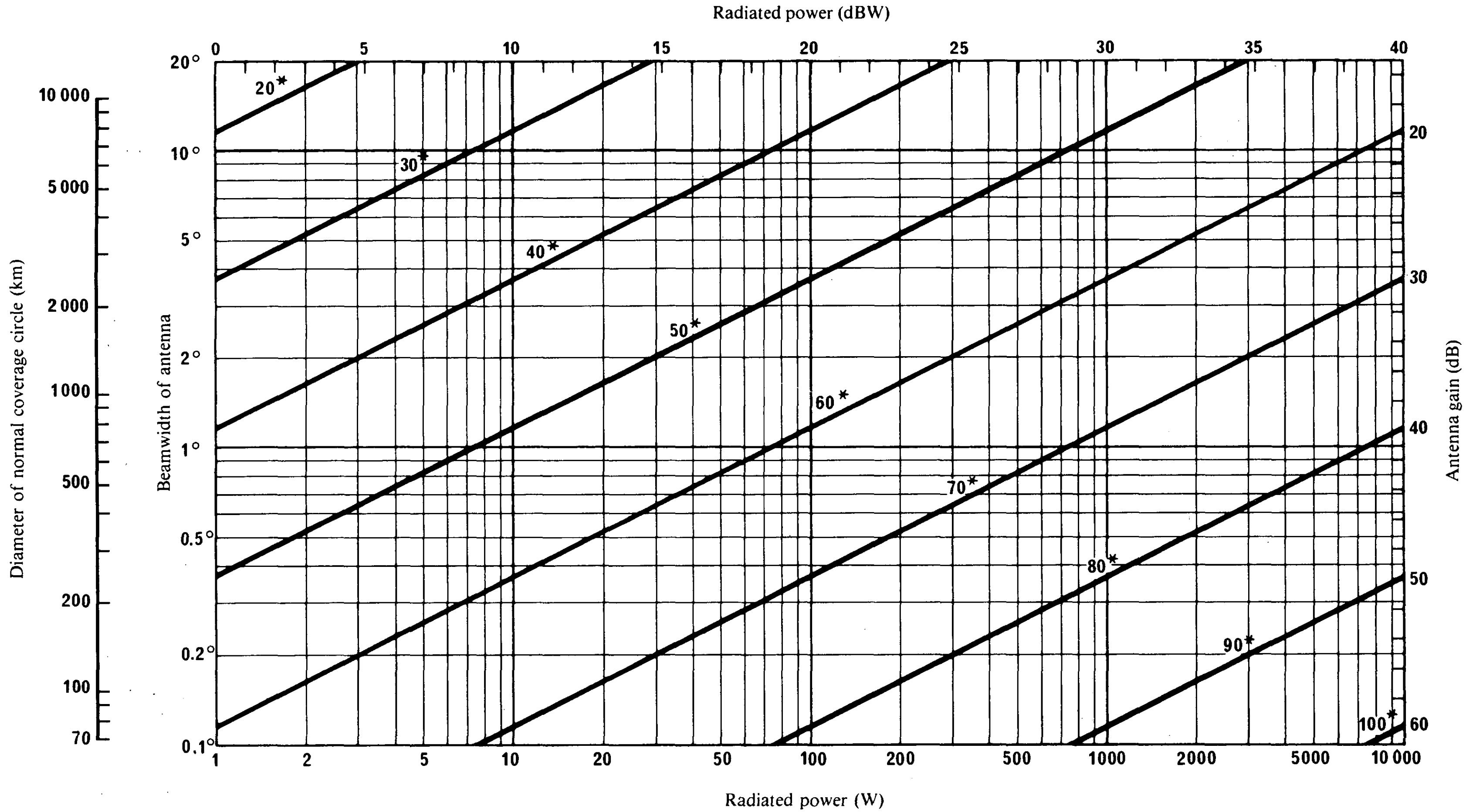
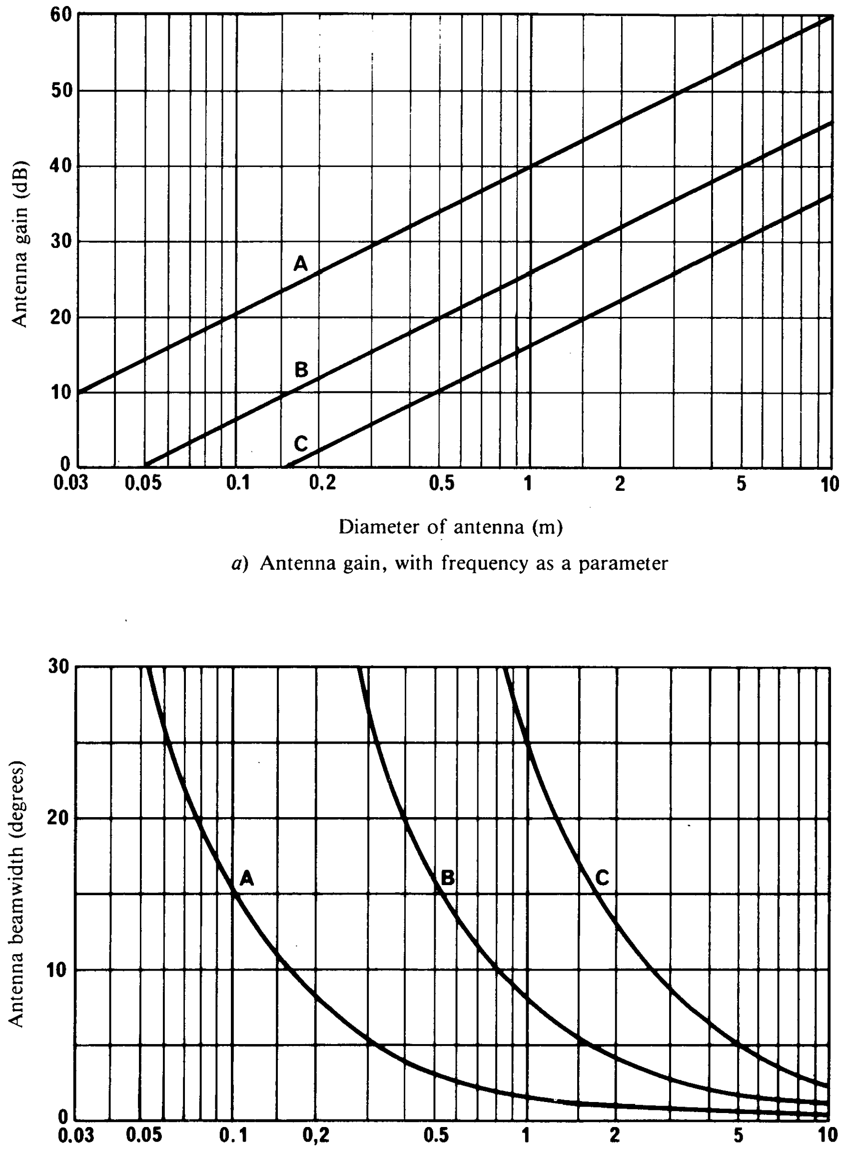


FIGURE 1-1 – *E.i.r.p. of satellite as a function of the radiated power and the beamwidth of the antenna*

* The e.i.r.p. is shown in dBW, as the parameter of the diagram.



a) Antenna gain, with frequency as a parameter

b) Antenna beamwidth, with frequency as a parameter

FIGURE 1-2 – *Antenna gain and beamwidth as function of diameter*

Curves A: 12 GHz
B: 2.6 GHz
C: 700 MHz

The bands 620-790, 2500-2690 MHz and 11.7-12.5 GHz are already feasible for use with current techniques, and are now being used for experimental systems.

The bands allocated to the broadcasting-satellite service are shared with other services. Sharing aspects are discussed in detail in Chapter 3 on the feasibility of broadcasting-satellite systems.

6.2 *Frequency bands for the broadcasting-satellite service (sound)*

The WARC-79 considered the allocation of a frequency band for broadcasting-satellite services (sound). It did not decide in favour of a specific allocation. However, the Conference adopted Resolution No. 505 (relating to BSS (sound)) which provides that administrations shall be encouraged to carry out experiments with BSS (sound) within the band 0.5-2 GHz in appropriately placed narrow sub-bands subject to the agreement of administrations concerned. The frequency band 1429-1525 MHz was particularly mentioned for consideration for such experiments.

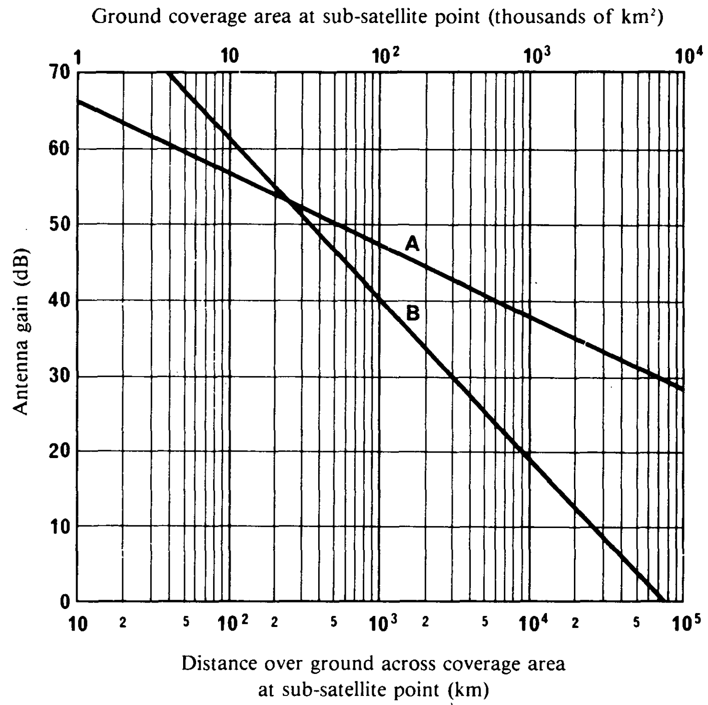


FIGURE 1-3 – *Guide to selection of antenna gain as a function of ground distance and coverage area*

Curves A: coverage area
B: ground distance

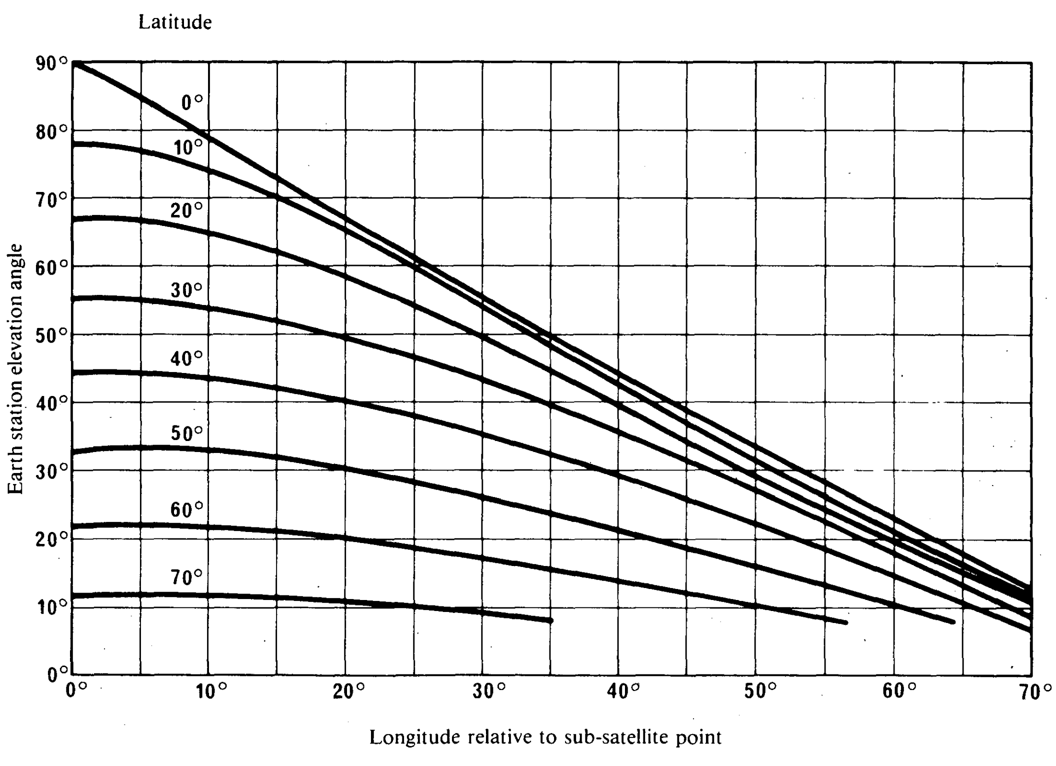


FIGURE 1-4 – *Earth station elevation angle for a given geographical position*

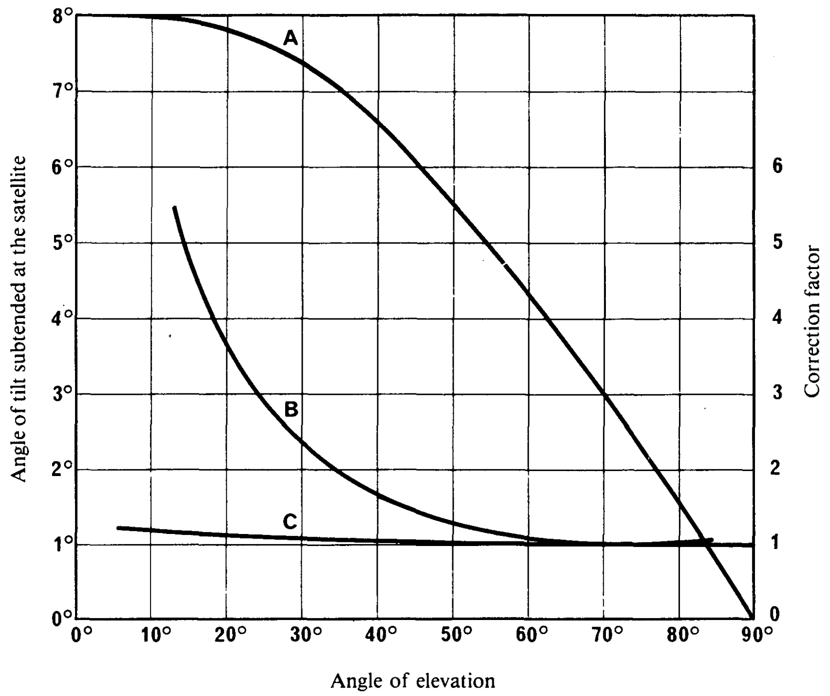


FIGURE 1-5 – *Correction factors for the ground distances of Fig. 1-3 as a function of the angle of elevation*

Curves A: angle of tilt subtended at the satellite
B: length of the elliptical area
C: width of the elliptical area

6.3 *Frequency bands for BSS feeder links*

Table 1-IV gives suitable feeder-link frequency bands for the three main BSS bands.

7. Orbit and frequency planning

7.1 *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.

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

– it is assumed that all broadcasting-satellite services of the same kind, to the same service area, would be provided from the same geostationary orbital position to permit the use of fixed receiving antennas; (however, services designed for different audiences (e.g., programmes for individual reception and programmes for community reception) may well be provided from different orbital positions);

– 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;

TABLE 1-IV – *Feeder-link frequency bands for the main BSS bands*

BSS band and bandwidth	Possible feeder-link band(s)	Remarks
700 MHz band (170 MHz) *and* *2600 MHz band* (190 MHz)	*Region 1 only* 5725-5850 MHz (125 MHz) *Regions 2 and 3 only* 2655-2690 MHz (35 MHz) *All Regions* 5850-7075 MHz (1225 MHz) and 7900-8400 MHz (500 MHz)	
12 GHz band		
Region 1 800 MHz spectrum width as per BSS Plan (App. 30 to the RR)	10.7-11.7 GHz	Bidirectional allocation
	14.0-14.5 GHz	Subject to coordination. May be used for feeder links of BSS (reserved for countries outside Europe and for Malta) (RR 858)
	14.5-14.8 GHz	Use by FSS limited to feeder links of BSS (reserved for countries outside Europe and for Malta) (RR 863)
	17.3-18.1 GHz	Use by FSS limited to feeder links of BSS (RR 869)
Region 2 500 MHz spectrum width	14.0-14.5 GHz	Subject to coordination. May be used for feeder links of BSS (RR 858)
Orbit/frequency planning done by RARC SAT-83 (Resolution No. 701 of the RR)*	14.5-14.8 GHz	Use by FSS limited to feeder links of BSS (RR 863)
	17.3-18.1 GHz	Use by FSS limited to feeder links of BSS (RR 869)
Region 3 500 MHz spectrum width as per BSS Plan (App. 30 to the RR), plus 250 MHz limited to community reception.	14.0-14.5 GHz	Subject to coordination. May be used for feeder links of BSS (RR 858)
	14.5-14.8 GHz	Use by FSS limited to feeder links of BSS (RR 863)
	17.3-18.1 GHz	Use by FSS limited to feeder links of BSS (RR 869)

* RARC SAT-83 prepared Plans for the BSS in Region 2 in the band 12.2-12.7 GHz and associated feeder links in the band 17.3-17.8 GHz.

– 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.

7.2 *Planning approaches*

The following are possible approaches to planning which are, in general, applicable to both feeder links and down links in the BSS. Not all these approaches are necessarily applicable to all allocated broadcasting satellite frequency bands.

7.2.1 *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 so that it can develop its system or concepts within a defined framework.

7.2.2 *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 nature of 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. Specific channel and polarization assignments would be made at the time an administration was ready to implement a system for that 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.

7.2.3 *Detailed frequency assignment and orbital arc allotment plan*

Under this scheme, individual administrations would be allotted 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 constraints must be assumed, including channel bandwidth.

7.2.4 *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 § 7.2.5. 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.

7.2.5 *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.

7.3 *Planning of the 12 GHz band*

The WARC-BS-77 adopted two different approaches to planning the broadcasting-satellite services in the 12 GHz band. Regions 1 and 3 adopted a detailed *a priori* orbital position and frequency assignment plan which became effective on 1 January 1979 (see Appendix 30 of the Radio Regulations). Region 2 adopted a set of provisions to govern the use of the 12 GHz band pending the establishment of a detailed plan. The WARC-79 adopted significantly different regulations governing the use of the band 11.7 to 12.7 GHz in Region 2, including a significantly different allocation of frequencies and associated footnotes, and Resolution No. 701 which relates to the convening of a Region 2 Administrative Radio Conference for the detailed planning of the broadcasting-satellite service in the band 12.3 to 12.7 GHz, a portion of the band 12.1 to 12.3 GHz, and of the associated feeder links in the lower part of the band 17.3 to 18.1 GHz. This Conference should be held not later than 1983.

Method of planning in Region 2

The method of planning the broadcasting-satellite services in Region 2 will probably include some of the same concepts as were used in Regions 1 and 3 in 1977. However, there are significant differences which will affect the work and outcome of the 1983 Regional Conference. The most important are the following:

- the Conference will sub-allocate the band 12.1 to 12.3 GHz into two sub-bands, allocating the fixed-satellite service to the lower sub-band and the broadcasting-satellite service to the upper sub-band, and will plan the broadcasting-satellite service in that upper portion and in the band 12.3 to 12.7 GHz;
- a detailed orbit/spectrum plan for the broadcasting-satellite service in Region 2 will be drawn up in 1983. Thus, technological advances and better definition of requirements may be included in the plan at the time of the Regional Conference;
- in some countries of Region 2, many systems in the fixed service are already operating in the 12 GHz band which they share with the broadcasting-satellite service. However, while terrestrial systems must not impose restrictions on the elaboration of such a plan, some administrations may want to consider the possibility of re-assigning frequencies to the terrestrial systems within their own service area;
- there are indications that a greater variety of different kinds of broadcasting-satellite services, particularly for community reception, will be planned in at least some countries of Region 2, than were provided for in the Plan for Regions 1 and 3;
- feeder links will be planned in the band 17.3 to 18.1 GHz at the same time as the 12 GHz band is being planned. This will allow overall protection ratios, noise levels and methods of providing energy dispersal to be traded off between the feeder links and down links of each planned network;
- significant geographical characteristics of Region 2 can be taken advantage of in the development of a Plan. These include the fact that the severity of the inter-network interference problem between some systems of Region 2 and some of Regions 1 and 3 is reduced because of the presence of the Atlantic and Pacific Oceans. This and other special features are discussed in § 10.2 and 10.3 of Report 633;
- the plan will incorporate sufficient flexibility to allow for future technical developments, various system design approaches and other uncertainties (see § 5, Annex 6 of Appendix 30 to the Radio Regulations).

More detailed information on a possible planning method is given in § 10.3 of Report 633.

7.4 *Planning considerations for other bands in which the broadcasting-satellite service has an allocation*

7.4.1 *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.

7.4.2 *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.)

The results of a study for community reception (Report 633) are included in Table 1-V.

TABLE 1-V

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: $\Delta G =$ 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.

7.4.3 *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:

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.

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.

* 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 the sharing with existing equipment operating in accordance with their assignments.

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 (Report 633) and the results are shown in Fig. 1-6. A receiving antenna for community reception was assumed. These are provisional results for a single example and further study is required.

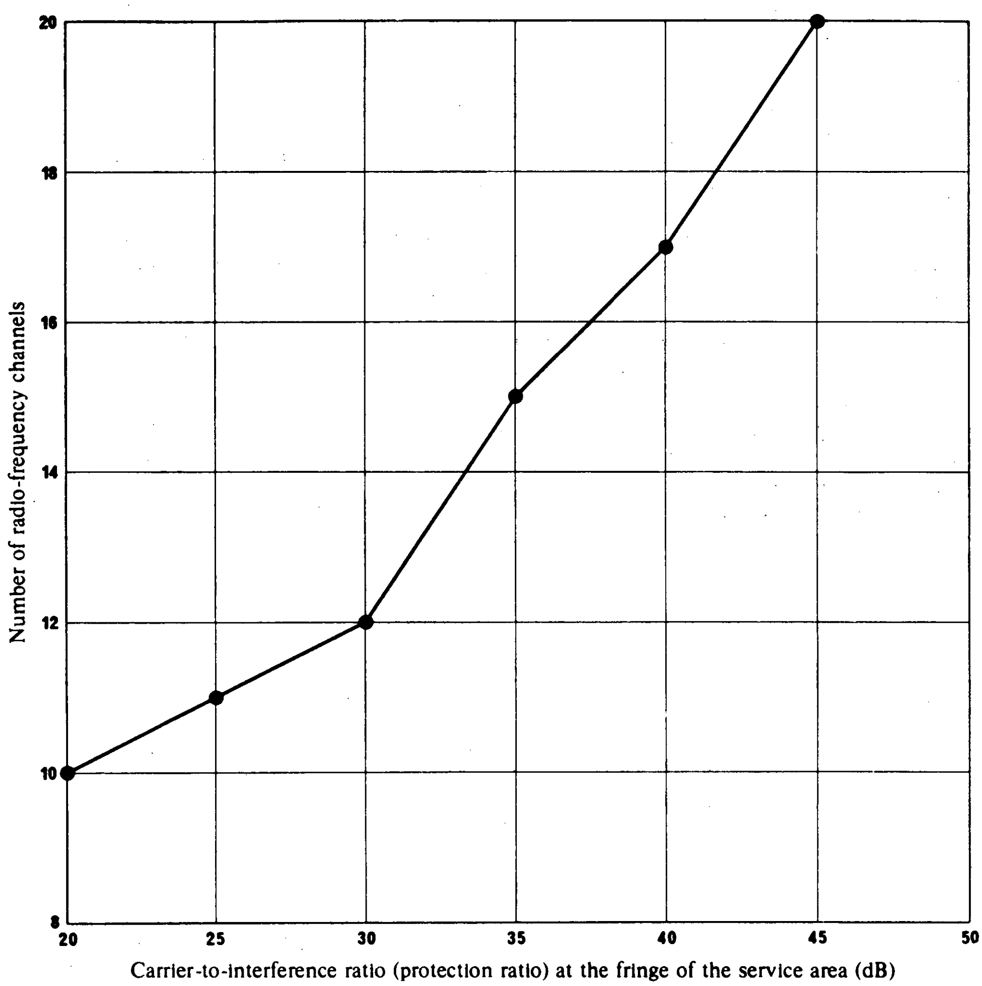


FIGURE 1-6 – *Number of radio-frequency channels required to provide one national programme to about thirty countries of a continent as a function of the carrier-to-interference ratio*

(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: $7° > \varphi \geq 3°$

Detailed discussion of the elements and methods for planning a broadcast satellite system may be found in [Mertens *et al.*, 1976; Reinhart, 1974] and in Reports 633, 811 and 812.

8. Picture quality

8.1 *General considerations*

The satellite communication system can make television programmes available to viewers either by rebroadcast through conventional television stations or through direct reception on augmented domestic television receivers.

The rebroadcast type of link is comparable with a long distance television network and the rebroadcast stations should meet the performance standards laid down in Recommendation 567.

The quality of the television image on the receiving screen depends on the signal-to-noise ratio, the level and nature of any interference and on the various distortions occurring in the transmission chain (studio, terrestrial link, feeder link, satellite transmitter, signal path, receiver). Various methods of making subjective assessments of the quality of television pictures and the parameters involved are given in the references of Report 313. Scales for assessing the quality of television pictures are considered in Report 405. The signal-to-noise ratio is a very important parameter in calculating television systems and planning transmission networks and for this reason attention is focused on this particular parameter. In selecting the required value of the signal-to-noise ratio, account must in many cases also be taken of other television signal distortions. In television, the signal-to-noise ratio at video frequencies is defined as the ratio, expressed in decibels, of the nominal peak-to-peak amplitude of the picture-luminance signal to the r.m.s. value of the noise in the working video frequency band (Recommendation 567).

The quality of service provided by a broadcasting-satellite system (which will be substantially uniform over the whole service area) should be higher than that recommended for the edge of a terrestrial broadcasting service area (in which the quality is very much better at the centre than at the edge). Two grades of reception quality (primary and secondary) are defined in Recommendation 566.

The objectives to be aimed at for reception quality for community reception should be good, to meet the special requirements of educational programmes in television transmission and should certainly not be lower than those considered appropriate to a terrestrial broadcasting system intended for individual viewing.

The subjective effect of noise depends upon the spectral distribution of the noise energy within the video-frequency band. When measuring noise power, it is common practice to use weighting networks which take account of this fact, with the result that the weighted noise power at video frequencies is lower than the total noise power by a factor depending on the spectral distribution. For most television systems, the available weighting networks are designed so that, for various spectral distributions of the noise, the measurements more closely represent the subjective impression on monochrome pictures than do unweighted noise measurements; for colour television, the subjective effect needs special consideration.

TABLE 1-VI – *Video-frequency noise weighting-network reduction factor for monochrome television*

System	Weighting (dB)		Weighting including de-emphasis, k_w (dB)
	White noise	Triangular noise	Triangular noise
B, C, E, F, G, H and M (Japan)	8.5	16.3	16.3
D, K, L	9.3	17.8	18.1
I	6.5	12.3	12.9
M (Canada, USA) (1)	6.8	10.2	13.8

(1) Weighting factors for 525-lines System M (Canada, USA) are based on Recommendation 567. (Values according to Report 637).

Note – When using pre-emphasis according to Recommendation 405, the combined effect of weighting and de-emphasis for triangular noise is approximately the same as that of weighting alone. More details are given in Report 637.

The weighting factors shown in Table 1-VI are not valid when a frequency-modulation system is working near the threshold, where the noise loses its Gaussian characteristics and becomes impulsive. In this connection, tests have been carried out with a frequency-modulation system working near the threshold, in order to investigate the influence of the different types of noise on the picture quality. Such tests have shown that the impairment of the picture quality due to impulsive noise is greater than that due to Gaussian noise, when the value of the unweighted signal-to-noise ratio is the same in both cases.

8.2 *Values of signal-to-noise ratio for various systems*

A method of calculation of signal-to-noise ratio at the input of a receiver for frequency-modulation television signals is given as follows:

In a frequency-modulation system:

$$S/N = C/N + F_{dB} + k_w$$

where:

S/N: ratio of peak-to-peak luminance amplitude to weighted r.m.s. noise (dB)

C/N: pre-detection carrier-to-noise ratio in the radio-frequency bandwidth (dB)

F: $3(D_{p\text{-}p}/f_v)^2 \cdot (b/2f_v)$ (power ratio which equals F_{dB}, when expressed in dB)

$D_{p\text{-}p}$: peak-to-peak deviation by video signal (including synchronization pulses)

f_v: highest video frequency; (e.g. 4.2 MHz in the case of System M)

b: radio-frequency bandwidth (usually taken as $D_{p\text{-}p} + 2f_v$)

k_w: combined de-emphasis and weighting improvement factor in frequency modulation systems (dB) (see Table 1-VI).

Utilization of amplitude-modulation vestigial-sideband techniques in the broadcasting-satellite service at the present time is very unlikely because of the excessively high level of transmitter power necessary on board the satellite and because of the high protection ratio required between such systems with its consequent requirement for wider orbital spacings than for satellites with frequency-modulation systems.

A broadcasting-satellite system will normally be a component part of an overall television system, from the studio to the domestic receiver. Therefore the received picture quality will depend not only upon the characteristics of the satellite system but upon those of each component part of the overall system. Furthermore the picture quality depends not only on the signal-to-noise ratio but also on the presence of distortions.

Therefore, the quality standards should be established considering the satellite circuit as a part of a complete transmission system, giving the value of all parameters having an influence on the resulting picture quality.

Examples of picture quality as a function of some important parameters for various systems are given in Table 1-VII which is the same as Table 4-I.

TABLE 1-VII

Grade (See Note 7 of Report 405)	Radio-frequency signal-to-noise ratio for the percentage of viewers indicated (dB) (1)	
	50%	75%
1.5 half-way between excellent and fine	39.5	42.5
2 fine	35.2	38.2
3 passable	30.0	33.0
4 marginal	25.6	28.6
5 inferior	20.4	23.4

(1) Radio-frequency r.m.s. signal during sync. peaks, no weighting, over 6 MHz bandwidth, amplitude-modulation vestigial-sideband.

8.2.1 *525-line system/NTSC (System M: USA and Canada)*

Equivalent rectangular bandwidth in transmission:

– Frequency-modulation: 18 MHz
– Amplitude-modulation, vestigial-sideband: 4 MHz

Ratio of luminance signal to weighted r.m.s. noise value is 43 dB (approximately 46 dB for System M: Japan) (rated "excellent" by 50% of the viewers).

8.2.2 *625-line system. Colour television signal (B, G, I and L system)*

Effective video bandwidth 5 MHz, frequency multiplexing of frequency-modulated sub-carrier transmitting sound at approximately 5.7 MHz.

- 45 dB weighted in the luminance (weighting in accordance with Recommendation 567);
- 33 dB in the chrominance (filter in accordance with Recommendation 567);
- 50 dB in the sound channel (40 to 15 000 Hz).

8.2.3 *625-line system (System K)*

Equivalent noise band of amplitude-modulation receiver: 4.6 MHz.

Three main classes of picture quality are considered:

Class I: picture of excellent quality (on a picture tube of any screen size). When the picture is viewed from a distance equal to 5 to 6 times the height of the screen, the noise is on the threshold of perception.

Class II: picture of very satisfactory quality (on picture tube of medium and small screen size). The noise is perceptible, but causes no interference to the picture and is not objectionable to the viewer.

Class III: picture still acceptable on inexpensive television receivers with small screens. The noise is quite noticeable and causes interference to a degree which can be accepted.

Appropriate values for the signal-to-noise ratio are given in Table 1-VIII.

TABLE 1-VIII

Class of picture quality	I	II	III
Ratio of picture signal-to-weighted r.m.s. noise value at the picture tube control electrode (dB)	46	39	32
Carrier-to-noise ratio at receiver input (dB)	44	37	30

8.2.4 *625-line system. Colour television signal (PAL system)*

Assuming a chain consisting of a studio, a terrestrial radio-relay link, a broadcasting-satellite system and a domestic receiver, and when all the impairments have values quoted in Table 1-IX, the overall subjective quality grade will be 2.6 (on the 5-point scale; see Recommendation 500). The overall grade would be 2.9 if the signal-to-noise ratio of the down link were increased by 3 dB, the other impairments remaining at the same value.

9. Influence of the atmosphere

The influence of the atmosphere (attenuation of signals due to atmospheric attenuation and depolarization from precipitation) depends on frequency.

9.1 *Down link (12 GHz region)*

9.1.1 *Attenuation*

Extensive measurements of sky noise temperature at 11.5 GHz covering the European region have been carried out by the European Space Agency for a number of years. Atmospheric attenuation was expected to vary with the angle of elevation and with the local climate. However, in the European region and for the range of angles of elevation (from 20° to 45°) covered by the experiment, these dependencies are so small that they need not be taken into account when compared with the random year-to-year variations in attenuation values. The values of the worst-month attenuation obtained from the measurements are listed in Table 1-X. For system planning, it is proposed to use the median values, corresponding to the worst month in an average year.

Further information is contained in Reports 564 and 565, and a method for calculating rain attenuation can be found in Report 563.

For any frequency f(GHz), other than 11.5 GHz, the atmospheric attenuation A_f may be calculated from the values for 11.5 GHz, $A_{11.5}$, by means of the following formula which is valid from 11.0 to 14.5 GHz:

$$A_f = A_{11.5}\,[1 + 0.2\,(f - 11.5)] \qquad \text{dB}$$

TABLE 1-IX — *Parameter values*

Component of the chain	Parameter				
	Differential phase (degrees)	Differential gain (%)	Chrominance/ luminance gain inequality (%)	Chrominance/ luminance delay inequality (ns)	Signal-to-noise ratio (weighted) (dB)
Studio	± 5(1)	± 5(1)	± 5(1)	± 10	48
Terrestrial circuit	± 5(1)	± 10(1)	± 10(1)	± 50	56(2)
Satellite system	± 5(1)	± 10(1)	± 10(1)	± 50	
Domestic receiver	± 10(5)	± 15(5)	(3)	± 100	46(4)

(1) Statistical variable and not exceeded at least for 80% of any month.

(2) Exceeded at least for 80% of any month.

(3) It is assumed that the receiver distortion is equalized by manual chroma control.

(4) This assumes an unweighted signal-to-noise ratio of 33 dB, and a noise-weighting factor (including effect of pre-emphasis) of 13 dB. The minimum performance would be achieved at the edge of the service area in the least favourable case, for 99% of the time.

(5) Studies have shown that these tolerances can be achieved in practice with simple filters without correction circuits in the receiver, when the frequency deviation is about 14 MHz/V and the —3 dB bandwidth is 27 MHz. As a first approximation, these values may be considered as constant with time.

TABLE 1-X — *Worst-month attenuation at 11.5 GHz (Europe)*

Time fraction (%)	Attenuation not exceeded during worst months (dB)		
	90% value	median value	10% value
20	0.3	0.4	0.6
5	0.4	0.6	0.9
1	0.9	1.1	1.4
0.3	1.2	1.8	2.4
0.1	1.5	3.3	6.0
0.03	3.1	7.3	11.0

For Region 3, measurements of atmospheric attenuation in the 12 GHz band have been carried out using the broadcasting satellite for experimental purposes (BSE) in Japan and using a radiometer in Malaysia, which are situated respectively in the moderate and tropical climate areas in Asia. The results are summarized in Table 1-XI (see also Table 4-IV). While the data presented should be regarded as provisional, they may be considered useful until more precise data become available.

The values in Japan in Table 1-XI are medians of the data in the worst months for 12 to 14 months in 12 locations, which have been distributed all over Japan, angles of elevations ranging from about 30° to 60°. Measurements in Malaysia were corrected with respect to an elevation angle of 45° by using the cosecant law (Report 215).

Measurements of rain attenuation at 11.7 GHz were carried out at Greenbelt, Maryland and Rosman, North Carolina in the United States by the NASA/Goddard Space Flight Center by monitoring the beacon on the Communications Technology Satellite (CTS). Measurements commenced at Greenbelt, Maryland in June 1976 and were completed in autumn of 1979. The elevation angles to CTS from Greenbelt and Rosman are 29.5° and 36° respectively.

TABLE 1-XI – *Worst month attenuation observed at 12 GHz in Japan and Malaysia*

Location of measurement	Period	Attenuation not exceeded during the worst month (dB)	
		99% of the worst month in an average year	99.9% of the worst month in an average year
12 locations in Japan	August 1978 to December 1979	2.4	6.9
Klang in Malaysia	October 1970 to November 1972	1.7	8.7

Measurements of rain attenuation at 20 GHz and 30 GHz were also carried out at Rosman using the ATS-6 satellite [Ippolito, 1975].

Table 1-XII summarizes the results of these measurements for the two worst months of the measurement period.

TABLE 1-XII — *Rain attenuation observed at 11.7 GHz (CTS) and 20 and 30 GHz (ATS-6) in Maryland and North Carolina, USA*

Location	Frequency (GHz)	Month	One-minute mean attenuation (dB), not exceeded during month for given percentage of the time		
			99%	99.9%	99.99%
Greenbelt (Maryland)	11.7	June, 1976 August, 1976	<1 <1	1.6 5.4	9.2 15.6
Rosman (North Carolina)	11.7 20 30	July, 1976 July, 1974 July, 1974	1 1.5 2.4	1.8 11.0 19.5	8.3 >20 >35

In 1978-1980 attenuation and cross-polarization measurements were carried out by CNES-TDF (France) in Brittany (11 700 hours) and near Paris (3500 hours) receiving 11.8 GHz circularly polarized and 11.6 GHz linearly polarized beacon signals respectively from the OTS satellite (Report 215). Attenuation values not exceeded for 99% and 99.9% of the worst month were 1.8 and 4 dB respectively for Paris and 1.5 and 3 dB respectively for Brittany. Polarization isolation of the circularly polarized beacon was only above 20 dB for 99.9% of the worst month and 99.99% of the entire measurement period, and was never less than 30 dB for the linearly polarized beacon.

CCIR Interim Working Party 5/4 has considered appropriate percentage-of-time availability criteria for both terrestrial and satellite systems when used for domestic (for example, rural) applications in developing countries. The point was made that the economic difference between 99.9% and 99% of the time for the same signal-to-noise ratio is considerable, while actual system availabilities very often do not approach these figures in any case. The use of a more appropriate figure than 99.9% of the time, say 99%, would greatly reduce the effect of rainfall factors to be allowed for in planning both terrestrial and satellite applications in tropical climates and thus would lead directly to substantial economies in site engineering and hardware. A worthwhile step towards the solving of the problems encountered by the developing countries in the provision of radiocommunications to remote or rural areas of low traffic density could perhaps be achieved in this way.

9.1.2 *Depolarization*

In addition to their effects on attenuation, clouds and rain can cause depolarization of the signal. Statistical analysis of measured results with circular polarization in Region 1 suggests that the level of the depolarized component (relative to the level of the co-polar component after attenuation) can be expressed approximately in terms of the attenuation caused by the atmosphere, according to the following equation:

Relative level of depolarized component (for circular polarization):

$$\approx -[30 - 20 \log A] \qquad \text{dB}$$

where A is the atmospheric attenuation, in decibels. If, for purposes of planning, it were desired to adopt a single figure for the level of the depolarized component, it would be necessary to choose the fraction of the time for which the figure is to apply. If this were taken as 1% of the worst month, then on the basis of the median values given in Table 1-X, -30 dB would be an appropriate value. If, however, it were necessary to take the case of 0.1% of the worst month, the value would become approximately -20 dB. (These values apply to 11.5 GHz.)

Also, depolarization measurements were taken with the CTS satellite launched in 1976 in the 12 GHz region, using both circular and vertical polarization. Actual measurements statistics from this programme have been analyzed in Report 564.

Report 564 shows that the cross-polarization discrimination (XPD) due to rain may be predicted from the co-polar attenuation (CPA) by an equation of the form:

$$XPD_{\text{dB}} = -[U - V \log (CPA_{\text{dB}})]$$

where parameters U and V are functions of frequency, polarization tilt angle, elevation angle, canting angle, distribution of the rain drops, and to a much lesser extent, on drop-size distribution.

For circular polarization over slanted paths, reasonable approximations for U and V result in the following equation:

$$XPD_{\text{dB}} = -[(30 \log f_{\text{GHz}} - 40 \log (\cos \varepsilon)) - 20 \log (CPA_{\text{dB}})]$$

where:

f: frequency (GHz)

ε : elevation angle (degrees).

This provisional equation appears to be valid over the following parameter ranges:

$10° \leqslant \varepsilon \leqslant 60°$

$8 \text{ GHz} \leqslant f \leqslant 40 \text{ GHz}$

$1 \text{ dB} \leqslant CPA \leqslant 15 \text{ dB}$

$10 \text{ dB} \leqslant |XPD| \leqslant 40 \text{ dB}$.

Thus for 12 GHz circularly polarized transmissions, the cross-polarization discrimination due to rain can be expressed by:

$$XPD_{\text{dB}} = -[32.4 - 40 \log (\cos \varepsilon) - 20 \log (CPA_{\text{dB}})]$$

(A more detailed discussion of depolarization effects due to precipitation can be found in Report 814.)

9.2 *Feeder links*

With reference to § 6.3, WARC-79 considered the problem of frequency allocations for the feeder links to the broadcasting satellites operating in the 12 GHz band. Certain frequency bands were allocated for this purpose to the fixed-satellite service (Earth-to-space), but limited for the feeder links to the broadcasting satellites. The influence of the atmosphere on feeder links is considered in Chapter 3. Also Report 215, § 4.4 gives a method for partitioning of noise contribution between feeder and down links.

10. Modulation and bandwidth considerations

10.1 *Technically suitable methods of modulation*

There are a large number of possible methods of modulation for the broadcasting-satellite service, the choice depending on several factors. This section discusses different technically suitable methods for the broadcasting-satellite service in all the frequency bands allocated to this service.

As regards the broadcasting-satellite service in the 12 GHz band, it should be borne in mind that the planning at the WARC-BS-77 was carried out on the assumption that a television programme would have only one sound channel, transmitted using a frequency-modulation sub-carrier positioned at the inter-carrier spacing of the television system used in the service area under consideration. Nevertheless, the WARC-BS-77 did not exclude the use of modulation signals having different characteristics, provided that the use of those different characteristics did not result in greater interference than that caused by the system considered in the Plan.

10.1.1 *Analogue television with an associated sound channel*

This section relates to the broadcasting of an analogue picture signal associated with a sub-carrier for one analogue sound channel.

The two types of analogue modulation best suited to satellite television broadcasting seem to be vestigial side-band amplitude modulation and frequency modulation.

For a given quality of service and a given figure of merit of the receiving installation, frequency modulation permits a much lower satellite transmitter power than amplitude modulation. However, in frequency bands for which there are existing terrestrial television receivers, amplitude modulation would allow these receivers to be used without modification. From the point of view of planning, frequency modulation requires wider channels, but the protection ratios are lower than for amplitude modulation, so either type of modulation may be advantageous, depending on the circumstances.

When frequency modulation is used, it is desirable that, after demodulation, the composite vision and sound signals should be the same as in the terrestrial service in the given geographical area; this would simplify the design of compatible receivers. This implies the use of a sub-carrier for the sound signal at a frequency equal to the spacing between the vision and sound carriers used for the terrestrial service. However a sub-carrier of high amplitude can cause a visible beat pattern with the colour sub-carrier, and a buzz of the sound. Experiments by EBU members have shown that the receiver bandwidth need not be wider than is necessary to achieve a good quality of the picture alone, when the sound sub-carrier has an amplitude giving about 30% of the total peak-to-peak deviation of the carrier. Nevertheless, in some of these experiments the best signal-to-weighted-noise ratio which was achieved for the sound was 50 dB, as a result of buzz caused by variations in group delay of the receiver filter characteristics. If better sound quality is required (for example, with a signal-to-weighted-noise ratio of 60 dB), it may be necessary to abandon the analogue sub-carrier principle, and to transmit the sound by other methods. One suitable method could consist of using a separate RF carrier with the same modulation characteristics as those which may be used for sound broadcasting from satellites.

In frequency-modulation television, the signal bandwidth limitation arising from radio-frequency and intermediate-frequency filtering causes distortion which may significantly impair the picture quality. The most critical part of the system in this respect is the receiver; this must have cheap and simple filters, which may not be phase-corrected. In the absence of sub-carriers for the sound signals, the most critical distortions for a colour picture are the differential phase and gain of the colour sub-carrier. These distortions should be taken into account when deriving the relationship between the frequency deviation and the equivalent rectangular bandwidth of the receiver. Studies made by EBU members have shown that it is possible to obtain reasonable values of the distortions, as mentioned in Table 1-IX with a peak-to-peak frequency deviation of approximately 14 MHz/V at the reference frequency of the pre-emphasis characteristic, and a receiver bandwidth of 27 MHz. Studies carried out in Japan (Report 632) with the 525-line M/NTSC system have shown that there are suitable combinations of carrier frequency deviations due to a video and a sound sub-carrier signal and the sub-carrier frequency deviation due to a sound signal which make it possible to obtain the required signal-to-noise ratios without producing a visible beat pattern and truncation noise.

10.1.2 *Analogue television with several sound channels*

This section describes the modulation methods which enable several sound channels and an analogue picture signal to be broadcast in the same radio frequency channel.

10.1.2.1 *Objectives*

There will probably be a need in the future for a capability within the satellite broadcasting channel for a number of sound channels beside the picture and, if possible, for using that capability flexibly for the emission of high quality sound (including stereophony), multilingual commentaries and even data or sound not directly related to the picture.

The systems used for this purpose in the 12 GHz band in Regions 1 and 3 will have to meet the requirements laid down by WARC-BS-77 relating, *inter alia*, to the occupied bandwidth and interference with other services; similarly, the decisions of the 12 GHz broadcasting satellite planning conference for Region 2 (RARC SAT-R2) will have to be followed. Furthermore, it is desirable that the standards for the sound accompaniment in broadcasting by satellite and terrestrial transmitters in the long term be brought into line. In the short term, however, compatibility with existing receivers is a less critical problem in satellite broadcasting in so far as inexpensive signal processing circuits can be built into the modulation converter needed for satellite reception.

The sound quality should be at least as good as that attained under the single FM sub-carrier system mentioned in § 10.1.1 above. The following objectives may be considered for high quality monophonic sound:

- audio bandwidth: 15 kHz;
- for analogue systems, a signal-to-noise ratio for 99% of the time of at least 50 dB, and, if possible, 60 dB as quasi-peak value with the weighting network described in Recommendation 468;
- for digital systems using companding to reduce the total bit rate, a dynamic range equivalent, for example, to that provided by a basic analogue to digital conversion at 14 bits per sample.

It would also be useful to envisage replacing one high quality sound channel by two or three commentary channels having the same signal-to-noise ratio but a smaller bandwidth.

Another important objective in designing broadcasting systems for the public is the cost of receiving equipment, which should be kept as low as possible. The same applies to any changes that may be required in cable distribution networks.

10.1.2.2 *Frequency multiplexing* (see Report 632)

a) *Use of several analogue sub-carriers*

Frequency-multiplexing of several sub-carriers modulated by the sound signals results in a particularly economical arrangement for the receiver, at the same time needing only a moderate increase in the width of the radio-frequency channel. However, intermodulation between the picture and sound signals, and between the various sound signals, may significantly impair the quality.

Studies carried out in France and the Federal Republic of Germany using the video characteristics of L-SECAM and G-PAL systems have shown that if the frequency separation between the sub-carriers is subject to a tight tolerance, the intermodulation products fall between the spectral lines of the picture signal.

If a two-carrier sound system were adopted in terrestrial television, it would be desirable that the sub-carrier frequencies in the satellite television system should be equal to the spacings between the vision carrier and the sound carriers in terrestrial television.

Studies carried out in Japan have shown that a second frequency modulated sub-carrier and pulse time multiplexing may be used to transmit up to six additional sound channels without increasing the bandwidth of the receiver.

b) *Use of a digitally modulated sub-carrier*

From the many possibilities, one that is of special interest is that in which a single sub-carrier is modulated by a digital multiplex having a bit rate of approximately 700 kbit/s, 1400 kbit/s or 2100 kbit/s (i.e. the equivalent of two, four or possibly six high-quality monophonic sound channels).

c) *Use of a digitally modulated sub-carrier plus a sub-carrier with analogue FM modulation*

The possibility of broadcasting simultaneously an analogue sub-carrier and a digitally modulated sub-carrier would make it possible, depending upon the nature of the receiver used, to offer two possibilities, namely:

- the possibility, which would lead to very economical receivers, of the reception of a television programme having a good quality monophonic sound channel, and
- the possibility of access, in addition, to several complementary services, such as high-quality stereophonic or monophonic sound channels, commentaries, sub-titles, teletext and additional sound programmes. The bit rate would have to be chosen so as to make possible at least the equivalent of four high-quality sound channels.

In order to attain those objectives, the analogue sound sub-carrier must make it possible to obtain good sound quality, while the bit rate of the digital sub-carrier must be at least 1.4 Mbit/s with a bit error ratio of less than 10^{-4} for a C/N ratio greater than 10 dB.

In the case of an analogue sub-carrier and a digital sub-carrier, supplementary constraints become evident at the level of the digital sub-carrier filters at the sending and receiving ends. In effect, the sending-end filter has, in this case, to ensure the adequate protection of the analogue sub-carrier, which necessitates a greater reduction of the spectrum of the digital sub-carrier. Similarly, the digital demodulator filter has to be narrow enough to ensure good separation between the digital sub-carrier and the analogue sub-carrier. For a given bit rate, these constraints render the search for a satisfactory compromise between the characteristics of the sending-end and receiving-end filters more difficult than in the case of a single digital sub-carrier.

10.1.2.3 *Time-division multiplexing*

The procedures for setting up a digital multiplex may be similar to those described in Report 954.

a) *Baseband insertion of digital audio signals in the line-blanking interval*

The insertion of digital audio signals in the line-blanking interval is an attractive technique because it enables high-quality signals to be transmitted without increasing the width of the baseband or the RF channel.

This technique may also be used in satellite broadcasting, with similar constraints as for terrestrial television (see Report 958). However, disregarding the receiver cost, which is not so important in the case of community reception, compatibility with existing receivers would be less critical in the case of satellite television. This is because the signal processing including the regeneration of the synchronizing pulses, could be performed in the converter which must in any case be added to television receivers. Furthermore, multi-path propagation, which might cause impairment to the received picture when this system is used with terrestrial television, should not occur in the case of satellite broadcasting.

b) *Radio-frequency time-division multiplex using the line-blanking interval*

The carrier modulation is analogue FM during the active period of the lines and digital during the line-blanking interval. These systems have a higher potential capacity than those using baseband insertion, but require additional equipment to be installed in the receiver. Furthermore, it is not possible to introduce systems of this type ultimately into terrestrial television, even by means of a transitory phase, during which the new system and the present system would have to co-exist. These systems can thus be used only in satellite broadcasting.

10.1.2.4 *Combinations of the above techniques*

In order to increase the number of sound channels (in satellite broadcasting) it is possible to envisage combinations of systems with sub-carriers and systems using baseband insertion into the line-blanking interval.

10.1.3 *Digital television*

This section discusses digital modulation as a candidate technique for the transmission of television signals.

Digital encoding of television signals, as well as data-compression techniques for picture information redundancy reduction are currently under intensive study and investigation (Report 629). A broadcasting link using direct carrier modulation by the digitized video represents another alternative to analogue/FM modulation.

Annex I compares the power and bandwidth requirements of analogue/FM and digital modulation for 525-line system M/NTSC (USA, Canada) as a function of system parameters such as signal-to-noise ratio, data rate and digital modulation techniques.

Digital modulation has potential advantages over analogue/FM, including the possibility of lower satellite transmitter power and narrower channel bandwidth requirements if a sufficiently low bit rate can be achieved.

While this approach would be currently too expensive to implement for individual reception, the cost may not be prohibitive for community reception (Report 632). It is also likely that decoder hardware, once standardized, will show the same dramatic decrease in cost as has occurred with other digital hardware such as computers and calculators.

For further information about digital modulation techniques see § 6 of Report 632.

10.1.4 *Analogue component television signals*

Future television receivers are expected to have an input socket for component signals (*YUV* or *RGB*) and it may be possible to exploit this feature by transmitting the signal in component form. This could have important advantages in the future development of systems. They are:

- reduction of chrominance noise by shifting the chrominance information away from high video frequencies where the noise levels are greatest;
- improvement in quality arising from direct compatibility with programme source material generated as colour components;
- more efficient use of the bandwidth, by employing receiver processing, offers a compatible method of obtaining an extended definition system (Report 801);
- reduction of the impairments which arise from present in-band colour systems (e.g. cross colour, cross luminance, etc.).

One form of component transmission is under study. It employs a time-division multiplex of the luminance and chrominance analogue components which are compressed in time.

10.2 *Required bandwidth for frequency modulation television*

Detailed information for bandwidth requirements for different system types for frequency bands of 700 MHz, 2.6 GHz and 12 GHz is given in Report 215.

10.3 *Energy dispersal in feeder and down links*

Energy dispersal is used in connection with FM-TV transmissions via FSS satellites in order to reduce interference to other systems which share the same frequency bands. In the case of broadcasting-satellite transmissions, energy dispersal may be required on the down link in order to protect terrestrial radio-relay links while, on the feeder link, it may be required in order to protect transmissions to fixed-service satellites at neighbouring orbit locations, sharing the same frequency bands (e.g. 14 to 14.5 GHz). (*Note.* – The Earth-space allocations of the following bands are limited to feeder links for the BSS: 10.7 to 11.7 GHz in Region 1, 14.5 to 14.8 GHz for countries outside Europe and for Malta and 17.3 to 18.1 GHz (worldwide)).

In general, the required energy dispersal bandwidth is different in the two directions of transmission, typically being greater on the feeder link. On the other hand, it is desirable to use the smallest possible dispersal bandwidth on the down link so that the cost of removing the dispersal signal in home television receivers can be minimized. Similarly, dispersal at the television line frequency may be most effective in the feeder link for protecting fixed-satellite transmissions, while a television frame frequency dispersal signal may be less expensive to remove on the down link. If such a conflict arises between the requirements for the feeder and down links, consideration should be given to energy-dispersal modulation conversion in the broadcasting satellite as one possible means of improving orbit conservation. Further study is required on the need for and practicability of this technique (Report 215).

11. **Characteristics of ground receiving equipment** (see also § 4 of Chapter 2)

The characteristics to be adopted for ground receiving equipment for broadcasting-satellite systems offer a wide range of choice. These characteristics influence the size, mass and complexity of the satellite required to provide a given quality of service because of the compromise that must be made between receiver sensitivity and the power radiated by the satellite. They themselves are affected by the broadcasting standards selected. In particular, the characteristics of the ground receiving equipment will depend on whether it is required to receive only television signals (with only one or with more than one, accompanying sound signal), or only sound signals, or both.

It appears that signals broadcast from satellites could be received, not only by equipments of new design, but in some cases by existing receivers fitted with adaptive devices, provided that suitable standards were adopted for the satellite transmission.

A distinction should be made between installations intended for community reception and for individual reception.

11.1 *Individual and community reception*

Possible receiving systems must cater for one of two types of reception, namely "individual reception" or "community reception". Report 215 presents typical values of the power flux-density required for individual and community reception systems for the three frequency bands (700, 2500 and 12 000 MHz) of primary interest to satellite broadcasting.

The signal-to-noise ratio for community reception should be 3 to 5 dB higher than the value given for individual reception. This is justified to compensate for the degradation introduced by the distribution network, e.g., cable or re-broadcasting, and to provide a sufficient quality for collective viewing on large screens.

11.2 *Receiving equipment*

The overall characteristics of the receiving terminal are specified by the figure of merit, G/T (see Report 473). The different sub-systems of the receiving terminal may be chosen so that the overall value of G/T is attained and the system will be the most economical.

A typical receiving terminal consists of the following sub-systems:

– antenna,
– input stage,
– intermediate-frequency stage,
– demodulator and/or mode adapter.

Examples of community reception systems are given in Table 1-XIII.

TABLE 1-XIII – *Experimental ground receiving equipment characteristics (Community reception)*

System		ATS-6	ATS-6	CTS	BSE-Japan	Anik-B
Frequency (GHz)		0.860	2.5	12	12	12
G/T (1) (dB(K^{-1}))		−6	+8	+15	+16	+13 and +16.5
Antenna	Dia. (m)	3	3	1.8	1.6	1.2 and 1.8
	Material	Expanded aluminium mesh	Epoxy fibreglass	Epoxy fibreglass	Aluminium press-stretch (2)	Aluminium
	Tracking	None	Limited manual	Limited step track	None	None
Input stage		Bipolar silicon transistor	Bipolar silicon transistor	Image enhanced diode mixer		GaAs FET amplifier
Noise figure (dB)		6.5	4	6	4.5	4.5
Number of channels		1	1	1	2	Continuously tunable over 500 MHz
Number of frequency changes		1	None	1	1	1
Intermediate frequency (MHz)		70	None	70	400	900 to 1400

(1) Not taking into account pointing and polarization losses and ageing degradation (β).

(2) An example.

12. Examples of television system parameters

Tables 1-XIVa and 1-XIVb present examples of community reception and individual reception television systems respectively with different frequencies, operating and quality conditions. Columns 1 to 7, 9, 12 and 14 to 18 refer to television system M, Columns 1 to 7 and 9 for community reception and Columns 12 and 14 to 18 for individual reception.

Column 13 relates to individual reception with systems G, I or L; the calculations are based on angles of elevation from 20° to 45° using a value for the peak-to-peak deviation of 13.3 MHz for 1 V of video signal at the reference frequency of the pre-emphasis curve in Recommendation 405. In the example described by this column, the sound channel is constituted by the sub-carrier at a frequency of 6 MHz, modulated with a 50 kHz peak-to-peak deviation, which produces a carrier deviation of ± 2.8 MHz.

For the examples relating to system M (USA, Canada) a value of 43.3 dB is assumed for the luminance signal-to-weighted r.m.s. noise ratio at the edge of beam, this value being representative of the primary reception quality; for secondary quality, a value of 36.3 dB could be adopted, which would require an e.i.r.p. only 1.5 dB below the value for primary quality.

For the example relating to systems G, I and L, and with the figure of merit given in Report 473, the signal-to-noise ratios remain respectively above the values of 33 dB (unweighted) for luminance and 50 dB (weighted) for sound for 99% of the most unfavourable month (in European climatic conditions) throughout the entire service area during the entire useful life of the satellite and the receiving installation and with the angle of elevation giving the least favourable result. Under the same conditions, the carrier-to-noise ratio at the receiver input remains above 10 dB for 99.9% of the most unfavourable month with the atmospheric margin defined in § 2.4 of Report 215.

Column 8 of Table 1-XIVa refers to a community reception system which may be considered practical and economical in the use of space and Earth segments, although the grade of service (S/N and margin above threshold) is lower than that in Column 4. For some applications, such reception may be subjectively satisfactory, and, where limited numbers of receiving terminals are expected, such a system could be used for individual reception although the receiver G/T is higher than for typical individual receivers (Report 215).

Column 9 of Table 1-XIVa relates to the pre-operational use of the 14/12 GHz portion of the Canadian Anik-B satellite, located at 109° W longitude. The 14/12 GHz portion of Anik-B is a multi-function system, being used for voice and data transmission, audio and video teleconferencing for tele-health and tele-education applications, as well as for television broadcasting to individual and community terminals. For this reason the values in the "required" e.i.r.p. and satellite transmitter power rows of Column 9 refer to the actual spacecraft values, not necessarily to values which would have been used if the system were designed and operated solely as a direct-broadcasting satellite. In its BSS mode of operation, the satellite is being used in a field trial of network television programme delivery to approximately 100 locations in two parts of Canada: northern Ontario and British Colombia. Some fifty 1.2 m terminals are being used in the central part of the Ontario beam for both individual and community reception. A similar number of 1.8 m terminals are being used, some in the fringe areas of the Ontario beam and some in the central part of the British Columbia beam to receive two network television signals being transmitted through the same 20 W transponder. The results obtained to date in the field trials indicate that fully-operational dedicated 12 GHz broadcasting-satellite systems with received maximum power flux-density values in the -105 dB(W/m^2) to -110 dB(W/m^2) range might be used (Report 215). These pfd values can be achieved in clear air by e.i.r.p. values of 58 and 53 dBW respectively. Assuming the gain of an antenna with a 2° circular beam, this would require satellite power amplifiers of 140 W and 45 W respectively per channel (Report 215).

The system examples at 23, 42 and 85 GHz are shown in Columns 5, 6, 7 and 18 of Table 1-XIVa and 1-XIVb. This is done for purposes of comparison with 12 GHz systems, assuming that all systems use the existing 525-line television standard, though in some cases, these frequency bands might be used for different television standards not compatible with the existing systems (Report 801). Therefore this is not to imply that the parameter values shown represent an optimum or even feasible system.

For comparison purposes, some parameters in Columns 5 and 6 contain some of the same assumptions as the example in Column 3 for 12 GHz, i.e., beamwidth of the receiving antenna and luminance signal-to-weighted noise ratio. Thus the required satellite transmitter powers are 440 W, 1.7 kW and 43 kW, which are higher than those at 12 GHz, but this is not to say that these systems will not be implemented.

Columns 10 and 11 are for high-definition television systems (Report 215). Examples at bands above 12 GHz are preliminary, e.g. it is not certain what the relative sizes of community and individual earth stations will be.

Column 16 refers to one possible individual reception system designed to provide three channels of television to all of the contiguous United States (CONUS). Significant efforts were made to balance picture quality considerations and total system costs, including several million home receiving installations. Four operating satellites are used to provide CONUS service, with each satellite serving (approximately) one of four time zones in CONUS from a location sufficiently west so that eclipses do not start until after 0200 h local time. An orbital separation of 20° is provided between satellites to re-use the same three frequencies. The parameters listed in

Column 16 under section 2 (receiving installation) are values used for a typical location. Locations with different precipitation attenuation values have different e.i.r.p. requirements (between 55.3 and 58.2 dBW). Receiving installations with 0.6 m and 0.9 m antennas are also used to further equalize the grade of service. Feeder links at 17 GHz for all satellites originate from a comparatively small area (230 km radius) inside the westernmost broadcast service area; accordingly, the feeder links for the three easternmost satellites originate outside their broadcast service areas. This small area can be covered from the satellites with a spot beam which is about 0.8° wide and which results in a high satellite G/T (about $+8$ dB(K^{-1}). Because of the high satellite G/T and the fact that the station is in rain climatic zone 5 (least rain), the station can meet all system requirements under virtually all atmospheric attenuation conditions. An 11 m antenna (63.5 dB gain) and three 200 W transmitters (one for each channel) are used to feed programming to each of the four satellites, with enough margin to overcome rain attenuation for all but about 10 minutes per year (Report 215).

Some administrations may find it necessary to use the 40 and 80 GHz bands to establish systems in the future because of frequency congestion in other bands, or because of heavy terrestrial use of lower bands, in particular 11.7 to 12.2 GHz. In such cases, the use of lower values of S/N, less margin for atmospheric attenuation, and smaller satellite and receiving installation antenna beamwidths may be acceptable. These savings, in conjunction with lower loss and lower noise temperature designs all have the effect of reducing the required satellite transmitter power to levels that may be technically and economically feasible.

Table 1-XV is intended to illustrate a simplified form of presentation; numerical values should, of course, be revised if necessary to take into account any new system examples.

13. Satellite sound broadcasting

13.1 *Methods of modulation*

When sound broadcasting is the main service on the carrier(s) considered, the following methods of modulation may be used.

13.1.1 *Analogue methods of modulation*

Among analogue methods of modulation, it seems preferable to use frequency modulation with the same standards as those used for terrestrial sound broadcasting (see Recommendations 412 and 450); but they could be different in certain cases. In particular, it may be desirable to use a higher deviation in order to reduce the necessary satellite transmitter power, especially in the frequency bands where new receivers or additional equipment for existing receivers would in any case be required.

For stereophonic broadcasting using a frequency-modulation multiplex system (Recommendation 450), it is necessary to increase by about 20 dB the values of field strength, power flux-density, and satellite e.i.r.p. or the figure of merit of the receiving earth station. Stereophony could also use two identical channels, carrying the left and right signals, but there may be some problems for compatible monophonic reception.

13.1.2 *Digital methods of modulation*

For the broadcasting of a large number of sound channels, it may be advantageous to use TDM digital techniques.

The information on digital coding characteristics of high quality sound signals with 15 kHz bandwidth is given in Report 953.

13.1.2.1 *Organization of a digital multiplex*

In the case of digital modulation systems, two kinds of procedure may be used to reassign the capacity of a multiplex to sound channels of different characteristics (or even to data channels) depending on the demand. One is the organization of the multiplex for continuous transmission and the other packet transmission. The latter consists of grouping the data into packets consisting of two parts:

– an area termed the "prefix" which is used to synchronize the receiver and to identify the source of the data,

– a useful data field.

TABLE 1-XIVa – *Examples of community reception television system parameters*

Parameter (1)	1	2	3	4 (15)	5	6	7	8	9a	9b (16)	10		11
1. *System*													
Frequency of carrier (MHz)	700	2600	12 000	12 000	22 750	42 000	85 000	12 500	12 000	12 000	22 750		41 500
Type of modulation	FM	FM	FM	FM	FM	FM	FM	FM	FM	FM	FM		FM
Angle of elevation (degrees)								25-70	⩾ 10	⩾ 10			
Approximate equivalent rectangular bandwidth (MHz)	19	20	17	25	40	40	44	17.5	18	18	125		125
Carrier-to-noise ratio before demodulation (exceeded for 99% of the time) (dB) (2)	16	15	18	22	11	11	11	11	9	8.5	17		17
Number of lines in system	525	525	525	525	525	525	525	625	525	525	1125		1125
Corresponding luminance signal-to-weighted r.m.s. noise ratio (edge of beam) (dB) (3)	43.3	43.3	43.3	50		43.3	43.3				46 (18)		46 (18)
Luminance signal-to-unweighted noise ratio measured in a nominal bandwidth (edge of beam) (dB) (4)	31.8	31.8	31.8	36.2	38	31.8	31.8	29.3			40		40
Audio-frequency signal-to-weighted noise ratio (weighting specified in Recommendation 468 pre-emphasis is 50 μs) measured in a 15 kHz audio-frequency band (edge of beam) (dB)													
2. *Receiving installation*													
Figure of merit, G/T, (dB(K^{-1})) (13)				24				14	11	15			
System noise factor (dB) (5)	5.6	5.6	5.6	4.4				4.5	4.5	4.5			
System noise temperature (K)	750	750	750	500	1100			670	970	970	1100		1100
Noise power in radio-frequency bandwidth for the above noise factor (dBW) (6)	– 127	– 127	– 128	– 127.6	– 122.2	– 123.7	– 122.7	– 127.9	– 126.2	– 126.2	– 117		– 117
Carrier power required (dBW)	– 111	– 112	– 110	– 105.6	– 111.2	– 112.7	– 111.7	– 116.9	– 117.2	– 117.7	– 100		– 100
Antenna diameter (m) (7)	3.4	3	1.5	3.66	0.8	0.5	0.254	1.4	1.2	1.8	0.8		0.5
Receiving antenna gain, relative to an isotropic source (dB) (8) (9)	25	36	43	50.7	43	44	44	42.3	41.6	45.2	43		44
Effective area of antenna, S (m^2) 10 log S	7	6	0	7.6	– 5.6	– 9.6	– 15.6		– 1.34	2.19	– 5.6		– 9.6
Required flux (edge of beam) (99% of the time) (dB(W/m^2))	– 118	– 118	– 110	– 113.2	– 105.6	– 103.1	– 96.1	– 114.8 (17)			– 94		– 90
Equivalent field strength (edge of beam):													
(dB(μV/m))	28	28	36	32.6		42.9	49.9	31.2			51.4		55.4
(μV/m)	25	25	63	42.7		140	310				372		589
Free-space attenuation between isotropic sources 39 000 km apart (dB)	181	192	206	206					206	206	211		216
Total atmospheric attenuation exceeded for less than 1% of the time (dB) (10)	0	0	1						1.6	1.6			
Free-space attenuation between isotropic sources 35 786 km apart (dB)					210.6	217	223		204.9	204.9			
Additional free-space attenuation (dB)					2 (14)	2 (14)	2 (14)				2		2
Additional loss equivalent to up-path noise (provisional value) (dB)				0.4	0.5	0.5	0.5		0.1	0.1	0.5		0.5
Atmospheric attenuation for 99% of the most unfavourable month				1	4	8	15				4		8
Required e.i.r.p. from satellite at beam edge (dBW)	45	44	54	51.2	62.9	69.3	83.3	47	49.5	45	75		83
3. *Satellite transmitter*													
Antenna beamwidth at – 3 dB points (degrees)	1.4	1.4	1.4	2.3	1.4	1.4	1.4	2.4	2	2	1	0.6	0.6
Antenna gain at the edge of service area, relative to an isotropic source (dB) (12)	38	38	38	33	38	38	38	33.2	36.5	36.5	41	46	46
Loss in feeders, filters, joints, etc. (dB)	1	1	1	1	1	1	1	1	1	1	1	1	1
Required satellite transmitter power: (dBW)	8	7	17	19.2	26.4	32.3	46.3	14.8	13	8.5	35	30	39
(W)	6.3	5	50	83	440	1700	43 000	30	20	7	3200	1000	8000

TABLE 1-XIVb – *Examples of individual reception television system parameters*

Parameter (1)	12	13 (11)	14	15 (15)	16	17 (20)	18
1. *System*							
Frequency of carrier (MHz)	700	12 000	12 000	12 000	12 500	12 000	22 750
Type of modulation	FM	FM	FM	FM	FM	FM	FM
Angle of elevation (degrees)		20 a 45	10		10-44	30-50	
Approximate equivalent rectangular bandwidth (MHz)	19	27	23	18	16	27	40
Carrier-to-noise ratio before demodulation (exceeded for 99% of the time) (dB) (2)	16	14	13.5	17.7	16	14	11
Number of lines in system	525	625	525	525	525	525	525
Corresponding luminance signal-to-weighted r.m.s. noise ratio (edge of beam) (dB) (3)	43.3		43	44	44		
Luminance signal-to-unweighted noise ratio measured in a nominal bandwidth (edge of beam) (dB) (4)	31.8	33.5	29.2	30.2	34	38	38
Audio-frequency signal-to-weighted noise ratio (weighting specified in Recommendation 468 pre-emphasis is 50 μs) measured in a 15 kHz audio-frequency band) (edge of beam) (dB)		50					
2. *Receiving installation*							
Figure of merit, G/T, (dB(K^{-1})) (13)		6		12	8.8		
System noise factor (dB) (5)	6		8	4.4	4.5		
System noise temperature (K)					546	600	1100
Noise power in radio-frequency bandwidth for the above noise factor (dBW) (6)	−125		−123	−129	−129.2	−126.5	−122.2
Carrier power required (dBW)	−109		−109.5	−111.3	−110.2	−112.5	−111.2
Antenna diameter (m) (7)			1.0	1.0	0.75	1.1 (21)	0.5
Receiving antenna gain, relative to an isotropic source (dB) (8) (9)	16		39.4	39.4	36.8	40.6	39
Effective area of antenna, S (m^2) 10 log S	−2		−3.6	−3.6	−6.1	−3.6	−9.6
Required flux (edge of beam) (99% of the time) (dB(W/m^2))	−107	−103	−105.9	−107.7	−105.5	−108.9	−101.6
Equivalent field strength (edge of beam): (dB(μV/m))	39	42.8	40.3	38.1	40		
(μV/m)	89	138	103.5	80.3	100		
Free-space attenuation between isotropic sources 39 000 km apart (dB)	181					205.6	
Total atmospheric attenuation exceeded for less than 1% of the time (dB) (10)	0						
Free-space attenuation between isotropic sources 35 786 km apart (dB)		205.1	205.9	205.9			210.6
Additional free-space attenuation (dB)		0.8		1.0			2 (14)
Additional loss equivalent to up-path noise (provisional value) (dB)		0.5	1.0	0.4	0.2	0.2	0.5
Atmospheric attenuation for 99% of the most unfavourable month		2.5			2	2 (21)	4
Required e.i.r.p. from satellite at beam edge (dBW)	56	62.2	61	56.7	57	54.7	66.9
3. *Satellite transmitter*							
Antenna beamwidth at −3 dB points (degrees)	1.4	1	1.8	2.3	2.3 (0.6) (19)		1.4
Antenna gain at the edge of service area, relative to an isotropic source (dB) (12)	38	41	36	34	35.5	37	38
Loss in feeders, filters, joints, etc. (dB)	1	1.5	1.0	1.0	1.2		1.0
Required satellite transmitter power: (dBW)	19	24	26	23.7	22.7	20	30.4
(W)	80	251	400	235	185	100	1100

Notes relative to Tables 1-XIVa and 1-XIVb:

(1) In columns 1, 2, 3, 6, 7 and 12 no account was taken of pre-emphasis. For columns 4, 14 and 15 the use of pre-emphasis as specified in Recommendation 405 was assumed.

(2) The carrier level considered is the r.m.s. value of the unmodulated carrier and the carrier-to-noise ratio at threshold is assumed to be 11 dB in columns 1, 2, 3 and 12 and 10 dB in column 13. In columns 13 and 14, the threshold is assumed to be reached for 0.1% of the most unfavourable month.

(3) These values will normally be degraded slightly (typically by 0.5 dB) by the noise contribution of the Earth-to-satellite path. The values are derived assuming weighting according to Recommendation 567, Annex II to Part C.

(4) The term equivalent to the noise on the Earth-to-satellite part was explicitely introduced with a tentative value in column 13. In the same column the luminance signal-to-noise ratio is indicated as an unweighted value, particularly owing to the existence of different weighting networks in systems G, I and L. For the sound signal-to-noise ratio, the weighting is that specified in Recommendation 468.

(5) A pre-amplifier or frequency-changer near the antenna is assumed.

(6) The figure listed in columns 1, 2, 3 and 12 are valid for an antenna temperature of about 300 K. The antenna temperature assumed in column 14 is 100 K.

(7) For individual reception at 700 MHZ, the receiving antenna is assumed to be a crossed yagi or a helical array with a gain of 16 dB: paraboloid antennas are assumed for the other cases. For community reception at 12 GHz, the choice of a 1.5 m paraboloid antenna was to some extent dictated by beam pointing considerations and satellite positional errors. For column 14 other antenna sizes such as 75 cm may be used depending on the *G/T* chosen.

(8) An antenna efficiency of 55% is assumed.

(9) Circularly polarized antennas are assumed at both the transmitting and receiving ends. Allowances for ellipticity losses due to imperfections in the antenna, movement of the supporting structures, etc., and perturbations in the position of the satellite have been included in the margin above threshold.

(10) These examples apply to an angle of elevation of 30° and to temperate climates, where atmospheric attenuation is negligible at 700 MHz and 2600 MHz and small at 12 GHz. In other regions, especially tropical and sub-tropical areas, atmospheric attenuation will require a higher margin.

(11) These examples apply to European climatic conditions.

(12) In the example taken for columns 1, 2, 3 and 6, the beamwidth would cover an area about 1000 km in the east-west direction and about 1000 km or more (depending on the geographical latitude) in the north-south direction. The example taken for columns 7 and 12 may correspond to the coverage of a European country of average size. In this example, a reduction of ΔG_0 equal to 3 dB of the antenna gain at the edge of beam in relation to the maximum gain was assumed. For the same coverage area, the parameter ΔG_0 may be chosen arbitrarily in a range from about 3 to 6 dB. This results in a variation of the maximum antenna gain, but the required satellite transmitter power remains practically unchanged. In the case of an elevation angle of 15°, if we take, for example, $\Delta G_0 = 4.34$ dB, which corresponds to the theoretically optimum value, the maximum antenna gain is 45.6 dB (instead of 44 dB) and the transmitter power is reduced by 0.3 dB.

(13) In accordance with the definition in the example shown in Annex I to Report 473.

(14) Imperfect polarization and antenna pointing loss.

(15) The examples shown in columns 4 and 15 reflect the US assessment of the anticipated state-of-the-art with regard to earth station sensitivity; the values given show more sensitive receiving systems than adopted at WARC-BS-77. For community reception (column 4) the assessment is based on systems where very large numbers of earth stations are not required. It also reflects the possibility for establishing an improved environment for sharing with the fixed-satellite service in Region 2.

(16) The numbers in column 9b represent the case where two television programmes are transmitted through the same wideband satellite transponder. In this application the e.i.r.p. per television programme is 4.5 dB less than that in the case where one programme per transponder is transmitted.

(17) No allowance is made for rain attenuation, but receiver performance is assumed to be degraded 1 dB relative to the *G/T* assumed (14 dB(K^{-1})) to take account of receiver variations in production, receiver ageing, maladjustment of receivers and antenna pointing errors.

(18) This value is equivalent to a mean subjective grade of 3.5, based on a laboratory test.

(19) This system uses a shaped beam satellite antenna. The first value represents the half-power beamwidth of an equivalent circular beam whose coverage area has the same size as that of the shaped beam. The second value (in brackets) is the half-power beamwidth of the individual "beamlets" used to generate the shaped beam; satellite reflector size can be deduced from this value.

(20) The example in column 17 corresponds to a system, in which 27 MHz channel width is used for transmission of frequency-modulated television signals (525-line/NTSC System M: Japan).

The output power from satellite transmitter is 100 W, and use of shaped beam transmitting antenna and higher *G/T* receiver than 6 dB(K^{-1}) are assumed, based on the experiment of the BSE of Japan.

(21) The diameter of receiving antennas, such as less than 1 m or up to 1.6 m would be selected, depending on the amount of rain attenuation in each site.

TABLE 1-XV – *Power flux densities required at the edge of the beam on the basis of the examples given in Tables 1-XIVa and 1-XIVb* (System M: (USA, Canada), frequency-modulation television, primary service grade)*

Category of power flux-density (1)	Power flux-density (dB(W/m²)) at frequency (MHz)		
	700	2600	12000
High	-101 (I, U)		-99 (I, U) -99 (I, R)
Medium	-107 (I, R)		-110 (C, U) -110 (C, R)
Low	-114 (C, U) -118 (C, R)	-118 (C, U) -118 (C, R)	

I: Individual U: Urban
C: Community R: Rural

* The values in dB(W/m²), are the total power flux-density as measured with an antenna that matches the polarization of the transmitter. The required flux density is about 1 dB greater for 625-line systems. The required flux density is approximately 1.5 dB less for secondary service rather than primary service. Since the values are the minimum requirements at beam adge, it should be noted that the values will be greater in other areas and when propagation conditions are favourable.

(1) These power flux-densities represent an attempt to categorize levels in accordance with Recommendation 566.

Further studies are necessary on the two possible ways of organizing the multiplex. The packet arrangement seems more flexible as far as evolutive sharing of the resource is concerned, but care will have to be taken to avoid transmission errors resulting in too high a packet loss or even desynchronization of the receiver, which would impair the subjective sound quality (see Report 954).

13.1.2.2 *Modulation*

The modulation must be selected as a function of criteria such as spectrum congestion, noise and interference immunity. In the case of individual reception, the choice must also take into account the simplicity and cost of the demodulator. The modulation methods which appear to be suitable include two- or four-phase PSK modulation, continuous phase half-index frequency shift-keying and frequency shift-keying using the principles of partial response coding. The last-named offers the advantage of a narrow power spectrum associated with a constant envelope (Report 632, § 6).

13.2 *Satellite sound broadcasting with portable receivers and receivers installed in automobiles*

The feasibility of a sound broadcasting-satellite system depends upon the technical characteristics of the space station, the technical characteristics of the terrestrial receiving stations, and the system cost.

13.2.1 *Quality objectives and suitable modulation methods*

Studies performed by several administrations demonstrate in principle the technical feasibility of sound broadcasting from geostationary satellites using antennas large enough (e.g. 8 to 20 m diameter at 1 GHz), providing national coverage, and designed for reception with low-cost portable domestic receivers and receivers installed in automobiles.

For the studies conducted to date, the proposed modulation characteristics of such a system are the same as those used in the VHF sound broadcasting band. Consequently, the receiver could be identical to those available on the current market, with a simple addition (or exchange) of the frequency converter at the input stage. The receiving antenna would be small and would have limited directivity.

The service quality objective to be chosen for satellite sound broadcasting may have a significant effect on the overall broadcasting-satellite system design and cost. In Report 955 a high quality sound channel was assumed. For the cases considered, the test-tone to noise power ratio at the output of the receiver ranged between 40 and 57 dB in a 15 kHz baseband bandwidth. The need for sound channels of such quality needs further study taking into account economic factors.

13.2.2 *Suitable frequency bands*

Such a system is feasible in a frequency band in the vicinity of 1 GHz. The lower and upper frequency limits are dictated by the following considerations:

- for the lower limit (around 500 MHz):
  - the man-made noise increases proportionally with decreasing frequency;
  - the diameter of the satellite transmit antenna increases proportionally with decreasing frequency;
- for the upper limit (around 2 GHz):
  - the effective area of the receive antenna which is necessary for such a system diminishes with increasing frequency; this entails an increase in satellite transmit power.

13.2.3 *Link budget*

Contributions by the EBU and the United States have given specific examples of link budgets for certain angles of elevation, conditions of reception (urban or rural) and other parameters. Table 1-XVI gives a reference budget in which a range of link margins have been assumed to allow for various sources of degradation, while certain other parameters have been fixed. It can therefore serve to illustrate a range of performance for portable receivers or reception in automobiles under various conditions and for various service qualities; in particular the following parameters require further explanation.

13.2.3.1 *Carrier-to-noise ratio*

A value of C/N of 10 dB representing the FM threshold will give an audio frequency signal-to-noise ratio, with the modulation parameters indicated, of about 40 dB (CCIR quasi peak), weighted, in the case of 50 μs pre-emphasis, or a slightly higher value for 75 μs pre-emphasis.

13.2.3.2 *Receiving antenna gain*

The use of a simple antenna (e.g., crossed-dipole or cavity-backed dipoles) giving an effective gain of 3 dB (isotropic) has been assumed. For stationary installations, higher receiver antenna gain (e.g., a helix) can be used thus providing a higher service quality.

13.2.3.3 *Carrier frequency*

Most of the available data on the link margin (see below) has been determined for frequencies near 1000 MHz which has been used for the reference budget of Table 1-XVI. For a constant receiver antenna gain the required power flux-density and hence e.i.r.p. would vary in proportion to the square of the frequency in order to maintain the same signal level in the receiver under line-of-sight conditions; for example at 1.5 GHz the required power would be 3.5 dB greater. In addition to this the frequency also affects to some extent the link margin needed for a specific service quality. Further details are given in Annex IV of Report 955.

13.2.3.4 *Link margin*

Four values of link margin have been assumed in Table 1-XVI. These are estimates of the allowances required in the various cases listed below. Further discussion of this problem is given in Annex IV of Report 955.

Case A: In this case a margin of 6 dB is used. This should give a C/N of at least 10 dB for 90% of receiving points in a rural area, and for an angle of elevation of the satellite exceeding 70°, corresponding to a service in low-latitude areas. Mobile reception on roads in these circumstances should be satisfactory, i.e. above threshold, except when close to tall obstructions that would be obvious to the listener.

Case B: The 15 dB margin covers the case of Annex I of Report 955, namely reception in an urban area, for 20° angle of elevation of the satellite (high-latitude country) and to a service quality corresponding to a $C/N >$ 10 dB at 90% of sites.

Case C: The 25 dB margin covers the case of reception in urban areas where 90% of areas are served in such a way that 90% of receiving points within the area receive a *C/N* of at least 10 dB. (See § 3.1 of Annex IV of Report 955.)

Case D: As for Case C but with 95% of areas having 90% of points with a *C/N* value of at least 10 dB. (See Annex II of Report 955.)

Some indication may be given of the satellite powers required in specific cases. Low-latitude rural coverage in a 2.5° beam corresponding to Case A requires a power into the satellite antenna of the order of 200 W at 1000 MHz (8 m antenna) or 400 W at 1500 MHz (5.5 m antenna). Urban coverage in a 1° beam at medium latitude corresponding to Case C requires powers of the order of 3 kW at 1000 MHz (20 m antenna) increasing to 7 kW at 1500 MHz (13 m antenna).

13.2.4 *Sharing considerations*

Some studies of sharing with services presently allocated in the 500 MHz to 2000 MHz band are in progress (see Report 955).

13.2.5 *Bandwidth considerations*

Based on the parameters with appropriate modification used for the planning of the broadcasting-satellite services in the 12 GHz band in Region 1, one can conclude from a study covering almost the whole of Africa and Europe that approximately 60 channels with a spacing of 150 kHz and thus a total bandwidth of about 9 MHz is necessary to provide one broadcast sound programme per country. Similar approaches should be possible for other Regions.

13.2.6 *Feeder-link considerations*

Regarding the feeder-link connection to the satellite, no significant study has been made. It should, however, be technically feasible to provide the audio bandwidth links within the bands allocated to the fixed-satellite service or those used for feeder links to broadcasting satellites, principally for television, possibly without requiring additional spectrum.

TABLE 1-XVI – *Link budgets for sound-broadcasting satellite systems*

	Standard of service			
	A	B	C	D
Type of modulation	FM			
Type of polarization	circular			
Carrier deviation (kHz)	±75			
Noise bandwidth (kHz)	250			
Carrier-to-noise ratio (dB)	10			
Coupling loss (dB)	1			
Receive antenna gain (dBi)	3			
Receive system noise temperature (K)	2000			
Carrier frequency (MHz)	1000			
Link margin (dB)	6	15	25	33
Line-of-sight pfd at edge of beam (−3 dB), (dB(W/m²))	−106.4	−97.4	−87.4	−79.4
Equivalent field strength (dB(μV/m))	39.4	48.4	58.4	66.4
Maximum spreading loss (dB/m²)	163	163	163	163
E.i.r.p. on axis (dBW)	59.6	68.6	78.6	86.6

13.3 *Examples of satellite sound broadcasting* (12 GHz)

Tables 1-XVII and 1-XVIII present alternative examples of parameters for providing a number of sound channels each suitable for monophonic services for individual reception at 12 GHz. Stereophonic broadcasts can be made using two (or more) such channels (see § 10). Some sound channels could also be associated with television programmes, additional to the sound channel transmitted as proposed in § 12 for 625-line television systems.

It is possible to combine up to four sound broadcasting carriers on the same transponder with the television signal and its associated sound (system B), as shown in Table 1-XIVa, Column 8. If the sound broadcasting carriers are grouped within a frequency range of 20 MHz, they may be block-converted to the 88-108 MHz band for final demodulation in standard VHF monophonic FM receivers (see Example 6 of Table 1-XVII).

However, it must be noted that intermodulation between the carriers will degrade the quality of the received picture. This is particularly so for a system operating close to FM threshold. This degradation can be expressed as the amount by which the received television carrier-to-noise ratio must be increased to maintain the same picture quality when the sound carriers are introduced. Factors contributing to this degradation are the level of intermodulation products (which can be regarded as noise) and the decrease in vision carrier power due to sharing between the other carriers. To minimize the degradation it is necessary to increase the input back-off of the television carrier, thereby suffering further loss of power from the vision carrier. Measurements conducted by Australia, through a satellite transponder simulator and through the European OTS satellite from Fucino, Italy, have verified the feasibility of such a combined system and established practical parameters and associated penalties. The total degradation measured for two, three and four carriers at an output level of -17 dB with respect to the vision carrier is shown in Table 1-XIX. The carrier-to-noise ratio of the vision carrier before the sound carriers were introduced was 10 dB in this case. After the sound carriers were introduced the carrier-to-thermal noise ratio of the vision carrier was increased to maintain an effective carrier-to-noise ratio of 10 dB. The degradations given in Table 1-XIX are the sum of this carrier-to-thermal noise ratio increase and the amount by which the vision carrier output power must be reduced from the saturated output level. Other system parameters are given in Tables 1-XIVa, Column 8, and 1-XVII, Column 6.

14. Spacecraft service functions

The Radio Regulations, No. 25, states that the accommodation of spacecraft service functions (TTC) will normally be provided within the service in which the space station is operated. For the broadcasting-satellite service this means within the satellite broadcast down-link and corresponding feeder-link bands, including the possibility of using the guard bands. The services to be provided are summarized in Table 1-XX.

To allow for decoupling of the RF sensing signal (for satellite antenna tracking) from the feeder link in the satellite, a certain amount of minimum frequency separation between these signals will be necessary.

The accommodation of TTC signals within the broadcast feeder-link band will be subject to mutual compatibility with the broadcast and other services sharing the same or adjacent frequency bands. Studies by the French Administration and the European Space Agency (Report 952) show that, in the case of collocated satellites, in addition to satellite antenna discrimination, cross-polarization discrimination may also have to be employed to ensure compatibility between the TTC signals and the adjacent broadcast feeder-link channel. These aspects are further addressed in Report 634.

The inter-relations of feeder links and TTC links suggest that the two services be considered together. Further studies are required to arrive at mutually compatible frequency and polarization assignments.

15. Experimental satellite systems

Several countries have launched satellites to conduct experiments in broadcasting. A short summary of some of these experimental programmes is given below and more detailed information may be obtained from the literature or from the countries concerned.

15.1 *Applications Technology Satellite (ATS)*

The purpose of the ATS programme is to investigate new and advanced spacecraft stabilization technology, and to conduct experiments in several application areas, including communications. Six satellites in this programme have been launched since 1966. The ATS-6 was launched on 30 May 1974. For the first year of operation it was located in a geostationary orbit at 94° W longitude.

The satellite has a 9 m unfurlable mesh antenna which, together with its associated transmitters provides an e.i.r.p. of about 52 dBW in the 860 MHz and 2600 MHz bands. Table 1-XIII includes a summary of the characteristics of the ground receiving equipment.

A total of about twenty scientific, technological and communication applications were conducted. Two of these experiments, the Health, Education, Telecommunications (HET) experiment and the Television Relay Using Small Terminals (TRUST) have provided practical experience in the application of broadcast satellite and low cost terminal technology to meet social needs and engineering data on the total system performance.

TABLE 1-XVII – *Examples of system parameters for monophonic sound broadcasting for individual reception* (1)

Parameter	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6(5)
1. *System*						
Frequency of carrier (MHz)	12 000(1)	12 000	12 000	12 000	12 000	12 500
Type of modulation	FM	FM	FM/FM	FM/PSK	FSK	FM
Frequency deviation (pre-emphasis 50 μs) (kHz)	± 75	± 300				± 100
Frequency deviation (kHz)			± 8600	± 4000	± 3000	
Audio-frequency bandwidth (kHz)	15	15				15
Number of audio channels			12	16	20	up to 4
Total radio-frequency bandwidth (kHz)	180	800	22 000	18 000	12 000	200(6)
Carrier-to-noise ratio before demodulation (for 99% of the time in the least favourable month) (edge of beam) (dB)	19	13.3	14	14	14	12.6
Corresponding audio-frequency signal-to-unweighed noise ratio (edge of beam) (dB)	56	69	69	69	69	52.4
Audio-frequency signal-to-weighted noise ratio (dB)	47	60	60	60	60	43.4
2. *Receiving installation*						
Figure of merit, *G/T*, of receiver (dB(K^{-1}))(2)	4	4	4	4	4	14
Flux (edge of beam) (99% of time in most unfavourable month) (dB(W/m^2))	– 117.5	– 116.7	– 103	– 103	– 105	– 132.6(7)
Equivalent field strength (edge of beam):						
(dB(μV/m))	28.2	29.1	44	43	41	13.2
(μV/m)	26	28	160	140	110	4.6
Free-space attenuation between isotropic sources 35 786 km apart (dB)	205.1	205.1	205	205	205	
Additional free-space attenuation for an angle of elevation of 40° (dB)	0.5	0.5	0.5	0.5	0.5	
Total atmospheric attenuation for 99% of the time in the most unfavourable month (dB)(3)	1.5	1.5	1.5	1.5	1.5	
Up-path noise (provisional value) (dB)	0.5	0.5	0.5	0.5	0.5	
E.i.r.p. from satellite at edge of beam (dBW)	47	47.7	63	62	60	30(6)
3. *Satellite transmitter*						
Antenna beamwidth at – 3 dB points (degrees)	1.4	1	1	1	1	2.4
Antenna gain at edge of service area relative to an isotropic source (dB)(4)	38	41	41	41	41	33.2
Loss in feeders, filters, joints, etc. (dB)	1	1	1	1	1	1
Satellite transmitter power: (dBW)	10	7.7	23	22	20	– 2(6)
(W)	10	6	200	160	100	0.63(6)

(1) These examples will probably not be valid for sound broadcasting alone, unless the receiving antenna and the preamplifier or frequency-changer were also used for television.

(2) In accordance with the definition in the example shown in Annex I to Report 473.

(3) Examples valid for an angle of elevation of about 40° and European climatic conditions.

(4) An antenna efficiency of 55% is assumed.

(5) See §13.3 of this Chapter.

(6) Values quoted are for single channel.

(7) Allowance for rain attenuation is 0 dB.

TABLE 1-XVIII — *Multiple-channel systems assumed in examples for monophonic sound broadcasting*

Parameter	Example 3	Example 4	Example 5
Number of sub-carriers	12	8	—
Number of audio channels per sub-carrier	1	2	—
Sub-carrier channel spacing (kHz)	230	600	—
Sub-carrier frequencies (kHz)	300, 530 ... 2830	1000, 1600 ... 5200	— —
Sub-carrier modulation	FM	PSK (4-phase)	—
Peak deviation of sub-carrier (kHz)	± 75		—
Noise bandwidth of sub-carrier channel (kHz)	180	350	—
C/N in sub-carrier channel (dB) when main-carrier C/N = 14 dB	32	17.5	—
Main-carrier peak deviation by each sub-carrier (radians)	± 1.0	± 0.3	(FSK)
Total quasi-peak main-carrier deviation (MHz)	± 8.6	± 4.0	± 3.0
Bits per sample (with non-linear coding or companding)	—	10	10
Sampling rate (kHz)	—	32	32
Total system bit rate (kbit/s) (approx. with framing allowance)	—	$8 \times 2 \times 350 = 5600$	$20 \times 350 = 7000$

Note on Example 3. — 12 sub-carriers are used, each modulated as analogue FM sound channels with ± 75 kHz deviation. The highest baseband frequency is below 3 MHz. An alternative system with 12 sub-carriers deviated ± 150 kHz, and each deviating the main carrier ± 0.5 radian would give similar performance in approximately the same r.f. bandwidth; the highest baseband frequency would be less than 5 MHz.

Note on Example 4. — 8 sub-carriers are used, each carrying two digitally coded sound signals by 4-phase PSK. The highest sub-carrier is 5.2 MHz. The C/N of 17.5 dB in the sub-carrier channel provides a 3 dB margin above a 1 in 10^6 error rate level.

Note on Example 5. — 20 sound channels are transmitted in digital form by a single 7 Mbit/s stream. Frequency modulation of the main carrier (FSK) by the binary NRZ signal is assumed. The system will then be similar to other systems in immunity to effects of hard limiting in the satellite repeater or receiver. The baseband signal can be bandwidth limited to 5 MHz in the receiver. A carrier-to-noise ratio of 14 dB provides a 3 dB margin above an error rate level of 1 in 10^6.

TABLE 1-XIX – *Subjective degradation of a TV picture due to addition of sound carriers*

Number of sound carriers	Degradation (dB)
4	3.3
3	2.2
2	1.5

In mid-May 1975, ATS-6 started to move eastward towards an orbital position of 35° E longitude, arriving on station just prior to the end of June. For about one week in July 1975 the ATS-6 was used to receive television transmissions from the joint USA/U.S.S.R. Apollo-Soyouz Test Project (ASTP) and relay them to an earth station in Spain for world-wide television distribution.

References [Engineering Foundation of Rocky Mountain States, 1976; Ippolito, 1975] provide a comprehensive description of the ATS-6 programme and the technical results of the first year of experimental operation. Another reference [ITU, 1974] provides an overall view of the ATS-6 satellite and of the major first-year experiments.

TABLE 1-XX – *Basic spacecraft service functions*

Function	Notes
Earth-to-space:	
– telecommand	Non-continuous low data rate transmission
– ranging	Non-continuous tone or code ranging
– satellite antenna tracking	Continuous RF-sensing, on CW or swept carrier (e.g. residual carrier of telecommand signal)
Space-to-Earth:	
– 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

15.2 *Communications Technology Satellite (CTS)*

The Communications Technology Satellite (CTS) was an experimental communications satellite that was launched on 17 January 1976. It was developed jointly by the Canadian Department of Communications and the US National Aeronautics and Space Administration (NASA), under an agreement between Canada and the US signed in 1971. The agreement provided for Canada to design and build the spacecraft and for the United States to furnish the high-power travelling-wave tube (TWT) and associated power conditioning and thermal control, the launch vehicle, and environmental test and operational support. The use of the satellite for technological and communications experiments was shared equally between the two countries.

The principal technological objectives of the CTS programme were:

– to develop and flight-test a travelling-wave tube having an efficiency greater than 50% and a saturated power output of 200 W at a frequency of 12 GHz;

– to develop and flight-test a light-weight extendible solar array with an initial power output greater than 1 kW;

– to develop and flight-test a 3-axis stabilization system to maintain accurate antenna boresight positioning on a spacecraft having large flexible appendages;

– to conduct satellite communications systems experiments using 12 and 14 GHz bands;

These experiments permitted investigation not only of the applications of new technology to communications problems but also of the social, cultural and economic impact of the eventual introduction of services that can be provided.

The satellite was a 3-axis stabilized spacecraft with flexible solar arrays. It had two 2-axis gimballed antennas each having a 2.5° circular beamwidth.

The receive earth terminals consisted of a 9 m control antenna, 3 m antennas for remote television transmissions, 2 m antennas for television receive-only and two-way voice and 1 m antennas for two-way voice transmissions.

15.3 *Anik-B1* [Day *et al.*, 1979]

The Canadian satellite Anik-B1 was launched in December 1978. Specific objectives of the 12 GHz satellite experiment, among others, are to:

– demonstrate, evaluate and obtain field experience with a direct to-home and small community programme delivery service,

– provide a prototype testing ground and a small initial market for the development of competitive hardware for application in domestic and foreign direct broadcasting satellite markets,

– provide information which will contribute to policy development and plans respecting the future operational applications of broadcasting satellites within the country.

The satellite operates in the 12/14 GHz frequency bands. Four 20 W TWTAs are segmented into six 80 MHz RF channels with each RF channel having 72 MHz of usable bandwidth. All Canada coverage is provided with four 2.5° spot beams and the e.i.r.p. ranges from 51 dBW at boresight to 46.5 dBW at the outer footprint.

Two modes of operation are used:

- one TV programme per channel,
- two TV programmes per channel, using separate carriers per TV programme.

Three different types of terminal were implemented, depending on the location and whether single or two TV programmes per channel mode of reception is required:

- terminals equipped with 1.2 m diameter antennas and low cost electronics. These terminals are suitable for direct reception and e.i.r.p. > 49 dBW, for channels carrying one TV programme per channel;
- terminals equipped with 1.8 m diameter antennas with the same electronics package as above. These terminals are suitable for direct reception and e.i.r.p. > 46 dBW with channels carrying one programme or for two programmes per channel for terminals located near beam centre;
- terminals equipped with 3 m diameter antennas. These terminals are suitable for single or dual channel community reception for feeding cable systems or low power broadcast transmitters used for community distribution.

15.4 *Broadcasting satellite for experimental purposes (BSE) of Japan*

The three-axis stabilized geostationary satellite with about 350 kg mass on orbit is stationed at 110° E above the equator. This satellite uses 12 GHz for down path and 14 GHz for the feeder link and transmits two TV channels.

The antenna provides a specially shaped beam which has been developed to conform to the shape of the service area in which the mainland and the remote islands of Japan are included, using an elliptical parabolic reflector and three primary radiations. The combination of this shaped beam antenna and transmitter output power of 100 W/ch facilitates the usage of 1.6 m diameter antennas for community reception in the mainland and 4.5 m diameter antennas in remote islands.

The experiment objectives are summarized as follows:

- tests of the characteristics of television signal transmission;
- measurement of the rainfall effect on 12 GHz radio wave propagation;
- evaluation of the performance of the satellite on-board equipment and ground terminals;
- experiments on frequency sharing with terrestrial communications;
- experience with satellite control techniques;
- experiments on satellite broadcasting systems operation;
- assessment of TV signal reception quality.

16. Operational satellite systems

In the next few years, operational satellites will be launched. A few examples are given below:

16.1 *Indian domestic satellite system (INSAT-1)*

The Indian National Satellite System, INSAT-1, is a multipurpose system. It is planned to provide domestic telecommunication, meteorological, direct TV broadcasting (community reception), radio-networking and disaster warning services. The system consists of two identical satellites positioned in the geostationary orbit at 74° E ± 0.1° and 94° E ± 0.1°. The first satellite was launched early in 1982; the second one will be launched about one year later.

Twelve, 36 MHz wide telecommunication channels operating in the frequency bands of 6 GHz (up link)/4 GHz (down link), with 32 dBW (minimum) end-of-life e.i.r.p. over the primary coverage area will be available.

Two, 36 MHz wide direct TV broadcast channels in 6 GHz (feeder link)/2.6 GHz (down link) frequency bands with 42 dBW (minimum) end-of-life e.i.r.p over the primary coverage area will also be available.

Earth terminal characteristics for broadcasting are shown in Table 1-XXI.

Low level injected carriers have been introduced in each of the 2.5 GHz broadcast transponders for radio networking service outside the bandwidth occupied by the TV broadcasting emission.

TABLE 1-XXI – *Characteristics of receive-only terminals for INSAT-1 (2.6 GHz)*

	G/T (dB (K^{-1}))	Antenna diameter (m)
Direct reception TV receivers	8.2	3.6
Receive terminals for radio program networking	9	3.6

16.2 *French broadcasting satellite TDF-1*

The satellite TDF-1, which will be launched in 1984 by the Ariane launch vehicle, will be able to broadcast three television programmes.

The transmitting antenna (12 GHz) is elliptical (2.4 m × 0.9 m) and provides coverage for all the country. The pointing accuracy of the beam will be ± 0.1°. The receiving antenna (18 GHz) is circular, with a beamwidth of 0.7°; it will be pointed with an accuracy of ± 0.2°.

Amplification is provided by solid state stages (field effect transistor) and TWTs of 250 W. Six TWTs working on five frequencies ensure redundancy. This structure will make easy the evolution towards a second generation satellite with five channels.

A typical earth terminal for individual reception will be equipped with a 0.8 m parabolic antenna. The receiver might have a minimum value of G/T of 6 dB(K^{-1}).

16.3 *Saudi Arabian broadcast satellite system (SABS)*

The objectives of the SABS system are to provide the following services:

- to provide initially two channels of television programmes for the entire Kingdom in the 12 GHz band;
- to provide a channel of Islamic programmes to the neighbouring countries in the Gulf area;
- to provide networking of all medium wave sound broadcasting stations for enabling high quality reception.

The satellite would be launched by the STS shuttle or an advanced version of Ariane in 1984.

The SABS is proposed to be equipped with broadband receivers and five channels for broadcast television with TWT power amplifiers.

The individual earth receivers may have a median value of G/T of about 9 dB(K^{-1}); higher G/T (approximately 12 dB(K^{-1})) would however be achievable with insignificant cost difference within the time frame of the SABS system becoming operational. The individual receivers will be equipped with a 1 m diameter parabolic antenna.

The parameters of the proposed SABS system are published in [IFRB, 1979].

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ANNEX 1-I

COMPARISON OF DIGITAL AND ANALOGUE/FM MODULATION TECHNIQUES FOR SATELLITE BROADCASTING (TELEVISION)

Figure 1-7 presents theoretical curves of required C/N_0 versus required channel bandwidth for FM and several digital modulation techniques.

Curves A and B are for FM modulation of the carrier by a 525-line television system M video signal. Power-bandwidth and post-detection signal-to-noise ratio trade-offs are possible using FM, as illustrated by Curves A and B. The FM improvement factor is proportional to the square of the carrier frequency deviation ΔF, whereas bandwidth is a linear function of ΔF. The FM bandwidth of Curves A and B is the Carson's Rule bandwidth, which is defined by the following expression:

$$BW = 2\,(\Delta F + f_m)$$

where:

ΔF: peak frequency deviation of the carrier;

f_m: highest modulating frequency (4.2 MHz for systems M).

Curves C, D, E and F illustrate required C/N_0 versus bandwidth for digital modulation. In each case the signal bandwidth is restricted to 2 Hz per channel symbol and the bit error ratio is 10^{-5}. The curves are annotated with the approximate bit rate which can be achieved for each type of modulation used.

Curve C assumes four level (four bits per channel symbol) quadrature amplitude shift keying (QASK), or multiple amplitude minimum shift keying (MAMSK).

Curve D assumes four phase (two bits per channel symbol) quadrature amplitude shift keying (QASK), or minimum shift keying (MSK).

The bit error ratio can be lowered either by increasing C/N_0 or through error-correction coding. If the bit error ratio and bandwidth are held constant, error-correction coding will allow the C/N_0 to be reduced but will also require the use of a lower data rate. This effect is illustrated by Curves E and F. While many types of coding are possible, convolutional encoding has been chosen to illustrate the example. Curve E shows the effect of a rate 7/8 (eight code symbols per seven channel symbols) convolutional code on Curve D. Curve F shows the effect of a rate 1/2 (two code symbols per channel symbol) convolutional code on Curve D. Applying the same coding to Curve C would produce an equivalent C/N_0 and data rate reduction.

Figure 1-7 gives the power and bandwidth requirements for FM and digital modulations. The key to a power-bandwidth trade-off between FM and digital modulation for television is how low a data rate can be achieved through data compression, and which digital modulation/encoding scheme is chosen for the broadcasting link.

It is interesting to note that QPSK modulation (Curve D) offers an advantage over FM (Curve B) in terms of power and bandwidth requirements if the bit rate of the encoded picture is less than about 30 Mbit/s.

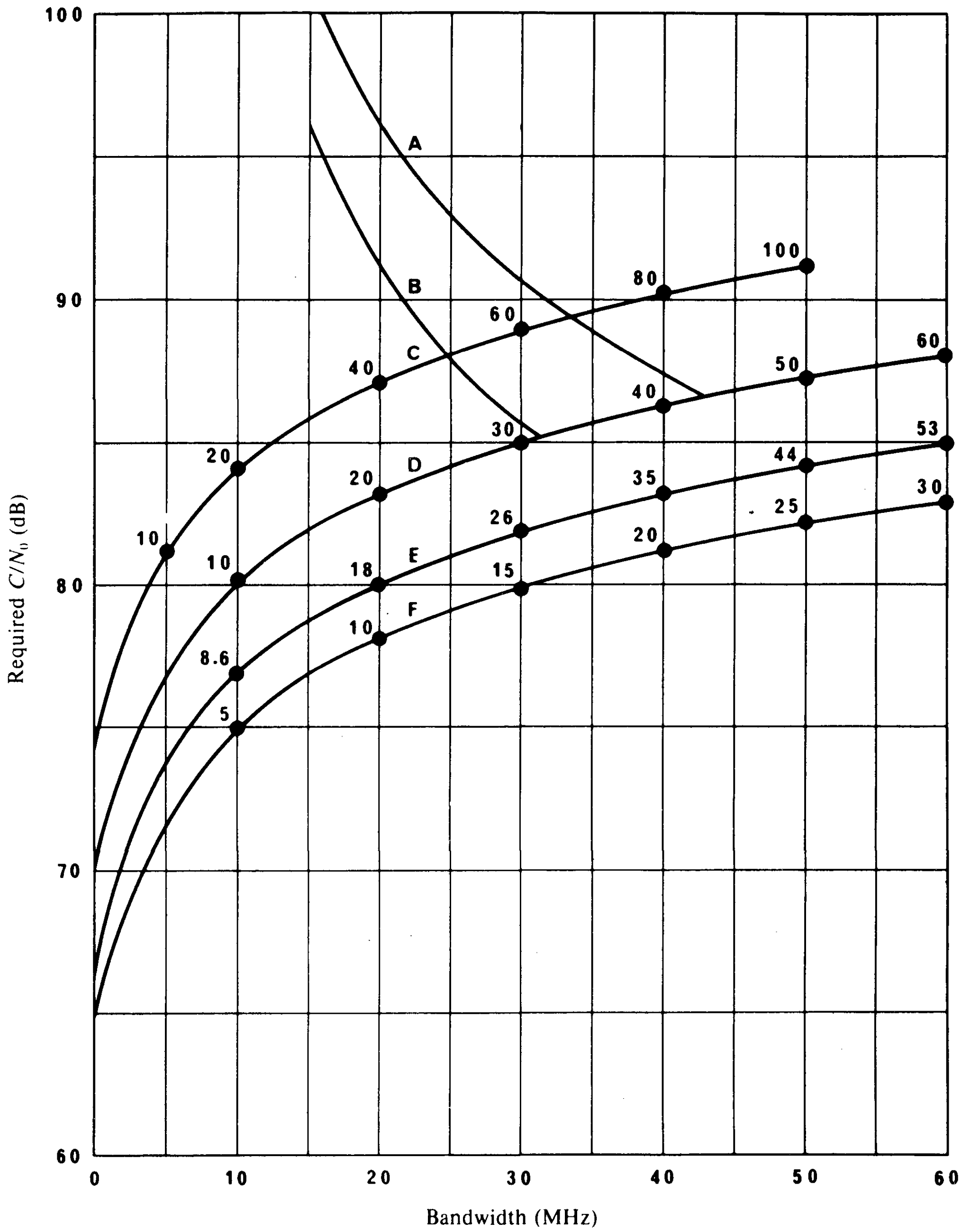

FIGURE 1-7 – *Required C/N_0 as a function of bandwidth*

Curves A: FM S/N* = 53 dB
B: FM S/N* = 48 dB
C: QASK or MAMSK
D: QPSK or MSK
E: QPSK convolutional code rate = 7/8
F: QPSK convolutional code rate = 1/2

Curves A, B: FM modulation
C, D, E, F: digital modulation, numbers indicate data rate in Mbit/s
($P_e = 10^{-5}$)

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* P-p video to r.m.s. noise CCIR weighted.

CHAPTER 2

BROADCASTING-SATELLITE SYSTEM TECHNOLOGY

1. Introduction

The primary function of communication satellites is to support a communication payload which is used to relay information between points on the Earth's surface. Although some satellites with on-board signal processing are being planned, most applications in both the fixed-satellite service (FSS) and broadcasting-satellite service (BSS) require that the satellite only re-broadcast whatever signal it receives from the ground.

The primary communication satellite payload, either BSS or FSS, consists of a receiving antenna, a receiver, a means of translating each up-link channel to a down-link channel, an amplifier for each down-link channel, and a transmitting antenna. BSS down links differ from those of the FSS mainly in higher per channel RF power and e.i.r.p. Examples of dual function BSS/FSS satellites include the Insat and the proposed Arabsat spacecraft.

The BSS is just emerging from the experimental stage. Because of spacecraft prime power limitations, BSS spacecraft to date have been limited to one or two active channels. Prime power capacity is gradually expanding through growth in launch vehicle capacity and spacecraft technology. Spacecraft with more channels and wider coverage areas are becoming practical.

Several BSS spacecraft design studies have been completed in preparation for direct broadcasting service (DBS) to the United States. An example drawn from one of these studies [Cohen, 1981] will serve as an introduction to examination of the payload requirements and technology of a fairly large DBS spacecraft.

The Model "A" spacecraft was designed to provide several channels of frequency-modulated, system M television to each of four time zones and five metropolitan areas of the United States. The communication payload for this spacecraft is shown in Fig. 2-1. The link budgets for the time zone and spot beams are given in Table 2-I.

1.1 *Growth of prime power capacity*

A satellite has a limited amount of d.c. power which is a function of the area and efficiency of the solar array. Part of this power is available for conversion to RF power which must then be divided among all the down-link channels. The conversion efficiency of d.c. power to RF power is in the range of 30% to 45% depending on the type of power amplifier used. Broadcasting satellites that normally use high power amplifiers achieve a conversion efficiency towards the high end of this range. Taking into account the other uses of electrical power in a satellite, the ratio of RF power to total prime power falls in the range of 20% to 30%.

Satellite prime power capacity has grown as a result of improvements in launch vehicle capability, light-weight spacecraft structural materials and solar cell efficiency. If the increased weight can be accommodated, it is otherwise not difficult to increase solar array size for 3-axis stabilized spacecraft. For spin-stabilized spacecraft, where the number of solar cells is limited by the available surface area of the spinning drum, solar array size increase has been achieved by such means as telescopic skirts.

Spacecraft prime power is generally related to spacecraft weight as illustrated in Fig. 2-2. Note the higher power-to-weight ratio for BSS satellites. (See Chapter 4 for procedure for spacecraft weight estimation on the basis of prime power.) The present power capability of spacecraft in the 1000 kg (Atlas/Centaur-compatible) class is under 2 kW. Further improvements in solar cell and light-weight panel technology are expected to provide prime power capabilities of 3 to 5 kW for 3-axis spacecraft in the 1000 kg class.

A 1.5 kW roll-out array has been successfully flight tested. Present estimates suggest that a reliable 12 kW (decreasing to 10 kW at the end of five years) roll-out array could be designed. The performance characteristics which might be expected from new developments in light-weight, deployable solar array technology are discussed in Report 808.

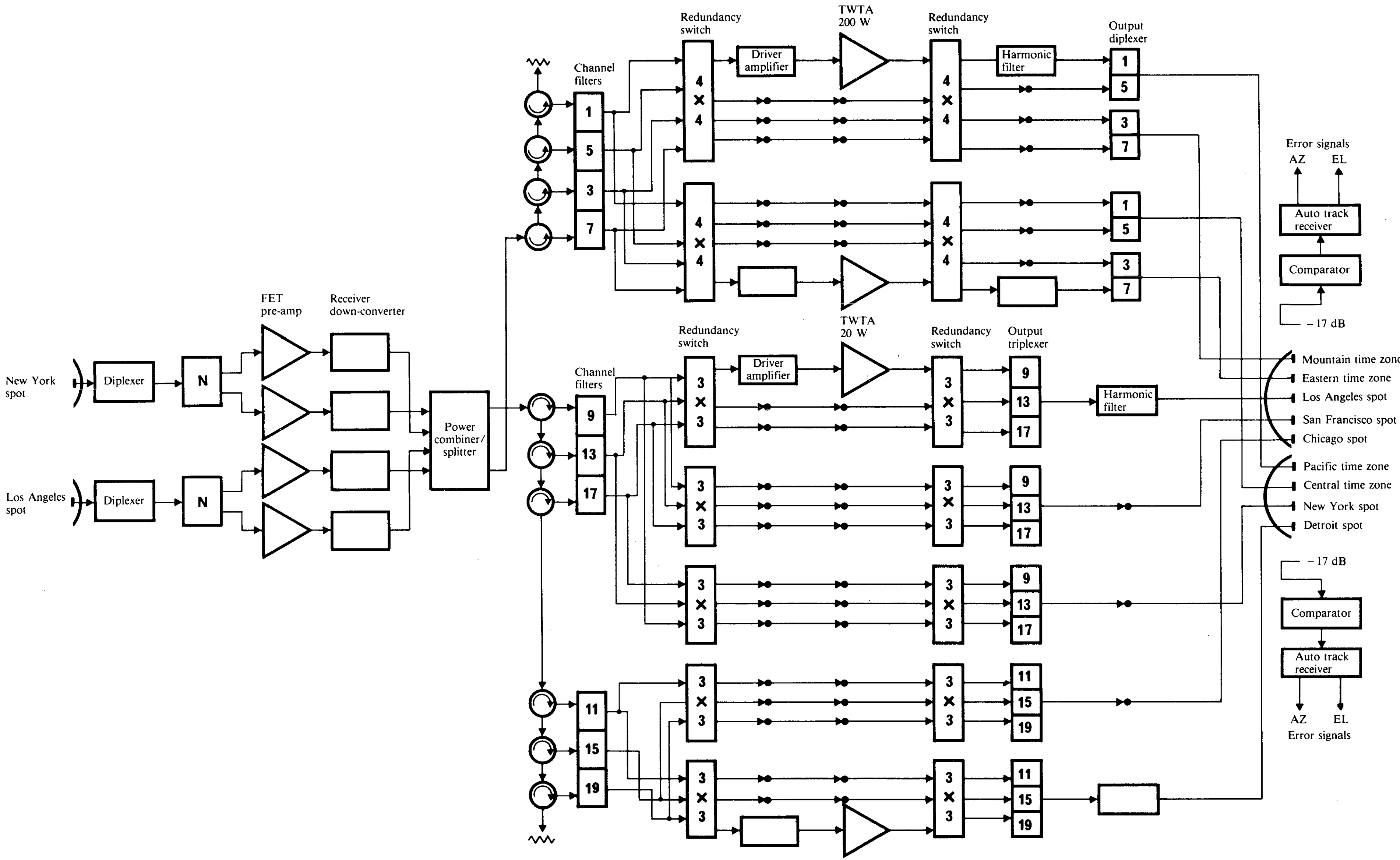


FIGURE 2-1 – *Model "A" spacecraft communication payload*

TABLE 2-I – *Model "A" system link budgets*

Parameter	Eastern time zone	New York spot (0.6°)
Output power (end of life EOL) (dBW)	22.9	12.9
Output losses (dBW)	1.3	1.4
Antenna peak gain (dB)	38.2	47.6
Peak e.i.r.p. (EOL) (dBW)	59.8	59.1
Relative gain (EOL) (dB)	− 2.0	− 3.0
Space loss (12.5 GHz) (dB)	206.4	206.4
Received carrier (dBW)	− 148.6	− 150.3
Terminal G/T (dB(K^{-1}))	10.0	10.0
Received C/N_0 (dBHz)	90.0	88.3
Receiver noise bandwidth (18 MHz) (dB)	72.6	72.6
Clear weather C/N (dB)	17.4	15.7
Reference C/N (dB)	14.0	14.0
Margin (dB)	3.4	1.7

A solar array does not provide power during passage in the shadow of the Earth or of the Moon. With a geostationary satellite there is one Earth solar eclipse each day, but only within the periods of approximately 27 February to 12 April and 1 September to 15 October. Near the centre of these periods, the eclipse lasts about seventy minutes about midnight at the satellite longitude; the duration is less towards the beginning and end of the periods. In the case of longer eclipses, sufficient warm-up time must be allowed after the end of the eclipse. In the past, about half an hour has been required.

Eclipses due to Moon shadow are not as regular in terms of times of occurrence, duration, and depth as Earth solar eclipses. An example of Moon shadow events over a six-year period is given in Report 808. The number of Moon solar eclipse occurrences per orbital location per year ranges from zero to four with an average of two per year; eclipses can occur twice within a twenty-four hour period. The duration of eclipses ranges from a few minutes to over two hours with an average duration of about forty minutes. Special problems in connection with battery recharging and spacecraft thermal reliability could arise when Moon solar eclipses of long duration and appreciable depth occur during the same period as Earth solar eclipses. It is possible to predict the characteristics of Moon shadow events with reasonable accuracy. Because of the irregular nature of the Earth and Moon orbits, recurrence of similar Moon solar eclipses occurs at a minimum of one Saros cycle (approximately 18 years) and can be as long as three Saros cycles [Ehara, 1979; Siocos, 1981].

The practical consequences of Earth solar eclipse outage can be minimized by having the service break occur after midnight in the service area, by placing the satellite to the west of its service area. Due to irregularity of Moon solar eclipses, resulting outages of the service cannot be similarly controlled by orbit placement.

Batteries can be employed to provide operational capability (protection) during eclipse, with some increase in the weight of the spacecraft. The trade-off between the degree of eclipse protection and spacecraft weight can be made using the detailed spacecraft weight estimation procedures of Chapter 4.

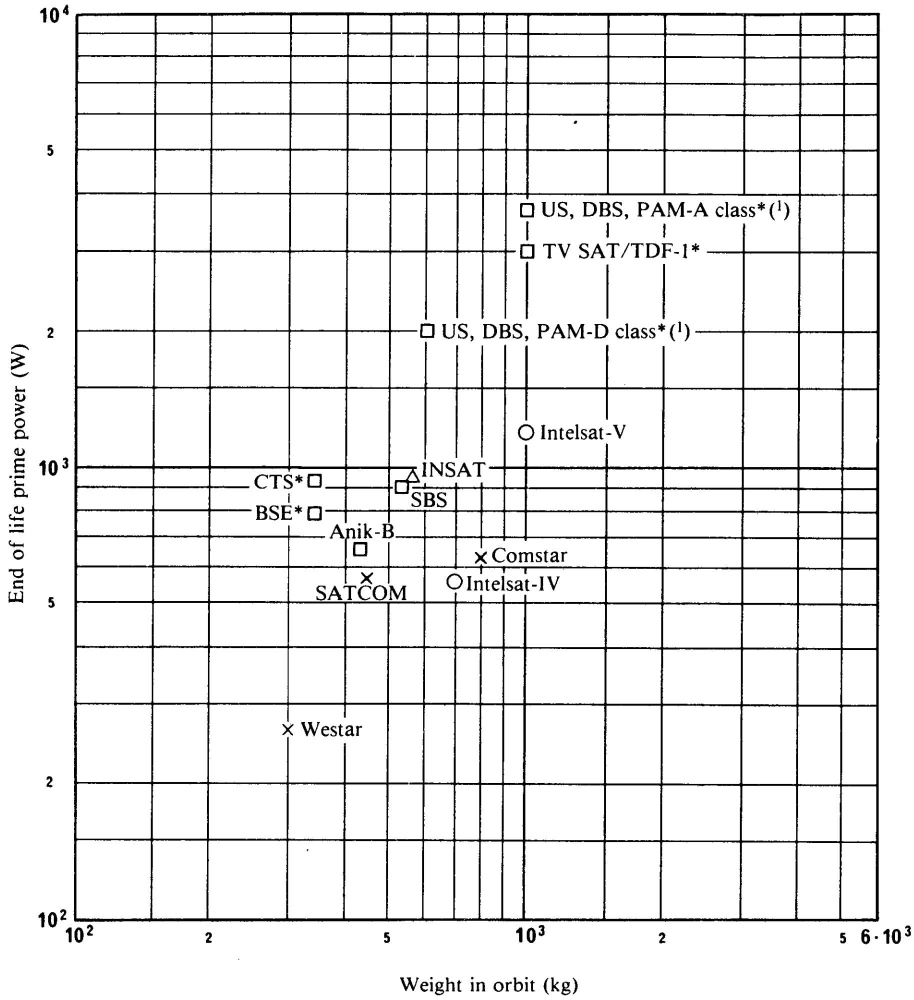


FIGURE 2-2 – *Spacecraft prime power versus weight*

□ 12 GHz

× 4 GHz US domestic

○ 4 GHz, INTELSAT

△ INSAT multipurpose

* BSS satellites

([1]) Several DBS systems have been proposed for the USA. The values given represent the upper and lower weights and powers of the proposed spacecraft.

1.2 *E.i.r.p. trends*

In a communication satellite network with few receiving stations, economic considerations favour a system of moderate e.i.r.p. satellites and relatively expensive, high G/T receiving stations. This keeps ground segment cost in balance with space segment cost.

As the number of receiving stations increases, the balance shifts in favour of higher e.i.r.p. satellites and less expensive, lower G/T receiving stations. This is especially true in the BSS where a very large number of receiving terminals may be involved. The historical trend of satellite e.i.r.p., for both the BSS and FSS, is shown in Fig. 2-3.

There are practical as well as regulatory limitations to satellite e.i.r.p. The way to moderate the trend towards higher e.i.r.p. is through the development of low cost receiving terminal technology. Such development has recently received a great deal of emphasis and has achieved some success. Consequently, several administrations are experimenting with or planning direct broadcasting systems with satellite e.i.r.p.s below 60 dBW for both community and individual reception.

The final trade-off between satellite e.i.r.p. and ground terminal G/T therefore involves many technical as well as economic considerations. A procedure for arriving at the proper design compromise is covered in Chapter 4 of this report.

1.3 *Trend towards low-cost receiving terminals*

A broadcasting-satellite system for individual reception requires low-cost receiving terminals to make it economically attractive to the end user. In accomplishing this objective, however, one must not overlook the need to maximize those characteristics and technologies such as antenna discrimination, needed to make efficient use of the valuable spectrum/orbit resource (see § 2 of this Chapter).

Lower cost is usually realized through standardization, high volume production and competition so that the cost of receiving terminals can be expected to decline with time. A dramatic example of this is the roughly tenfold decrease in cost of 4 GHz television receive-only terminals in the two-year period of 1979-1980.

The growth of broadcasting-satellite systems should result in increasing demand for receiving terminals. This, combined with certain technological advances such as low noise GaAs FET amplifiers should result in high performance and reasonable cost. For examples of receiving terminal cost projections see Chapter 4 of this report and Report 473.

2. Use of technology for greater spectrum/orbit capacity

The desirability of efficient use of the geostationary orbit and the available spectrum has long been recognized. For example, regarding the proposed planning principles for Region 2, the Final Acts of the WARC-BS-77 state: "The plan for Region 2 shall use, to the maximum extent technically and economically practicable, the techniques available so as to make the most efficient use of the geostationary orbit and the frequency spectrum to fulfil the requirements both of the Region as a whole and of the individual administrations."

Technology factors relevant to spectrum/orbit utilization are discussed in this section.

2.1 *Modulation*

The use of narrow-band modulation can result in more users per given bandwidth. Narrower bandwidth, however, usually has to be compensated by greater transmitter power and correspondingly higher protection ratio requirements (see Report 634). Certain types of modulation are also more tolerant to interfering signals, including those which are not co-channel, but whose spectra overlap a portion of the desired signal band. Modulation and spectrum shaping are therefore important considerations in frequency re-use.

Analogue FM is currently the most widely used modulation technique for transmission of television signals through satellites. Digital modulation for television without any processing requires more bandwidth. Recent developments in video compression, however, combined with bandwidth efficient modulation techniques have brought digital transmission of television signals to the point of becoming competitive with analogue FM on the basis of both bandwidth and power. One current drawback to digital television for broadcasting is the cost of the receiving and signal processing equipment.

For a detailed discussion of suitable modulation techniques for television, including analogue/digital trade-offs, see Report 632.

2.2 *Antennas*

The achievable characteristics of antennas, both transmitting and receiving, are very important in determining the efficiency of spectrum/orbit usage. Desirable characteristics of antennas include low side lobes, fast fall-off of gain outside of the desired beam, and good cross-polar discrimination. Not meeting these "ideal" characteristics causes signals to arrive outside of the desired coverage areas as well as signals to be received from sources other than the desired one.

The effect of antennas on spectrum/orbit utilization is discussed below. Recommended and achievable antenna characteristics are discussed in greater detail in Report 810.

2.2.1 *Frequency re-use by multiple beams*

A given segment of spectrum can be re-used many times, even by the same satellite. A satellite can transmit two or more independent beams at the same frequency if the beam footprints are sufficiently separated. Figure 2-4 illustrates this principle, showing three frequencies being used to cover the United States. While no two beams at the same frequency are adjacent, there will be some interference due to the

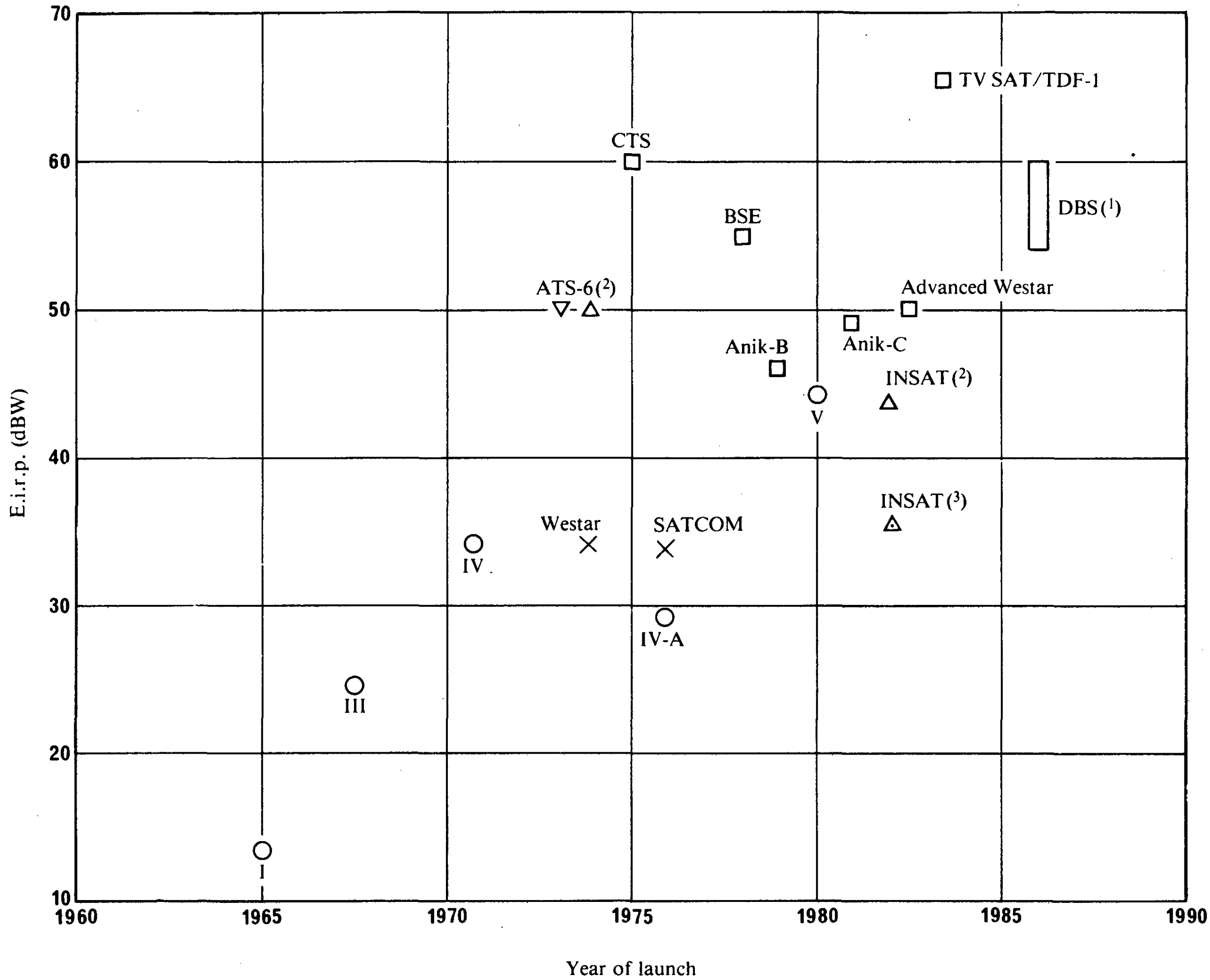


FIGURE 2-3 – *E.i.r.p. for representative FSS and BSS spacecraft*

▽ 850 MHz

○ 4 GHz INTELSAT

✕ 4 GHz US domestic

□ 12 GHz

△ 2.5 GHz

△ 4 GHz

(1) The e.i.r.p. range of the proposed 12 GHz DBS systems for the USA.
(2) E.i.r.p. for broadcasting transponders.
(3) E.i.r.p. for telecommunication transponders.

finite side lobes of the beams. Figure 2-5 illustrates the interference to a receiver located ψ_A° from the centre of the desired beam, from a transmitter radiating a co-channel beam towards another point. The receiver receives a desired signal level of C and an interfering signal I due to the side lobes of the other co-channel beam. The interfering signal level increases as more co-channel beams are added although at a progressively slower rate since the additional beams are further and further away. For computation of C/I, side-lobe envelopes rather than true antenna patterns are usually used, as shown in Fig. 2-6, where the −30 dB side-lobe envelope is the recommended limit for BSS transmitting antennas (Appendix 30 to the Radio Regulations). C/I (for the beam in the centre of the cluster) is illustrated in Fig. 2-7 as a function of the number of transmitted beams and side-lobe levels. Note that as the number of frequency "colours" increases from 3 to 19, a higher value of C/I is obtained. However, for a given total spectrum, the available bandwidth per beam, i.e., number of channels over a given geographical area, decreases.

2.2.2 *Beam shaping*

For many BSS applications it may be desirable to transmit the same programming over a larger area (e.g. a time zone or a country) than that covered by a single beam of Fig. 2-4. This can be accomplished by combining the small beams to form complex beam shapes as illustrated in Fig. 2-8. A shaped beam has several advantages over a simple circular or elliptical beam. It concentrates the transmitted power into the service area which minimizes transmitter power and lessens the probability of interference to receivers outside this area. Also, the illumination in the beam is more uniform due to the addition of composite beams as illustrated in Fig. 2-9. Furthermore the energy falls off more rapidly away from the beam centre, thus allowing closer spacing of co-channel beams. The latter factor maximizes the frequency re-use that can be realized over a given geographical area.

As a disadvantage, a shaped beam antenna requires a larger reflector. In the example of Fig. 2-9, the antenna reflector diameter of B (multi-beam pattern) is three times that of A (single-beam pattern). The basic limitation to how closely a beam can be matched to a complex service area contour comes from the minimum beamwidth of the individual beams. Therefore, the larger the physical antenna size, the better this match.

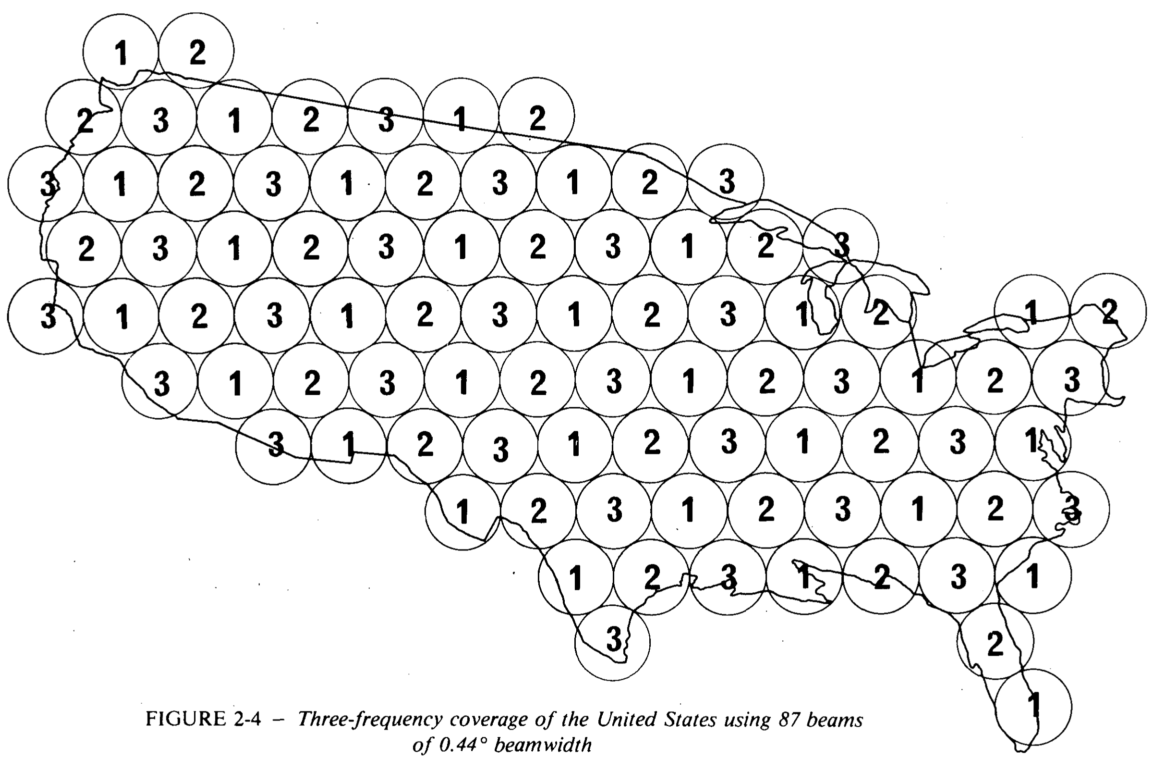


FIGURE 2-4 – *Three-frequency coverage of the United States using 87 beams of 0.44° beamwidth*

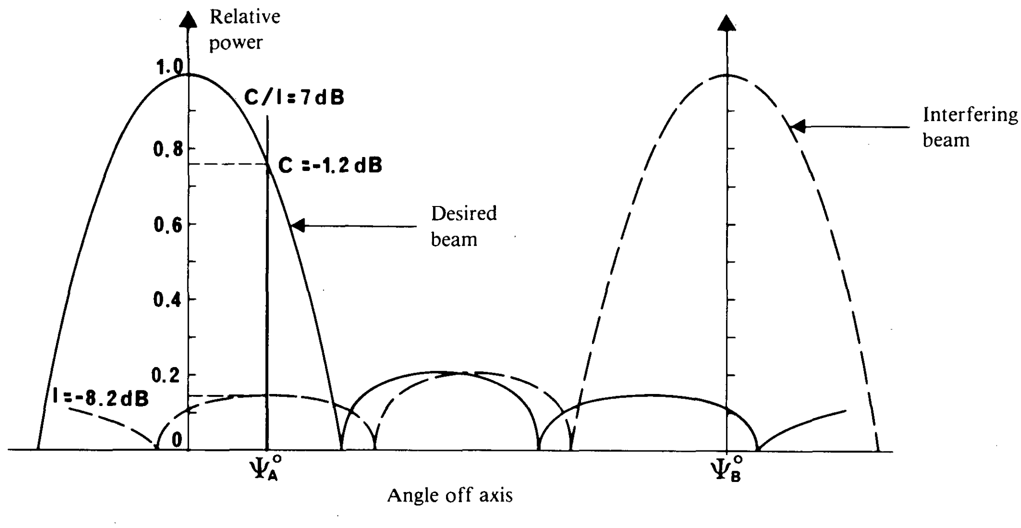


FIGURE 2-5 – *Geometry for calculating C/I at ψ_A^o from desired beam boresight. Interfering beam at ψ_B^o from desired beam boresight*

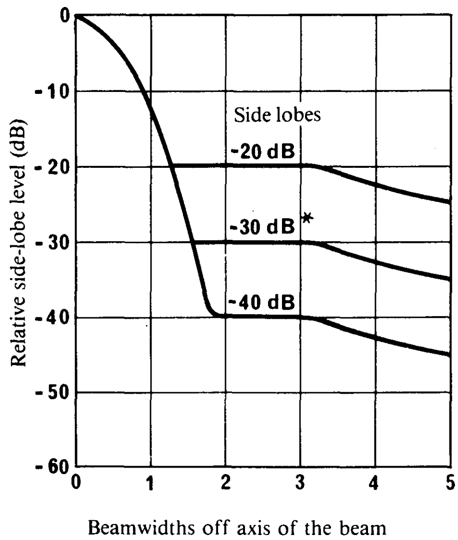


FIGURE 2-6 – *BSS transmitting antenna patterns*

Representative patterns used for *C/I* computations (see also Fig. 2-7)

* Recommended side-lobe limit: see Fig. 6, Annex 8, Appendix 30, RR.

2.2.3 *Antenna pointing*

Antenna pointing accuracy is important to minimize coverage area and signal spill-over outside the intended service area. A particular point on a satellite beam will move approximately θ times 630 km along the ground at the sub-satellite point for an antenna pointing error of $\theta°$ at the satellite. Away from the sub-satellite point the movement will be even greater. The amount of horizontal movement that can be tolerated thus sets the satellite antenna pointing requirements. For non-circular beams the rotational movement of the satellite beam becomes important as well. The consequences of beam misalignment are likely to be greater for shaped beams because more receivers will be close to the beam edge and the signal fall-off beyond the beam edge will be faster.

2.3 *Low side-lobe receiving antennas*

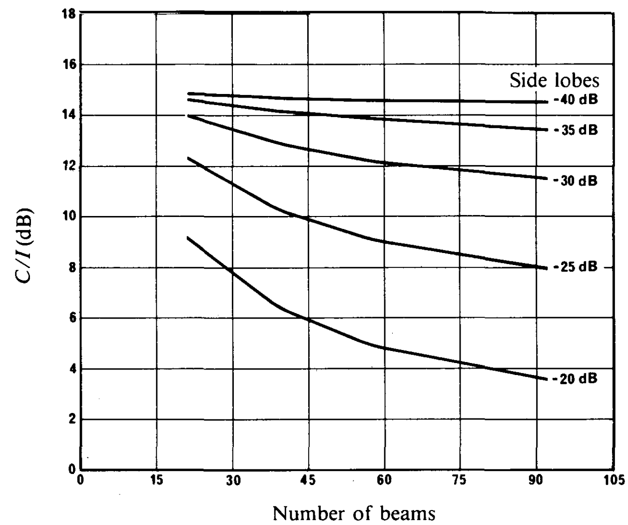
The ground receiving antenna provides discrimination for co-channel signals coming from satellites some angular distance away from the desired satellite (see Fig. 2-10). The level of interfering signals relative to the desired signal will be reduced by an amount equal to the reduction in antenna gain in the direction of the interfering satellite. It is therefore important that receiving antenna gain and side lobes fall off rapidly with angle away from boresight. Minimum satellite spacing and orbit capacity will therefore depend on the beamwidth and side-lobe characteristics of the receiving antenna.

Since interfering satellites may have different values of e.i.r.p. and other key characteristics, interference analyses are best made on a case-by-case basis. Various computer programs (e.g., SOUP), suitable for running these analyses, are available (see Report 812).

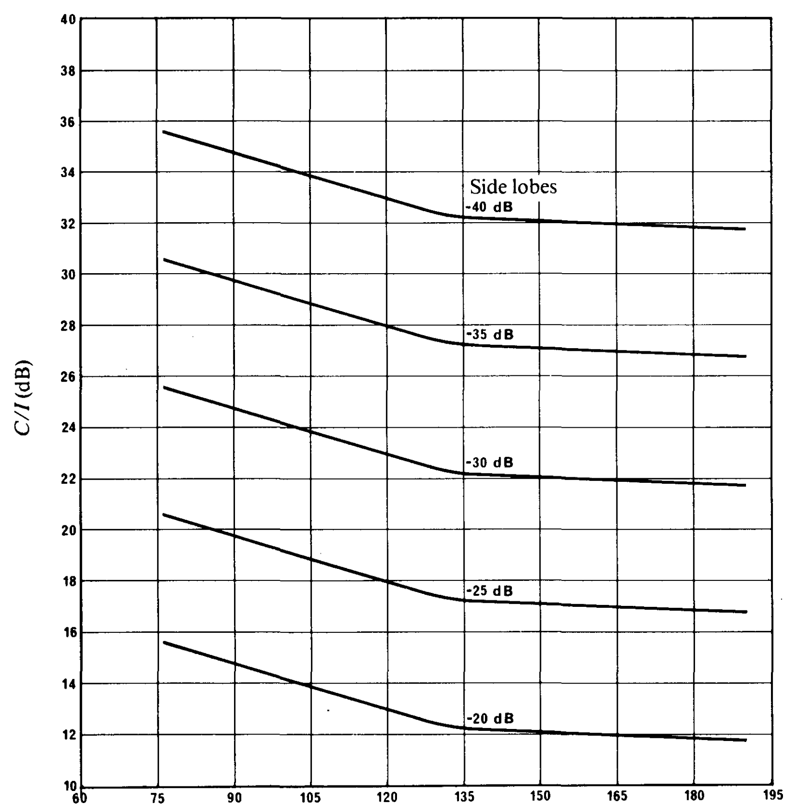
3. **Space-segment technology summary**

This section presents a summary of the key satellite technologies. More detailed information can be found in the references at the end of this Chapter and in the referenced CCIR Reports.

A satellite has a weight and power limitation determined by the characteristics of the launch vehicle. Various spacecraft capabilities and requirements must therefore be traded against each other. The effects of the technology discussed in this Chapter on spacecraft design are summarized in Table 2-II.



a) 3 frequencies



b) 19 frequencies

FIGURE 2-7 – *Frequency re-use capacity*

Modified CCIR reference pattern axisymmetric reflector
Calculation: —3 dB down from peak of the main beam
Beam separation: 1 half power beamwidth of the main beam

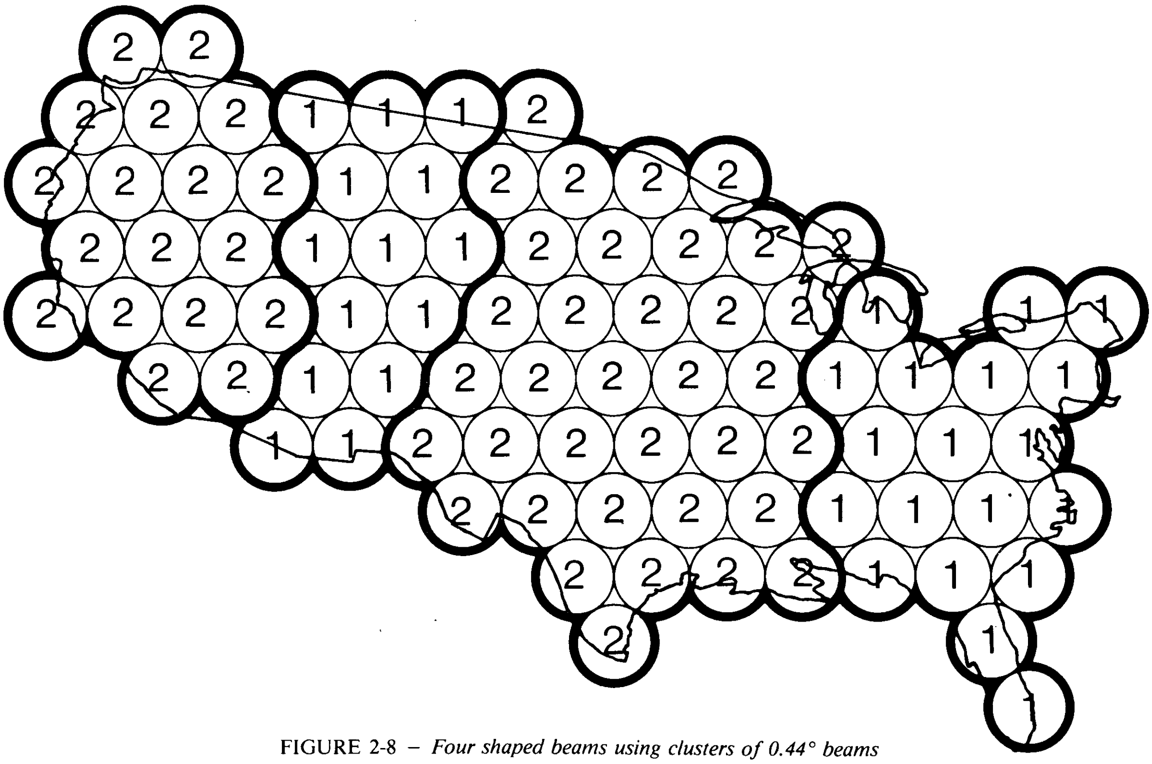


FIGURE 2-8 – *Four shaped beams using clusters of 0.44° beams*

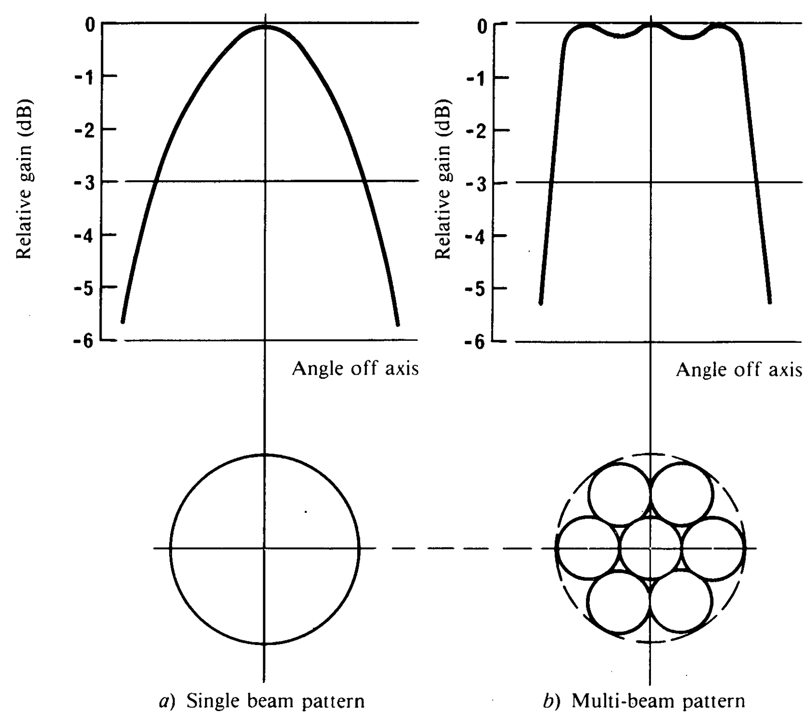


FIGURE 2-9 – *Beam-shaping by use of multiple narrow beams*

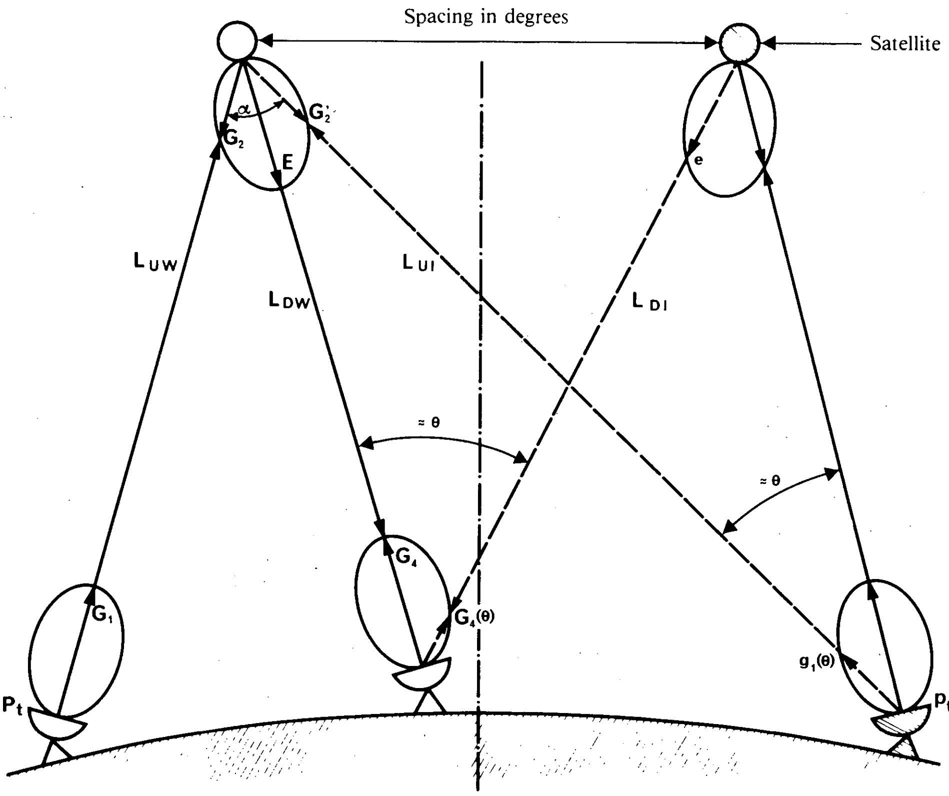


FIGURE 2-10 – *Receiving antenna discrimination of unwanted satellite signal*
(Interference geometry between satellite networks)

———— Wanted signal paths
— — — — Interfering signal paths

$G_4 - G_4$ (θ): receiving antenna discrimination

P_t, p_t:	transmit powers of wanted and interfering carriers delivered to the associated earth-station antenna (dBW);
G_1, G_4:	transmit and receive antenna gains of one or more wanted earth stations (dB);
L_{UW}:	up link loss, wanted signal path;
L_{DW}:	down link loss, wanted signal path;
L_{UI}:	up link loss, interfering signal path;
L_{DI}:	down link loss, interfering signal path;
$g_1(\theta)$:	antenna gain component at the unwanted earth station towards the wanted satellite (dB);
θ:	geocentric minimum angular satellite spacing at the interfering earth station;
G_2:	receive antenna gain at the wanted satellite toward the wanted earth station(s);
G'_2:	receive antenna gain at the wanted satellite toward the interfering earth station;
E, e:	e.i.r.p. of the wanted and interfering carriers in the direction of the wanted earth station (dBW);
$G_4(\theta)$:	antenna gain component at the wanted earth station toward the interfering satellite (dB).

TABLE 2-II – *Design decisions for a geostationary BSS system*

Design factor	Decision	Primary impact	Status and trends	Other impacts
Service area shape	Shaped beam or circular/elliptical	Satellite antenna size and weight	§ 3.1 of this Chapter	Prime power requirements
E.i.r.p.	E.i.r.p.-G/T trade-off	Power amplifier selection Solar array size	§ 3.2 of this Chapter Chapter 4	Thermal control
Eclipse coverage	Number of operational channels during eclipse	Battery size		Orbit position if no batteries
Lifetime	Economic factors Spares philosophy	Attitude control fuel	Chapter 4 for economic considerations Current design lifetimes 7-10 years	Solar cell degradation
Stabilization	3-axis or spinner	Important mostly for high power satellites	§ 1.1 of this Chapter	Launch vehicle shape factor
Station-keeping	Accuracy	Station-keeping fuel	§ 3.3 of this Chapter	
Antenna pointing	Accuracy	Attitude control sub-system complexity	§ 3.3 of this Chapter	

3.1 *Spacecraft transmitting antennas*

It is likely that initial planning will be based on the assumption that the beams emitted from the satellite have elliptical or circular cross-section, and the reference patterns described below are based on this case. Antennas with specially shaped beams may also be very useful for broadcasting satellites because they minimize RF power requirements and would facilitate the suppression of undesirable spill-over to neighbouring countries, while maintaining an effective coverage in the intended area.

The reference patterns shown in Fig. 2-11 are for the 12 GHz band, but may be used for lower bands as well.

These values (cross-polar around boresight and co-polar around $\varphi/\varphi_0 = 1.5$) may be difficult to achieve in practice.

A good example of shaped beams is the Intelsat-V antenna pattern which is illustrated in Fig. 2-12. The zone and hemisphere beams also achieve frequency re-use and polarization diversity. Another example of beam shaping is the 20/30 GHz Japanese CS satellite which uses antenna reflector contouring to help achieve the required beam shape. Figure 2-13 shows the theoretical and measured patterns of an antenna designed to cover the eastern time zone of the United States [Cohen, 1981]. This figure illustrates the low side-lobe levels achievable outside the desired coverage area.

Note. – Good side-lobe control may be difficult to achieve in practice in some sectors far outside the main beam (see Fig. 3b of Report 810).

The impact on orbit/spectrum capacity of various beam shapes is covered in Report 633. The requirements and actual characteristics of non-shaped-beam antennas are covered in Report 810.

If elliptical beams are used, service area coverage can be optimized using the methods described in Report 812.

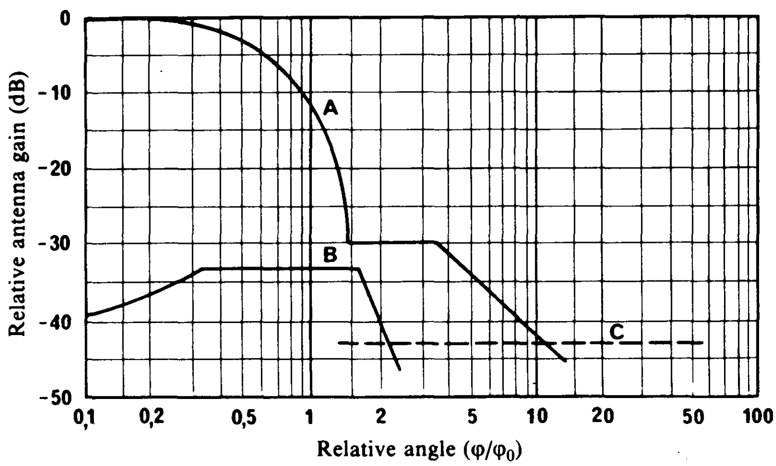
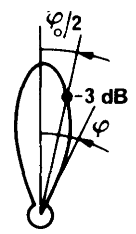


FIGURE 2-11 – *Reference patterns for co-polar and cross-polar components for a single-feed satellite transmitting antenna producing a beam of circular or elliptical cross-section*



Curve A: Co-polar component (dB)
- $- \; 12\,(\varphi/\varphi_0)^2$ for $0 \leqslant \varphi \leqslant 1.58\,\varphi_0$
- $- \; 30$ for $1.58\,\varphi_0 < \varphi \leqslant 3.16\,\varphi_0$
- $- \; [17.5 + 25 \log(\varphi/\varphi_0)]$ for $3.16\,\varphi_0 < \varphi$

After intersection with Curve C: as Curve C

B: Cross-polar component (dB)
- $- \; (40 + 40 \log|(\varphi/\varphi_0) - 1|)$ for $0 \leqslant \varphi \leqslant 0.33\,\varphi_0$
- $- \; 33$ for $0.33\,\varphi_0 \leqslant \varphi \leqslant 1.67\,\varphi_0$
- $- \; (40 + 40 \log|(\varphi/\varphi_0) - 1|)$ for $1.67\,\varphi_0 < \varphi$

After intersection with Curve C: as Curve C

C: minus the on-axis gain (dB)

3.2 *Power amplifiers*

Travelling wave tube amplifiers (TWTAs) and solid state amplifiers (SSAs) are the two major candidates for power amplification in broadcasting amplifiers. SSAs have the advantages of a simpler power supply and better linearity with less power back-off than required by TWTAs. The projected channel availability of SSAs is also higher. TWTAs, on the other hand, have greater power capability, especially at higher frequencies. Figure 2-14 compares TWTA and SSA availability for the advanced Satcom [Braun and Keigler, 1980]. The present and projected boundaries between solid state and TWT amplifiers are illustrated in Fig. 2-15.

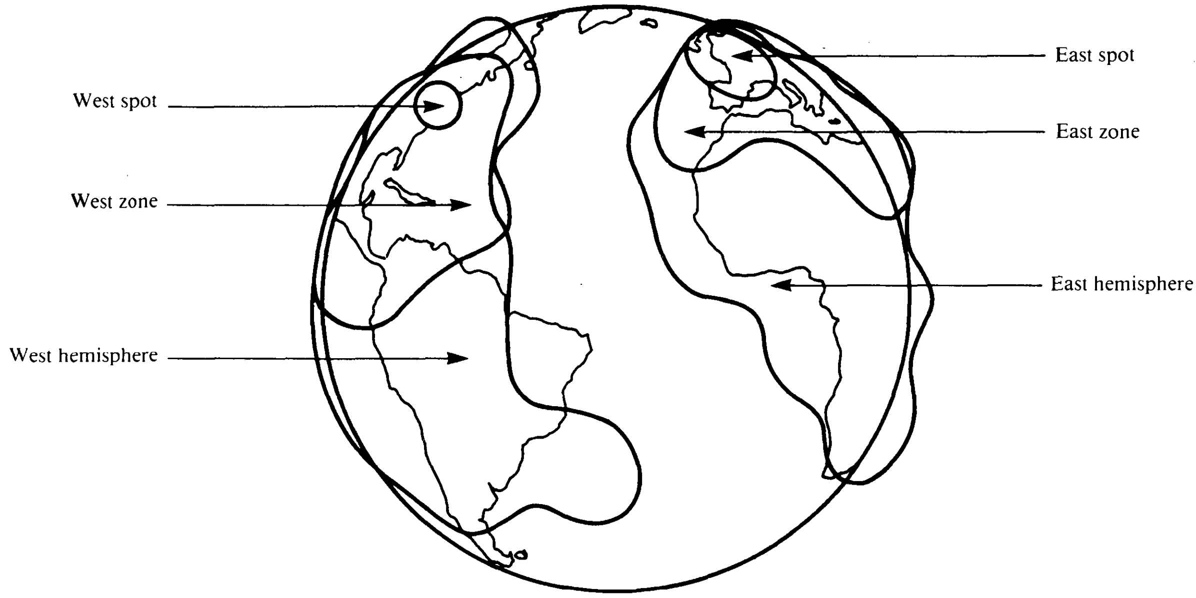
Table 2-III lists some representative SSAs and Table 2-IV lists some specific TWTs that have been developed for space applications.

TWT power supplies, usually called EPCs (electronic power conditioners), are also a critical component, especially for the high power tubes used in broadcasting satellite applications. Three of the key TWT suppliers, namely Hughes, AEG-Telefunken, and Watkins Johnson, are capable of delivering a complete TWTA (TWT + EPC). In most cases the EPC has been built and integrated with the TWT by the spacecraft contractor, for example General Electric (JBS-1) and TRW (CTS).

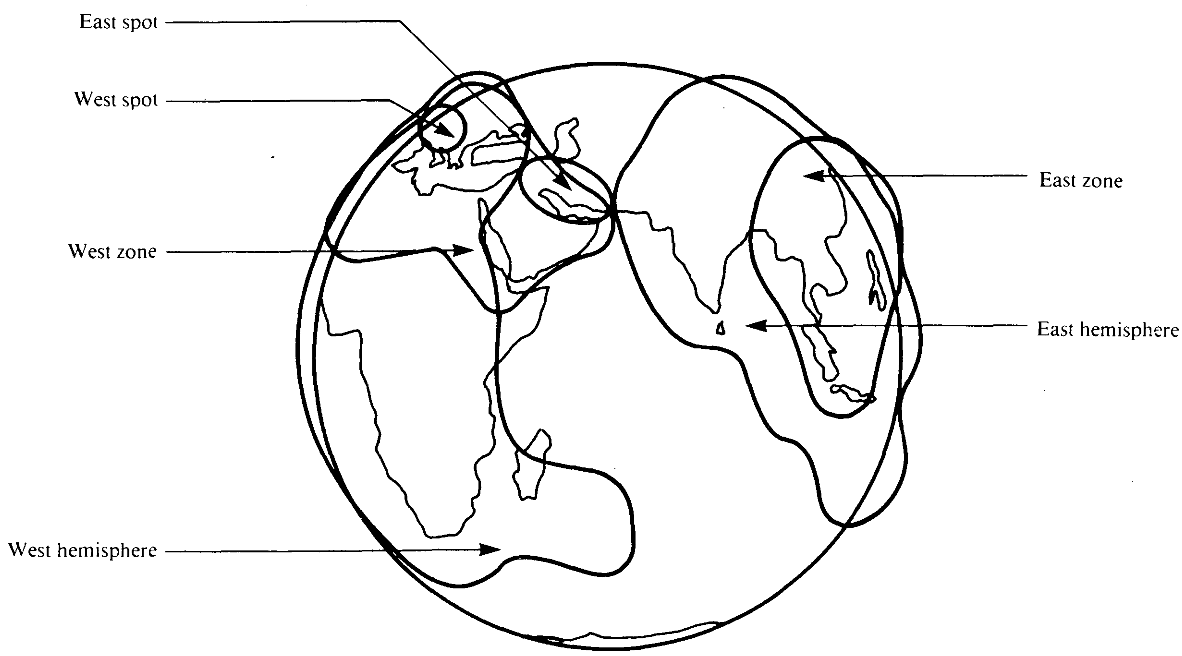
3.3 *Station-keeping and antenna pointing*

Satellite station-keeping capabilities are currently such that maintaining position within $\pm\,0.1°$ along the orbit is easily accomplished. North-south station keeping uses up most of the station-keeping fuel. North-south and longitudinal station-keeping requirements are shown in Table 2-V and Fig. 2-16, respectively. Electric propulsion is a promising technology for minimizing station-keeping fuel weight.

The basic function of the attitude control sub-system is to maintain spacecraft attitude with sufficient accuracy to properly orient the solar arrays towards the Sun and to point the antenna beams towards the intended coverage areas. With the trend towards narrower beams, antenna pointing requirements determine attitude control limits.



a) Intelsat-V Atlantic Ocean coverages



b) Intelsat-V Indian Ocean coverages

FIGURE 2-12 – *Intelsat-V antenna patterns*

Zone and hemisphere beams use 3.7-4.2 GHz
Spot beams use 11-11.7 GHz

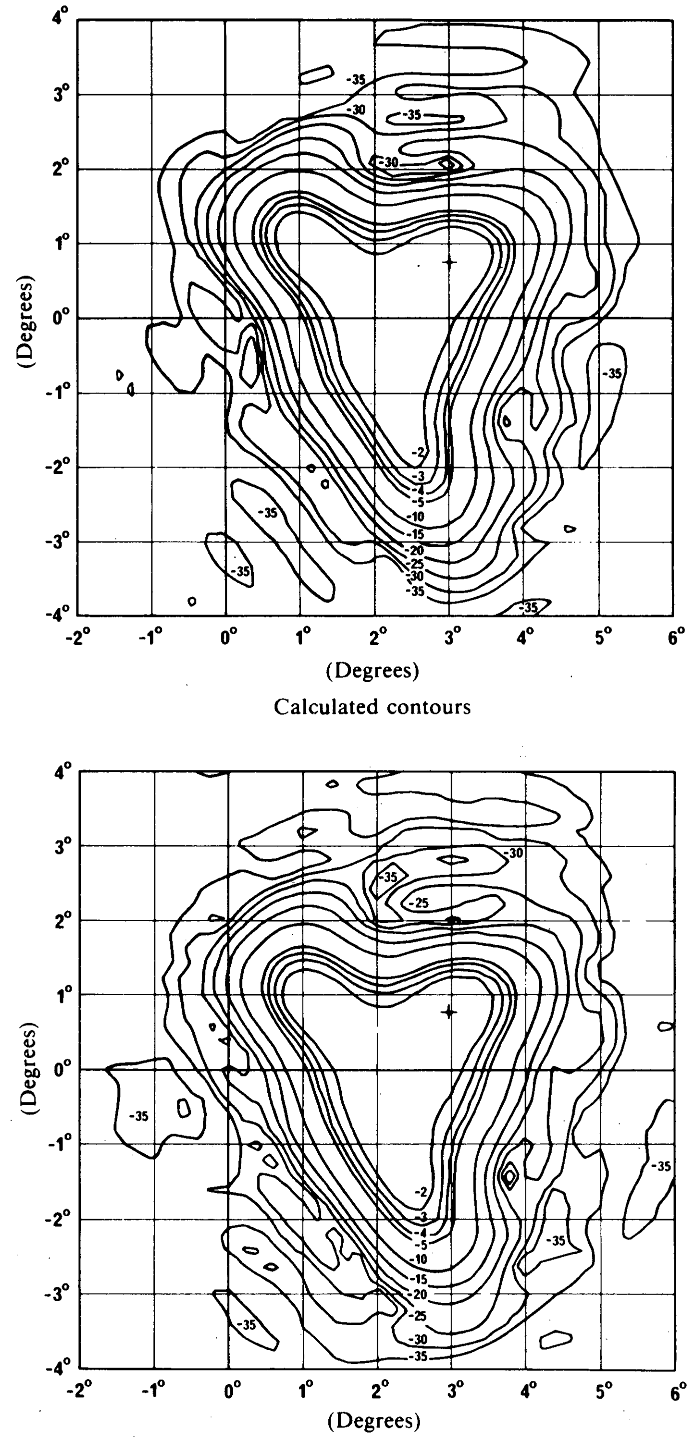


FIGURE 2-13 — *Comparison of calculated and measured gain contours at 11.7 GHz for shaped beam antenna pattern*

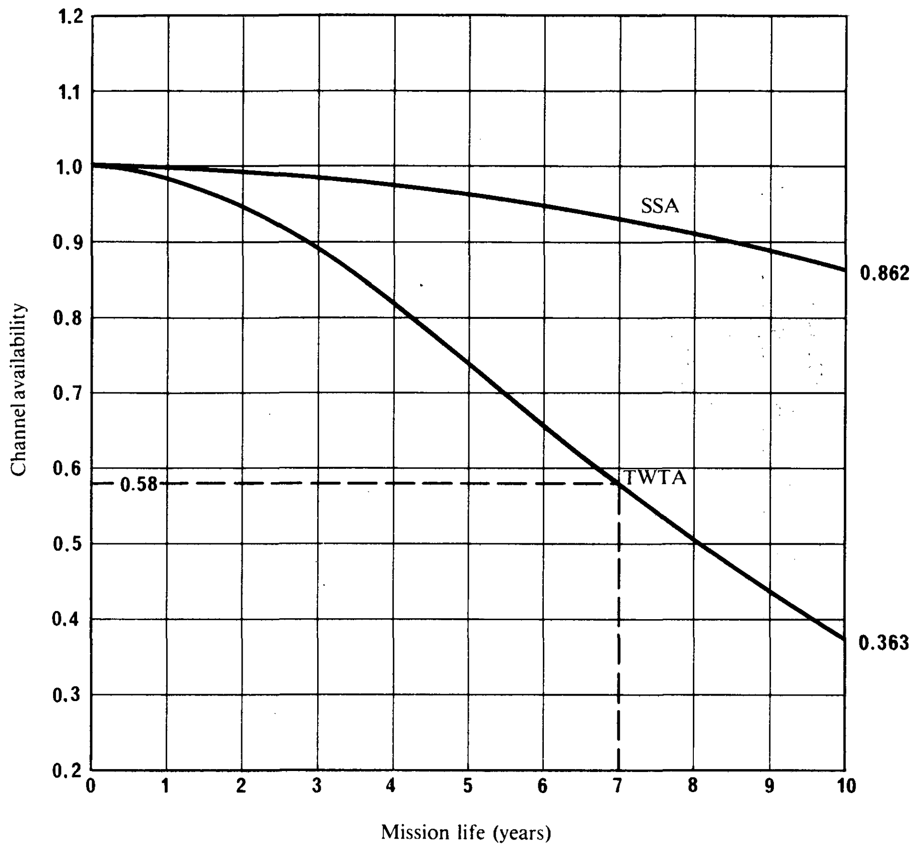


FIGURE 2-14 – *Solid state amplifier versus travelling wave tube amplifier availability trade-off for the advanced RCA Satcom*

Availability: probability of all 24 channels operable (7 for 6 redundancy)

The two basic methods of spacecraft stabilization are three-axis, where the entire spacecraft is maintained inertially stable with respect to a spacecraft-Earth vector, and dual-spin where the spacecraft spins on an axis parallel to the Earth's rotation axis and an antenna platform is despun to point along a spacecraft-Earth vector.

Attitude control accuracy is generally measured along three axes:

– *Roll:* a spacecraft rotation along the flight axis, produces north-south displacement of an antenna beam at the Earth's surface.

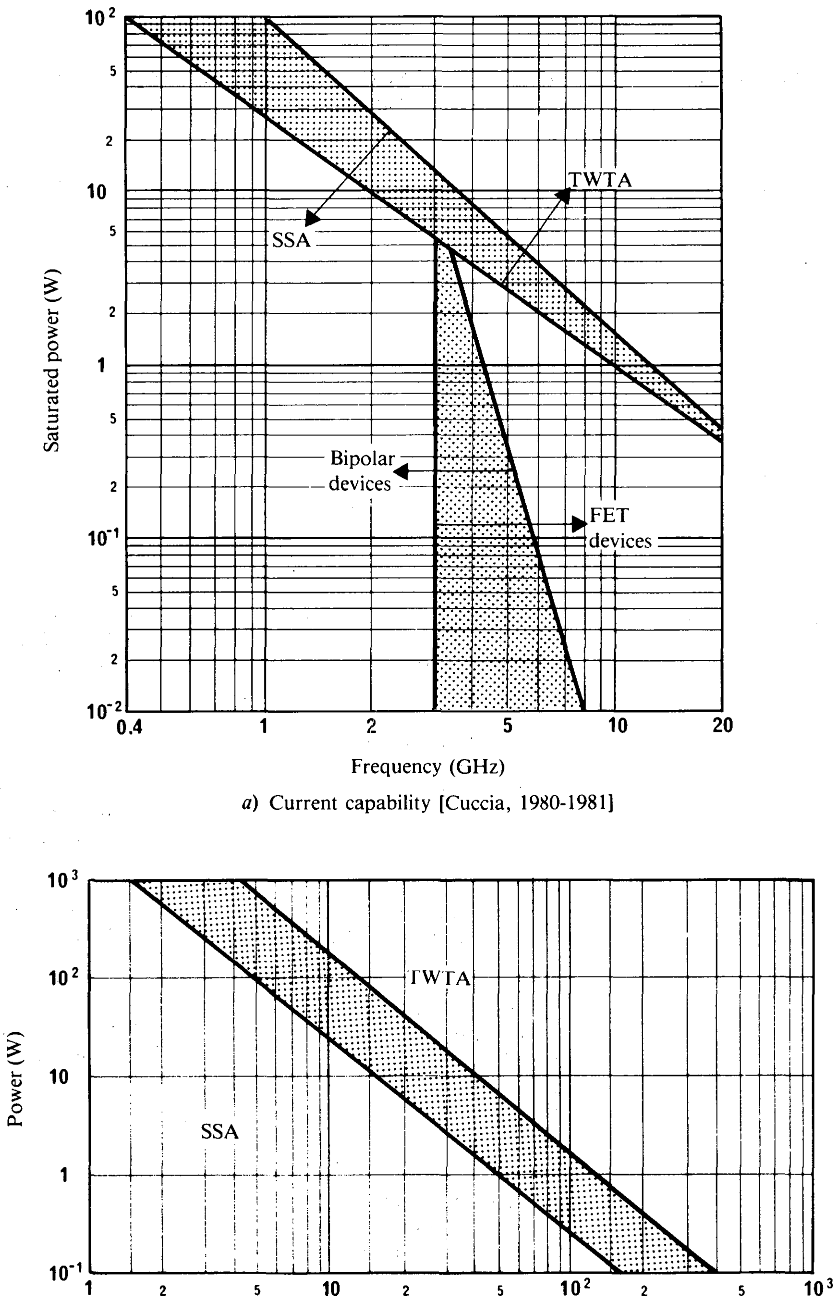
– *Pitch:* a spacecraft rotation about its north-south axis, produces east-west displacement of an antenna beam at the Earth's surface.

– *Yaw:* a spacecraft rotation about the spacecraft-Earth vector, produces antenna beam rotation at the sub-satellite point, and beam displacement together with rotation at other points on the Earth's surface.

In general, greater errors can be tolerated in yaw than in pitch or roll. In any case the magnitude of the attitude control error is a function of both the sensors which sense the attitude errors in any of the three axes, and of the method used to control spacecraft attitude.

Spacecraft attitude, in the three-axis stabilization mode, is usually maintained by means of reaction wheels which can be unloaded by means of small thrusters. Control by thrusters alone produces attitude limit cycling and is wasteful of fuel.

When very precise antenna pointing is a requirement, antenna axis misalignment errors as well as any thermal deformations in the vicinity of attitude sensors become important. The use of monopulse error sensors is useful in cancelling some of these errors. For very large spacecraft and antennas, electronic antenna beam steering is a possible future solution to the problem of antenna beam pointing accuracy.



a) Current capability [Cuccia, 1980-1981]

b) Projected capability

FIGURE 2-15 – *Solid state amplifier and travelling wave tube amplifier capabilities*

The pointing accuracy which can be achieved depends on the types and quality of attitude sensors employed for each axis (see Report 808).

With the present state of technology for controlling the 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, Report 546) this radius could be reduced to 0.1°. Studies performed in the USA and Europe indicate that eventually an accuracy of 0.05° can be achieved for a significant and predictable portion of the operational lifetime.

TABLE 2-III – *Typical operational and experimental solid state power amplifiers for communication applications*

Frequency	Bipolar transistor	IMPATT amplifiers	Power FET amplifiers
860 MHz	110 W: ATS-6	—	—
1550 MHz	40 W: ATS-6, GPS	—	—
1685 MHz	20 W: SMS	—	—
2075 MHz	20 W: ATS-6	—	—
2300 MHz	24 W: Voyager	—	—
4-6 GHz	7 W: Terrestrial Radio	1-10 W: Terrestrial Radio 15.8 W: SRI	20 W: Fujitsu 8.5 W: RCA Satcom 10 W: ATT BELSTAR
7-8 GHz	—	3 W: Hewlett Packard 4 W: Hughes 12.8 W: Varian	1 W: Terrestrial radio (Japan) 4.4 W: Westinghouse 10 W: Experimental-G.E. 10 W: Experimental-TRW
11 GHz	—	3.5 W: Terrestrial radio 13 W: Experimental-UK	100 mW: CTS 20 W: Experimental-TRW
18-20 GHz	—	200 mW: Terrestrial radio 800 mW: Comstar 10-20 W: TRW(1)	2 W: Experimental 6-7.5 W: TRW, TI(1)
30 GHz	—	800 mW: Comstar	—
35 GHz	—	100 mW: ETS-II 500 mW: LES 8/9 5 W: Experimental-TRW	—
55-60 GHz	—	200 mW: Hughes	—

(1) NASA 30/20 GHz program.

Present attitude control systems used on most geostationary communications satellites can control yaw so that the error is in the range of ± 0.3° to ± 0.8°, depending on various factors. The lower values (of the order of ± 0.3°) can be achieved by using two separate attitude references sufficiently far apart; for example, use of an RF sensor and an IR sensor (when the coverage area is sufficiently far away from the sub-satellite point) or use of two RF sensors (when the coverage area is large enough). Yaw stabilization to within ± 0.1° has already been demonstrated in orbit with the ATS-6 satellite by using star sensors [Redisch, 1975] but such sensors represent a significant increase in the mass and complexity of the satellite.

TABLE 2-IV – *Space travelling wave tube amplifier suppliers*

(Helix type unless specified)

Frequency (GHz)	Power level (W)	Company	Country	User	Status
2-2.7	25	Hughes	USA	TDRSS	Qualified
	50	Hughes Electro Dynamics	USA	Insat-I	Qualified
	50-75	Hughes	USA	Arabsat	In development
	150	Watkins Johnson	USA	Shuttle	Qualified
3.7-4.2	0.5	Hughes	USA	Intelsat-IV	Flight qualified
	4.5	Hughes	USA	Intelsat-IV, IV-A	Flight qualified
	4.5	NEC	Japan	JCS	Flight qualified
	5.0	Hughes	USA	Anik-A	Flight qualified
	8	Hughes	USA	Intelsat-V	Flight qualified
	10	Telefunken AEG	FRG	Anik-B	Flight qualified
	10	Hughes	USA	ATS-6	Flight qualified
	13	Telefunken AEG	FRG	Symphonie	Flight qualified
	13	Hughes	USA	Intelsat-III	Flight qualified
11.7-12.2 (Nominal)	1.7	Hughes	USA	TDRSS	Qualified
	10	Hughes	USA	Sirio	Flight qualified
	10	Thomson-CSF	France	Intelsat-V	Flight qualified
	15	Telefunken AEG	FRG	Anik-C	Qualified
	20	Thomson-CSF	France	OTS, CTS	Flight qualified
	20	Telefunken AEG	FRG	OTS, Anik-B	Flight qualified
	25	Telefunken AEG	FRG	SBS	Flight qualified
	30	Telefunken AEG	FRG	TDRSS	Qualified
	100(1)	Hughes	USA	Japan BSE-1	Flight qualified
	100	Thomson-CSF	France	Japan BSE-2	Qualified
	100	NEC	Japan		In development
	150	Thomson-CSF	France	H-SAT	Qualified
	200(1)	Litton	USA	CTS	Flight qualified
	200-230	Thomson-CSF	France	TV SAT/TDF-1	In development
	260-280	Telefunken AEG	FRG	TV SAT/TDF-1	In development
	450(1)	Telefunken AEG	FRG	Nordsat	Engineering model
	700(1)	Telefunken AEG	FRG		Experimental
	700(1)	Siemens	FRG		Experimental
	700-1000(2)	Valvo	FRG		Experimental
17.7-20.2	2.5	Hughes	USA	ATS-6	Flight qualified
	4	Hughes	USA	JCS	Flight qualified
	4	NEC	Japan	JCS	Flight qualified
	3.75-30	Hughes	USA	ATT (Exper.)	Breadboard
	7.5-75	Hughes	USA	NASA 20/30 GHz	In development
	20	Telefunken AEG	FRG		In development
	20	Thomson-CSF	France		In development

(1) Coupled cavity type.
(2) Klystron.

The BSE experimental satellite of Japan limited the dynamic errors of its attitude control by zero-momentum three-axis stabilization, within ± 0.03° for pitch and roll by the use of the earth sensor, and ± 0.3° for yaw by the use of the combination of the earth sensor and the radio-frequency monopulse sensor, almost throughout the day [Shimuzu *et al.*, 1980].

TABLE 2-V – *North-south station-keeping velocity*

Year	Inclination rate (degrees/year)	Δ v	
		(m/s)	(ft/s)
1975	0.795	42.6	139.9
1976	0.770	41.3	135.6
1977	0.754	40.4	132.7
1978	0.748	40.1	131.6
1979	0.753	40.4	132.6
1980	0.769	41.2	135.3
1981	0.794	42.6	139.7
1982	0.824	44.2	145.0
1983	0.857	46.0	150.9
1984	0.889	47.7	156.5
1985	0.916	49.2	161.3
1986	0.936	50.2	164.7
1987	0.945	50.7	166.4
1988	0.944	50.6	166.1
1989	0.931	50.0	163.9
1990	0.909	48.8	160.0
1991	0.880	47.2	154.9
1992	0.848	45.5	149.2
1993	0.815	43.7	143.4
1994	0.786	42.2	138.3

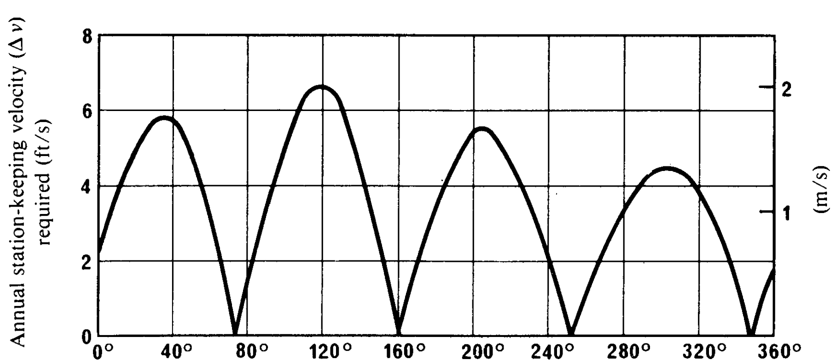


FIGURE 2-16 – *Required annual longitudinal station-keeping velocity*

4. Ground-segment technology summary

In the United States, studies covering the optimization of low cost television receive-only (TVRO) terminals were first funded by NASA in the early 1970s [NASA, 1972]. Operational experience with satellite broadcasting of television to low cost terminals was obtained with ATS-6 at 2.6 GHz and CTS at 12 GHz. Broadcasting experiments and receiving terminal development at 12 GHz also took place in Japan with the BSE and are continuing in Canada using Anik-B.

An economic necessity of BSS systems with a large number of receiving terminals is that the cost of the terminals be fairly low (see Chapter 4). Maintaining reasonable G/T is the primary technical challenge and has recently received a great deal of attention both in the 12 GHz BSS band and the 4 GHz FSS band. In the United States, 4 GHz TVRO terminals are currently undergoing substantial volume production (estimated 1000 per month). The technology and manufacturing techniques developed at 4 GHz are expected to be applicable to terminals in the BSS bands (see Chapter 4, § 3.5.4).

Once the BSS system design process determines the required receiving terminal G/T, the problem remains to optimize the terminal design in terms of antenna size and receiver noise figure. The typical cost versus noise temperature curve for low noise amplifiers is shown in Fig. 2-17 while the cost curve for antennas versus diameter is shown in Fig. 2-18. A cost minimum exists for any G/T at a certain antenna size as illustrated in Fig. 2-19. In recent years, this minimum has moved towards smaller antenna sizes. This trend cannot continue indefinitely because reducing amplifier noise figure below a certain point becomes ineffective due to weather and other noise contributors. Also antennas cannot be decreased in size indefinitely because beamwidth and side lobes increase with a potential impact on spectrum/orbit utilization. More detailed information on the system aspects of ground terminal G/T is available in Report 215.

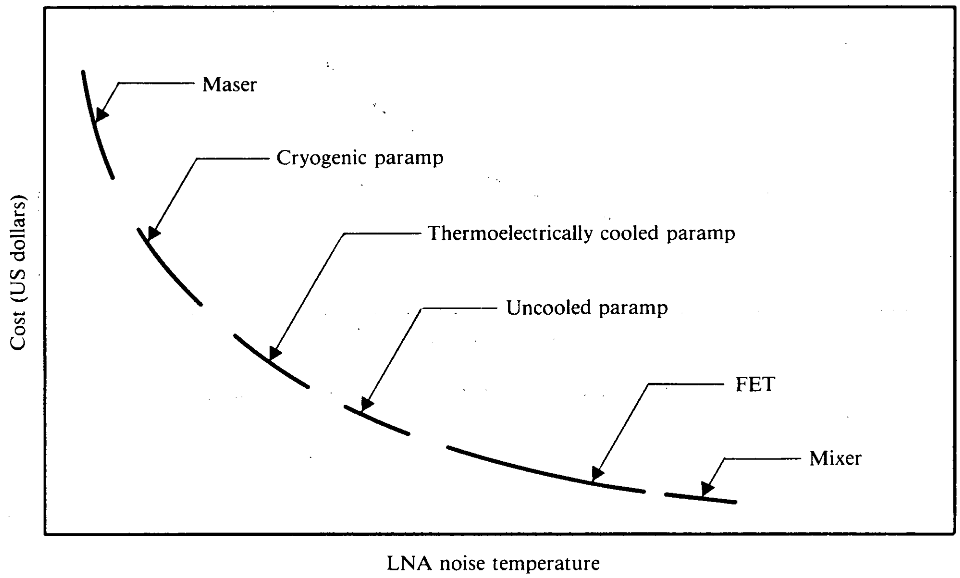


FIGURE 2-17 – *Low noise amplifier cost versus noise temperature*

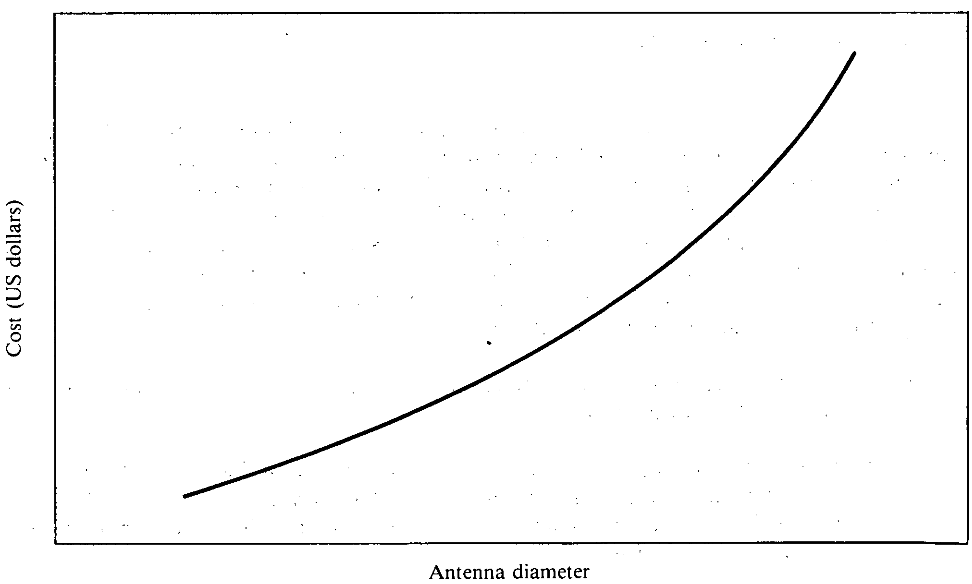


FIGURE 2-18 – *Antenna cost versus diameter*

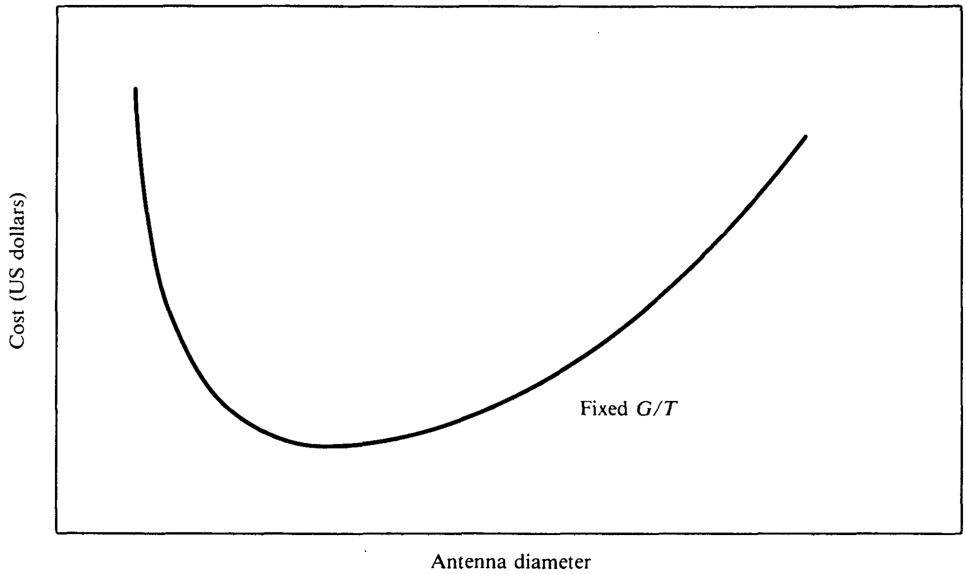


FIGURE 2-19 – *Receiving terminal cost versus antenna diameter*

4.1 *Receivers*

A receiver can be functionally divided into three parts: input stages, intermediate frequency stages and demodulation or adaptor stages.

4.1.1 *Input stages* [Konishi *et al.*, 1974]

These stages are an important part of the receiver. They should consist of a frequency down-converter which may or may not be preceded by low noise radio-frequency amplifier stages. If the latter are required, they may be achieved by means of tunnel-diodes or special transistors, or even by parametric amplifiers in the case of community reception receivers. The converter can use Schottky-barrier diodes. For wideband reception, with frequency-modulation television, a solid-state direct local oscillator source, such as a Gunn device, or a field-effect transistor (FET), may be used. However, even if some form of automatic frequency control (a.f.c.) of this or any subsequent oscillator can be assumed, some care will still be necessary to minimize frequency drift with temperature.

The design of the a.f.c. loop will depend on whether d.c. or a.c. coupling is used in the frequency-modulation transmitter modulator.

In France [Dessert and Harrop, 1980] a 12 GHz receiving unit has been designed based on the exclusive use of FETs for the three main sub-assemblies: SHF preamplifier, local oscillator and mixer. In the course of tests, the receiver head demonstrated its ability to provide television pictures of excellent quality from 12 GHz satellite transmissions.

The receiver head is based on thin-layer technology (microwave integrated circuits) whereby the chips holding the FETs and the associated passive elements are mounted on the same alumina substrate. An overall noise figure of 3.6 dB is achieved with a 400 MHz tuning range. The fact that this receiver head uses only FETs as active devices suggests that it should be possible to achieve a more integrated version. One may therefore foresee a future trend towards the development of monolithically integrated versions (e.g. active components integrated with the same GaAs chip). This design is likely to lower costs, which is a decisive factor for any product intended for a wide market.

In Japan [Konishi, 1979; 1980] development of broadcasting-satellite receivers has progressed rapidly in the field of direct converter systems as well as GaAs FET preamplifier systems. According to results obtained from development and the BSE experiments, it may be observed that both types of receivers, namely, direct converter and GaAs FET preamplifier have comparable noise figure performance. About 4 dB total noise figure has been achieved over 800 MHz receiver bandwidth, and 3.4 to 3.6 dB for 300 to 500 MHz tuning range, using a direct converter.

Similar progress in receivers for 12 GHz has been made in the USA and Canada as well as in Europe. In the light of these improvements and corresponding developments in lower frequency bands, it can be assumed that noise figures of the order of 1.5 dB at 700 MHz and 2.5 GHz and 4 dB at 12 GHz will soon be obtainable at reasonable cost for both community and individual reception. By assuming a noise figure of the order of 4.5 dB for 12 GHz receivers it is possible to reduce or eliminate the need for manual involvement in the receiver manufacturing process thereby reducing costs and providing a practical manufacturing margin.

In the United States, GaAs FET amplifiers are in widespread use for the reception of satellite television signals in the 4 GHz band. The noise figures of these receivers are in the 1.1 dB to 1.5 dB range. Given the development of high yield, monolithically integrated amplifier production techniques, reasonable cost receivers will be obtainable in the 700 MHz and 2.5 GHz bands.

A measurement of the distribution of the characteristics of direct converter 12 GHz receivers, which were selected among about 100 receivers developed for the BSE experiment, was carried out in Japan. As for distribution of noise figure, the result shows that the initial value was 4.1 dB on an average with a standard deviation of 0.25 dB, and degradation during two years was 0.15 dB.

During the past decade considerable progress has been made in the reduction of the noise figure of GaAs FET devices. GaAs FET device noise figures at 4 GHz have come down from 4 dB in 1971 to approximately 0.5 dB in 1981. While 4 GHz devices are now close to their theoretical noise figure minimums, devices at higher frequencies are still being improved. In early 1980 a projection was made [Barrera, 1980] that 10 GHz devices would achieve noise figures of around 1.3 dB and 18 GHz devices would approach 1.5 dB by 1981. The current goal is to bring the noise figure of 12 GHz devices below 1 dB. Commercially available GaAs device and GaAs FET low noise amplifier noise figure data are shown in Fig. 2-20.

4.1.2 *Intermediate-frequency stages*

For reception at 12 GHz the design will probably entail two frequency changes to ease problems of selectivity, image rejection and local oscillator radiation, but installations with only one frequency change cannot be ruled out. For the 700 MHz and 2600 MHz bands either arrangement may be attractive. When there is more than one frequency change, the first down-converter, equipped with a fixed frequency oscillator, should be placed close to, or on, the antenna. For 12 GHz reception, the choice of the value of the first intermediate frequency presents some difficulties, since these frequencies must be chosen so as to avoid interference by terrestrial broadcasting transmitters or by other services using radio transmissions of a certain power.

Apart from this constraint the intermediate frequency should not be too high because, if a suitably low noise figure is to be maintained in the intermediate frequency amplifier, its cost increases significantly with frequency; likewise the down-lead coaxial cable tends to cost more for higher frequencies.

On the other hand, if the intermediate frequency is too low, it will be difficult to eliminate the image frequency. As, in the WARC-BS Plan for Regions 1 and 3, the frequency channels for most service areas form a group of four or five, lying within a bandwidth of up to 400 MHz, the tuning range of the receiver and consequently the range of the first intermediate frequency must cover at least 400 MHz and in some cases 800 MHz. Under those conditions, the best choice for the first intermediate frequency is within the band 900 to 1700 MHz. With a local-oscillator frequency lower than the signal frequency, the first image frequency might lie, in Region 1, within the band 9.1 to 10.3 GHz; an iris filter incorporated in the waveguide of the antenna connection would make it possible to obtain an attenuation of 80 dB of that image frequency, which may be necessary in some areas to give protection against maritime radar and other high-power navigational systems (see § 10.2 of Report 473).

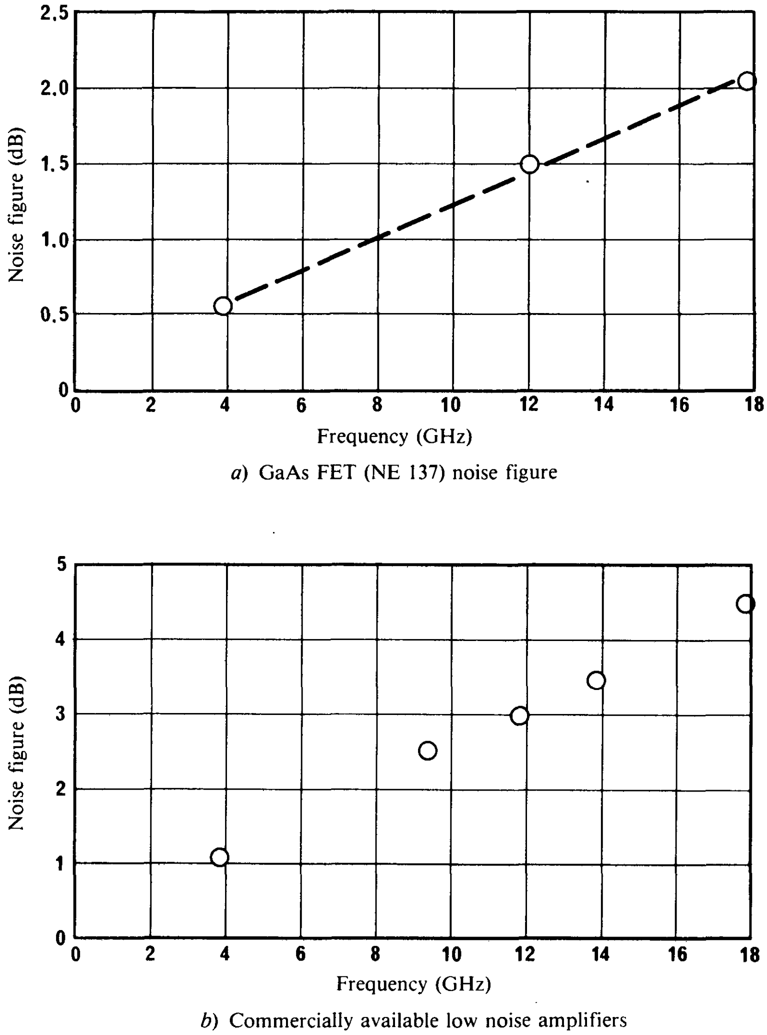


FIGURE 2-20 – *Recent achievements in GaAs low noise amplification*

The second intermediate frequency, having a bandwidth of 27 MHz, might be chosen in the vicinity of 125 MHz, which would again make it possible to avoid the broadcasting bands. For a receiver used in Regions 1 or 3, this could be achieved through use of a 27 MHz four-pole filter. The attenuation at the second image frequency should be at least 30 dB.

On the other hand most of the 4 GHz satellite television receivers in the fixed-satellite service in use in the United States use a second intermediate frequency of 70 MHz. A considerable amount of operating experience has been accumulated, and in addition a number of circuit designs have been developed and field tested. This technology should be directly applicable to 12 GHz receivers and receivers operating in other bands.

An alternative approach is the use of a phase-locked loop to obtain the video signal. If this can operate directly at the first intermediate frequency it avoids the need for a second intermediate frequency. It should be noted, however, that the loop bandwidth of some phase-locked-loop designs is comparatively wide and may result in the demodulation of adjacent channels. Therefore, use of some phase-locked-loop designs as described may be limited to areas where the received BSS channels are separated by a sufficient spacing and where signals from transmitters operating in other services, the fixed service for example, do not lie too near the desired BSS channels. A large percentage of 4 GHz satellite television receivers in use in the United States use a phase-locked-loop to demodulate the TV carrier at the second IF. This is accomplished with an integrated circuit in one of two ways. Since the operating frequency specification of the particular integrated circuit being used is 50 MHz and the second IF frequency is 70 MHz, either the integrated circuits are screened for reliable operation at 70 MHz, or the output of the second IF amplifier is divided by two and the resulting 35 MHz TV carrier is fed to the phase-locked-loop integrated circuit.

4.1.3 *Demodulation or adaptor stages*

For television, use can be made of a frequency demodulator which will deliver the video signal (and possibly a frequency modulated sound signal on a subcarrier, if a subcarrier is used for sound component transmission). In the long term it is expected that these stages, together with the programme selection stages referred to in § 5 of Report 473, would be incorporated into television receivers designed for reception of both frequency-modulated satellite and amplitude-modulated terrestrial emissions. In the interim period, the video signal can directly feed a receiver at video frequency, or amplitude modulate a carrier, to produce a conventional signal which then feeds an ordinary type of domestic receiver. In the latter case, generation of a standard vestigial-sideband signal is ideally desirable, but in practice is not essential. Devices for direct FM-AM conversion without intermediate demodulation are under study but the possible use of signal pre-emphasis and/or energy dispersal may complicate their design.

In order to reduce the possibility of interference to other services, a measure of energy dispersal is often required for satellite broadcast signals. For individual reception in the 12 GHz band, the WARC-BS-77 adopted the use of energy dispersal to ensure that the energy in any 4 kHz band is at least 22 dB below the total assigned power. For television signals, such dispersal may be achieved by adding to the video signal, before application to the feeder link, a periodic sawtooth or symmetrical triangular waveform with a repetition frequency equal to a half, or a quarter, of the field frequency. A peak-to-peak carrier deviation of 600 kHz arising from the dispersal waveform is sufficient to meet the requirement. The dispersal waveform must be removed from the video signal obtained from the demodulator if it is not to cause visible effects on the displayed picture. Experience suggests that a simple low-cost d.c. restorer will be adequate for this purpose when using a dispersal waveform of the magnitude indicated.

In Region 2 a new energy dispersal technique appears to be particularly suitable for community reception type receivers operating in the 12 GHz band. However, further study is required to determine the impact of its use on the design complexity and cost of the demodulator or adaptor stages.

As for the distribution of video signal impairments, measurements on receivers used for the BSE experiment showed that the differential gain and phase had average values of 2.1% and 1.8° with a standard deviation of 0.9% and 0.8° respectively. The measurements also indicated that degradations in differential gain and phase were 1% and 0.5° during two years.

4.2 *Low side-lobe antennas*

Because broadcasting systems involve the use of numerous receiving antennas (whether for individual or community reception), the standards of performance that are reasonable on economic grounds will tend to be poorer than for transmitting antennas. Moreover, when specifying the reference pattern, account must be taken of the probable inaccuracy of pointing the antenna towards the wanted satellite.

Figure 2-21 presents the co-polar and the cross-polar patterns of antennas for individual and community reception at 12 GHz. If parabolic antennas are used, the same patterns might apply to 2600 MHz systems and also to 700 MHz systems. It is to be noted that antennas for community reception would be expected to have somewhat better side-lobe suppression than antennas for individual reception. Moreover, side-lobe suppression techniques could be used to improve the side-lobe response of antennas, as demonstrated by Curve A″ in Fig. 2-21.

The suggested values of φ_0 to be assumed for different types of broadcasting service are given in Table 2-VI.

TABLE 2-VI – *Half-power beamwidths, φ_0 of ground receiving antennas*
(typical diameters are given in brackets)

Frequency	Broadcasting-satellite service		Terrestrial broadcasting service
	Community reception	Individual reception	
12 GHz(1)	1.0° (1.8 m)	2.0° (Regions 1 and 3) (0.9 m) 1.8° (Region 2) (1 m)	3.0°(2) (0.6 m)
2600 MHz	2.7° (3 m)	8° (1 m)	
700 MHz	9° (3.4 m)	15° (2 m parabola) 30° (Yagi)	See Recommendation 419

(1) These are the values of φ_0 adopted at WARC-BS-77 for planning of the 12 GHz broadcasting-satellite service.

(2) Some administrations propose a different value for this parameter.

Higher-gain antennas may be used in some receiving installations, for example, to obtain a better signal-to-noise ratio, but the Table is intended to indicate the values of φ_0 for the types of antenna expected to be used in the majority of receiving installations.

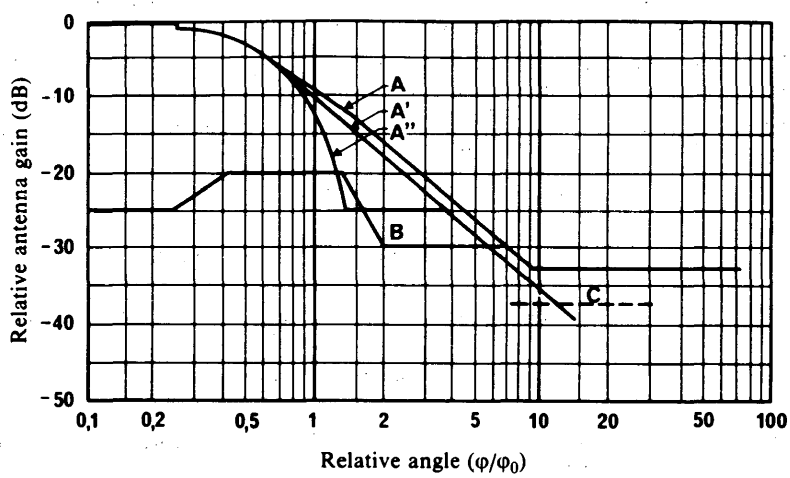
Attention is drawn to the fact that antennas with smaller beamwidths will require careful alignment and careful mounting to prevent degradation in reception, and that they may also call for a specification of maximum satellite motion more demanding than that of satellites for other services.

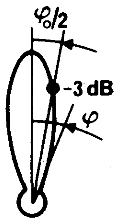
A focal-fed parabolic antenna is preferred to a Cassegrain antenna, for reasons of simplicity in design and lower cost.

Currently the antenna designs used most widely in receiving terminals are axi-symmetrical focal-point-fed parabolic. Axi-symmetric antennas, whether focal-point-fed or Cassegrain have the problem of aperture blockage by the feed or sub-reflector which places a lower limit on achievable side lobes. Techniques of lowering side lobes within this constraint have received considerable attention [NASA, 1979]. Offset fed reflectors provide the potential for a significant reduction in side lobes. For an even greater potential reduction of side lobes, techniques such as phased arrays offer possibilities [Cuccia, 1980-1981].

4.3 *Mass production and integrated circuits*

Continuing development of cost effective terrestrial television receivers has led to the development of integrated circuits which perform the same basic functions required in a satellite television receiver. Mass production and integrated circuits can be expected to keep the cost of satellite television receivers at a reasonable level, as long as sufficient standardization is maintained. A good discussion of television technology and its impact on BSS ground terminals is available in [Cuccia, 1980-1981]. Report 473 summarizes the ground terminal cost projections which have been made on the basis of this technology.





Relative antenna gain (dB):

Co-polar component

A: individual reception without sidelobe suppression

0 for $0 \leq \varphi \leq 0.25\,\varphi_0$

$-\ 12\,(\varphi/\varphi_0)$ for $0.25\,\varphi_0 < \varphi \leq 0.707\,\varphi_0$

$-\ [9.0 + 20 \log (\varphi/\varphi_0)]$ for $0.707\,\varphi_0 < \varphi \leq 1.26\,\varphi_0$

$-\ [8.5 + 25 \log (\varphi/\varphi_0)]$ for $1.26\,\varphi_0 < \varphi \leq 9.55\,\varphi_0$

$-\ 33$ for $9.55\,\varphi_0 < \varphi$

A′: community reception without sidelobe suppression

0 for $0 \leq \varphi/\varphi_0 \leq 0.25$

$-\ 12\,(\varphi/\varphi_0)^2$ for $0.25 < \varphi/\varphi_0 \leq 0.86$

$-\ [10.5 + 25 \log (\varphi/\varphi_0)]$ for $0.86 < \varphi/\varphi_0$

A″: feasible for community and possibly for individual reception when sidelobe-suppression techniques are used

0 for $0 \leq \varphi/\varphi_0 \leq 0.25$

$-\ 12(\varphi/\varphi_0)^2$ for $0.25 < \varphi/\varphi_0 \leq 1.414$

$-\ 25$ for $1.414 < \varphi/\varphi_0 < 3.8$

$-\ [10.5 + 25 \log (\varphi/\varphi_0)]$ for $3.8 < \varphi/\varphi_0$

B: *Cross-polar component (both types of reception)*

$-\ 25$ for $0 \leq \varphi \leq 0.25\,\varphi_0$

$-\ (30 + 40 \log |(\varphi/\varphi_0) - 1|)$ for $0.25\,\varphi_0 < \varphi \leq 0.44\,\varphi_0$

$-\ 20$ for $0.44\,\varphi_0 < \varphi \leq 1.4\,\varphi_0$

$-\ (30 + 25 \log |(\varphi/\varphi_0) - 1|)$ for $1.4\,\varphi_0 < \varphi \leq 2\varphi_0$

$-\ 30$ until intersection with co-polar component curve; then as for co-polar component

C: *Minus the on-axis gain*

FIGURE 2-21 – *Reference patterns for co-polar and cross-polar components for receiving antenna (Regions 1 and 3)*

Note. – The flat portion of the curves up to $\varphi/\varphi_0 = 0.25$ takes account of the pointing error of the antenna.

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CHAPTER 3

COMPATIBILITY BETWEEN BROADCASTING-SATELLITE SYSTEMS AND OTHER SYSTEMS

1. Broadcasting-satellite systems

There are at present two possibilities for satellite broadcasting systems:

- satellite dedicated for broadcasting,
- multi-purpose satellite for broadcasting and for communications.

Various features of these systems and possible variants are discussed below.

2. Broadcasting satellite

Such a system envisages a satellite with broadcasting capacity only. As the cost of the ground segment is the major component of total system cost, it is important to reduce it as much as possible. This implies a high-power satellite, capable of providing a high power flux-density at the surface of the Earth (within the limits set by the Radio Regulations).

The desired coverage of the service area could be achieved by either single-beam or spot-beam coverage.

2.1 *Single-beam coverage*

The normal diameter of the coverage circle with respect to antenna beamwidth and the e.i.r.p. of the satellite is shown in Fig. 1-1 which shows that, for a greater coverage with a given e.i.r.p. of the satellite, a larger antenna beamwidth (lower antenna gain) is desirable.

2.2 *Multi-beam coverage*

To provide greater power flux-density in a required area a higher-gain satellite antenna is needed, thereby limiting the service area and consequently requiring a greater number of spot beams for a larger required area. In such an approach, careful frequency separation is desirable. A slight increase in the cost of the multi-beam antenna of the satellite could lead to considerable reduction in the cost of the ground segment. System cost evaluations are discussed in Chapter 4.

3. Multi-purpose satellite for both broadcasting and communications

To produce a cost effective system, a mixed satellite system combining communication links with broadcasting could be envisaged in terms of either single-beam coverage or spot-beam coverage. Frequency considerations both for the FSS and for the BSS respectively will have to be in accordance with the Radio Regulations.

4. Frequency bands for the broadcasting-satellite service

The WARC-79 revised the Radio Regulations and allocated six frequency bands for satellite broadcasting. These frequency bands along with the other services sharing them, power flux-density (pfd) and other constraints, are given in Table I-III.

5. Frequency sharing and interference

Optimum use should be made of the geostationary orbit and the frequency bands allocated to the BSS. Satellite broadcasting may cover large areas of the surface of the Earth, consequently other services operating in the same frequency bands, terrestrial broadcasting, fixed and mobile services may experience harmful interference. Therefore, an administration planning a satellite broadcasting system should take every precaution not to cause harmful interference to the services of other administrations. In this respect, the following aspects need special consideration:

– *Agreements and associated plans*

Resolution No. 507 of the WARC-79 states:

"1. that stations in the broadcasting-satellite service shall be established and operated in accordance with agreements and associated plans adopted by world or regional administrative conferences, as the case may be, in which all the administrations concerned and the administrations whose services are liable to be affected may participate."

A frequency and orbit position assignment plan for the BSS for the band 11.7-12.5 GHz in Region 1 and 11.7-12.2 GHz in Region 3, was formulated by the WARC-BS-77. This Conference specified sharing conditions for broadcasting-satellite systems serving these Regions in this band. The WARC-79 annexed this Orbit/Frequency Assignment Plan to the Radio Regulations as Appendix 30. Based on the recommendation of the WARC-BS-77, the WARC-79 resolved (Resolution No. 701) that a regional administrative radio conference for planning in Region 2 should be held not later than 1983. Principles and criteria for sharing in the interim period are given in Article 12 and Annexes 7 and 9 of Appendix 30 to the Radio Regulations. This conference was held in Geneva in June/July 1983 and the resulting down-link and feeder-link Plans for Region 2 may be found in the Final Acts of RARC SAT-83. These Plans are scheduled to be incorporated into the Radio Regulations by WARC ORB-85.

6. Elements to be considered in frequency sharing

In establishing the bases for frequency sharing between two types of services, certain elements should be considered. These include the protection ratio necessary to ensure that the interference from one of the services will be acceptable to the others.

Values for protection ratios involving the broadcasting-satellite and terrestrial services are listed in Report 634. Also, the factors to be taken into account are the technical characteristics related to sharing, such as e.i.r.p., antenna aperture, side-lobe levels, receiver sensitivity and the kind of modulation used, as well as geographical considerations (such as the line of direction from the interfered-with to the interfering position and the establishment of "exclusion areas" and service areas). Constraints and limitations to these factors may be required to permit frequency sharing. Further sharing in a common area may be achieved by time sharing.

If co-area, co-frequency sharing is not possible, constraints and limitations necessary to permit sharing through the use of geographical frequency sharing arrangements would be required.

– *Sound broadcasting*

In existing broadcasting-satellite allocations, there is no distinction made between sound and television systems. Satellite broadcasting in the 620-790 MHz band is permitted by footnote 693 but is limited to FM television.

The WARC-79 recommended that the band 500-2000 MHz be analyzed to establish optimum locations for satellite sound broadcasting. Further study is required to determine if there is any specific segment of this band that is particularly desirable. Further study is also required to determine if sharing is feasible and, if so, under what conditions. Thus the remaining portion of this Chapter deals only with television broadcasting.

7. General equation for the limiting value of power flux-density of the unwanted signal to protect the wanted service

As previously noted, when a broadcasting-satellite service shares frequencies with a terrestrial service, it may be necessary to impose limitations on the power flux-density produced by the unwanted signal at the receiving stations of the wanted service. A general equation for determining the limit on power flux-density is:

$$F_s = F_{tqp} - R_q + D_d + D_p - M_r - M_i \qquad (1)$$

(*Note.* – This equation may not be valid when the satellite signal arrives near grazing incidence. In this case an additional margin must be included.)

where:

- F_s: maximum power flux-density (dB(W/m^2)) to be allowed at the protected station,
- F_{tqp}: minimum power flux-density (dB(W/m^2)) to be protected, i.e. the power flux-density which, in the face of thermal noise only, yields the output signal quality q that is to be exceeded for some specified high percentage of the time p,
- R_q: protection ratio (ratio of the wanted-to-interference signal power at the receiver input) (dB) for barely detectable interference when the output signal quality has been degraded by the thermal noise to q,
- D_d: discrimination (dB) against the interfering signal due to directivity of the receiving antenna,
- D_p: discrimination (dB) against the interfering signal due to polarization of the receiving antenna. This factor is often combined with D_d as a single term,
- M_r: margin (dB) for possible ground reflection of interfering signal,
- M_i: margin (dB) for possible multiple interference entries.

The limit on power flux-density given by equation (1) ensures that the output signal quality at the receiving station of the wanted signal will be equal to q even when the power flux-density of the system has faded to the level F_{tqp}. During $p\%$ of the time, the power flux-density of the system will be higher than F_{tqp} and the output signal quality will be higher than q.

If it is desired to express F_s in terms of the median value of power flux-density from the wanted system, F_{tqm}, which yields the same output quality statistics, the equation is:

$$F_s = F_{tqm} - M_p - R_q + D_d + D_p - M_r - M_i \tag{2}$$

where M_p is the difference (dB) between the median value of the wanted signal level and the level exceeded $p\%$ of the time.

Equations (1) and (2) can be applied to calculate the limits on the unwanted power flux-density, appropriate to any given wanted service. In the case of the terrestrial broadcasting service, the receiving station to be protected is assumed to be on the boundary of the potential service area of the terrestrial transmitter. This boundary is defined as the geographic contour within which the power flux-density from the terrestrial transmitter equals or exceeds that required to produce an output signal (television picture or sound) of acceptable quality in the absence of interference and man-made noise at 50% of the locations for at least $p\%$ of the time, where for example, p has a specified value in the range from 90% to 99%. In the terrestrial broadcasting service it is also traditional to describe the incident signal in terms of field strength in dB(μV/m) rather than in terms of power flux-density in dB(W/m^2). The former can be obtained from the latter by adding 146 dB.

7.1 *Power flux-density requirements*

The power flux-density required to permit individual or community reception has been defined in Chapter 1, § 4.4 and Table 1-XIV a and b.

Corresponding values for the 12 GHz band were given in Report 627-1 (Kyoto, 1978) for terrestrial AM-TV broadcasting services.

7.2 *Calculation of power flux-density*

To examine the possibility of an interference-free broadcasting-satellite system to neighbouring countries, it is essential that the power flux-density produced at the surface of the Earth from the proposed satellite emission be determined and compared with the permissible power flux-density as laid down by the Radio Regulations. Annex 3-I to this Chapter deals with a method for calculation of power flux-density.

7.3 *Field strengths and power flux-densities to be protected*

The field strengths and power flux-densities requiring protection are discussed in the sections concerning each frequency band.

7.4 *Protection ratios*

Report 634 deals with this subject in some detail and presents required values of protection ratio for different systems.

7.5 *Use of special techniques to meet limitations on power flux-density*

Energy dispersal techniques for frequency-modulation could be considered to spread the radiated power over a wider radio frequency bandwidth to meet power flux-density limitations when specified for narrow bandwidths such as 4 kHz. Careful consideration, however, should be given to the technical and economic impacts of the application of such techniques.

Some examples of the use of energy dispersal are given in the sections concerned.

7.6 *Unwanted emissions*

In addition to the required parameters for frequency sharing in the same band, thought must be given to services operating in adjacent bands, and to the harmonically related bands.

8. **Sharing in the 620 to 790 MHz band**

Television broadcasting from satellites using only frequency modulation is dealt with in this section.

8.1 *Sharing with the terrestrial broadcasting service*

Frequency-sharing between a broadcasting-satellite system and a terrestrial broadcasting system requires that the receivers of each system be protected against interference from the emissions of the other system. The terrestrial receivers can be protected by imposing limits on the power flux-density produced by the broadcasting satellite at points within the terrestrial service area, as described in § 8.1.1. Conversely, the broadcasting-satellite system receivers can be protected against interference by requiring adequate separation between the terrestrial transmitter and the satellite receiver. An example of the separation required in a particular case is given in Fig. 3-2.

8.1.1 *Protection of the terrestrial broadcasting service*

To protect the terrestrial television broadcasting service from interference from a television broadcasting satellite, it is necessary to place a limit on the power flux-density that the satellite is allowed to produce at points within the service areas of the terrestrial television broadcasting stations.

A provisional value for this limit in the band 620 to 790 MHz is given in Recommendation No. 705 of the WARC-79:

$$F_s = \left\{ \begin{array}{l} -129 \\ -129 + 0.4\,(\delta - 20) \\ -113 \end{array} \right\} \text{dB(W/m}^2\text{)} \qquad \begin{array}{ll} \text{for} & \delta \leqslant 20^\circ \\ \text{for } 20^\circ < & \delta \leqslant 60^\circ \\ \text{for } 60^\circ < & \delta \leqslant 90^\circ \end{array}$$

where δ (degrees) is the angle of arrival of the satellite signal above the horizontal plane.

In Recommendation No. 705, the CCIR was urged to study the frequency-sharing criteria to be applied in this band and to recommend a value to be used in lieu of the provisional limit. Several administrations subsequently conducted such studies and have made their individual suggestions regarding the limit on power flux-density that should be adopted.

In each case, the limit was calculated from an equation equivalent to equation (1) or equation (2). While there was not unanimity in the suggested limits on power flux-density the differences can be understood in terms of the differences between the values assumed for the parameters in the equations. A summary of assumptions is given in Table I of Report 631.

8.2 *Sharing with fixed and mobile services*

Limitations on power flux-densities which would have to be imposed on the broadcasting-satellite television service to protect fixed and mobile services, including trans-horizon radio-relay systems, at present allocated the same frequency bands as the broadcasting service, may cause difficulties in such sharing. Careful consideration is, therefore, necessary before introducing the broadcasting-satellite service. Tropospheric scatter systems which point towards the geostationary orbit are particularly vulnerable. Examples of the required power flux-density limits in the case of sharing with land mobile services are given in Annex 3-II.

8.3 *Protection of the broadcasting-satellite service*

Protection of the broadcasting satellite ground receiving stations is normally achieved by maintaining a minimum separation between them and the terrestrial transmitter. The minimum separation depends on the characteristics of both the earth receiving installation and the transmitting station in the terrestrial broadcasting system. An example of the terrestrial power flux-density and separation distance required to protect the satellite service is given in Figs. 3-1 and 3-2 for the following characteristics:

8.3.1 *Terrestrial broadcasting system*

- transmit station e.i.r.p.: 1 MW;
- transmit antenna height above average terrain: 300 m;
- luminance signal-to-unweighted r.m.s. noise, for just perceptible interference: 36 dB (525 lines), 45 dB (625 lines);
- minimum signal to be protected: 64 dB(μV/m) (525 lines), 65 dB(μV/m) (625 lines);
- receive antenna maximum gain (Recommendation 419): 16 dB;
- required protection ratio from satellite service: 42 dB (525 lines) and 52 dB (625 lines).

8.3.2 *Broadcasting-satellite service for community reception*

Frequency modulation with peak-to-peak deviation: 10.6 MHz (525 lines), 13 MHz (625 lines):

- luminance-signal-to-unweighted r.m.s. noise (beam edge): 36 dB (525 lines), 45 dB (625 lines);
- satellite power flux-density at beam edge:
  -118 dB(W/m^2) (525 lines),
  -110 dB(W/m^2) (625 lines);

- receive antenna gain (3.3 m diameter, 9° beamwidth): 25 dB;
- receive antenna discrimination (Report 810): $(10.5 + 25 \log \varphi/\varphi_0)$;
- required protection ratio from terrestrial service: 18 dB (525 lines), 28 dB (625 lines).

Note. – The calculations do not include allowance for polarization discrimination nor for ground reflections or multiple interference. Note also that the example shown in this section uses a protection ratio of 18 dB which would result in a picture impairment level between 3.5 and 4 for less sensitive material. Report 634 now indicates that protection ratios as high as 32 dB may be required for less impairment of more sensitive material. Such protection ratios would result in larger required separation distances and larger required angles of discrimination.

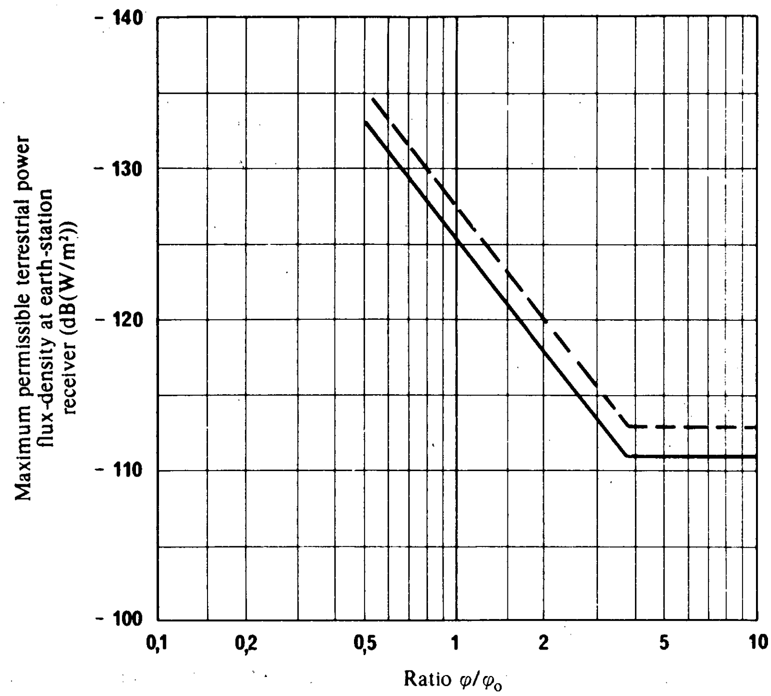


FIGURE 3-1 — *Example of maximum permissible power flux-density from a terrestrial transmitter to protect an earth-station receiver*

φ : direction of terrestrial transmitter relative to the axis of the main beam of the earth-station antenna

φ_0 : 3 dB beamwidth of earth-station antenna

———— : 525-line system M (Canada, USA)

— — — — : 625-line systems

9. Sharing in the frequency band 2500 to 2690 MHz

In accordance with No. 2562 of the Radio Regulations, the following permissible limits for power flux-density at the surface of the Earth are established:

$$\left.\begin{array}{l} -152 \\ -152 + \dfrac{3(\delta-5)}{4} \\ -137 \end{array}\right\} \text{dB (W/m}^2\text{) in any 4 kHz band for } \begin{array}{l} 0^\circ \leqslant \delta \leqslant 5^\circ \\ 5^\circ < \delta \leqslant 25^\circ \\ 25^\circ < \delta \leqslant 90^\circ \end{array}$$

where δ is the angle of arrival (in degrees) above the horizontal plane.

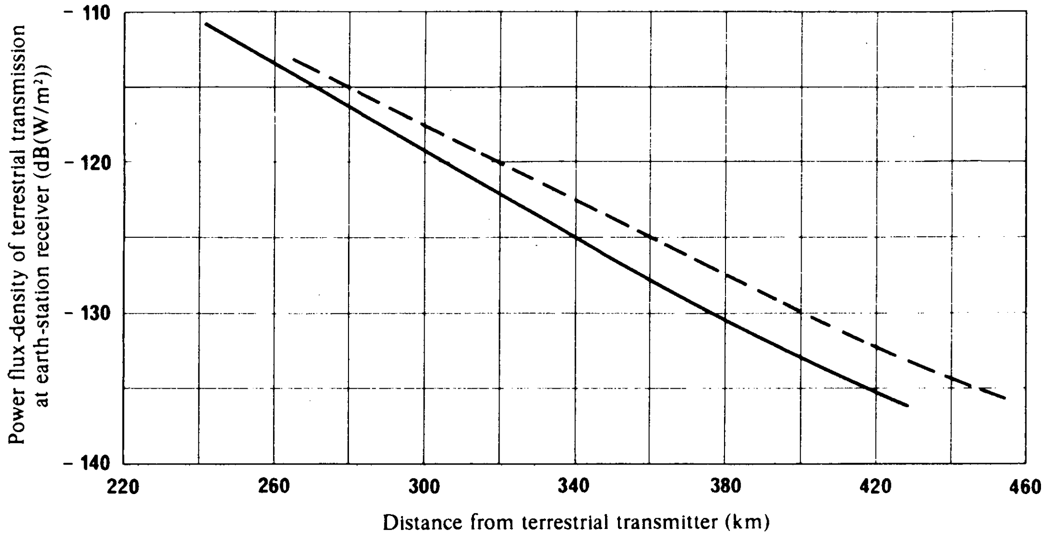


FIGURE 3-2 — *Example of separation distance to protect earth-station receivers from terrestrial transmitters*

Terrestrial transmitter e.i.r.p.: 1 MW

Antenna height above average terrain: 300 m

Frequency: 700 MHz

——— : 525-line system M (Canada, USA)

— — — : 625-line systems

9.1 *Sharing with line-of-sight radio-relay systems*

Co-channel operation between a broadcasting-satellite system and a terrestrial radio-relay system results in a number of limitations because the presence of a transmitter of a terrestrial radio-relay system within, or in the neighbourhood of, the service area of the broadcasting-satellite system gives rise to a "hole" in the broadcasting service area. This makes planning of the radio-relay channelling very difficult.

9.2 *Sharing with trans-horizon radio-relay systems*

Trans-horizon radio-relay systems are subject to geographical and frequency constraints which limit planning flexibility and could make it difficult to avoid potential interfering configurations. Sharing involves consideration of the directions of pointing of the antennas of the trans-horizon system to protect the trans-horizon system receivers as well as considerations of the directivity of the satellite antenna where the trans-horizon receiver is within the coverage area of the broadcasting satellite and suitable protection is not available; one possible remedy would be to modify the trans-horizon system to use different frequencies. Alternatively, sharing with trans-horizon radio-relay systems in this band is only feasible if the limitations placed on the power flux-density as laid down in No. 2564 of the Radio Regulations are observed. This Regulation states:

> "The power flux-density values given in No. **2562** are derived on the basis of protecting the fixed service using line-of-sight techniques. Where a fixed service using tropospheric scatter operates in the band mentioned in No. **2563** and where there is insufficient frequency separation, there must be sufficient angular separation between the direction to the space station and the direction of maximum radiation of the antenna of the receiving station of the fixed service using tropospheric scatter to ensure that the interference power at the receiver input of the station of the fixed service does not exceed −168 dBW in any 4 kHz band."

9.3 *Protection of broadcasting-satellite systems*

The receivers of the broadcasting-satellite service would be susceptible to interference from trans-horizon radio-relay transmitters within an elongated zone which extends for a considerable distance in the direction in which the trans-horizon antenna is pointed; the extent of this zone is a function of the antenna directivity and the relative directions of the trans-horizon link and the satellite.

The Radio Regulations have laid down the following additional provisions to protect the broadcasting-satellite service in the band 2500 to 2690 MHz.

> "When planning new tropospheric scatter radio-relay links in the band 2500-2690 MHz, all possible measures shall be taken to avoid directing the antennas of these links towards the geostationary-satellite orbit." (RR 764)

> "Administrations shall make all practicable efforts to avoid developing new tropospheric scatter systems in the band 2500-2690 MHz." (RR 762)

9.4 *Sharing with a certain type of fixed terrestrial television distribution system*

An example of the characteristics of the type of terrestrial television distribution system in question is given in Table 3-I. These characteristics are typical of the Instructional Television Fixed Service (ITFS) system used in parts of Region 2. Specifically, such systems utilize approximately 10 W transmitters with omnidirectional, or directional, antennas and specified receiving points (educational institutions) which employ directional parabolic receiving antennas. It is believed that this type of service is comparable to that of community reception such as defined by the BSS. A range of more or less standardized receiving antennas is used with apertures of 0.61, 1.22, 1.83 and 2.44 m (2, 4, 6 and 8 ft). The appropriate antenna is selected for the distance from the transmitter. The receiver noise figure in many of the systems is 9 dB. However, recent technological advances will permit use of receivers with noise figures as low as 3.5 dB.

Frequency-sharing in the vicinity of 2600 MHz between a broadcasting-satellite system and an ITFS system is technically feasible under certain conditions. A limit on the power flux-density of the satellite signal would have to be specified to protect the ITFS service and a "hole" or an area of interference within the satellite service zone would be created due to interference from the ITFS operation. The size of this area of interference depends on the transmitter power and height of the transmitting antenna of the ITFS system, the angular discrimination of the earth receiving antennas of the broadcasting-satellite system, and the angle of elevation of the satellite.

TABLE 3-I – *Example of characteristics for a typical ITFS system (operating in the vicinity of 2600 MHz)*

Amplitude modulation, vestigial sideband, System M (USA and Canada)		Omnidirectional
E.i.r.p.	(dBW)	20
Service range (approximate)	(km)	50
Received signal to be protected	(dB(μV/m))	56
Luminance signal-to-unweighted r.m.s. noise	(dB)	43
Receiving antenna gain: for diameter (m): 0.61 1.22 1.83 2.44	(dB)	 21.5 27.5 31 33.5
Receiving antenna discrimination: where: φ : angle off the main beam axis, φ_0: angle between the half-power points.	(dB)	$10.5 + 25 \log(\varphi/\varphi_0)$
Required protection ratio from satellite signals	(dB)	50
Receiving antenna beamwidth	(degrees)	12.8; 6.4; 4.3 and 3.2

9.5 *Protection of the ITFS system*

The television broadcasting-satellite service using wideband frequency-modulation can share frequencies with ITFS in the 2600 MHz band provided the satellite power flux-density for each channel is limited in accordance with the values shown in Fig. 3-3.

It can be shown that the allowable interfering power flux-density ρ_i is:

$$\rho_i = \frac{C/N}{C/I} \cdot \frac{4\pi kTB}{\lambda^2} \cdot \frac{1}{G(\varphi)} \tag{3}$$

where $G(\varphi)$ is the ITFS antenna gain at an off-axis angle φ.

In Fig. 3-3, curves are provided for each ITFS antenna aperture for noise figures of 9 and 3.5 dB, and for a luminance signal-to-unweighted r.m.s. noise ratio of 43 dB, representing the likely range of system performance. The dashed line shows the pfd for the broadcasting-satellite system based on a satellite field strength of 28 dB (μV/m) to be protected at beam centre (i.e. -115 dB(W/m^2) beam centre).

For the contiguous United States, angles of elevation are almost always greater than 30° for satellites in mid-continental locations. Note also that the offset angle (between the main beam of the broadcasting-satellite earth-station antenna and a terrestrial station antenna) will never be less than the angle of elevation to the satellite, regardless of terrestrial system azimuths. Therefore, as can be seen from Fig. 3-3, a broadcasting-satellite system would not cause interference to a 43 dB *S/N* ITFS system having the characteristics shown in Table 3-I even if the ITFS receiver has a noise figure as low as 3.5 dB (as can be seen in Curves 1A, 2A, 3A, 1B, 2B and 3B).

9.6 *Protection of the television broadcasting-satellite system*

An earth receiving installation for community reception can be protected from ITFS interference provided that the power flux-density of the latter is limited to a maximum of -115 dB(W/m^2) as seen from Fig. 3-4. This protection is achievable at a minimum angle of elevation for the satellite of 31°.

The necessary separation between the earth receiving installation location and the ITFS transmitter for different values of the ITFS power flux-density and angles of discrimination in the range from 60 km to over 140 km is shown in Fig. 3-5. These values assume no site shielding, and were calculated from the following formula:

$$E_t(d,\ r)\ \text{E.i.r.p.}_t\ -\ 10 \log (4\pi d^2)\ -\ L_t(d,\ r)\ +\ 146 \tag{4}$$

where:

- $E_t(d,\ r)$: signal emitted by terrestrial transmitter at distance, d, with probability, r(%), (dB(μV/m)),
- d : distance from terrestrial transmitter,
- $L_t(d,\ r)$: attenuation in excess of the spreading loss at distance, d, not exceeded for r% of the time (here, assumed 1%).

Note that a protection ratio of 30 dB is used in this example, which is consistent with Report 634 and the value of $L_t(d,\ r)$ is consistent with Report 569 and assumes a value of H = 200 m.

The separation distances shown in Fig. 3-5 are theoretical, worst-case values. Some observations have been made of interference from ITFS transmitters to receivers similar to those that might be used in the broadcasting-satellite service. These interference values were obtained from experiments conducted with the ATS-6 spacecraft and a multiplicity of small receiving installations, some of which were sited near ITFS transmitters or at various locations within their antenna patterns.

Although the actual separation distances and discrimination angles were not, in several cases, sufficient to ensure interference-free reception based on the criteria of Report 631, no interference was noted even though such receivers were quite close to the transmitter or almost in its main beam.

Although these observations were not sufficiently detailed or extensive enough to dictate changes in the methods of calculation described in Report 631, they do suggest that the methods therein are conservative, and that there may be more interference-free locations and areas than indicated by the curves in Report 631.

Results and conclusions in this section are based on theoretical considerations. Precise measurements of interference in the vicinity of terrestrial systems in the band 2500 to 2690 MHz are needed to confirm these predictions.

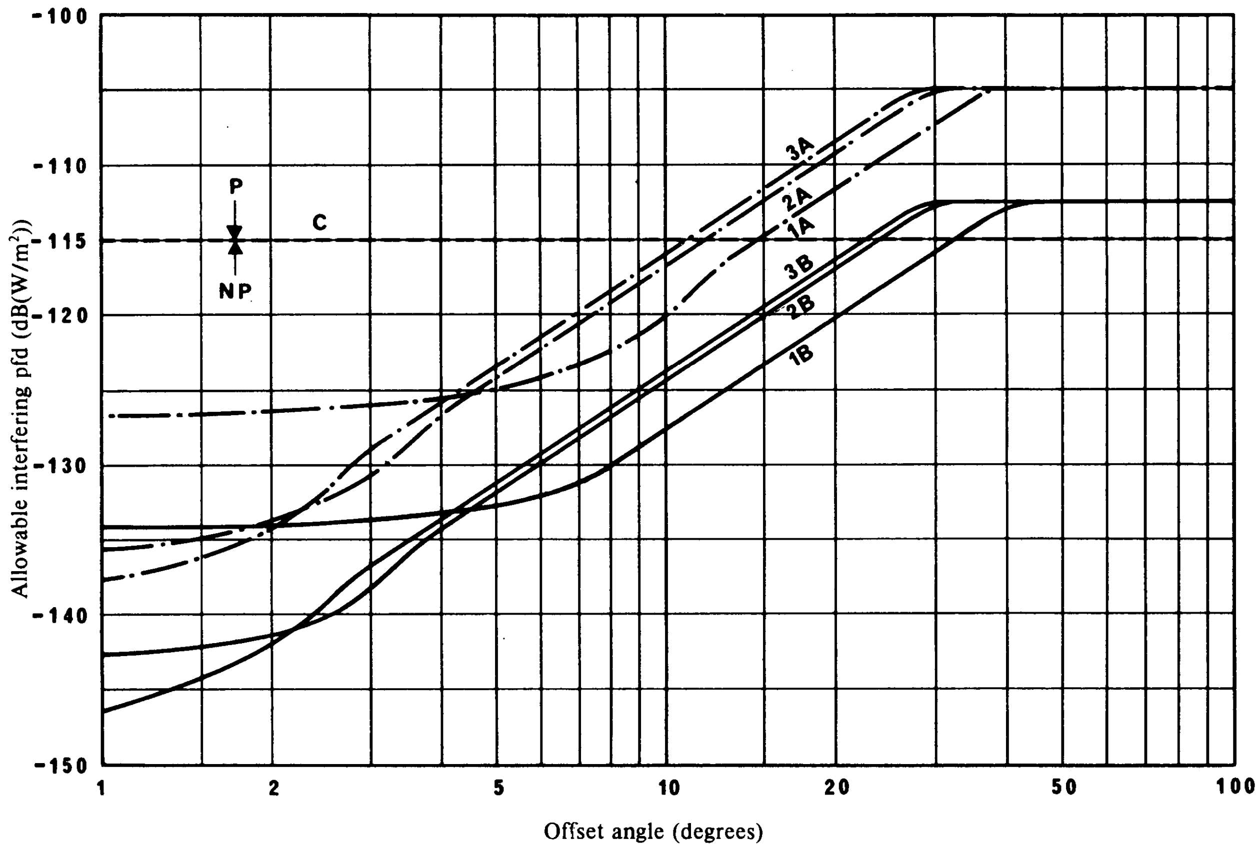


FIGURE 3-3 – *Allowable interfering broadcasting satellite power flux-density as a function of offset angle (for protection of the ITFS system)*

Curve	Diameter, D (m)	Noise figure (dB)
1A	0.6	9
1B	0.6	3.5
2A	1.83	9
2B	1.83	3.5
3A	2.44	9
3B	2.44	3.5

Note. – S/N = 43 dB and C/I = 50 dB for all curves.

C – – – – Signal to be protected (beam centre pfd, −115 dB(W/m^2))
P : protected
NP: not protected

9.7 *Energy dispersal*

The use of energy dispersal in the 2.6 GHz band has been examined by one administration. Calculation of the required bandwidth and corresponding signal-to-noise ratio leads to the conclusion that the performance of a 2.6 GHz broadcasting-satellite system using small receiving antennas can be severely limited by the need to provide energy dispersal.

9.8 *Sharing with the radioastronomy service*

Report 224 discusses sharing between the radioastronomy service and the broadcasting-satellite service. In the shared band, the possibilities of geographical sharing need to be explored. In making assignments, the attention of administrations is drawn to the adjacent band problems discussed in Reports 224 and 807.

10. Sharing in the 12 GHz frequency band

Operation of the various services in the band 11.7-12.75 GHz as well as sharing with other services should be in accordance with the Table of Frequency Allocations of the Radio Regulations and the related footnotes Nos. 836 to 850.

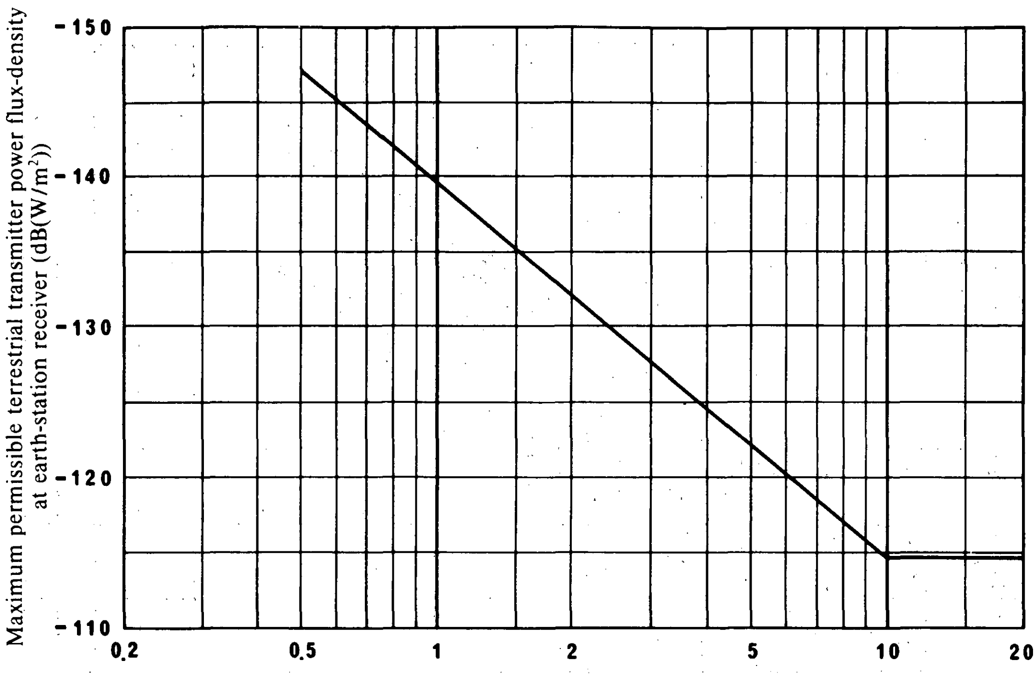


FIGURE 3-4 – *Example of maximum permissible power flux-density from terrestrial station transmitters to protect BSS earth-station receivers*
(ITFS at 2.6 GHz)

φ : direction of satellite relative to axis of main beam of terrestrial receiving antenna
φ_0: 3 dB beamwidth of terrestrial receiving antenna

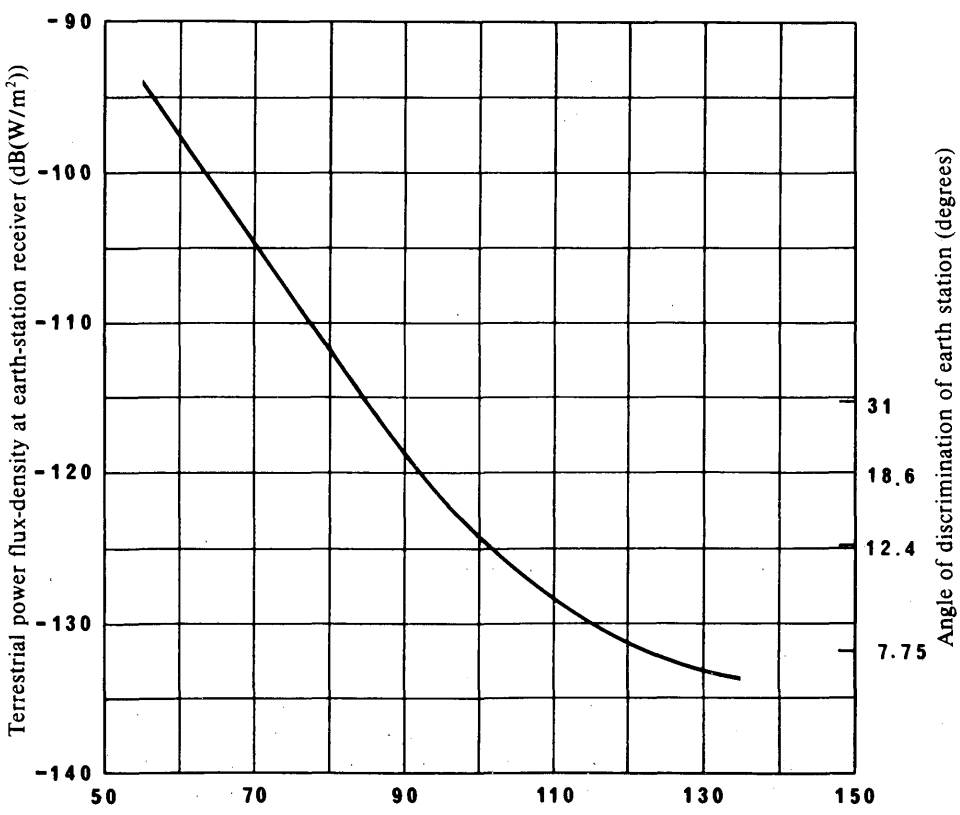


FIGURE 3-5 – *Example of separation distance to protect earth-station receivers from terrestrial transmitters*
(ITFS at 2.6 GHz)
E.i.r.p.: 20 dBW

It is inherent in the concept of a broadcasting-satellite service that a large number of receiving stations will be distributed at random over the service area. For reasons of economy and by the nature of the domestic environment, the installations are unlikely to offer a high degree of protection against interference. Any terrestrial service operating within the service area of a broadcasting satellite and sharing the same channel will therefore be a potential source of interference to the broadcasting receivers within a distance from the terrestrial transmitter, determined by its power and radiation characteristics.

In some climates, rainfall attenuation may require large propagation margins if service of a high reliability is to be provided. The effect of this margin should be taken into account when considering sharing problems. Tables 1-X to 1-XII give atmospheric attenuation data for different climatic conditions.

10.1 *Conditions for the protection of terrestrial systems against interference from broadcasting satellites*

10.1.1 *General considerations*

The bandwidth of a 625-line broadcasting-satellite emission is given as an example in Report 215 as 27 MHz. For conditions where no video information is present or where the video information is repetitive in certain ways, the power can collect itself in the form of spikes of energy. Since some terrestrial services may be affected by power spectral density rather than total interfering power it is important to try and relate the power of a broadcasting satellite emission to the power in different bandwidths. This leads to consideration of applying energy dispersal to the broadcasting-satellite emission or interfered-with service.

For terrestrial systems carrying analogue FDM-FM telephony, in which a 4 kHz bandwidth is considered when assessing interference levels, the advantages of energy dispersal are significant. Studies of energy dispersal in the broadcasting-satellite service have shown that "natural" dispersion values of the order of 10 dB exist (Report 631).

The WARC-BS-77 adopted the use of energy dispersal for the broadcasting-satellite service specifying the value of 600 kHz.

With such a value the advantage for terrestrial systems carrying television signals would appear to be negligible. The subjective effect of a dispersed FM-signal on an AM-TV signal actually gives a reduction in protection ratio of about 1.5 dB per MHz peak-to-peak deviation of the dispersed signal (see Report 634).

It is unlikely that there will be widespread use of energy dispersal by terrestrial services such as the fixed service.

The power flux-density in a 4 kHz bandwidth from a broadcasting satellite emission can be simply obtained by subtracting the appropriate value in Table 3-II from the total power flux-density in the 27 MHz bandwidth.

TABLE 3-II — *Energy dispersal advantage relative to a 4 kHz band*

Condition of dispersal	Energy dispersal (dB)
Natural	10
600 kHz (WARC-BS)	22
1 MHz	25
2 MHz	27
4 MHz	30

An additional protection advantage also dependent on the spectrum of a broadcasting-satellite emission may be obtained in certain circumstances by offsetting the terrestrial channels from the broadcasting-satellite channels. Such protection will of course depend on the terrestrial emission having a bandwidth equal to, or less than, the spacing between the satellite broadcast channels; and the precise advantage will depend on the spectrum of the two signals. Further study is required to produce numerical values but may lie in the range 0 to 10 dB depending on the aforementioned factors. Since Report 634 indicates that energy dispersal has an adverse effect on protection ratios it would appear to follow that energy dispersal would have an adverse effect on the advantage to terrestrial services from offsetting their emissions from those of broadcasting satellites.

The WARC-BS-77 adopted circular polarization for the broadcasting-satellite service. Terrestrial systems employing linear polarization should not rely on more than 3 dB of polarization discrimination.

10.1.2 *Interference to terrestrial broadcasting from the BSS*

Interference to terrestrial broadcasting from broadcasting satellites is treated in this section as depicted in Fig. 3-6. The figure shows the two essential elements of sharing in this situation: that of the satellite antenna discrimination (which can be expressed as a function of the off beam angle, φ) and that of the terrestrial receiver antenna discrimination (which can be expressed as a function of the angle of arrival, θ).

To illustrate the concepts of this sharing model, the beam centre indicated in Fig. 3-6 is assumed to be aimed at a point 40° north and the beamwidth of the satellite antenna is assumed to be 2°. The resulting power flux-density at that longitude is shown in Fig. 3-7 by the solid line. The different values result from the satellite antenna discrimination. The dashed line indicates for the example of a radio-relay system carrying television (line 2 in Table 3-III), the interfering power flux-density which can be accepted. The different values result from the radio-relay antenna discrimination. Where the dashed line is above the solid line, sharing is feasible for any direction of azimuth of the terrestrial receiver. Where the solid line is above the dashed line, sharing is only feasible when the radio-relay antenna is displaced in azimuth by a suitable amount from the satellite position on the geostationary orbit. This same example is plotted in Fig. 3-8 in the form of a contour map showing that with this particular example of terrestrial systems sharing is feasible in the non-hatched portions with no restrictions. Sharing is feasible in the hatched portions only with restrictions on the pointing direction of the radio-relay antenna.

It should be noted that the above example only considers the case of a single satellite beam. Whilst a 2° beam at 40° N is considered a fairly worst-case example, the precise geographical area over which sharing is feasible will depend on the outcome of the actual orbit position/frequency assignment plan which is established. The geographical area will also depend significantly on the sensitivity of the particular terrestrial services using the band.

The above example is for a single value of satellite antenna beamwidth. A more general way of expressing the sharing criteria for any satellite beamwidth is illustrated below for the example of a terrestrial broadcasting system.

In the example, the necessary value for the protection ratio for just perceptible interference, PR_0, is 56 dB (wanted signal AM-VSB, 625 lines; unwanted signal FM, nominal peak-to-peak frequency deviation 8 MHz). However, taking into account the masking of interference by random noise, a lower value, PR_1, for the protection ratio, calculated according to the formula:

$$PR_1 = PR_0 - (49 - S/N) \tag{5}$$

has been adopted in our calculations, where S/N is the peak-to-peak luminance signal-to-r.m.s. weighted noise, exceeded for 99% of the time at the edge of the coverage area in the terrestrial broadcasting system. This signal-to-noise ratio is assumed to be 39 dB.

Thus,

$$PR_1 = 56 - (49 - 39) = 46 \text{ dB} \tag{6}$$

The minimum power flux-density of the wanted signal at the edge of the coverage area in the terrestrial broadcasting system, exceeded for 99% of the time is -85.5 dB(W/m^2). Thus, the interfering power flux-density of a signal arriving from the least favourable direction in the horizontal plane should not exceed -131.5 dB(W/m^2).

On the assumption that a typical power flux-density produced on Earth by the broadcasting-satellite at the beam centre in clear weather is -98 dB(W/m^2), a discrimination of about 33.5 dB must be ensured.

The envelope side-lobe diagram of the receiving antenna in the terrestrial broadcasting system is assumed to comply with the reference curve A given in Fig. 2-21. Values for the antenna gain according to this reference curve are shown in Table 3-IV.

It appears from Table 3-IV that the required discrimination of 33.5 dB cannot be obtained from the angular response of the receiving antenna in the terrestrial broadcasting system alone. Thus, co-channel operation of the terrestrial service using amplitude modulation within the broadcasting-satellite service area is not possible.

TABLE 3-III – *Examples for interfering power flux-densities acceptable by systems in the 12 GHz band*

Wanted system	Percentage of time	Maximum interfering power flux-density (dB(W/m²)) for angle of arrival of 0° relative to the main axis of terrestrial antenna	Antenna off-beam discrimination(1)
1	2	3	4
Line-of-sight FM-radio relay links carrying telephony (3)	99.9	—128/4 kHz (2) at any angle of arrival	35-25 log φ
Line-of-sight FM-radio relay links carrying television programmes (3)	99.9	—125/5 MHz	$10.5+25 \log (\varphi/\varphi_0)$
Line-of-sight AM multi-channel systems carrying television programmes (3)	99.9	—134/5 MHz	$10.5+25 \log (\varphi/\varphi_0)$
Terrestrial AM television system	99	—130/5 MHz	$9+20 \log (\varphi/\varphi_0)$
Terrestrial FM television system	99	—130/27 MHz	$9+20 \log (\varphi/\varphi_0)$
Broadcasting-satellite system (individual reception)	99	—131/27 MHz	$-(9+20 \log (\varphi/\varphi_0))$ (2) for $0.707\varphi_0<\varphi\leqslant 1.26\varphi_0$ $-(8.5+25 \log (\varphi/\varphi_0))$ for $1.26\varphi_0<\varphi\leqslant 9.55\varphi_0$

(1) Antenna off-beam gain.

(2) See Report 810.

(3) For further information on parameters of these systems consult Report 608 (Kyoto, 1978).

TABLE 3-IV – *Gain and angular discrimination for receiving antennas in the terrestrial broadcasting system*

Off-beam angle θ (degrees)	Antenna gain (dB)	
	Relative to isotropic radiator	Relative to maximum main-lobe gain (34.5 dB)
10	13.5	−21.0
15	8.0	−26.5
20	5.5	−29.0
25	3.0	−31.5
⩾ 29.65	1.5	−33.0

However, outside the broadcasting-satellite service area additional angular discrimination is obtained, due to the angular discrimination of the broadcasting-satellite transmitter antenna (see Fig. 3-6).

The relative gain of the broadcasting-satellite transmitter antenna is assumed to comply with Fig. 2.11, Curve A. The required value of φ/φ_0 (Fig. 3-6) to obtain sufficient additional angular discrimination has been calculated and is shown in Table 3-V.

TABLE 3-V – *Required value of additional angular discrimination of BC-SAT transmitter antenna*

BC-SAT elevation angle at receiving point (degrees)	Required value for the angular discrimination of the BC-SAT transmitter antenna (dB)	Required value for φ/φ_0
10	12.5	0.98
15	7.0	0.60
20	4.5	0.54
25	2.0	0.33
⩾29.65	0.5	0.25

Another example of a terrestrial broadcasting system, in which the minimum power flux-density at the fringe of the service area is assumed to be -78.2 dB(W/m^2), can accept an interfering power flux-density arriving from the least favourable direction in the horizontal plane not exceeding -124.2 dB(W/m^2). Such a value would enable feasible sharing over larger geographical areas than is indicated for the example in Table 3-V.

As a result of experiments with NTSC 525-line television signals in Japan, it was found that satellite broadcasting signals did not cause harmful interference to a 12 GHz AM-VSB terrestrial broadcasting system within its coverage area even with overlapping channels in the case where the pfd from the BSE satellite was -106 dB(W/m^2) at about 40° elevation, while the terrestrial service is assumed to have a maximum range corresponding to a pfd of -70 dB(W/m^2).

10.1.3 *Interference to the fixed service from the BSS*

Interference to terrestrial radio-relay systems can result from broadcasting-satellite transmissions. The power flux-density at the surface of the Earth produced by any space station in the broadcasting-satellite service on the territory of other countries is limited to a value of the order of -128 dB(W/(m$^2 \cdot$ 4 kHz)) independent of the angle of arrival.

Under these conditions it is possible to formulate restrictions on the choice of a radio-relay path with which the associated interference power in the telephone channel of a reference 50 station radio-relay link does not exceed 1000 pW with the power flux-density at the surface of the Earth being -128 dB(W/(m$^2 \cdot$ 4 kHz)) independent of an angle of arrival.

The following approximation is used in the calculations:

$$P = P_{tn} \cdot W \cdot (G(\theta)/S_i)\,^* \tag{7}$$

where:

W: permissible power flux-density at the surface of the Earth, assumed in this case to be equivalent to -128 dB(W/(m$^2 \cdot$ 4 kHz));

P: interference power of the telephone channel (W);

P_{tn}: thermal noise in the telephone channel assumed to be 20 pW;

$G(\theta)$: radio-relay receiving antenna gain in the direction of the interfering signal arriving from a space station,

$10 \log G(\theta) = 35 - 25 \log (\theta)$

$S_i = 4\pi kTb/\lambda^2$

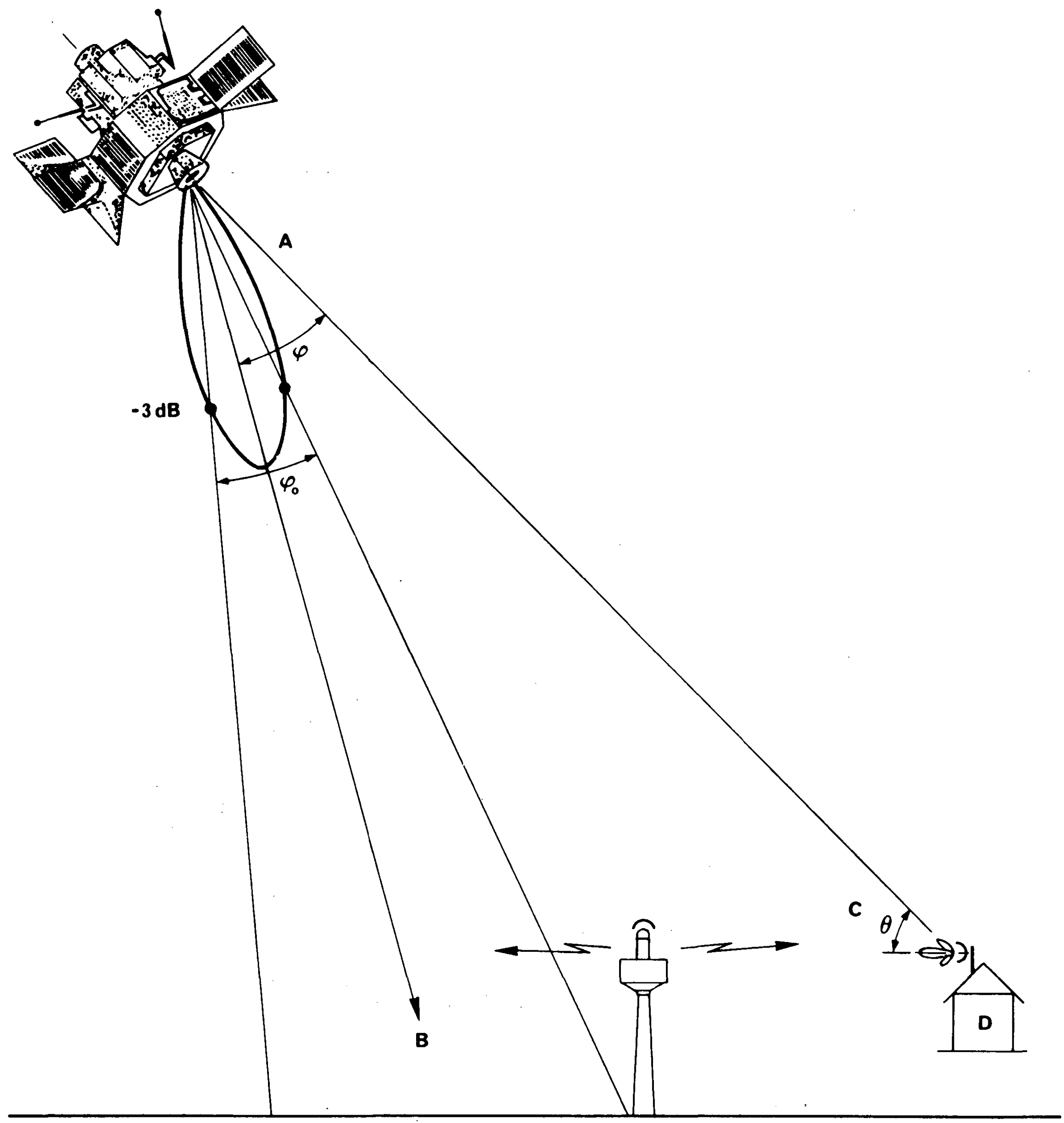
$k = 1.38 \times 10^{-23}$

$\lambda = 2.5$ cm

$T = 890$ K

$b = 4$ kHz.

* Care must be taken to use consistent units in the calculations.



Service area of broadcasting satellite

FIGURE 3-6 — *Interference to receiver of terrestrial broadcast from broadcasting-satellite transmitter*

A : off-beam angle of satellite antenna
B : beam centre
C : angle of arrival
D : terrestrial receiver

As the calculations show, with the assumptions adopted, the associated interference power does not exceed 1000 pW if, for example, the direction of one radio-relay receiving antenna differs from that to the interfering space station by 3°; and the directions of other antennas differ from the direction to interfering space stations by 16°, or if the directions of all antennas differ from the directions to interfering space stations by approximately 13°.

The limitations given can be realized both in low and high latitudes. It is also natural that restrictions on the choice of radio-relay paths are different in high and low latitudes.

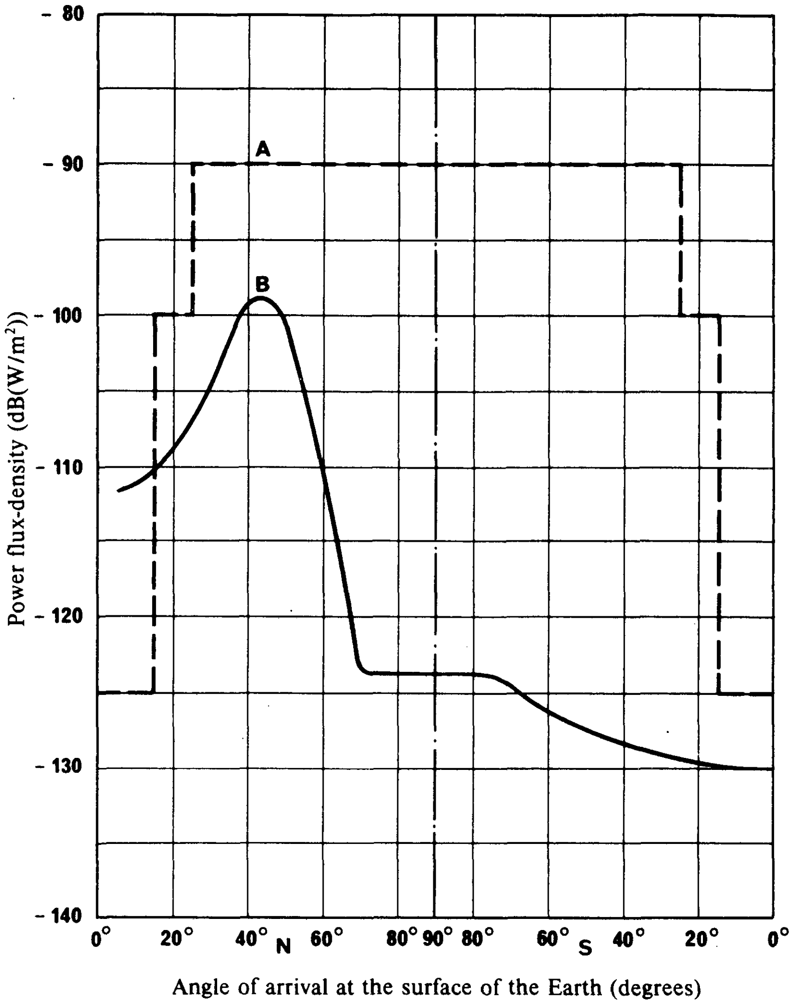


FIGURE 3-7 – *Example for sharing model 2 showing feasibility of frequency sharing between a broadcasting satellite providing individual reception and a radio relay carrying television*

10.1.3.1 *Interference to a terrestrial radio-relay system carrying FDM-FM*

As discussed in a study conducted in the United States [Akima, 1980] from which much of the material in this section is taken, many short-range FDM-FM telephony systems are in operation in the fixed service in this band in the United States.

Typical receiver bandwidths are 12 MHz and 20 MHz. In an FDM-FM telephony system, degradation of the system performance caused by an interfering signal depends on the power spectral density of the interfering signal as well as the total power of the interfering signal. Even if the total interfering signal power is so small that the wanted FDM-FM system continues to operate above its threshold, some telephone channels may be degraded severely if the power spectral density of the interfering signal is very high in these channels.

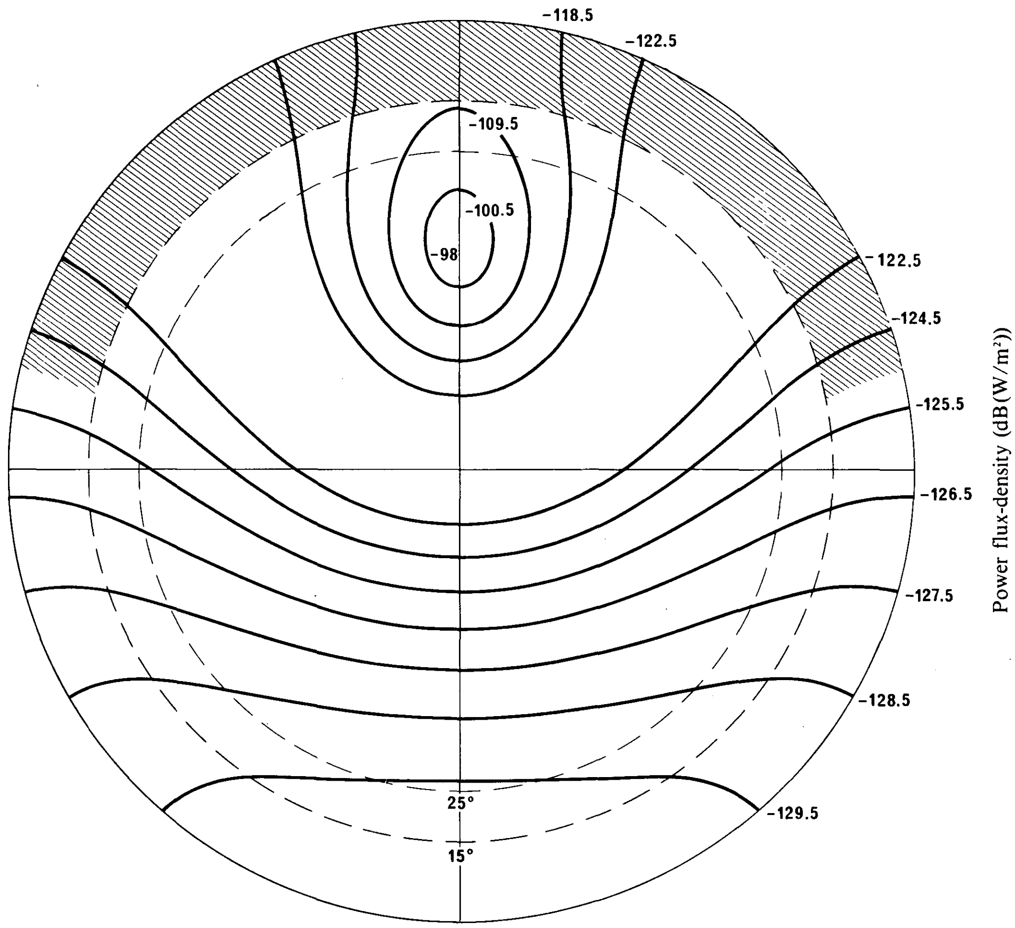


FIGURE 3-8 – *Power flux-density from a broadcasting satellite with a 2° beam aiming at a latitude of 40° N*

Note. – The hatched regions in the above diagram indicate the area of the surface of the Earth where the maximum permissible interference power flux-density into a television radio-relay link is exceeded.

First, we will compare the total power of the interfering BSS signal with that of the noise. The total noise power is −123 dBW in a 12 MHz bandwidth, and −121 dBW in a 20 MHz bandwidth. These values are several decibels higher than −127 dBW, which is the interfering BSS signal power in the worst case given in Table 3-VI. This Table shows the *maximum* value of BSS signal power at a fixed service receiver for various values of off-axis angles and for several different receiving antenna diameters. Values given in this Table have been derived using the reference antenna pattern given in Report 614 and an assumed Region 2 pfd of −102 dB(W/m^2) for not less than 99% of the worst month. Typical interfering powers will be assumed as 3.8 dB lower. These maximum values are based on the variation in pfd from one BSS service area to another observed in the WARC-BS-77 Plan for Regions 1 and 3. Such variations are probably typical of those to be found in such allotment plans. The total power of noise plus interfering signal is only one decibel higher, at most, than the noise power alone in this case. Therefore, the operation of the wanted FDM-FM system should remain above the threshold in all cases if the system is designed with a reasonable margin in S/N.

Next, we will compare the power spectral density of the interfering signal with that of noise. The WARC-BS-77 specified that energy dispersal which corresponds to a peak-to-peak deviation of 600 kHz be employed by broadcasting satellites in the Geneva Plan for Regions 1 and 3. That value will be used in this example although energy dispersal was not adopted within the Region for broadcasting satellites in Region 2. Thus, we will assume as a worst case that the entire power of the BSS signal is contained in a 600 kHz bandwidth.

TABLE 3-VI – *Maximum value of the BSS signal power at an FS receiver (φ denotes the off-axis angle, and D denotes the antenna diameter)*
(A receiver noise figure of 10 dB is assumed.)

φ (degrees)	Signal power (dBW)				
	$D = 0.6$ m	1.0	1.5	2.0	⩾2.41
20	−134.5	−136.7	−138.4	−139.7	−140.0
15	−131.4	−133.6	−135.3	−136.6	−137.4
10	−127.0	−129.2	−130.9	−132.2	−133.0

The noise power in a 600 kHz bandwidth is estimated to be $-134 + 10 \log 0.6 = -136.2$ dBW including a 10 dB contribution from receiver noise. Since this value is about the same order as the values of the BSS signal power given in Table 3-VI, the effect of the interfering BSS signal is not considered negligible. The post-demodulation baseband noise power in a telephone channel is 3 dB higher with the noise plus interference, than with the noise alone if the power spectral density of the interfering signal is equal to that of the noise. Tables 3-VII and 3-VIII show the increases in the baseband noise power caused by the interfering BSS signal, calculated with Table 3-VI. These tables show the relations among: the off-axis angle of the BSS satellite from the main beam of the FS receiving antenna, the FS receiving antenna diameter, and the required system margin against the interference in the design of the FS system. In the worst case of $\varphi = 10°$ and $D = 0.6$ m considered in Table 3-VIII a margin of 10 dB is required. The required system margin decreases as the off-axis angle and/or the antenna diameter increases. In the receiving site where the elevation angle of the BSS satellite is 20°, the required system margin is less than 4 dB regardless of the antenna diameter. When the antenna diameter is equal to or greater than 2.4 m, the required system margin is less than 5 dB even if the angle of elevation is 10°.

10.1.3.2 *Interference to a radio-relay system carrying FM-TV*

An FM-TV relay system of a small number of hops (not more than five hops) is considered as an FS system in this band. The channel bandwidth considered in this system is 27 MHz. (The FS system considered in the preceding section is used also to transmit an FM-TV signal in the USA.) Consideration of interference to an FM-TV system is essentially the same as that of interference to an FDM-FM telephony system in that both the total power and the power spectral density of the interfering signal must be considered.

In so far as the total interfering signal power is concerned, the discussion of the FDM-FM telephony system given in the preceding section also applies. Even with the interfering signal, the system remains operating above its threshold.

Since the power spectrum of the BSS signal is considered to be uniform in a 600 kHz bandwidth for the purpose of interference analysis, the discussion of the interference to the FDM-FM telephone system given in the preceding section also applies to the interference to an FM-TV system. The interfering BSS signal causes the baseband noise power spectral density in the victim FM-TV system to increase in a part of the baseband by the ratio given in Tables 3-VII and 3-VIII. If the system margin is greater than this ratio, the interference is considered tolerable.

TABLE 3-VII – *Increase in the baseband noise power due to the interfering BSS signal (Typical values of BSS signal power, 3.8 dB below those shown in Table 3-VI have been used. φ denotes the off-axis angle, and D denotes the diameter of the FS receiving antenna.)*

φ (degrees)	Increase in baseband noise power (dB)				
	$D = 0.6$ m	1.0	1.5	2.0	⩾2.41
20	2.1	1.4	1.0	0.7	0.7
15	3.5	2.4	1.8	1.4	1.2
10	6.5	4.9	3.8	3.1	2.7

TABLE 3-VIII – *Increase in the baseband noise power due to the interfering BSS signal (Maximum values of BSS signal power shown in Table 3-VI are used. φ denotes the off-axis angle, and D denotes the diameter of the FS receiving antenna.)*

φ (degrees)	Increase in baseband noise power (dB)				
	$D = 0.6$ m	1.0	1.5	2.0	≥ 2.41
20	3.9	2.8	2.0	1.6	1.5
15	5.3	4.5	3.5	2.8	2.5
10	9.3	7.8	6.4	5.5	4.9

10.1.3.3 *Summary regarding interference from the BSS to the fixed service*

Taking into account the assumptions used, results of studies and the analysis given in this section indicate that, with proper coordination, interference from the BSS to terrestrial fixed services will not be a serious problem.

10.2 *Interference to the BSS from terrestrial services*

Typical values of e.i.r.p. for some terrestrial services which use or may use the band 11.7 to 12.5 GHz and which may cause interference to an earth station receiver of the broadcasting-satellite service are indicated in Table 3-IX.

Equation (1) is also applicable for the case of protection for the satellite system provided that the factors are changed as necessary to represent the appropriate parameters of the satellite system.

Where the appropriate protection ratio is unknown, an alternative approach may be used for the determination of the maximum interfering power flux-density at the earth station receiver, based on the effective receiver input noise power. If the maximum acceptable level of interference is limited to 10% of the effective receiver input noise power, then even under conditions of a severe fade of the wanted signal, the interference will not further degrade the output signal-to-noise ratio of the receiver, provided that the fade does not cause the wanted signal to fall below the carrier threshold level.

If the protection ratios are known, similar curves to those given in Fig. 3-8 can be drawn. An example for a 625-line system is given in Fig. 3-9 of this report and is based on a power flux-density of -103 dB(W/m^2) and a single-entry protection ratio of 35 dB against frequency-modulation interfering signals for reception in the broadcasting-satellite service. From Fig. 3-9 the maximum tolerable interfering power flux-densities can be determined depending on the elevation angle of the earth station receiving antenna and the difference in azimuth of the directions of the satellite and the interfering signal. (These values of pfd are specified by the WARC-BS-77 for Regions 1 and 3.)

It should be noted that the expression $D_d = 8.5 + 25 \log (\varphi/\varphi_0)$ dB for the antenna discrimination represents the envelope of the maxima of the antenna side-lobes and thus the minimum discrimination (see Fig. 2-21).

If it is assumed that the mean discrimination at an angle is some 3 dB greater than the minimum discrimination at that angle, then it can be stated that, for example, in 90% of locations the interfering signal strength will not exceed a level 1.7 dB below the maximum permitted.

When the maximum acceptable power flux-density for any particular direction at the earth-station receiver has been determined from Fig. 3-9, then the separating distance required between an outside broadcasting link and the earth-station receiver may be determined from Fig. 3-10.

TABLE 3-IX – *Examples for e.i.r.p. of transmitters in the 12 GHz band*

Service	e.i.r.p. (dBW)
Line of sight radio-relay links:	
Telephony	36
Television programme distribution	41
Television multi-channel	23.5 to 46
Broadcasting:	
Amplitude-modulation	23.5 to 38
Frequency-modulation	26
Frequency-modulation (satellite system)	67.5

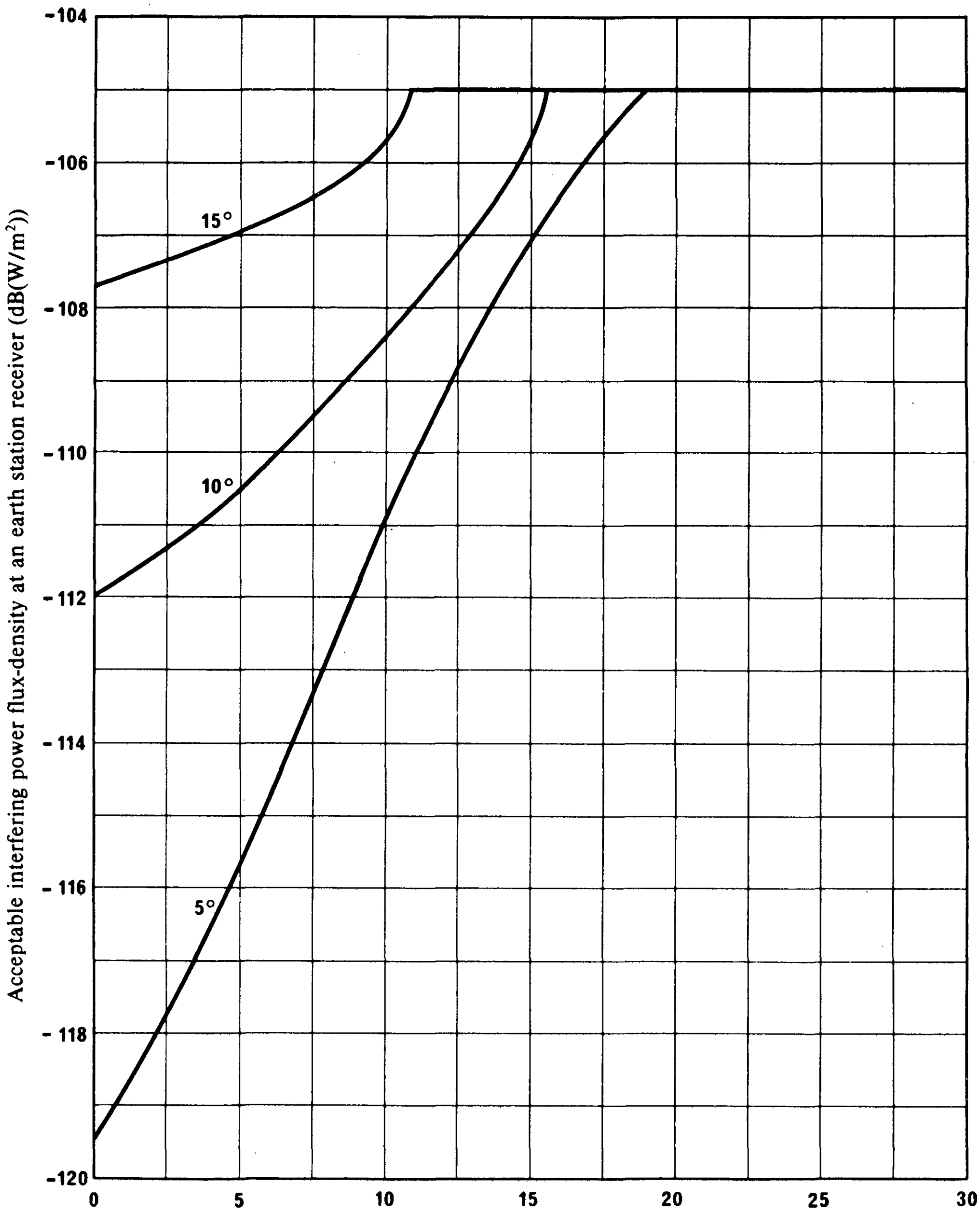


FIGURE 3-9 – *Acceptable interfering power flux-density from a terrestrial transmitter not to be exceeded for 99% of the time at an earth receiver (individual reception) for the example given in § 10·2*

(The angle of elevation of the satellite is shown as a parameter)

φ: Difference in azimuth between the directions of the satellite and the interfering signal.
Earth-receive antenna maximum off-beam gain: see Figure 2-21, curve A,
where: φ_0: Antenna 3 dB beamwidth
= 2.0° (for individual reception in Region 3) from Final Acts WARC-BS-77

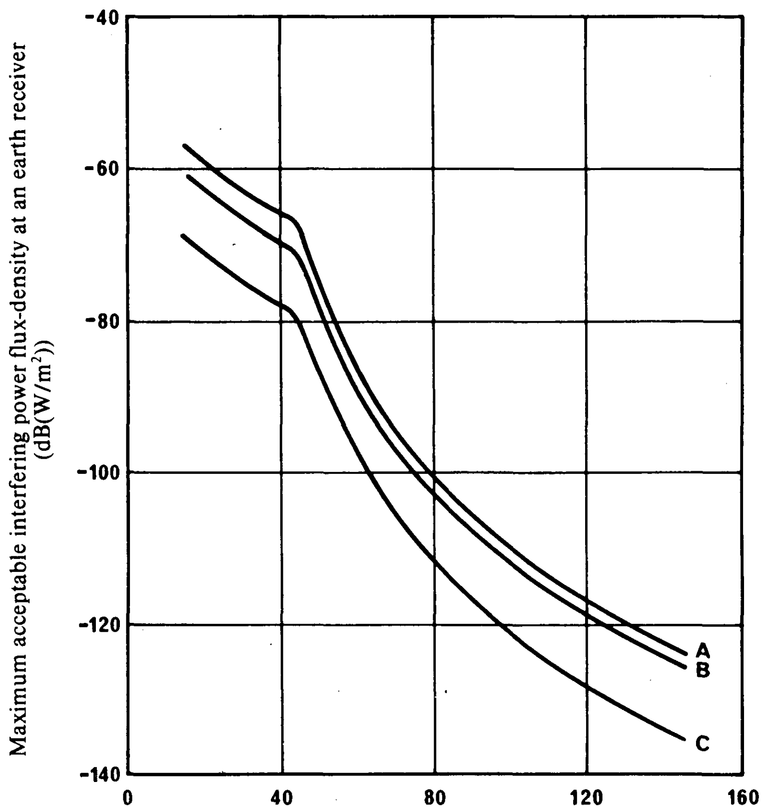


FIGURE 3-10 – *Required separation distance to protect an earth receiver from terrestrial transmitters*

(based on propagation curves for 50% of locations and 1% of time)

Power flux-density produced by:
A: Outside broadcast transmitter (e.i.r.p.: 34 dBW)
B: Amplitude-modulation television broadcasting (e.i.r.p.: 38 dBW; transmitting antenna 75 m above the ground)
C: Frequency-modulation television terrestrial broadcasting (26 dBW; transmitting antenna 75 m above the ground)

Figure 3-10 also gives the separation distances required for a given value of power flux-density between an earth station receiver and transmitters of an amplitude-modulation terrestrial broadcast and a frequency-modulation terrestrial broadcast. The Schmeller and Ulonska propagation curve for 50% of locations and 1% of the time [Goes *et al.*, 1968] has been used in the preparation of Fig. 3-10.

To protect a higher percentage of locations for the broadcasting-satellite service, which might be necessary because of the uniform distribution of the wanted power flux-density in the service area, a correction to the maximum acceptable interfering power flux-density should be applied similar to that given in Fig. 12 of Recommendation 370.

The value of M_i, the margin for possible multiple interference entries, depends on the number and type of possible interferers. In the band 12.1 to 12.7 GHz, interference to the BSS may be caused by other BSS transmitters, by satellite transmitters in the FSS, and by fixed, mobile and broadcasting transmitters. Further work is required to determine how the total allowable interference should be allocated.

It is evident from Fig. 3-10 that, for large areas, frequency sharing with a given broadcasting-satellite service area would best be accomplished over an appreciable portion of that area if the terrestrial service operated in portions of the band not used by the broadcasting-satellite service within that service area. Experimental work in Japan for the case of an AM-VSB terrestrial broadcasting service has given an example of frequency separation that would provide a useful degree of protection (see Report 631).

10.2.1 *Interference from the fixed service to the BSS*

The subject of interference from the fixed service to broadcasting satellite receivers, including a method of determining, in general, the interfering power flux-density at the edge of a BSS service area, is contained in Annex 3 to Appendix 30 to the Radio Regulations.

This section considers interference arising specifically from typical fixed service transmitters in operation in the United States and calculates the required separation distances to permit operation of broadcasting-satellite receivers without harmful interference.

Interference from the fixed to the broadcasting-satellite service (i.e. from fixed service transmitter to broadcasting-satellite receiver) is not uniform in a service area of the BSS, depending on the receiver location relative to the location and main-beam direction of the fixed station transmitting antenna.

The maximum permissible interfering signal power depends on the wanted BSS signal power and the required protection ratio.

First, determine the wanted signal power. The pfd to be exceeded for 99% of the worst month at the edge of the service area was specified by the WARC-BS-77 as -105 dB(W/m^2) as an interim value in Region 2. The received power can be determined using the effective area of the BSS receiving antenna.

For individual reception in Region 2, the receiving antenna half-power beamwidth is specified as 1.8°. This corresponds to a main-beam gain of 39.3 dBi. At 12 GHz, this requires an effective aperture of 0.4m^2 (i.e. an actual diameter of about 1 m for circular, parabolic antennas with efficiencies of 55%).

Thus, the wanted signal at the input to the BSS receiver, at the edge of the service area is:

$$-105 \text{ dB(W/m}^2) - 4 \text{ dB(m}^2) = -109 \text{ dBW}$$

Annex 9 to Appendix 30 to the Radio Regulations specifies the required co-channel protection ratio as 35 dB (single-entry) decreasing linearly to 0 dB for interfering signals 35 MHz away from the desired signal. Therefore, the protection ratio is reduced to 22.1 dB when the interfering signal is at the centre of the adjacent BSS channel (i.e. 19.18 MHz away), and 0 dB when the interfering signal is two or more channels (38.4 MHz) away. Thus, only co-channel and the next adjacent channel interference need be considered.

Interfering signal powers then become:

-109 dBW -35 dB $= -144$ dBW, co-channel, and

-109 dBW -22.1 dB $= -131.1$ dBW, adjacent channel.

The interfering signal power depends on the interfering transmitter power, transmitting antenna gain in the direction of the BSS receiver, propagation loss and the BSS receiving antenna gain in the direction of the interfering fixed transmitter.

Transmitter power varies from system to system. (When the interfering signal bandwidth is wider than the BSS receiver bandwidth, only the power in the latter's bandwidth need be considered.)

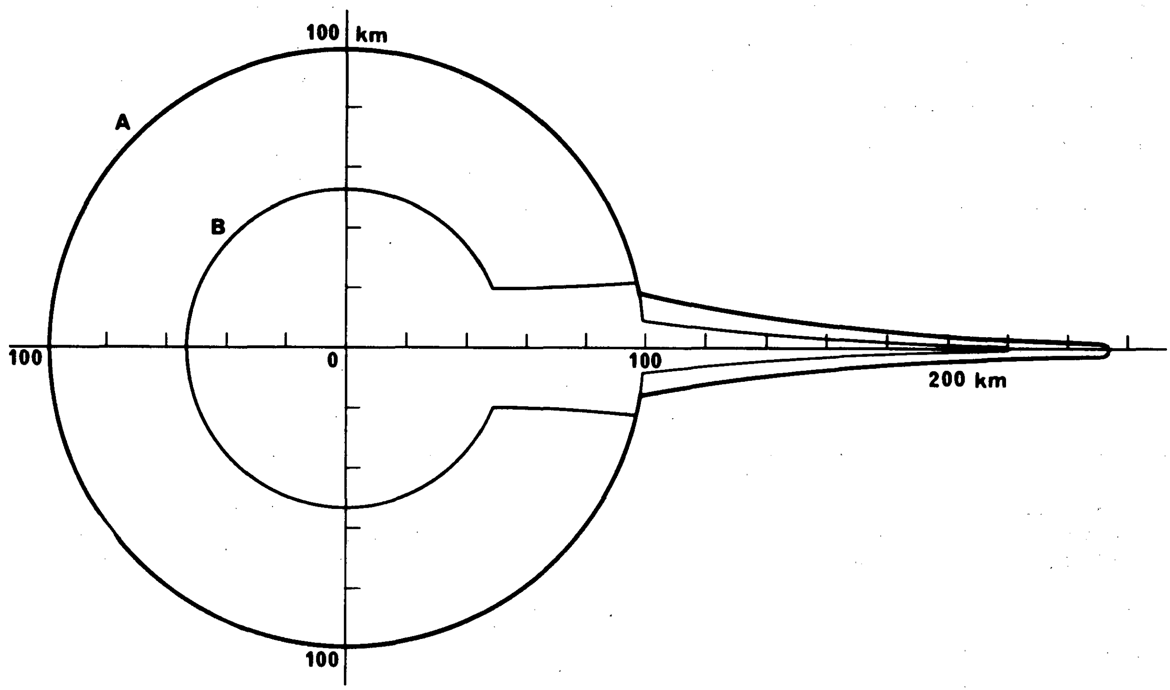
Reference radiation patterns for circular antennas used in fixed radio-relay systems are given in Report 614. On-axis gain is a function of D/λ and the side-lobe envelope pattern is a function of D/λ and φ, where D is the antenna diameter, λ is the wavelength, and φ is the off-axis angle. Gain in the far side lobes is assumed to fall to isotropic (0 dBi). The close-in side-lobe envelope pattern given in Report 614 is applicable between the first side lobe and the point where the gain has fallen to isotropic. For simplicity, assume that the gain near the main lobe (expressed in dB) is parabolic with respect to the off-axis angle down to the first side-lobe gain, constant at the gain of the first side lobe out to the angle where the gain would be isotropic, and isotropic everywhere else. This is a conservative simplifying assumption, because the actual gain will be equal to, or less than, the values assumed.

The relationship between propagation loss, path length and type of path is also given in Appendix 30 to the Radio Regulations. Here, we assume all paths are over land.

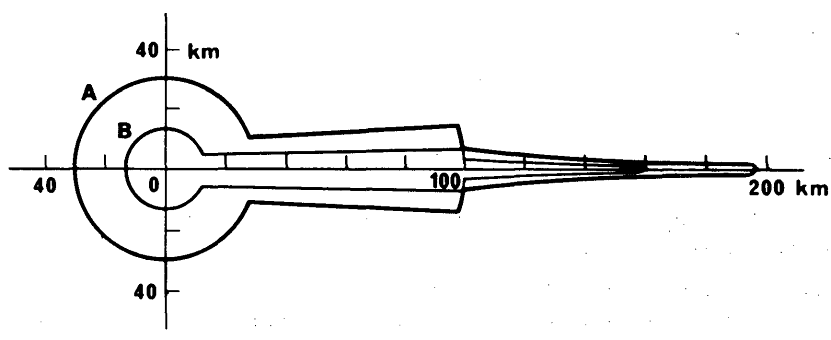
The reference pattern for the BSS receiving antenna in Region 2 is given in the form of off-axis gain relative to the on-axis gain (39.3 dB). Thus, the gain at off-axis angles of 10, 15, 20 and 27 degrees is 12.2 dB, 7.8 dB, 4.7 dB and 0 dB, respectively.

With these relations, the interfering signal power can be calculated, or the required separation distances can be determined. For each interfering transmitter, plot the minimum distance between the two locations against the off-axis angle of the interfering transmitter antenna with the location of the interferer at the origin. The resulting curve is the distance contour where the received, interfering signal reaches the permissible limit. The area inside the contour will have signals above the limit. Figure 3-11 is an example of such contours. These curves have been plotted for a typical US terrestrial system with a 1 W transmitter and a 1.8 m diameter antenna. Figure 3-11a) shows the co-channel case, and Fig. 3-11b) shows the case of adjacent-channel interference.

In Figs. 3-11a) and 3-11b), the outer contours are for the worst case, in which elevation angles of the BSS receiving antennas are 15°. The inner contours describe a more favourable case in which the BSS elevation angles are above 27°, where the gain has fallen to isotropic. (The difference between the inner and outer contours can be interpreted as representing the effect of the discrimination of the BSS receiving antenna.)



a) Co-channel interference



b) Adjacent-channel interference

FIGURE 3-11 – *Contours on which the received interfering FS signal power is equal to its maximum permissible limits for a 1 Watt (0 dBW) US fixed-service system*

BSS earth station elevation angle, θ :
A: θ = 15° (outer contour)
B: θ = 27° (inner contour)

Each contour has a sharp peak in the main-beam direction of the interfering antenna, while it is a circular arc for angles well outside the main beam. Distances corresponding to these two regions are shown in Tables 3-X and 3-XI for both co-channel and adjacent-channel cases, for both the 1 W system shown in Fig. 3-11, and for a lower e.i.r.p. system (type "B") employing a 10 mW (−20 dBW) transmitter and a 0.6 m diameter antenna.

TABLE 3-X – *Minimum separation distances necessary in the case of co-channel interference from FS to BSS*

FS system (typical of US usage)	Antenna diameter (m)	Transmitter power (dBW)		Distance (km)			
				Worst case		Most favourable case	
				On-axis	Distant	On-axis	Distant
Type "A"	1.8	Typical	0.0	254.0	100.0	220.4	53.1
		Max.	10.0	297.0	104.1	263.4	100.0
Type "B"	0.6	Typical	−20.0	126.8	13.0	100.0	5.3
		Max.	−3.0	200.0	92.2	166.4	37.6

TABLE 3-XI – *Minimum separation distances necessary in the case of adjacent-channel interference from FS to BSS*

FS system (typical of US usage)	Antenna diameter (m)	Transmitter power (dBW)		Distance (km)			
				Worst case		Most favourable case	
				On-axis	Distant	On-axis	Distant
Type "A"	1.8	Typical	0.0	198.4	29.5	164.9	12.0
		Max.	10.0	241.5	93.3	207.9	38.0
Type "B"	0.6	Typical	−20.0	100.0	3.0	69.8	1.2
		Max.	−3.0	144.5	20.9	110.9	8.5

10.2.2 *Summary concerning interference from terrestrial services to the BSS*

From the analyses shown here and the studies quoted, it can be seen that interference from fixed services to broadcasting-satellite earth stations will be a serious problem.

The two services can share the same frequencies (in accordance with the limits of harmful interference set forth in Appendix 30 to the Radio Regulations) by keeping terrestrial transmitters a sufficient distance from the service area of a broadcasting-satellite beam.

Such sharing can be accomplished by using some of the frequencies in a given geographic area for the broadcasting-satellite service, and the remainder of the frequencies in the band for terrestrial services.

10.3 *Aspects related to sharing between the broadcasting-satellite service and the fixed-satellite service*

10.3.1 *General considerations*

As a result of different regional allocations to the fixed-satellite service and the broadcasting-satellite service in the 12 GHz band, several inter-regional sharing situations arise between these space services.

The World Administrative Radio Conference for planning the broadcasting-satellite service in the frequency band 11.7 to 12.2 GHz (11.7 to 12.5 GHz in Region 1), Geneva, 1977 took the following action:

- it adopted a detailed orbital position and frequency assignment Plan for the broadcasting-satellite service in Regions 1 and 3;
- it adopted a set of provisions governing the broadcasting-satellite service in Region 2 pending the establishment of a detailed plan. These provisions include division of the available orbital arc into separate segments for the broadcasting-satellite service and the fixed-satellite service, and a Regional Administrative Conference held in 1983 for the purpose of carrying out detailed planning for the broadcasting-satellite service down links and fixed-satellite service feeder links in Region 2 (see Recommendation No. Sat-8 of the WARC-BS-77; see also Resolution No. 701 of the WARC-79 and § 5 of this Chapter).

Subsequently, the WARC-79 allocated separate frequency bands for the two space services in Region 2, thus obviating the need for orbital arc segmentation (see Resolution No. 504 of the WARC-79). The band allocated to the broadcasting-satellite service has a lower limit of 12.2 GHz determined at the Regional Administrative Radio Conference, RARC SAT-83, and an upper limit of 12.7 GHz. The various space service sharing situations are summarized in Table 3-XII which makes reference to the applicable footnotes in the Radio Regulations. Table 3-XII does not include the terrestrial services allocated in the band 11.7 to 12.75 GHz.

Characteristics of typical fixed-satellite systems are contained in Report 207. However, in Region 1, the band 12.5 to 12.75 GHz is allocated exclusively to the fixed-satellite service which may make its parameters different from fixed-satellite systems in which sharing is required.

Note from the Director, CCIR. – Radio Regulation footnotes 848, 849 and 850 allocate this band on a shared basis to other services in some countries of Region 1.

TABLE 3-XII – *FSS and BSS sharing situations in the 12 GHz band*

Frequency band (GHz)	Region 1		Region 2		Region 3	
11.7 to 12.1	BSS	(S-E)	FSS BSS (FN 836)	(S-E) (S-E)	BSS	(S-E)
12.1 to 12.2	BSS	(S-E)	FSS *or* BSS (FN 841)	(S-E)	BSS	(S-E)
12.2 to 12.3	BSS	(S-E)	FSS *or* BSS (FN 841)	(S-E)	FSS (FN 845)	(S-E)
12.3 to 12.5	BSS	(S-E)	BSS FSS (FN 846)	(S-E) (S-E)	FSS (FN 845)	(S-E)
12.5 to 12.7	FSS	(S-E) (E-S)	BSS FSS (FN 846)	(S-E) (S-E)	FSS BSS (FN 847)	(S-E) (S-E)
12.7 to 12.75	FSS	(S-E) (E-S)	FSS	(E-S)	FSS BSS (FN 847)	(S-E) (S-E)

(S-E): space-to-Earth
(E-S): Earth-to-space

FSS: fixed-satellite service
BSS: broadcasting-satellite service
FN: footnote

10.3.2 *Sharing between the broadcasting-satellite and fixed-satellite services*

The problem of sharing between the broadcasting-satellite service and the fixed-satellite service, particularly on space-to-Earth paths, is a problem of sharing between dissimilar (inhomogeneous) networks. The factors that tend to enhance orbit-spectrum utilization are reasonably well understood. The extent to which these factors can actually be exploited depends on many operational, economic and design constraints.

Sharing between the broadcasting-satellite service serving Regions 1 and 3 and the fixed-satellite service serving Region 2 is a case of sharing between dissimilar networks with two special features:

- The areas served by the two services are separated generally by large bodies of water with the boundaries running north-south, which facilitates sharing as the side-lobe discrimination of the space station antenna will tend to reduce the interference; and
- Regions 1 and 3 have established a detailed Plan for the broadcasting-satellite service while no such plan exists for the fixed-satellite service in Region 2.

This means that the burden of sharing rests with the Region 2 space services provided that the broadcasting-satellite service operates within the characteristics specified by the Plan for Regions 1 and 3.

Sharing criteria between these services can be established, in principle, in terms of a power flux-density limit over the area to be protected, or in terms of a minimum separation of space stations in the two services, or in terms of a combination of both. Appendix 30 to the Radio Regulations deals with the problem according to the last of these choices.

Considering, in addition, that the nominal spacing between space stations in the western portion of the arc serving Region 1 is 6° according to the Plan, this means that a space station in the fixed-satellite service with characteristics specified in the Radio Regulations (on-axis gain of the earth-station receiving antenna of 53 dB and side-lobe gain following the law:

$$\text{Gain (dBi)} = 32 - 25 \log \varphi \tag{8}$$

where φ is the off-axis angle in degrees) could be placed midway between two broadcasting satellites serving Region 1 providing its characteristics are such that it can tolerate an interfering flux-density of about -161 dB(W/m^2) at the specified test point. This imposes restrictions on the kind of service that can be provided by the fixed-satellite system, and may prevent certain sensitive systems, such as single-channel-per-carrier (SCPC) or 24-channels-per-carrier systems from using these orbital positions at certain frequencies. However, not all orbital locations in the Plan use all possible frequencies, and it may be possible to accommodate such carriers at these frequencies.

Similar considerations will apply to Region 1 and 3 fixed-satellite services sharing with the Region 2 broadcasting-satellite service after the 1983 RARC.

Under Resolution No. 503 of the WARC-79, the Region 2 broadcasting-satellite plan adopted in 1983 takes into account the planned Region 1 and 3 broadcasting-satellite services in the overlapping frequency band. (See also § 10.3.3, following.)

10.3.3 *Required orbital separation between Region 1 or 3 fixed satellites and Region 2 broadcasting satellites*

In the band 12.5-12.7 GHz, it is possible that broadcasting satellites in Region 2 could cause interference to fixed-satellite earth stations in Regions 1 and 3. However, the possibility of this interference is greatly reduced in most cases due to the separation between coverage areas and between satellites.

The discrimination of the broadcasting-satellite transmitting antenna (Curve A of Fig. 2-11) is $\geqslant 30$ dB for $\varphi/\varphi_0 \geqslant 1.6$, that is, a separation of greater than 1.6 beamwidths as seen from the satellite.

A further reduction of interference potential derives from the discrimination of the receiving antenna at the FSS earth station, and thus from the angular separation of fixed satellites in Regions 1 and 3 from broadcasting satellites in Region 2.

For example, consider a situation of a small FSS earth station resembling a community reception BSS antenna for which we could use the antenna pattern as given in Curve A′ of Fig. 4, Annex 8 of Appendix 30 to the Radio Regulations. A discrimination of 35 dB is achieved at a value of φ/φ_0 just less than 10. Thus assuming a 1° beamwidth antenna (minimum community broadcasting size per Annex 8), an approximately 10° separation of satellite position would achieve a discrimination of 35 dB in the *same* service area.

Taking into account discrimination due to *both* coverage area and satellite separations, and assuming a coverage area separation of 1.6 beamwidths (as above) for a 30 dB discrimination, we note that an additional 10 dB discrimination (for a total of 40 dB) will be achieved (using Fig. 4, Annex 8, Appendix 30 to the Radio Regulations) at φ/φ_0 of 1, which is a 1° satellite separation for the receiving antenna assumed.

While these examples illustrate the principle of using both coverage area separation and satellite angular separation to determine the need for coordination between the BSS in Region 2 and the FSS in Regions 1 and 3, the actual need for coordination depends on the particular systems being implemented, but can be quickly determined by the simple calculation shown below:

Coordination is not required when:

$$D_{B\,SAT} + D_{F\,Rx} > e.i.r.p._{B\,SAT} - e.i.r.p._{F\,SAT} + PR \tag{9}$$

where:

$D_{B\,SAT}$: discrimination of BSS satellite transmit antenna,

$D_{F\,Rx}$: discrimination of FSS earth station receive antenna,

$e.i.r.p._{B\,SAT}$: e.i.r.p. of BSS satellite,

$e.i.r.p._{F\,SAT}$: e.i.r.p. of FSS satellite,

PR: protection ratio required by the FSS down link.

As one example, assume an $e.i.r.p._{B\,SAT}$ of 60 dBW and an $e.i.r.p._{F\,SAT}$ of 40 dBW and an FSS earth station antenna of 3.6 m diameter ($\varphi_0 = 0.5°$). If the respective coverage areas are separated by at least 1.6 beamwidth, a $D_{B\,SAT} \geqslant 30$ dB will be provided. For a protection ratio of 35 dB, the required $D_{F\,Rx}$ of 25 dB will be achieved at a φ/φ_0 of approximately 4 (from Curve A′ of Fig. 4 mentioned above) which corresponds to an angular separation between the FSS satellite and the BSS satellite of 2°.

Further study of specific interference situations is required.

It should be noted that as the diameter of the FSS antenna is decreased, $D_{F\,Rx}$ decreases linearly thus worsening the sharing situation. However the gain of the FSS antenna decreases by the square. Thus, in the case where the remainder of the link budget parameters were designed for the smaller FSS antenna, $e.i.r.p._{F\,SAT}$ must increase by the square as well – which tends to improve the sharing situation. This is the equivalent of saying that the use of small FSS receiving antennas (and thus higher e.i.r.p.s of FSS satellites) reduces the inhomegeneity between such systems in Regions 1 and 3, and BSS systems in Region 2.

In spite of these considerations, there remain two significant problem areas. In the areas around the Bering and Denmark Straits, it is likely to be extremely difficult to achieve significant service area separation, so that satellite position separation will be the only source of discrimination, and may be inadequate in any case to provide adequate protection margins. Thus co-frequency inter-regional sharing in this area may be impossible to achieve. In the areas where West Africa and Eastern South America are closest, some service area discrimination due to space station antenna patterns is achievable, depending on coverage areas chosen. Coverage areas for both FSS serving West Africa and BSS serving Eastern South America should be chosen taking this possibility into consideration. In addition, carefully chosen shaped-beam spacecraft antennas can improve the sharing situation.

Guidelines for actual protection requirements are found in Annex 9 of Appendix 30 to the Radio Regulations. However the pW0p (interference power) requirements are not readily usable in this equation. Further study is required on the conversion of interference power in pW0p into a usable C/I protection requirement.

10.3.4 *Summary*

Sharing between services in the different regions is governed by the sharing criteria adopted by the WARC-BS-77 and by WARC-79 (including, in particular, Appendix 30 and Resolutions Nos. 31, 34, 700, 701, 703 and Recommendation No. 708). The system characteristics adopted in the Plan for the broadcasting-satellite service in Regions 1 and 3 impose restrictions on the use of certain orbital positions near and between the space stations of the Plan for certain sensitive fixed-satellite services.

11. Feeder links to the broadcasting-satellite service

11.1 *Introduction*

Since very little is known about the problems related to feeder links for broadcasting satellites operating at frequencies other than 12 GHz, this section will examine exclusively the feeder links for the 12 GHz broadcasting satellites. Additionally, the accommodation of spacecraft service functions is considered in Chapter 1.

11.2 *System concept and technical characteristics*

11.2.1 *General*

A feeder link for broadcasting satellites comprises the following elements:

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

The characteristics of these elements and particular constraints, where relevant, are discussed in §§ 11.3, 14 and 14.4 of this Chapter, while further general system considerations are summarized below.

In many cases, broadcasting satellites will have a single, feeder-link earth station for each set of down links within a single service area. Such feeder links will normally use an earth station with a larger antenna and a comparatively high transmit power. However, for some applications, different kinds and numbers of feeder-link stations may be required. Small fixed and transportable earth stations providing a direct connection to a broadcasting satellite have already been used and their number can be expected to increase as the broadcasting-satellite service develops.

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

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

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

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

Alternatively, to allocate separate orbital positions to all countries and to have sufficient angular separation between them to enable the same feeder-link frequencies to be used by every country would be very economical in the use of feeder-link frequency spectrum but would occupy a large orbital arc and limit the choice of orbital positions for each country. It could also involve greater space-sector costs in the long term.

Thus an optimum should be sought in which, both in the feeder link and the down link, orbital arc and frequency spectrum are used economically without unnecessary restrictions on the broadcasting channel plans and in which the particular feeder link requirements of individual administrations can be met without imposing unnecessary constraints on the down-link plans.

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

The interrelations of feeder links and links to provide spacecraft service functions (such as TTC) are discussed in § 14 of Chapter 1.

11.2.2 *Noise and interference contribution of the feeder link*

11.2.2.1 *Noise*

A maximum reduction of 0.5 dB in the signal-to-noise ratio of the down link, representing the contribution of the feeder link to the total signal-to-noise ratio, in 99% of the worst month, was found desirable for planning purposes during the WARC-BS-77. This corresponds to a difference in the signal-to-noise ratios of feeder links and down links of some 10 dB, hence the nominal feeder link carrier-to-noise ratio should be about 24 dB for a down link carrier-to-noise ratio of 14 dB. At frequencies above 12 GHz, special techniques may have to be applied to ensure that the degradation due to the feeder-link noise remains within reasonable limits. When feeder links are planned at the same time as the down links, it may be desirable to specify only the overall C/N.

Recent studies indicate that the following aspects have to be taken into account, among others:

- correlation between feeder-link fades and down-link fades, and
- degradation due to TWT AM/PM conversion (a degradation of 2 dB to TWT AM/PM conversion of 5 °/dB).

Finally, one would be led to choose an input C/N ratio of the order of 26 dB. However, if community receivers are used, these will have a higher C/N on the down link. It is possible for community reception that still higher values of C/N would be necessary on the feeder link (see Report 952, § 3.2).

11.2.2.2 *Interference*

The total interference must not result in an impairment worse than the 4.5 grading on the scale given in Recommendation 500 at any point of reception. Since the sources of interference in the satellite-Earth path, namely, the broadcasting satellites, are numerous and since this type of interference is liable to reduce the number of programmes broadcast to each country, the WARC-BS-77 decided for Regions 1 and 3 that, for planning purposes, the interference due to the Earth-satellite path should be 10% of the total interference and that the interference due to the satellite-Earth path should be 90%.

With a view to drawing up a satisfactory frequency plan for the feeder links of broadcasting satellites operating in accordance with the Final Acts of the WARC-BS-77, it is necessary to establish an appropriate ratio for such links. Too tight a protection ratio would make it difficult to draw up a plan and would entail excessive constraints for system operation (restriction as to satellite coverage in reception, and therefore as to the site of the transmitting station, restriction on the use of light-weight transportable installations, etc.). However, too lax a protection ratio would not ensure adequately the required quality of service (see Report 634).

This problem is dealt with in a number of documents, but there are discrepancies and inconsistencies. The arbitrary selection of one particular reference may lead to misunderstanding in discussions. It therefore appears essential that further studies are undertaken, which also will take into account the so far neglected performance of the feeder link channel filters.

Based on results obtained from the experiment using the medium-scale broadcasting-satellite for experimental purposes (BSE) and laboratory tests carried out in Japan, it is reported that just perceptible carrier-to-co-channel interference ratio between two similar FM-TV signals (deviation; 12 MHz peak-to-peak, 525 line system M) is about 38 dB under severe viewing conditions (closer viewing distance than given in Recommendation 500) for subjective assessment of high quality broadcasting signals.

Experiments conducted with the OTS satellite for a 625-line TV signal in conformity with the WARC-BS-77 Plan confirm the protection ratio of 30 dB for co-channel interference, whereas for adjacent channel interference a low value (7 dB instead of 14 dB) may be acceptable. Correspondingly, a lower value (for example, 17 dB) would be acceptable for feeder-link planning.

11.3 *Choice of frequency band and influence of the atmosphere*

11.3.1 *Frequency-band allocations*

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

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

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

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

In addition, it should be understood that any band of the fixed-satellite service (Earth-to-space) could also be used for the feeder links, with the normal coordination procedures, with the exception of the 14.0-14.5 GHz band for which the use for feeder links to the broadcasting-satellite service is reserved for countries outside Europe and for Malta.

The band 47.2 to 49.2 GHz was also recommended for use with the 40.5 GHz to 42.5 GHz BSS frequency band (see Radio Regulations, No. 901).

11.3.2 *Influence of the atmosphere*

The feeder-link signal will suffer attenuation and depolarization when passing through the atmosphere. These effects are of statistical nature and will also strongly depend on the feeder-link frequency and the location of the feeder station. Relevant data can be found in Report 564.

For the higher frequency bands under consideration (above 12 GHz) the atmospheric influence on the overall signal-to-noise ratio and on the signal-to-interference ratio is likely to be more significant. Provision of sufficient protection against rain fades could mean the application of site diversity or feeder-link power control. This could inhibit the use of small fixed and transportable earth stations and could also increase the cost of the feeder link.

11.3.3 *Depolarization*

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

12. Compensation methods

12.1 *Power control and/or margin*

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

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

However, the use of power control can worsen the interference situation. Studies have shown that the difference between interference levels in the case where power control is used at all stations, and where it is not used and, instead, all stations employ a margin, M, sufficiently high to take account of the attenuation experienced for all but a very small percentage of time, is given by:

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

where:

I_{pc}: interference with power control,

I_{npc}: interference with no power control,

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

M_w and M_i: margins on the wanted and interfering links, respectively. The difference in the interference level (equation (10)) does not depend on the instantaneous value of the transpolarization on the interfering path.

It is apparent from this equation that, for most of the interference situations and for most of the time, the interference will be the same with and without power control if the climatic conditions are statistically similar on the wanted and unwanted paths.

This conclusion must, however, be weighted by the following important consideration. When there is rain in the interfering link, increased depolarization will also take place. The power control system increases the transmitted power to compensate for the attenuation (that is, at the only times when power control performs its intended function). Thus, the cross-polarized, interfering signal will be above its clear-sky level because of two factors: both the absolute signal power and its depolarization have been increased. At such times, the use of power control makes the interference situation worse.

Therefore, based on information available to date, it appears that power control in isolation (that is, without compensation for the effects of depolarization) should not be adopted for planning purposes for use at all feeder-link stations.

However, case by case studies would be necessary to assess the desirability of different methods of power control that could be applied at certain stations (for example, at stations located in areas of heavy rain). In addition to power control that increases the power linearly (that is, 1 dB for every dB of rain attenuation) other methods can be envisaged. For example, the transmitter might employ a relatively small power margin most of the time, and the control system would increase this power only when the attenuation exceeded a specific value.

There is another disadvantage to the use of power control: the lower power being transmitted for most of the time would make such transmissions more susceptible to accidental or intentional interference from similarly lower power transmitters not authorized to operate in this service and on these frequencies.

These disadvantages of the use of large margins, coupled with the lack of information on the use of non-linear power control, emphasize the need for further studies on power control of feeder links.

12.2 *Compensation for depolarization*

Compensation for depolarization is the rapid, automatic adjustment of the polarization of feeder-link signals from earth stations to maintain the desired polarization at the satellite receiving antenna under varying atmospheric conditions. Theoretical studies indicate that the cross-polarized component of a circularly-polarized 18 GHz signal might be held 25 dB below the co-polarized component [Fromm and McEwan, 1981; Bradford University, 1981], during both clear-sky and rain (or ice) conditions. This technique which could be realized with little additional hardware in the transmitting station could thus permit the operation of feeder-link stations, especially transportable stations, at times when they would otherwise cause reduced, or even unacceptable C/I ratios at collocated or nearby satellites of other systems.

Further theoretical and experimental studies are required, of control systems which would compensate for depolarization by rain and ice, of circularly and linearly-polarized signals.

12.3 *Diversity operation of feeder-link stations*

The use of feeder-link stations in diversity, that is, two stations separated sufficiently so that it is extremely unlikely that heavy rain will be in both paths to the same satellite simultaneously, can overcome the effects of rain attenuation and depolarization. Due regard must be taken of not only the required separation between the stations, but the orientation of the line connecting them in relation to the prevailing direction of "squall lines", if they exist in that geographical region. (Clearly, the line connecting the two stations should be at right angles to the squall line.) However, the cost, and operational complexity of diversity stations is probably significantly greater than the use of sufficient margin at a single feeder-link station.

The use of diversity for transportable stations is particularly problematic from the standpoint of cost and operational complexity and system operators would probably accept the lower availability and lower C/I ratio at the desired satellite that the use of non-diversity transportable stations might cause, given their relatively infrequent use.

13. Choice of polarization for feeder links

The choice of feeder-link polarization affects:

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

Concerning the latter, the choice of feeder-link polarization will have to consider the down-link polarization too. The same polarization for down link and feeder link will normally benefit the spacecraft antenna, thus allowing for less complex and more mass-efficient antenna concepts.

Regarding sharing with other services, the choice of polarization makes little difference in the interference with terrestrial services.

The maximum advantage of linear polarization is limited by the shape of the rain drops being deformed in the vertical direction and also the misalignment resulting from the mechanical imprecision of the antennas.

For ice induced depolarization, the advantages of linear polarization are believed to be less significant, due to a more random orientation of the ice crystals.

In summary, there appear to be several difficulties in taking advantage of the better theoretical discrimination obtainable with linear polarization. Further studies are needed (see Report 952 for details).

14. Earth stations for feeder links

14.1 *Antenna considerations*

In most cases, feeder links to broadcasting satellites will be provided by an earth station of comparatively high power and with a comparatively large antenna. The noise and interference restrictions described in § 11.2.2 of this Chapter are applicable to such feeder links.

Since the feeder links to the broadcasting-satellite service are in the fixed-satellite service, the side-lobe radiation of the feeder link antenna should meet the reference pattern for the co-polar component as given in Recommendation 465 (for antennas where $D/\lambda \geqslant 100$). Studies are required to determine a suitable reference pattern for the cross-polar component, for which there is no Recommendation at present.

Studies done for the planning of feeder links to broadcasting satellites in Regions 1 and 3 showed that it would be advantageous to adopt antenna characteristics that produce negligible interference to adjacent satellite orbital locations.

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

If the diameter of the transmitting antenna becomes too small, it may introduce excessive interference into adjacent satellites. It would also complicate the required coordination with terrestrial or other services with which the feeder-link frequency band is shared. In general, it may be necessary to find a proper balance between earth-station antenna diameter and satellite spacing within the feeder-link plan.

In recent studies, interference characteristics in the feeder links at 14 GHz, which are assumed to connect to broadcasting satellites using the 12 GHz band in an Asian and Western Pacific area, as planned by the WARC-BS-77, are examined in relation to satellite orbital positions and size of earth transmitting antennas. The results show that the interference situation depends to some extent on longitudinal positions of satellites and in some cases, relatively smaller earth transmitting antennas may be used without increasing feeder-link interference levels.

14.2 *Influence of location*

Although restrictions on the location of earth stations, on e.i.r.p. and on the satellite receiving antenna beamwidth are representative elements of a feeder-link plan, it may be desirable that considerable numbers of small fixed or transportable feeder-link stations operate from any point within the broadcasting-satellite service area or, even in some cases, outside the service area.

This would place constraints on the planning process. Changes in the location of the earth station relative to the beam axis would require a higher e.i.r.p. thus possibly causing more interference to other feeder links. Some improvement of interference ratio could be expected from excluding some particular site points at the edges of the service areas, although this restriction may not be acceptable in certain cases.

14.3 *Interactive earth stations*

In addition to the use of the broadcasting-satellite service for the one-way transmission of programmes to individual or community receivers, some administrations envisage the use of broadcasting satellites in a "two-way", interactive mode, with voice or data on the return path, primarily for educational and other public service purposes (see Report 215, § 5.3.2).

Earth stations for such applications would often be small and transportable and might have to be located anywhere in the service area.

Such stations may place additional requirements on the orbit and spectrum in the form of additional frequency assignments and perhaps wider satellite spacings than would be possible for conventional systems.

14.4 *Satellite receiving antenna characteristics and noise temperature*

Beamwidth, pointing accuracy and the radiation pattern of the satellite receiving antenna will have to comply with certain requirements imposed by the overall feeder link requirements. These requirements, to some extent, will dictate the receiving antenna design concept.

A quantitative indication of the effect of relaxing the pointing accuracy requirement on the satellite receiving antenna from 0.1 ° to 0.2 ° is provided by a study in France (see Report 952, § 7.3).

From the standpoint of satellite cost, complexity and weight, a common transmit/receiving antenna would be advantageous. However, a separate receiving antenna would offer a more independent choice of the feeder-link frequency and polarization as well as receiving antenna beamwidth, beam pointing and radiation characteristics. With regard to the latter, an EBU study indicates that very tight requirements may not be necessary and could unduly constrain the design of the satellite receiving antenna. The EBU analyzed interference levels for two orbit positions in the 12 GHz WARC-BS-77 Plan using:

- the patterns in the Final Acts for the satellite antenna,
- a pattern with reduced near on-axis cross-polar performance,
- a pattern with less stringent requirements in the region of the first side lobe,
- a plan for feeder links deduced by a translation of the Plan for the broadcasting-satellite service established by the WARC-BS-77.

This analysis showed that the modifications had negligible effects on the interference margins.

This example shows that it is desirable to examine in general the effect of the satellite receiving antenna pattern on the effectiveness of feeder-link plans, bearing in mind that some portions of the antenna diagram may be critical, and that for other portions there may be less stringent requirements.

The sensitivity of the satellite receiver is considered to be non-critical, with the exception of those cases in which small fixed or transportable feeder-link earth stations are employed.

15. Sharing in the feeder-link bands

As a result of allocation actions taken by the WARC-79, the use of the frequency bands shown in § 11.3 of this Chapter by the fixed-satellite service (Earth-to-space) is limited to broadcasting-satellite feeder links (RR footnote Nos. 835, 863, 869).

The subject of frequency sharing between feeder links to broadcasting satellites and other services is discussed in Report 561. As can be seen in § 11.3 of this Chapter, sharing would probably occur between the down link in the fixed-satellite service and the feeder link for broadcasting satellites. In this case, the need to protect the fixed-satellite service receiving terminals may require a large diameter earth-station antenna for the feeder-link transmitter in order to permit sufficient flexibility in the siting of earth stations.

The other bands allocated to the fixed-satellite service (Earth-to-space) may also be used for the broadcasting-satellite feeder links, subject to coordination. Among these bands, the use of the 14.0 to 14.5 GHz band for the broadcasting-satellite feeder links is reserved for countries outside Europe and for Malta (footnote No. 858 of the Radio Regulations).

In this context, this section discusses interference problems at 14.0-14.5 GHz between up links to fixed satellites and feeder links to broadcasting satellites operating in accordance with the 12 GHz WARC-BS-77 Plan.

15.1 *Example 1*

An analysis carried out by Japan calculated the interference for particular cases in the band 14.0-14.5 GHz between up links to fixed satellites serving Region 3 having the characteristics shown in Report 561 for Intelsat-V and feeder links to broadcasting satellites in Region 3 operating according to the 12 GHz WARC-BS-77 Plan. The analysis shows the following results:

– for the technical parameters used in the study, the worst value of the carrier-to-interference ratio (C/I) on broadcasting-satellite feeder links interfered with by up links to Intelsat-V in the Indian Ocean region would be greater than the assumed protection ratio of 45 dB. The worst value of the C/I of up links to Intelsat-V interfered with by feeder links to the broadcasting satellite would be greater than 31 dB required for interference noise power of 400 pW0p in a 24 channel FDM-FM system;

– as for the interference situation between the assumed international fixed satellite positioned at 65° E and the broadcasting satellites, 15 m earth station antennas of the fixed-satellite system would cause interference to the broadcasting satellites in the orbital range from 62° E to 74° E. Therefore, the required orbital separation for protecting the broadcasting-satellite feeder links may be about 10°. On the other hand, interference from broadcasting-satellite earth stations to space stations in the fixed-satellite service would arise only from the feeder links earth stations to those broadcasting satellites nearest to the fixed satellite within 3° separation;

– as for the interference situation between the broadcasting satellites and the assumed domestic or sub-regional FSS satellites, located within the broadcasting-satellite positions, the interference to the broadcasting satellites would be dominant. In consequence, use of 4.5 m earth-transmitting antennas in the fixed-satellite system would cause interference to the broadcasting satellites which are located within about 30° from the fixed satellites, with protection ratios of less than 45 dB.

If different transmission characteristics and orbital locations were assumed for Intelsat-V, some of which may be employed in coming years (SCPC, 12 channel carriers, 66° E longitude position, etc.), they might lead to different conclusions concerning the required orbital separation between fixed and broadcasting satellites using the 14.0-14.5 GHz band in the Earth-to-space direction. Further study is necessary to take into account the range of system parameters that might be used.

15.2 *Example 2*

The study conducted by the French Administration in this example assumed the fixed-satellite orbital position located between two broadcasting satellites spaced 6° apart, and an FSS service area partially overlapping one of the BSS service areas. For this study and particular set of assumptions, it was concluded that even in the case of FSS networks using high-capacity FDM-FM carriers, adequate protection from interference to the FSS from the BSS feeder link cannot be assured unless the FSS satellite is placed in the proximity of those positions for which interference is minimum. The choice of these positions may entail severe constraints incompatible with the requirements of the FSS (such as the service arc). Furthermore, the use of a band shared between broadcasting-satellite feeder links and the up links of the fixed-satellite service over an entire region would presuppose that sharing is feasible at least for certain orbital positions, irrespective of the possible characteristics of the systems; however, it has been seen that in the case of SCPC or low-capacity channels in the FSS, it is impossible to find a position that suits the purpose.

Individual cases of sharing between FSS up links and BSS feeder links require detailed examination, taking into account the projected parameters and the possibilities of frequency coordination, which is under consideration in Study Group 4.

16. Sharing in the bands above 12.75 GHz

The WARC-79 allocated three frequency bands above 12.75 GHz to the broadcasting-satellite service; 22.5-23, 40.5-42.5 and 84-86 GHz. In the 40.5-42.5 GHz band, the broadcasting-satellite service is the only primary allocation and therefore frequency sharing from the BSS viewpoint is not necessary. In the 84-86 GHz band, the BSS, fixed, mobile and broadcasting services are all allocated on a primary basis. However, footnote 913 applying to this band, states that stations in these other services "shall not cause harmful interference to broadcasting-satellite stations operating in accordance with the decisions of the appropriate frequency assignment planning conference for the broadcasting-satellite service". This footnote, plus lack of detailed information concerning the technical characteristics of systems which may operate in this band, make it difficult to set forth a detailed sharing analysis for this portion of the spectrum.

16.1 *Sharing in the band 22.5 to 23 GHz between the BSS and other services* *

16.1.1 *Interference to the fixed and mobile services from broadcasting-satellite systems*

Assuming conventional frequency-modulation television, a broadcasting satellite operating near 22 GHz requires a higher e.i.r.p. than one operating in the vicinity of 12 GHz. A 4 dB increase is necessary to overcome the worst-case (99%) atmospheric loss (see Table 1-XIVa). Therefore, for a large percentage of time, the pfd at the surface of the Earth will be that much greater from 22 GHz broadcasting satellites, thus tending to cause somewhat greater interference to the fixed services using the same frequencies in the same geographical area (see § 10.2.2 of this Chapter).

16.1.2 *Interference to broadcasting-satellite earth station receivers from the fixed and mobile services*

The conclusions drawn in § 10.1 of this Chapter are that the broadcasting-satellite and fixed services operating near 12 GHz cannot operate in the same geographic area. This conclusion is based on the likelihood of interference from fixed service transmitters to broadcasting-satellite earth station receivers. Such interference is also likely for 22 GHz systems but definite conclusions cannot be drawn since the likely parameters of space and terrestrial systems in this band are not yet available.

16.1.3 *Interference between the broadcasting-satellite service and the inter-satellite service*

Interference between the BSS and the ISS is treated in Report 951.

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* This band is allocated to the BSS only in Regions 2 and 3.

17. Unwanted emissions from broadcasting-satellite space stations

17.1 *Introduction*

Space stations in the broadcasting-satellite service may have high values of e.i.r.p. and consequently the level of unwanted emissions may produce interference in networks using adjacent and harmonically related bands for other services.

Unwanted emissions consist of spurious emissions and out-of-band emissions (see Nos. 140, 138 and 139 of the Radio Regulations).

17.2 *Possible source of unwanted emissions from broadcasting satellites in adjacent bands*

These are:

(a) Radiation due to frequency conversion which is generated in the frequency conversion process and the local oscillator source in the satellite transponder and which will normally be quite negligible.

(b) Third order inter-modulation products caused by insufficient suppression of signals in adjacent channels in the satellite transponder; with careful design of branching filter, it is possible to suppress the signal in the adjacent channels and thus reduce this unwanted emission.

(c) Thermal noise generated by the satellite transponder; thermal noise in the down link is caused by:

- interaction of the thermal noise and RF carrier in the high power amplifier due to non-linearity;
- amplification and transmission of receiver noise;
- retransmission of received feeder-link noise.

Figure 3-12 represents the calculated results for the thermal noise spectral pfd as a function of frequency.

(d) Spreading of signal spectrum due to non-linearities.

Band limiting on the feeder link and in the transponder leads to carrier envelope variations at the input to the transponder high power amplifier which is typically a saturated amplifier and also has AM/PM conversion, so the envelope variations will generate RF intermodulation. This intermodulation will be reduced by increasing the bandwidth of the feeder link and of the transponder preceding the high power amplifier, but this will increase the system noise bandwidth.

The actual spectrum radiated by the satellite largely depends upon the TV signal transmitted. In Fig. 3-13 computer-calculated results on this subject are presented for illustrative purposes.

17.3 *Spurious emissions due to harmonics*

Studies have shown that if spurious emissions at harmonic frequencies are of the order of 60 dB below the level of the fundamental frequency, interference with other services at these frequencies may not be significant. However, further studies are necessary to assess the interference effects in individual bands.

17.4 *Protection of other services from unwanted emissions*

Guardbands necessary to protect the services operating in adjacent bands from unwanted emissions of 12 GHz broadcasting satellites are discussed in § 3.9 of Annex 8 of Appendix 30 to the Radio Regulations.

Similarly in other bands, adjacent services may be protected by establishing appropriate guardbands. The width of the guardbands depends upon the design affording a maximum feasible protection from interference outside the bandwidth required for satisfactory service (see Radio Regulations No. 301). Studies have shown that unwanted emissions outside the allocated band can be reduced by filters with a roll off of 2 dB/MHz up to an attenuation of 80 dB.

17.4.1 *Protection of the fixed-satellite service from unwanted emissions*

Report 712 addresses the protection of fixed-satellite earth stations operating in adjacent bands against unwanted emissions from 12 GHz broadcasting-satellite space stations and gives the values of maximum allowable power flux-density (pfd) at the edge of the band that would produce no more than 500 pW0p of interference in the worst channel of an FDM-FM carrier in the fixed-satellite service whose space station is collocated and serves the same area.

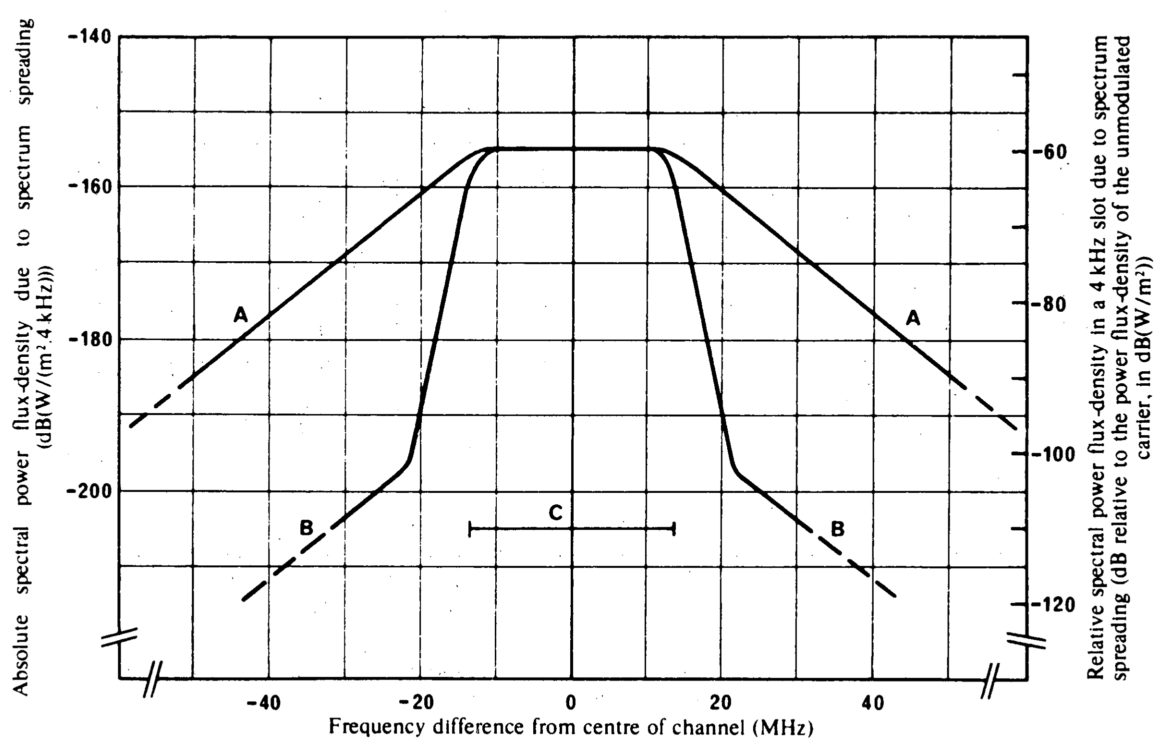

FIGURE 3-12 — *Typical envelopes of the thermal noise power spectrum radiated by the high-power output amplifier of a broadcasting satellite*

Curves A: Transponder with typical filtering

B: Estimated performance of transponder with additional filter before power amplifier

C: Nominal channel bandwidth (27 MHz)

Note. — The spectra shown by curves A and B assume the presence of an rf-carrier corresponding to a power flux-density of −94 dB(W/m²) at the centre of the beam and a carrier-to-noise power ratio of about 20 dB at the transponder output. In the absence of a carrier, the thermal noise spectrum envelopes increase by about 9 dB.

17.4.2 *Protection of fixed and mobile services*

Unwanted emissions from broadcasting satellites into fixed and mobile services are discussed in Report 789.

17.4.3 *Protection of radioastronomy services*

Harmonically related spurious emissions into the 23.6 to 24.0 GHz radioastronomy band are discussed in Annex II of Report 697 (Kyoto, 1978) and Annex II of Report 807.

17.4.4 *Conclusions*

It is concluded that the unwanted emissions from a broadcasting-satellite space station may not be negligible and are caused primarily by thermal noise and by frequency modulation of the carrier by the video waveform chosen. If it is practicable to use RF filters or narrowband multiplexers at the output of the broadcasting-satellite transponders which have sharp channel-edge decay rates, then the guardbands could be reduced.

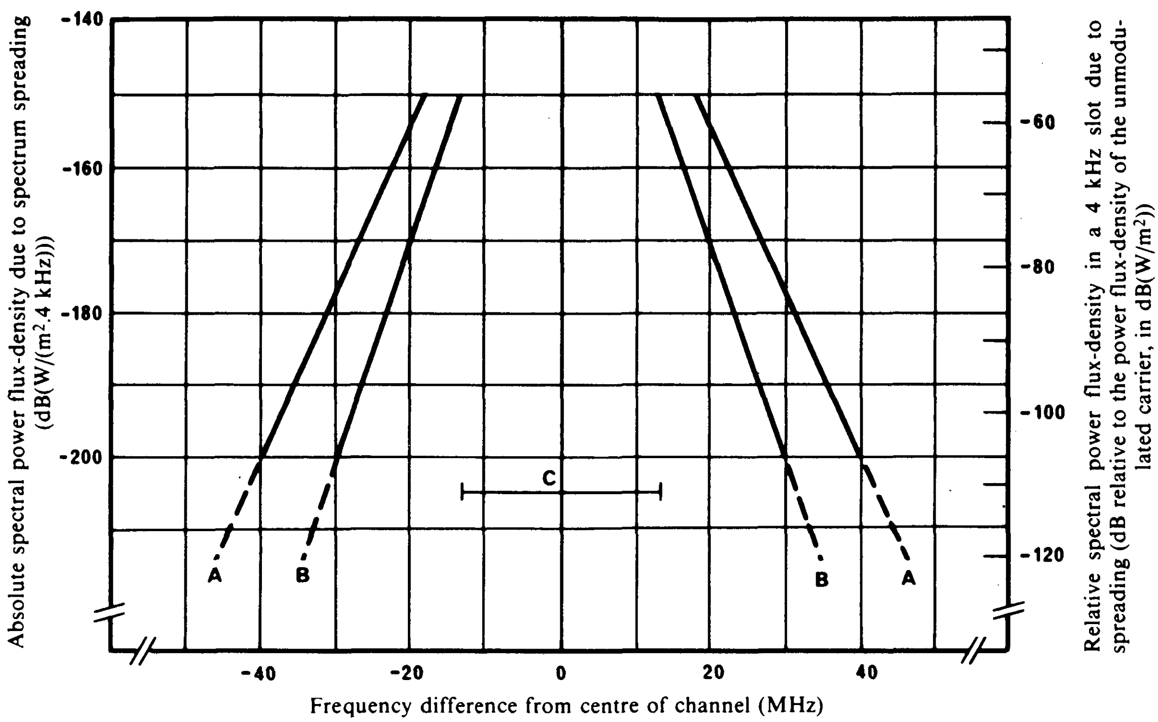

FIGURE 3-13 – *Typical out-of-band envelopes of the radio-frequency spectrum radiated by a television broadcasting satellite*

Curves A: envelope for 100 per cent colour-bar baseband signal, modulator AC coupled

B: envelope for line 330 insertion test signal, modulator AC coupled

C: nominal channel bandwidth (27 MHz)

Note 1. – For the left-hand scale, it is assumed that the e.i.r.p. of the satellite corresponds to a power flux-density of -94 dB(W/m^2) at the centre of the beam for an unmodulated carrier.

Note 2. – Minimum energy dispersal of $\pm$ 7.9 kHz is assumed.

Note 3. – Pre-emphasis according to Recommendation 405 is assumed.

ANNEX 3-I

DETAILED METHOD OF CALCULATING THE POWER FLUX-DENSITY PRODUCED AT A GIVEN POINT ON THE SURFACE OF THE EARTH BY THE EMISSION FROM A GEOSTATIONARY BROADCASTING SATELLITE

Required data:

For these calculations we require the following data:

- the position of the broadcasting satellite in the geostationary orbit. This is determined fully if the longitudinal position of the satellite is known;
- the latitude and longitude of the point on the surface of the Earth at which the power flux-density is required to be calculated;
- the available power at the input to the satellite antenna. Usually, the transmitter output power and the feeder loss, etc., are specified;
- the gain of the satellite antenna in the direction of the line joining the satellite to the ground station and encompassing the half-power beamwidth.

Normally, the first three data are readily available, but data in respect of the fourth requirement will have to be evaluated from other parameters.

1. Calculation of power flux-density

The power flux-density, *pfd*, produced by the transmitter in the satellite, feeding a power of p (W) at the input to the satellite antenna is given by:

$$pfd = (p \cdot g_{SA})/4\pi d_{SA}2 \qquad (\text{W/m}^2)$$

where g_{SA} is the gain of the satellite antenna in the direction of the point, A; d_{SA} is the distance (m) between the satellite and the point, A.

The above equation could be re-written as:

$$pfd = [(p \cdot g_{SA})/4\pi d_{SS}^2] \cdot (d_{SS}/d_{SA})^2 \qquad (\text{W/m}^2)$$

where d_{SS} is the height of the geostationary broadcasting satellite above the sub-satellite point. Expressed in dB(W/m^2), the power flux-density, *PFD*, is given by:

$$PFD = 10 \log p + 10 \log g_{SA} - 10 \log (4\pi d_{SS}^2) - 20 \log (d_{SA}/d_{SS})$$

For a geostationary satellite, d_{SS} is 35 870 km. The value of the term 10 log $(4\pi d_{SS}^2)$, is 162.1 dB, if d_{SS} is expressed in metres.

The angle of arrival can be determined from Fig. 3-14 and the additional range loss can then be ascertained from Fig. 3-16. The value of this variation varies from zero dB (at the sub-satellite point where the angle of arrival is 90°) to about 1.3 dB (where the angle of arrival is zero).

The variation in range loss can then be ascertained by reference to Fig. 3-16 of this Annex. The value of the power flux-density obtained above is under conditions of free-space propagation and the method of calculation does not take account of atmospheric absorption, etc.

2. Calculation of the gain of the satellite antenna in the pertinent direction

The term 10 log g_{SA} is the gain of the satellite antenna in the pertinent direction. Normally, the gain of the antenna is specified in the direction of maximum radiation. To determine g_{SA}, the "off-axis angle" must be calculated.

The off-axis angle is the angle between the direction of maximum radiation of the satellite antenna and the direction of the line joining the satellite antenna to the point on the surface of the Earth where the power flux-density is to be calculated. This parameter is most important and its evaluation is fairly involved.

2.1 *Calculation of off-axis angle*

Let

φ_A : the latitude of the point, A, on the surface of the Earth where the value of power flux-density is required;

λ_A : the longitude of the point, A, on the surface of the Earth where the power flux-density is required to be calculated;

φ_M : the latitude of the point, M, on the surface of the Earth, towards which the maximum radiation of the satellite antenna is directed;

λ_M : the longitude of the point, M, on the surface of the Earth, towards which the maximum radiation of the satellite antenna is directed;

λ_S : the longitudinal location of the satellite in the geostationary orbit;

λ_{RA} : $\lambda_S - \lambda_A$, the relative longitude.

By reference to Fig. 3-14 of this Annex we can obtain the angles of arrival (elevation). Knowing the angle of elevation, we can obtain the following angles from Fig. 3-17 of this Annex:

Angle of tilt, T_A : the angle between the directions joining the satellite to the point, A, and the satellite to the sub-satellite point.

Angle of tilt, T_M : the angle between the directions joining the satellite to the point, M, and that from the satellite to the sub-satellite point.

By reference to the set of curves in Fig. 3-15 of this Annex, we obtain the following data:

A_A : the azimuthal angle of the point, A, as observed from the sub-satellite point;

A_M : the azimuthal angle of the point, M, as observed from the sub-satellite point.

Now knowing, T_A, T_M, A_A, and A_M, we can calculate the angle T_{AM}, the off-axis angle, between the lines joining the satellite to the points A and M on the surface of the Earth from the following equation:

$$\cos T_{AM} = \cos T_M \cos T_A + \sin T_M \sin T_A \cos (A_A - A_M)$$

2.2 *Evaluation of g_{SA}*

The latest CCIR studies concerning the satellite transmitting antenna gain are summarized in Chapter 2.

For obtaining azimuthal angle in degrees east of True North at the sub-satellite point from the values as read from these curves, proceed as follows:

- for locations east of the satellite in the northern hemisphere: no change,
- for locations west of the satellite in the northern hemisphere: subtract the angle from 360°,
- for locations east of the satellite in the southern hemisphere: subtract the angle from 180°,
- for locations west of the satellite in the southern hemisphere: add 180° to the angle.

The factor, g_{SA}, can be calculated by substituting the angle, T_{AM}, in place of θ, in the antenna patterns given in Chapter 2.

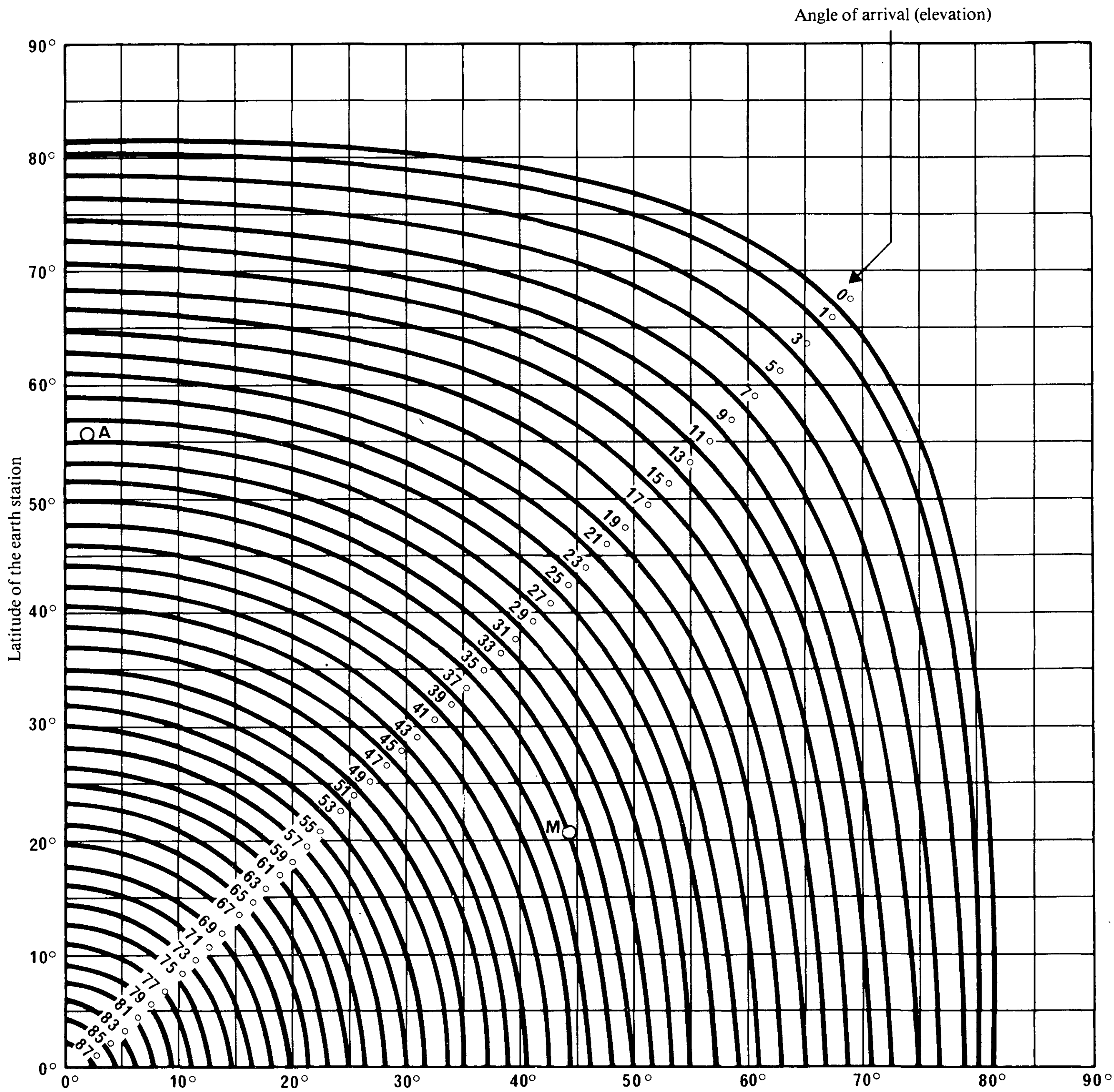

FIGURE 3-14 – *Angle of arrival as a function of the difference in longitude between the sub-satellite point and earth station and the latitude of the earth station*

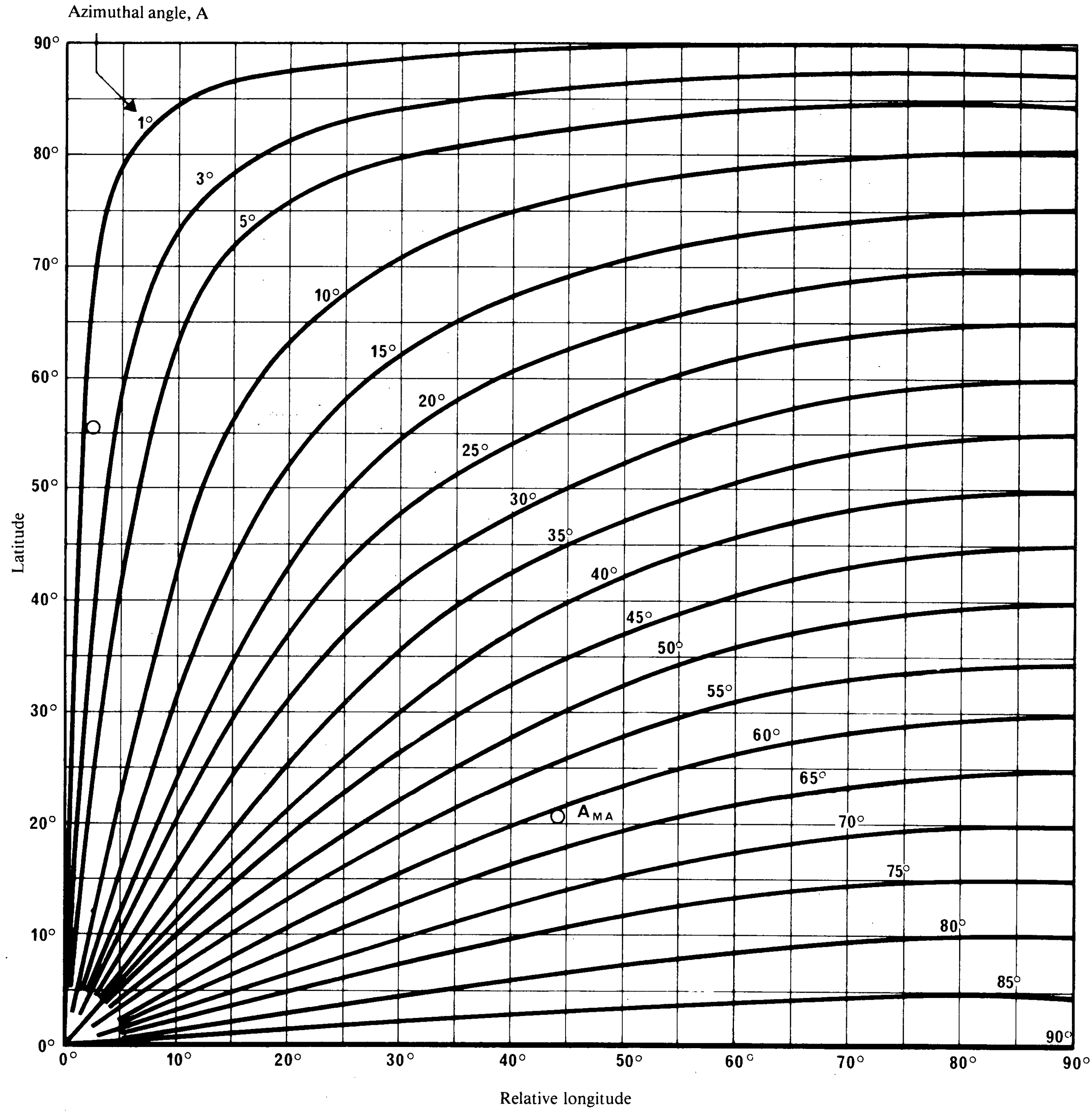

FIGURE 3-15 – *Variation of latitude with relative longitude for different points on the surface of the Earth, for various values of the azimuthal direction, A, as observed from the sub-satellite point of a satellite in the geostationary-satellite orbit*

Note. – The azimuthal angle, A, as observed from the sub-satellite point is the angle subtended between true north and the azimuthal direction for sub-satellite points in the northern hemisphere. For the southern hemisphere, it is the angle subtended between true south and the azimuthal direction of the sub-satellite point.

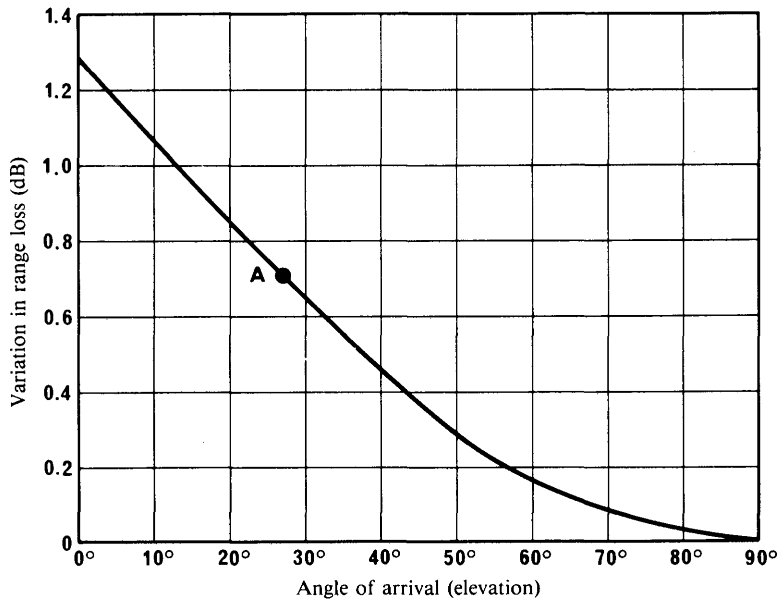

FIGURE 3-16 – *Variation in range loss as a function of the angle of arrival (elevation) of the satellite emission*

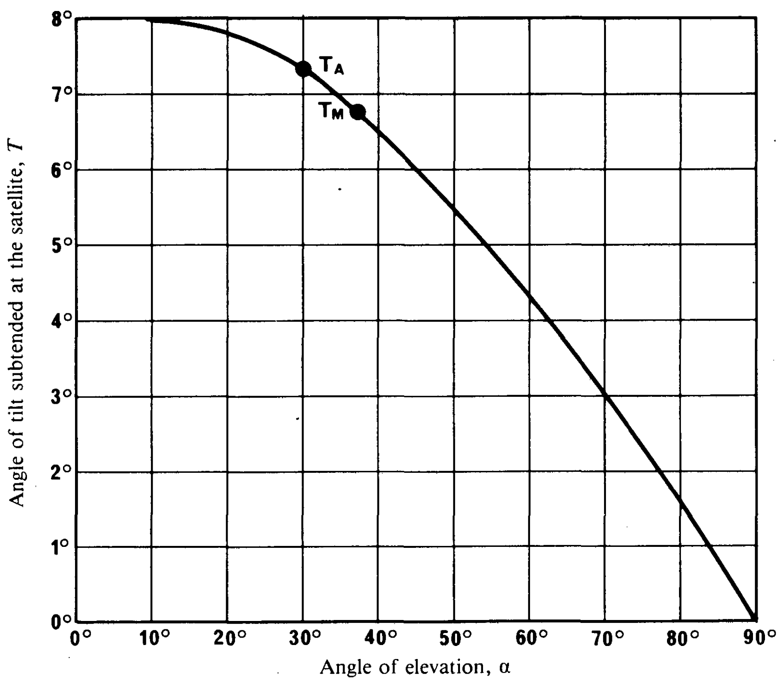

FIGURE 3-17 – *Angle of tilt, T, as a function of the angle of elevation, α*

2.3 *Mathematical relations for various curves described above*

Figures 3-14 to 3-17 of this Annex are based on the following mathematical relations existing between various geographic/geometrical parameters:

2.3.1 The great-circle distance (angle) ψ_A between the sub-satellite point and point, A, on the surface of the Earth is given by:

$$\cos \psi_A = \cos \varphi_A \cos \lambda_{RA}$$

2.3.2 The angle of arrival, α_A, of the geostationary satellite emission at point, A, is given by:

$$\tan \alpha_A = (\cos \psi_A - 0.15127)/\sin \psi_A$$

2.3.3 The angle of tilt, T_A, i.e., the angle between the lines joining the geostationary satellite to the point, A, and the sub-satellite point is given by:

$$T_A = 90° - \psi_A - \alpha_A \qquad \text{(degrees)}$$

2.3.4 The azimuthal angle of the point, A, (A_A) as seen from the sub-satellite point is given by:

$$\tan A_A = \sin \lambda_{RA}/\tan \varphi_A$$

2.3.5 $\cos \theta = \cos T_A \cdot \cos T_M + \sin T_A \cdot \sin T_M \cdot \cos (A_A - A_M)$ (where θ is the off-axis angle)

ANNEX 3-II

EXAMPLES OF POWER FLUX-DENSITY LIMITS REQUIRED TO PROTECT THE LAND MOBILE SERVICE AT ABOUT 800 MHz

For a single broadcasting satellite in the visible orbit, the acceptable value of power flux-density produced on the surface of the Earth by the satellite is:

- to protect a high grade service:
  -133 dB(W/(m^2 · 16 kHz)) at the receiving antenna of the mobile station;
  -146 dB(W/(m^2 · 16 kHz)) at the receiving antenna of the base station;
- to protect a minimum grade service:
  -127 dB(W/(m^2 · 40 kHz)) at the receiving antenna of the mobile station;
  -134 dB(W/(m^2 · 40 kHz)) at the receiving antenna of the base station.

These values are applicable only for the land mobile service at about 800 MHz.

The value of -146 dB(W/(m^2 · 16 kHz)) is based on currently available information and is, for example, necessary to protect a system operating in the land mobile service at about 800 MHz having the following characteristics:

- channel spacing: 25 kHz;
- receiver bandwidth: 16 kHz;
- receiver noise figure: 10 dB;
- improvement factor: 12 dB;
- antenna gain: 15 dB;
- radio-frequency protection ratio: 18 dB;
- polarization discrimination: 3 dB.

For different or additional characteristics, the power flux-density mentioned will change accordingly. This value takes into account low elevation angles of the broadcasting satellite.

It should be noted that if several broadcasting satellites are in a visible orbit, the power flux-density produced by each satellite must be correspondingly lower than that quoted above.

Before a general value of protection to systems in the land mobile service can be developed, it would be desirable to obtain more data on parameters of systems in operation or under development from other administrations. Further studies should therefore be undertaken on receipt of additional data.

At the present time it seems premature to judge whether sharing between the broadcasting-satellite service and the land mobile service is feasible at about 800 MHz.

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CHAPTER 4

SYSTEM SYNTHESIS AND COST ESTIMATION

1. Introduction

The purpose of this Chapter is to provide the reader with a method for synthesizing a broadcasting-satellite system for television, and a set of techniques for estimating the cost of the various elements of the system. The cost estimating techniques and cost data provided in this Chapter are useful for planning purposes and for system design trade-offs. However, because of rapidly changing technology and costs, final system costing should be done using as up-to-date cost data as possible, preferably direct quotations from equipment manufacturers.

A broadcasting-satellite system is made up of a space segment and a ground segment.

The space segment consists of one or more satellites. (In an operational mode, it is generally deemed necessary to keep at least two satellites in orbit at the same time and one spare satellite on the ground.) Often, the earth-located satellite control facilities are also considered part of the space segment.

The ground segment consists of a feeder-link station network (feeder link station(s) and radio links or cables between the station(s) and the programme production centres) and receiving terminals for community and, in certain cases, individual reception.

The two segments are connected via the feeder link (up link) between the feeder link station(s) and the satellite(s) and via the broadcasting link (down link) between the satellite(s) and the receiving terminals.

The space segment cost includes development and manufacturing costs for the satellite(s), launch costs, costs for the satellite control facilities (investment and operating and maintenance costs) and insurance costs (optional). The ground segment cost includes costs for the feeder-link station network (investment, operating and maintenance costs) and for the receiving terminals (equipment, installation and maintenance costs).

The two segments are economically dependent on each other in the following way:

– if the down-link e.i.r.p. is decreased (increased) and the down-link G/T correspondingly increased (decreased) the space segment cost decreases (increases) and the ground segment cost increases (decreases);
– if the feeder link e.i.r.p. is decreased (increased) and the up-link G/T correspondingly increased (decreased) the ground segment cost decreases (increases) and the space segment cost increases (decreases).

The costs for the satellite control facilities are not affected by such changes. Furthermore, altering the down-link parameters has much greater economic consequences for both segments than altering the feeder-link parameters. Therefore only the first-mentioned case will be treated in § 2 and 3.

Section 2 is a general discussion of the synthesis/costing methodology while the detailed step-by-step approach is delineated in § 3.

In making performance and cost trade-offs between the spacecraft and ground segments, regulatory constraints and financial situation must be kept in mind. There are regulatory constraints on parameters such as power flux-density, antenna side lobes, etc. These constraints are a function of factors such as frequency and geographic region of operation. Therefore, care must be taken in defining system technical requirements so as not to violate regulatory constraints.

For the 12 GHz broadcasting-satellite service in Regions 1 and 3, see Appendix 30 to the Radio Regulations.

When the whole system is to be financed from the same source, the economically optimum set of down-link parameters is that which implies the minimum system cost. However, if this is not the case, the usefulness of such an optimization may be questioned.

If, for example, the space segment is to be purchased by the administration and the receiving equipment is to be bought by the public on the consumer market, the optimization procedure should involve macro-economic considerations including assessment of the consequences for the private consumption, balance of trade, etc.

It should, in this context, be remembered that many countries especially in the third world, have to purchase the whole or the main part of the space system on the international market, whereas a great part of the ground segment may often be provided for by the domestic industry. Consequently, for many countries it may therefore be more advantageous to "put more money" into the ground segment than is suggested from the described trade-off analysis. A solution, which does *not* imply minimum system cost, may thus very well be considered to be optimum from a macro-economic point of view.

2. Methodology for estimating cost of space segment and ground receivers

2.1 *Overview*

The system to which this synthesis and costing method applies consists of a geostationary satellite broadcasting frequency-modulated television signals for community or individual reception. Each television signal can be accompanied by one or more sound channels. The satellite can employ one or several independent antenna beams and can have several television channels per beam. Each beam can be shaped by the use of several adjacent smaller beams.

The system is assumed to have a large number of receiving terminals. One of the goals of the system design, therefore, is to keep the cost of receiving terminals low. This must be done without violating any regulatory constraints and without making unreasonable demands on the satellite.

The system synthesis and costing procedure includes the following set of processes: requirement and constraint definition, system design, detailed design and costing. The procedure consists of a series of nine steps, each of which is described in sub-sections of § 3. A flow chart of the procedure, showing the steps and their interaction, is illustrated in Fig. 4-1.

A set of input parameters is needed to establish the system requirements. Input parameters and their effects on the system are treated in § 2.2. The output parameters are described in § 2.3.

Given a set of system technical requirements, system synthesis and the computation of ground and space segment costs, proceed in a sequence of nine steps as follows:

1. Determine system carrier power to noise spectral power density ratio C/N_0, at the receiver input as a function of signal quality requirements, e.g. the video signal-to-noise ratio and type of television standard.

2. Determine total path loss, L_p, considering satellite earth station geometry and rain loss factors.

3. Using the results of 1. and 2., calculate the system parameter X which equals the required e.i.r.p. per channel plus the earth station figure-of-merit, G/T. Select a reasonable interim value of G/T, thereby defining e.i.r.p. per channel.

4. For the chosen G/T, determine the combination of G (or earth station antenna diameter) and T (the system noise temperature) that minimizes the cost of the ground segment equipment within any constraints such as minimum antenna size.

5. Determine the total ground segment cost on the basis of the required number of terminals.

6. Using the calculated value of e.i.r.p. per channel and other selected inputs, estimate communication sub-system and spacecraft power.

7. Estimate communication sub-system and spacecraft weight.

8. Estimate the cost of the spacecraft.

9. Determine the launch vehicle to be used and its cost.

At this point it is possible, and usually desirable, to reiterate either through the entire procedure, selecting a different set of input parameters, or only through the design and costing procedures, choosing a slightly different value of G/T or changing some spacecraft parameter. This allows the determination of system cost sensitivity to various system parameters, and the synthesis of a minimum cost system within the existing constraints.

Various computer programs are available (Report 812) to perform some or all of the above steps. It must be recognized, however, that technology and costs change rapidly, and a computer program is only as up to date as its data base. Also, special circumstances, such as the availability of usable designs from existing systems, can influence the cost trade-offs. For this reason, an in-depth understanding of the step-by-step process of accomplishing the system design and costing is provided in § 3. The user can then evaluate existing computer programs, develop his own programs, or use the graphical method of system synthesis and optimization presented in § 3.

At a certain stage of design of the broadcasting-satellite system, it is necessary to perform a financial analysis which examines factors such as lifetime of space and ground equipment, their costs, their reliability and the trade-offs among these factors. Also the variation in cost as a function of time must be considered.

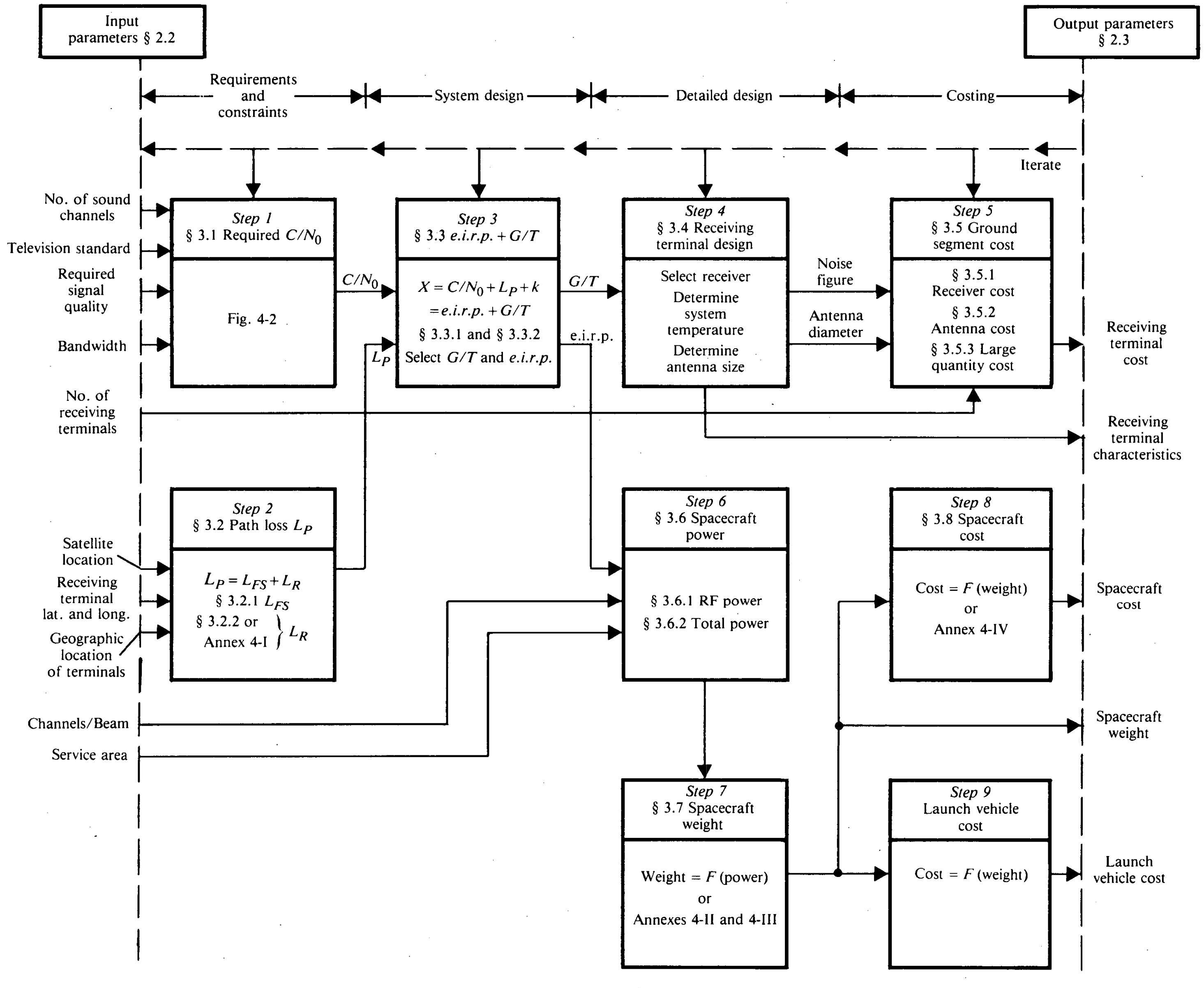

FIGURE 4-1 – *System synthesis and costing procedure*

2.2 *Input parameters*

Useful guidelines in the choice of characteristics for a satellite television broadcasting system are given in Appendix 30 to the Radio Regulations and Reports 811 and 215. The required inputs, with a brief explanation of the effect of each on the system, are listed below:

– *Signal quality* in terms of peak-to-peak signal to weighted r.m.s. noise ratio. This parameter defines the quality of the video signal. Picture quality ratings versus S/N can be found in § 3 as well as in Report 215. The minimum acceptable signal quality should be chosen since this parameter directly affects satellite power and ground terminal G/T.

– *Television standard.* This is the particular standard in use in a given country. For example, the 525-line system M is used in the United States of America. The characteristics of other standards can be found in Report 624.

– *RF bandwidth* *. RF bandwidth is a compromise between spectrum usage efficiency and FM improvement. In some cases it is constrained by regulations. Suggested values of bandwidth for various television systems are given in Report 215.

– *Number of sound channels per video channel.* This parameter has an effect on signal bandwidth and required C/N_0.

– *Service area* * is determined by the geographic location of receiving earth stations. Earth station location determines the rain climate which is used in determining atmospheric attenuation. Earth station location in conjunction with satellite longitude determines the elevation angle to the satellite. The receiving station with the minimum elevation angle has the greatest signal path loss and greatest system temperature contributions from antenna side lobes looking at the ground. The receiving station in the highest rainfall climate requires the highest link margin (at 12 GHz) due to rain-induced atmospheric attenuation and system temperature increase.

– *Satellite location* *. Relative longitude of the satellite with respect to local service area determines the time of earth solar eclipse in that area.

– *Required link availability* *. This parameter determines the link margin which must be included in the system design in order to maintain the required signal quality during periods of rain. Link margin requirements can become very high at high values of link availability. A recommended goal is to provide service during 99% of the worst month (Appendix 30 to the Radio Regulations). The relationship between worst month and average year rain statistics is climate dependent. Since average year rain statistics are more readily available they will be used in this Chapter.

– *Total number of earth stations.* This parameter affects ground terminal cost (per unit) as well as total ground segment costs.

– *Coverage area *, number of beams, and channels per beam.* These parameters determine the weight of the spacecraft antenna and the characteristics of the communication electronics.

2.3 *Output parameters*

The system synthesis and cost evaluation procedure described in detail in § 3 provides the design characteristics and cost of the receiving terminals and satellite, including launch costs.

2.3.1 *Receiving terminal characteristics*

The noise figure of the receiver and the size of the receiving antenna are determined as a function of the required G/T and rain margin.

2.3.2 *Receiving terminal costs*

The estimated purchase costs of the receivers and antennas are determined as a function of the number of receiving terminals.

2.3.3 *Satellite characteristics*

The weight and power of the spacecraft are estimated as a function of the required e.i.r.p. and service area size. It is possible to do an in-depth sub-system by sub-system spacecraft design by following the procedures of Annexes 4-II and 4-III.

---

* Bandwidth, service area, coverage area, satellite location, link availability etc., have been defined and specified at the WARC-BS-77 for the 12 GHz broadcasting-satellite service in Regions 1 and 3 and at the RARC SAT-83 for Region 2. (See also Chapter 1 of this report, Appendix 30 to the Radio Regulations and the Final Acts of RARC SAT-83.)

2.3.4 *Satellite cost*

The non-recurrent (design) and recurrent (manufacturing) costs of the spacecraft are estimated on the basis of its weight. The required launch vehicle and cost are also determined. Detailed spacecraft cost estimations as a function of different spacecraft parameters are possible using the procedures of Annex 4-IV.

3. Detailed approach

The sub-sections of this section correspond to the steps described in the overview, § 2.1. Figure 4-1 can be used as a guide through the procedure. It shows the interrelationships between the input parameters, steps, design curves, and back-up material.

The procedure is basically two level. The step-by-step procedure can be followed using simplified design relationships to obtain relatively quick answers, or the same procedure can be followed using more detailed design relationships provided in the Annexes to this Chapter. The latter approach allows the user to make more in-depth design evaluations, especially in the spacecraft area.

Annex 4-VI contains an example to illustrate the use of the procedure.

Step 1

3.1 *Required C/N_0*

Carrier power to noise spectral density, C/N_0, at the receiver is the fundamental parameter that determines signal-to-noise ratio, S/N, in FM systems. For a video signal, S/N is related to C/N_0 by the following expression:

$$S/N = C/N_0 + 10 \log [3/2 (\Delta f)^3/f_m^2] + k_W + k_L \qquad \text{dB} \qquad (1)$$

where:

S/N: ratio of peak-to-peak luminance signal amplitude to weighted r.m.s. noise (dB),

Δf: peak carrier deviation by the modulating signal (Hz),

f_m: highest modulating frequency (4.2 MHz in the case of system M),

k_W: combined de-emphasis and weighting improvement factor (13.8 dB for system M. See Report 215 for other systems),

k_L: conversion factor from r.m.s. to peak-to-peak carrier deviation (6 dB), and

C/N_0: system carrier power to noise spectral power density ratio (dB · Hz).

The radio-frequency bandwidth, B, can be approximated by Carson's Rule, *

$$B = 2 [\Delta f + F_m] \qquad \text{Hz (for video transmission)} \qquad (2)$$

The carrier-to-noise ratio, C/N, where $C/N = (C/N_0)(1/B)$, must also be greater than FM threshold, which is approximately 9 dB.

Figure 4-2 gives as an example for the 525-line system M, plots of constant video S/N versus RF bandwidth and C/N_0. Shown are plots of video only and video plus a sound sub-carrier at 6.8 MHz. Sound sub-carrier modulation index is selected for simultaneous video and sound threshold. The addition of other sound sub-carriers below 6.8 MHz will result in an RF bandwidth increase of approximately 1.5 MHz per sub-carrier.

Recommended values of RF bandwidth for various television systems are given in Report 215. Required video S/N depends on subjective picture quality requirements. Table 4-I gives an example of picture quality rating from Report 215.

Step 2

3.2 *Calculation of path loss*

L_p, the total path loss, is the sum of two components, the free-space path loss L_{FS}, and rain attenuation L_R.

* Better post detection S/N is achievable with "over-deviation" (in which the radio-frequency bandwidth is less than that determined by Carson's Rule); however transmission impairments such as impulse noise, differential phase and gain could be a problem (see Report 215, § 2.5).

TABLE 4-1 – *Example of picture quality rating*

Grade (See Note 7 of Report 405)	Radio-frequency signal-to-noise ratio for the percentage of viewers indicated (dB) (1)	
	50%	75%
1.5 half-way between excellent and fine	39.5	42.5
2 fine	35.2	38.2
3 passable	30.0	33.0
4 marginal	25.6	28.6
5 inferior	20.4	23.4

(1) Radio-frequency r.m.s. signal during sync. peaks, no weighting, over 6 MHz bandwidth, amplitude-modulation vestigial-sideband.

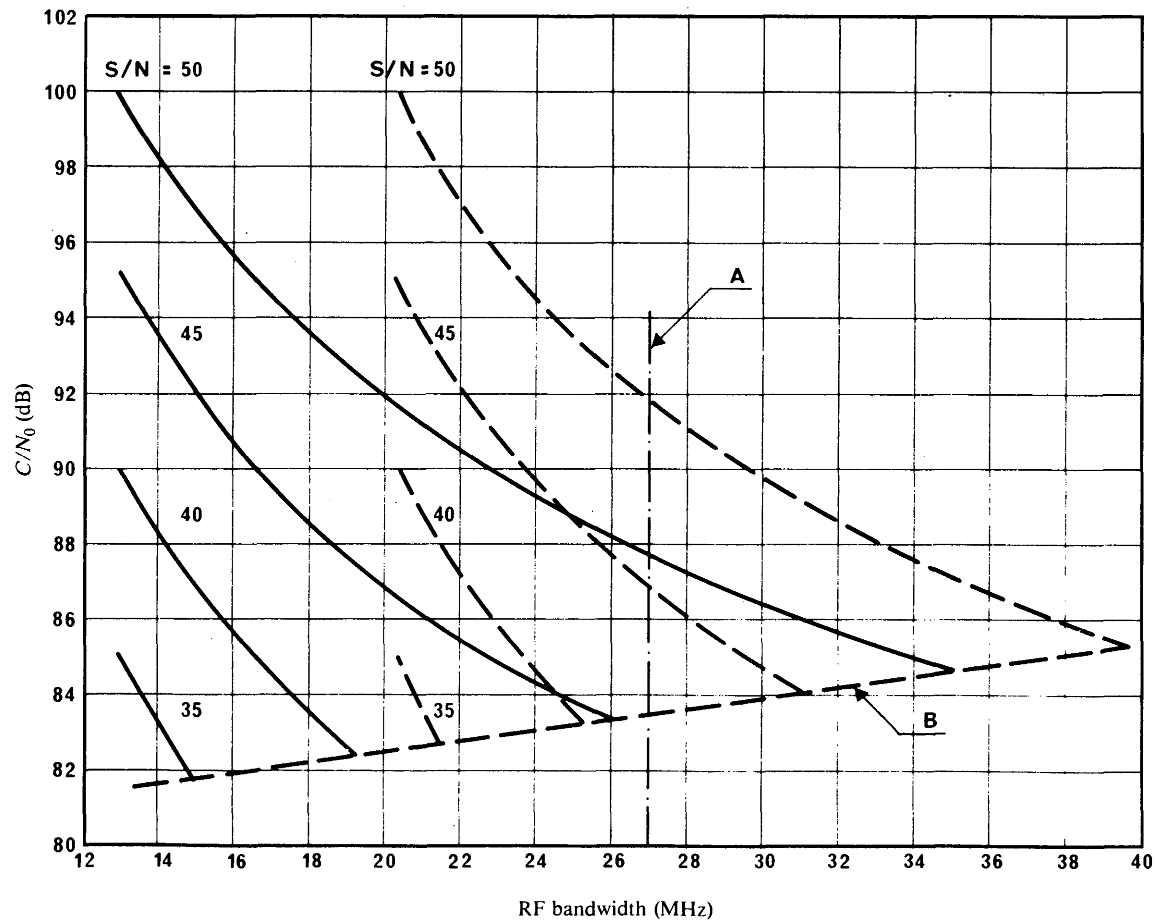

FIGURE 4-2 – *Required C/N_0 versus video S/N and RF bandwidth (525 line system M)*

——— : video only
— — : video + sound at 6.8 MHz
Line A: bandwidth adopted at the WARC-BS-77 for 12 GHz BSS for Regions 1 and 3
Limit B: FM threshold C/N = 9 dB

3.2.1 *Calculation of free-space path loss*

L_{FS} is given by the expression:

$$L_{FS} = 20 \log (\lambda / 4\pi D) \qquad \text{dB} \tag{3}$$

where:

D: distance from satellite to receiving terminal,

λ: wavelength in same units as D.

For a geostationary satellite, D is given by the following expression:

$$D = 6385 (\sqrt{\sin^2 \theta + 42.7794} - \sin \theta) \qquad \text{km} \tag{4}$$

where:

θ: angle of elevation to the satellite in degrees.

Angle of elevation to the satellite can be found from the latitude of the ground station and relative longitude of the satellite by referring to Fig. 4-3.

Table 4-II gives D and L_{FS} as a function of elevation angle to the satellite.

TABLE 4-II – *Free-space path loss versus elevation angle to satellite*

Elevation angle to satellite (θ)	Distance (km)	L_{FS} (dB)	
		2.6 GHz	12 GHz
90°	35 860	– 191.83	– 205.12
80°	35 945	– 191.85	– 205.14
70°	36 191	– 191.91	– 205.20
60°	36 597	– 192.01	– 205.29
50°	37 156	– 192.14	– 205.43
40°	37 859	– 192.30	– 205.59
30°	38 691	– 192.49	– 205.78
20°	39 635	– 192.70	– 206.00
10°	40 668	– 192.93	– 206.21
0°	41 762	– 193.16	– 206.44

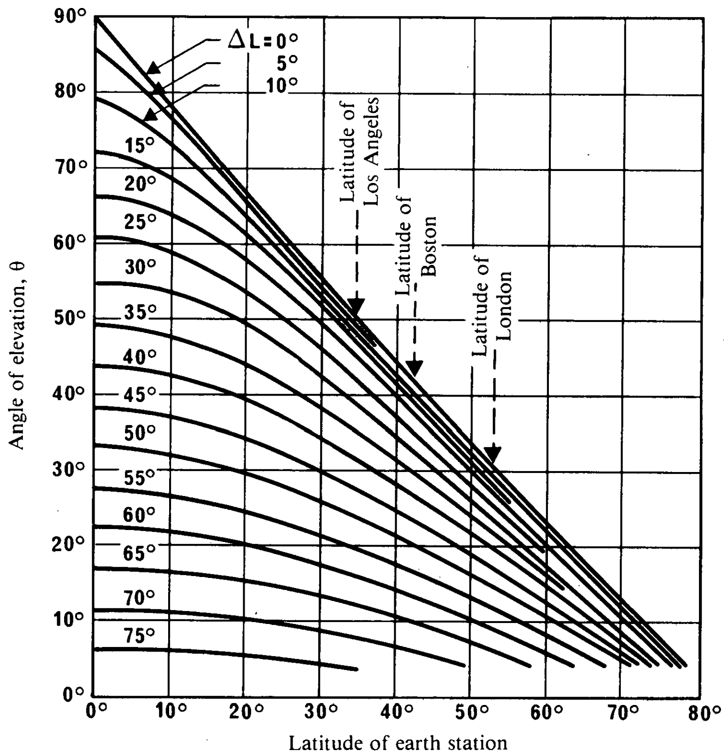

FIGURE 4-3 – *Angle of elevation to satellite as a function of latitude and relative longitude*

ΔL: difference between the earth station longitude and the satellite longitude

3.2.2 *Calculation of rain attenuation, L_R*

This component of total path loss can be neglected at 2.6 GHz, but has a significant impact on link design at 12 GHz and higher frequencies. The effect of atmospheric attenuation due to rain on link design is a function of the geographic location of the receiving terminals, location of the satellite and the desired level of link reliability. The procedure for computing rain attenuation for any geographic location is given in Annex 4-I. As an example, values of rain attenuation (L_R) are given in Table 4-III for six locations in the United States.

TABLE 4-III – *Examples of rain attenuation (L_R) for the United States*

Location	Rain zone	Elevation angle (satellite at 95° W)	Attenuation (dB) not exceeded during given percentage of average year					
			12.5 GHz			17.5 GHz		
			99 %	99.9 %	99.99 %	99 %	99.9 %	99.99 %
Portland, ME	B	33.5	−0.1	−1.0	−5.1	−0.3	−2.3	−10.8
Seattle, WA	C	29.0	−0.2	−1.4	−6.9	−0.4	−3.0	−14.6
San Francisco, CA	C	38.0	−0.4	−1.6	−7.3	−0.8	−3.5	−15.4
Chicago, IL	D2	41	−0.3	−2.5	−10.2	−0.7	−5.5	−21.4
Miami, FL	E	56	−1.2	−7.5	−21.7	−2.5	−15.9	−44.8
Los Angeles, CA	F	43.5	0.0	−1.2	−5.8	0.0	−2.6	−12.2

Computed attenuation at 12 GHz for slant paths, at an angle of elevation of 45°, in the worst month for different locations in India, together with measurements using a Sun tracking radiometer, are summarized in Table 4-IV (see Report 565).

TABLE 4-IV - *Attenuation (measured and calculated) due to rain at 12 GHz for slant paths of 45° angle of elevation in the worst month for different percentages of time and locations in tropical areas*

Parameters	Rain attenuation (dB) not exceeded for the indicated percentage of time					
	1%		0.1%		0.01%	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
50% of locations	1.6	2.02	8.5	8.02	15.7	12.2
90% of locations	4.3	4.81	11.6	9.99	> 18	> 13.4

Step 3

3.3 *Calculation of e.i.r.p. plus G/T*

The basic link equation for carrier-to-noise ratio, C/N, where all terms are in dB, is:

$$C/N = e.i.r.p. + L_p + G - kTB \tag{5}$$

or,

$$C - N = e.i.r.p. + L_p + G - k - T - B \tag{5a}$$

Since $N = B + N_0$,

$$C - N_0 = e.i.r.p. + L_p + G - k - T \tag{5b}$$

This equation can be rearranged as follows:

$$e.i.r.p. + G/T = X = C/N_0 - L_p + k \tag{6}$$

where:

C/N_0 : carrier power to noise spectral power density ratio (dB · Hz),

L_p : total path loss (dB),

k : Boltzmann's constant (-228.6 dB(W/(Hz · K))),

e.i.r.p. : sum of transmitter power and antenna gain (dBW),

G/T : receiving terminal figure of merit, i.e., antenna gain divided by system temperature (dB(K^{-1})),

B : signal bandwidth (dB · Hz).

The system parameter $X = e.i.r.p. + G/T$ therefore sets the combined requirements on the satellite and receiving terminals.

As a check on the procedure up to this point, Table 4-V gives some typical values for X for two values of S/N at 2.6 GHz and 12 GHz. L_p is referred to the sub-satellite point, and e.i.r.p. is specified in the direction of the receiving terminal. No rain attenuation margin is included.

TABLE 4-V – *Typical values for* $X = e.i.r.p. + G/T$

(System M video plus sound sub-carrier at 6.8 MHz)

Bandwidth (MHz)	Required satellite e.i.r.p. (dBW) + ground terminal G/T (dB(K^{-1}))			
	2.6 GHz		12 GHz	
	S/N = 50 dB	S/N = 45 dB	S/N = 50 dB	S/N = 45 dB
22	60.2	55.2	73.5	68.5
27	55.2	50.2	68.5	63.5
32	52.2	(1)	65.5	(1)

(1) Not achievable, C/N below threshold.

The system parameter $X = e.i.r.p. + G/T$ applies between the satellite and every receiving terminal. In general, spacecraft antenna gain will not be uniform towards every part of the service area. This variation will depend on the shape of the antenna beam with respect to the service area, and will have to be compensated for either by higher spacecraft e.i.r.p. or by higher G/T receiving terminals in some parts of the service area.

For very large service areas, non-uniform rain climate may produce large differences of rain attenuation between regions. In such cases a decision will have to be made whether to provide sufficient e.i.r.p. for the worst region case or require higher values of G/T in regions of high rainfall. Also the gain of the spacecraft antenna could be designed to compensate in some cases for variations in the rain attenuation over the service area.

The implications of the choice between higher e.i.r.p. versus higher G/T for some terminals can be determined by working several times through the remaining steps of the procedure.

3.3.1 *Selection of initial value of G/T and e.i.r.p.*

Optimum values of G/T and e.i.r.p. will be found by working several times through the procedure. Although the initial value of G/T is arbitrary, a reasonable value should be selected in order to avoid many iterations through the costing process. Appendix 30 to the Radio Regulations as well as planning considerations contained in Reports 811 and 215 should be consulted for recommended values of G/T. The availability of specific ground equipment designs may also influence the initial choice of G/T.

From Report 811 the recommended values of G/T in the 12 GHz band range from 4 dB to 12 dB for individual reception and 8 dB to 24 dB for community reception. Since antenna size is larger for the same G/T at 2.6 GHz, somewhat lower initial values of G/T should be used. Note that the 2.6 GHz band is to be used only for community reception systems.

The lower the G/T, the higher is the e.i.r.p. required. The impact of high e.i.r.p. on spacecraft design will depend on the size of the service area (the larger the service area, the higher the value of receiving terminal G/T which will produce an overall minimum cost design).

Having selected a value for G/T, the user must make sure that the resultant value of e.i.r.p. does not lead to the violation of any power flux-density limits given in the Radio Regulations.

In the case of 12 GHz broadcasting-satellite systems in Regions 1 and 3, attention should be given to the existence of the power flux-density limitation at the beam edge (see Appendix 30 to the Radio Regulations).

Step 4

3.4 *Receiving terminal design*

The receiver noise figure and antenna size (gain) are determined on the basis of the selected value of G/T.

The relationship between these factors is given by the following expressions:

$$G/T = 10 \log \left[\frac{aG_A}{aT_a + (1-a)\,T_0 + (n-1)\,T_0} \right] \quad \text{dB}\,(\text{K}^{-1}) \tag{7}$$

therefore

$$G_A = 10^{G/10T} \frac{aT_a + (1-a)\,T_0 + (n-1)\,T_0}{a} \tag{8}$$

where:

- a : signal transmission coefficient, expressed as a power ratio,
- G_A : effective gain of the receiving antenna, expressed as a power ratio,
- T_0 : 290 K,
- T_a : effective temperature of the antenna, K, which is made up of contributions from atmospheric noise, man-made noise, antenna side lobes pointing at the Earth, and attenuation of the signal by rain,
- n : noise factor of the receiver, where noise figure = 10 log (n)

and

$$T = \frac{aT_a + (1-a)\,T_0 + (n-1)\,T_0}{a} \quad \text{K} \tag{9}$$

where the antenna temperature T_a is given by:

$$T_a = 50 + 280\,(1 - 1/L) \tag{10}$$

$$L = 10^{-(LR/10)} \tag{11}$$

The expression for system noise temperature T is plotted in Fig. 4-4 for the case where the signal transmission coefficient (a) is assumed to be 1 (0 dB loss).

Representative values of noise figure are given in Table 4-VI for various available receivers. T, the system noise temperature, can be determined from Fig. 4-4 as a function of noise figure and rain attenuation, L_R.

Antenna diameter, D, can be related to antenna gain by the following expression:

$$D = \sqrt{\frac{G_A}{\eta}} \, \frac{\lambda}{\pi} \quad \text{m} \tag{12}$$

where η denotes the antenna efficiency.

The antenna diameter can also be determined for the required G/T, as a function of the system noise temperature, from Figs. 4-5 and 4-6 for 2.6 GHz and 12 GHz respectively.

The cost of the ground segment for a particular receiver and antenna is estimated in § 3.5. The system planner should choose that combination of parameters that minimizes cost for a given value of G/T. In making these evaluations, if the antenna is too small to meet minimum beamwidth requirements or some other criteria, then G/T can be raised until the antenna is the proper size, and e.i.r.p. can be correspondingly lowered.

If the antenna size appears too large, either e.i.r.p. must be raised or system noise temperature must be lowered through the use of a lower noise figure receiver.

The cost of raising e.i.r.p. can be found by iterating through the spacecraft costing procedure, steps 6 to 8 inclusive.

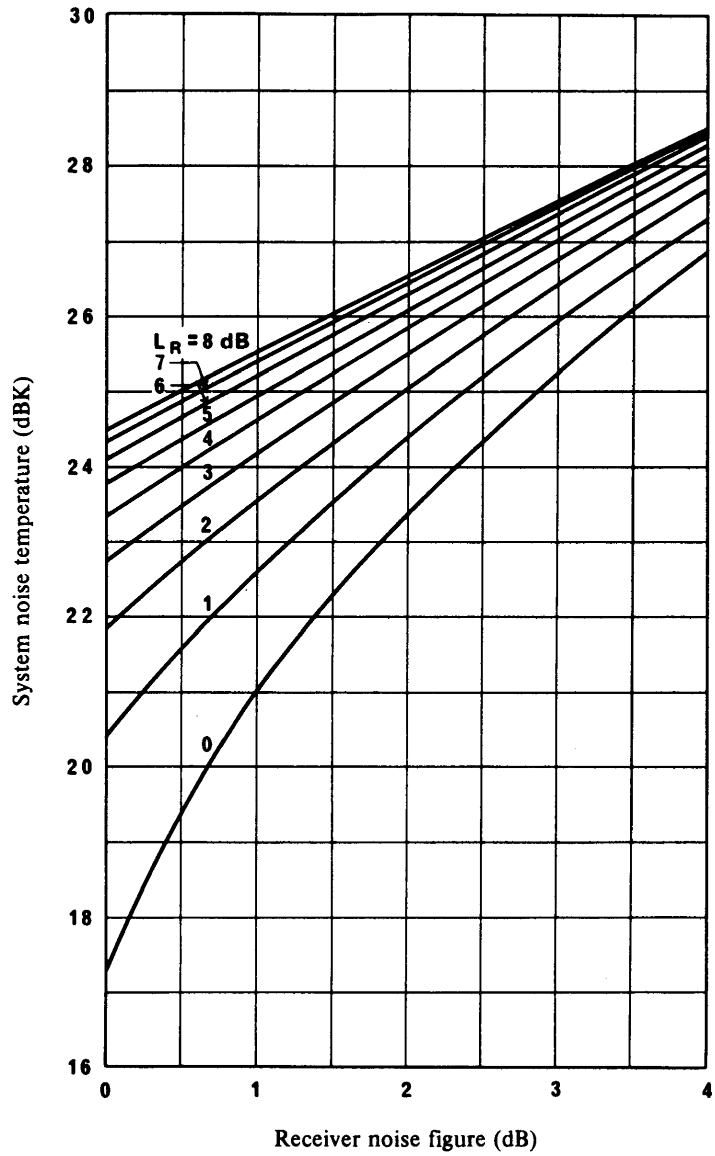

FIGURE 4–4 – *System noise temperature as a function of noise figure and rain attenuation L_R*

(Assumed antenna noise temperature: 50 K)

Step 5

3.5 *Ground segment costing*

This step gives the procedure for costing the receiving terminals. Receiving terminal cost is made up of receiver and antenna costs. Single unit receiver and antenna costs are established, then large quantity costs are projected by means of learning curves.

A generalized block diagram of a television receive-only (TVRO) earth terminal is shown in Fig. 4-7. The two main components of the terminal are the receiving antenna (including mount) and the receiver. An AM-VSB modulator is used to modulate the recovered video and sound from the receiver for input to a standard television set. The cost of the modulator is generally low compared to the cost of the receiver. If the receiving antenna is to be placed outdoors, the receiver may be physically divided into an indoor unit and an antenna-mounted outdoor unit.

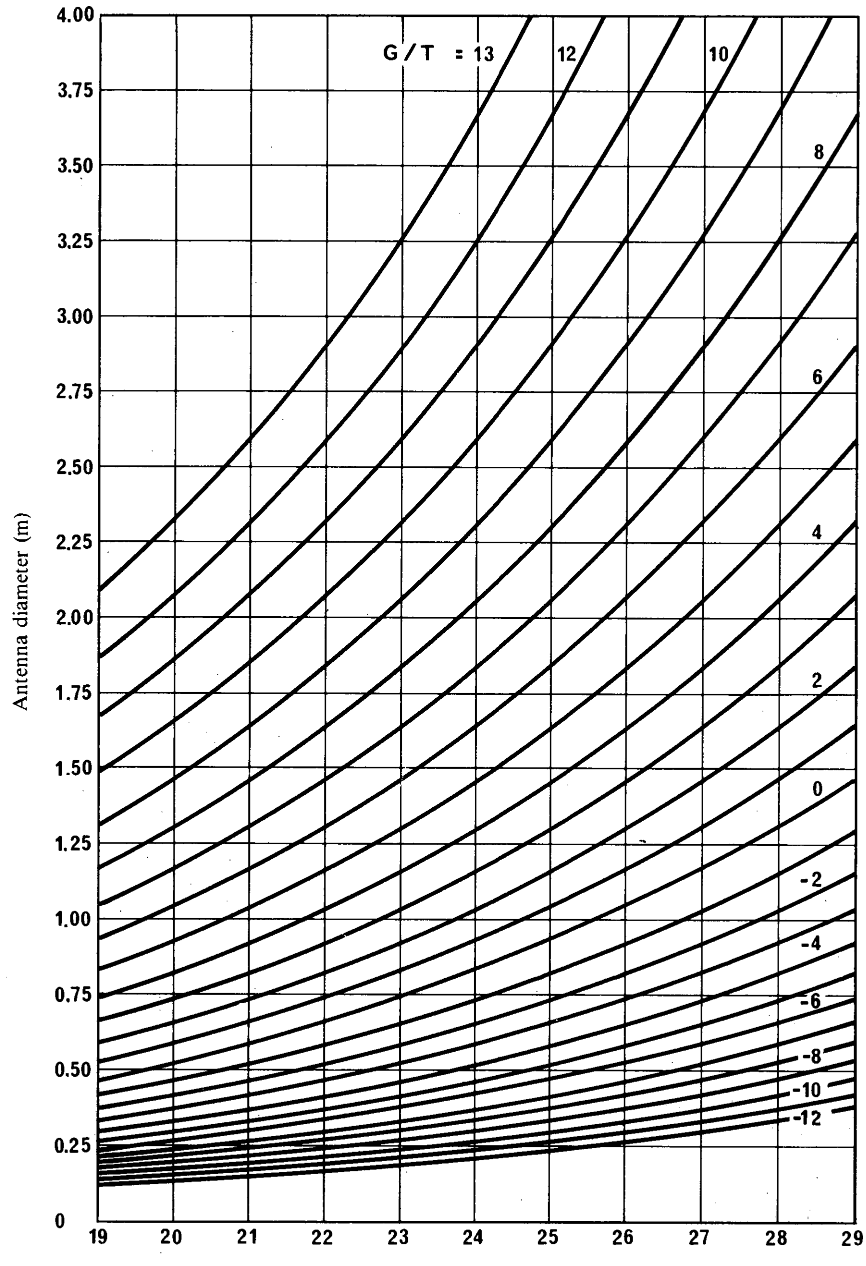

FIGURE 4-5 – *Antenna diameter versus system noise temperature and G/T (dB(K^{-1})) at 2.6 GHz*

The cost of the receiving terminal will depend upon performance-related parameters such as antenna size and receiver noise figure, as well as equipment quality. Equipment installation costs may also be significant, especially when large antennas are used.

The one factor that must be strongly emphasized is that earth terminal technology is currently in a very dynamic growth phase. In the United States, for example, this is especially true in the 3.7 to 4.2 GHz fixed-satellite service where the cost of a TVRO earth station has dropped by over a factor of ten during recent years. Because of the rapid pace of equipment innovation and cost change in this frequency band, much up to date detail does not exist in published form except in advertising brochures. However, Taylor [1980] and Cuccia [1980] contain good discussions of recent trends and projections of future technology and cost. What has occurred at 4 GHz can provide some insight into what can be expected in other frequency bands, as demand for equipment grows. Background material on the 4 GHz band earth terminals is provided after the costing discussion.

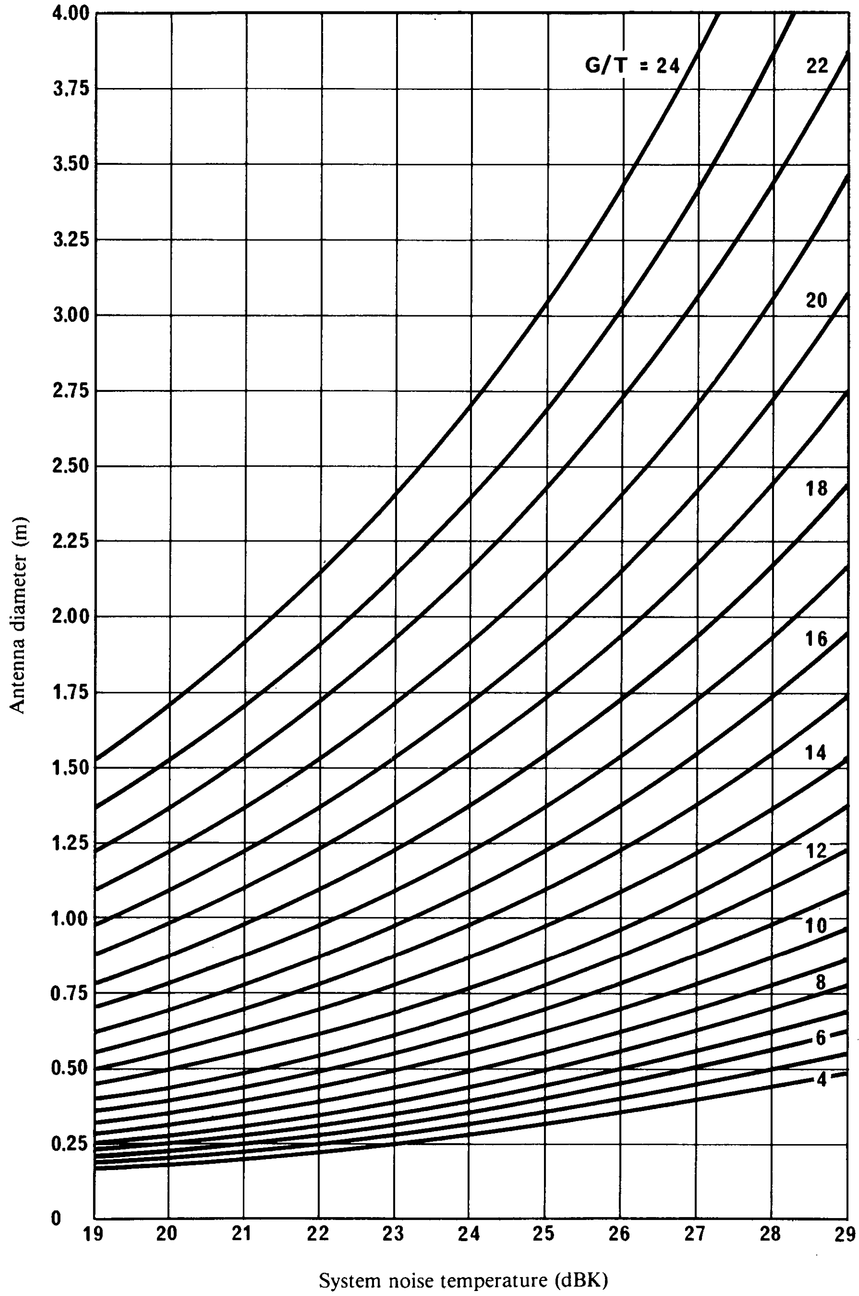

FIGURE 4-6 – *Antenna diameter versus system noise temperature and G/T (dB(K^{-1})) at 12 GHz*

3.5.1 *Receiver costs* (see also Report 473)

The function of the receiver in a TVRO terminal is to demodulate a frequency-modulated television signal. Since the receiver is the major contributor to the overall receiving system temperature, one of its most critical parameters is its noise figure (NF) which depends mainly on the type of input circuitry used. The input circuit is usually either the first down converter (or mixer), or an RF amplifier if the mixer does not provide a sufficiently low noise figure. Gallium-Arsenide (GaAs) FETs are usually used as low noise RF amplifiers (LNAs) where low noise figures are required at reasonable cost. Other types of low noise RF amplifiers such as parametric amplifiers are considerably more expensive.

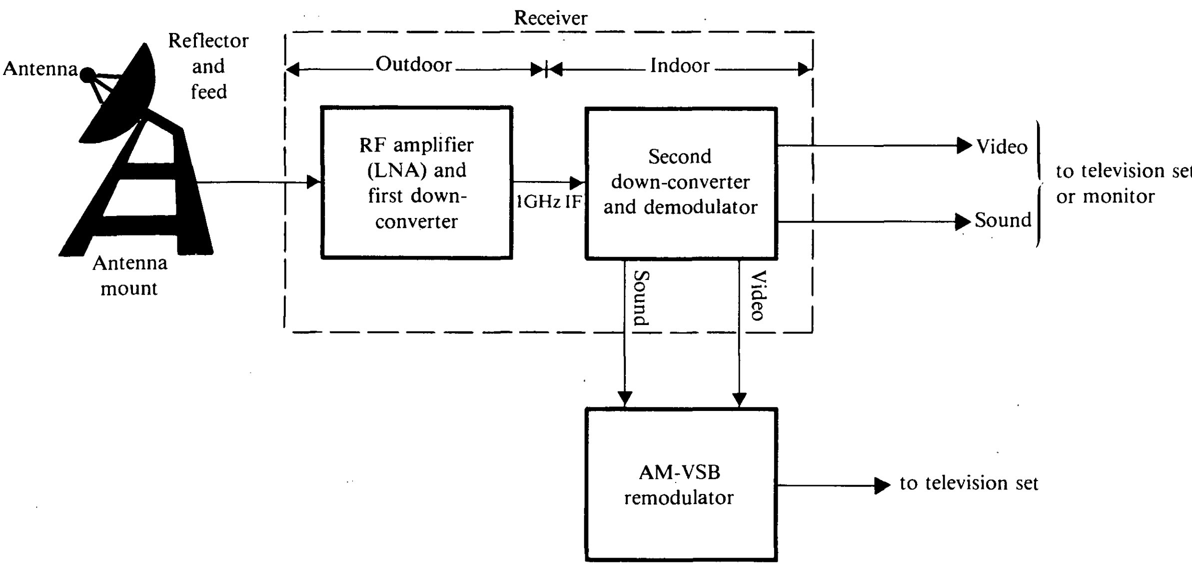

FIGURE 4-7 – *Television receive-only terminal block diagram*

Considerable receiver development has taken place in the 4 GHz band, with equipment being available from many manufacturers. Much less equipment is available for the 2.6 GHz and 12 GHz bands. Data for 4 GHz receivers is included because it can provide valuable insight into what will happen to receiver technology and costs in the 2.6 GHz and 12 GHz bands.

At 12 GHz, current GaAs FET technology is such that the lowest LNA temperature available at a reasonable price is around 360 K. However, this is expected to decrease to the 100 K to 200 K range in the near future. There is an image enhanced mixer input receiver available whose noise temperature is of the same order, i.e. 360 K. Use of an LNA at 12 GHz is therefore not cost effective at present.

At 2.6 GHz, approximately 290 K noise temperature can be achieved with inexpensive bipolar transistor technology. To go to 100 K requires a GaAs FET LNA. Complete 2.6 GHz satellite receivers are not commercially available in the United States, however there is 2 GHz equipment available for use in terrestrial systems which use amplitude modulation. Since front end technology is well developed and the rest can be borrowed from 4 GHz TVRO receivers, the cost of 2.6 GHz receivers should be similar to, or somewhat lower than, 4 GHz receivers, once they are produced in quantity (see § 3.5.4).

A summary of LNA and receiver costs at 2.6 GHz and 12 GHz is presented in Table 4-VI.

3.5.2 *Antenna costs*

Current, single unit antenna costs at 2.1 GHz (more commonly available than for 2.6 GHz) and 12 GHz are plotted versus diameter in Fig. 4-8. Note that there is a wide range of costs for a given diameter because of differing specifications (standard versus high performance). These specifications differ mostly in side-lobe levels and front to back ratios. Note that for these antennas cost is practically independent of frequency.

3.5.3 *Large quantity component costs*

The quantities of interest to the system planner are of the order of hundreds to millions depending on whether a community or individual reception network is contemplated. Given the dynamic state of the technology, prediction of large quantity costs is difficult. The techniques in general use for predicting quantity costs are presented below. The user has to use some judgement in applying these techniques.

TABLE 4-VI – *Receiver cost summary for small quantities (mid-1980 data)*

	Unit cost (US $)	Noise figure (1) (dB)
2.6 GHz		
LNA (Low noise amplifier)	1000-1500	1.4
LNA	50	3
Receiver	500-1000	
12 GHz		
Image-enhanced mixer-input receiver	3000	3.5
LNA	3400	3.6

(1) Receiver noise figure = 10 log $(1 + T_R/290)$, where T_R (K) is the noise temperature at the receiver input.

Estimated factory costs for antennas, receivers and ground terminals are given in Report 473, § 9 for quantities up to 1 million units. These costs are based on a substantial use of integrated circuitry in advanced production techniques.

3.5.3.1 *Learning curves*

A standard technique for predicting cost versus quantity is the technique of learning curves [Cunningham, 1980]. Learning curves assume that cost goes down by a given percentage learning factor each time the cumulative unit volume doubles. These curves also assume constant currency value.

Learning curves of 70% to 90% (learning factor L of 0.7 to 0.9) are plotted in Fig. 4-9. The single unit cost is multiplied by the relative cost factor $Q(N)$ for the desired quantity N. The learning curve percentage to be applied to any given component is a difficult parameter to select. Cuccia [1980] and Cunningham [1980] give examples of historically derived percentages for various technologies. Not enough historical data exists for the components of a ground terminal, but some judgements can be made on the basis of technological complexity.

3.5.3.2 *Cautionary factors*

The cost of a given ground terminal component includes both parts and labour costs. The cost of electronic parts tends to go down with improvements in manufacturing techniques, while labour costs rise with time. Cost projections are therefore time as well as quantity dependent.

Besides all other considerations, there is also the possibility of technological and innovative breakthrough, such as new approaches in antenna construction, which can drastically change costs in a short period of time.

3.5.3.3 *Antenna costs*

Since antennas are relatively simple structures, the user should apply a 90% learning curve ($L = 0.9$) in projecting high volume costs. It should be remembered that even for small size antennas, a price range of two to one or more may exist depending on such factors as sturdiness, tolerances, etc.

3.5.3.4 *Low noise amplifier (LNA) costs*

Low noise amplifier costs are currently high because of high GaAs FET prices. This is an area where a great deal of effort is being spent to bring costs down. The user should use about an 80% learning curve in predicting cost.

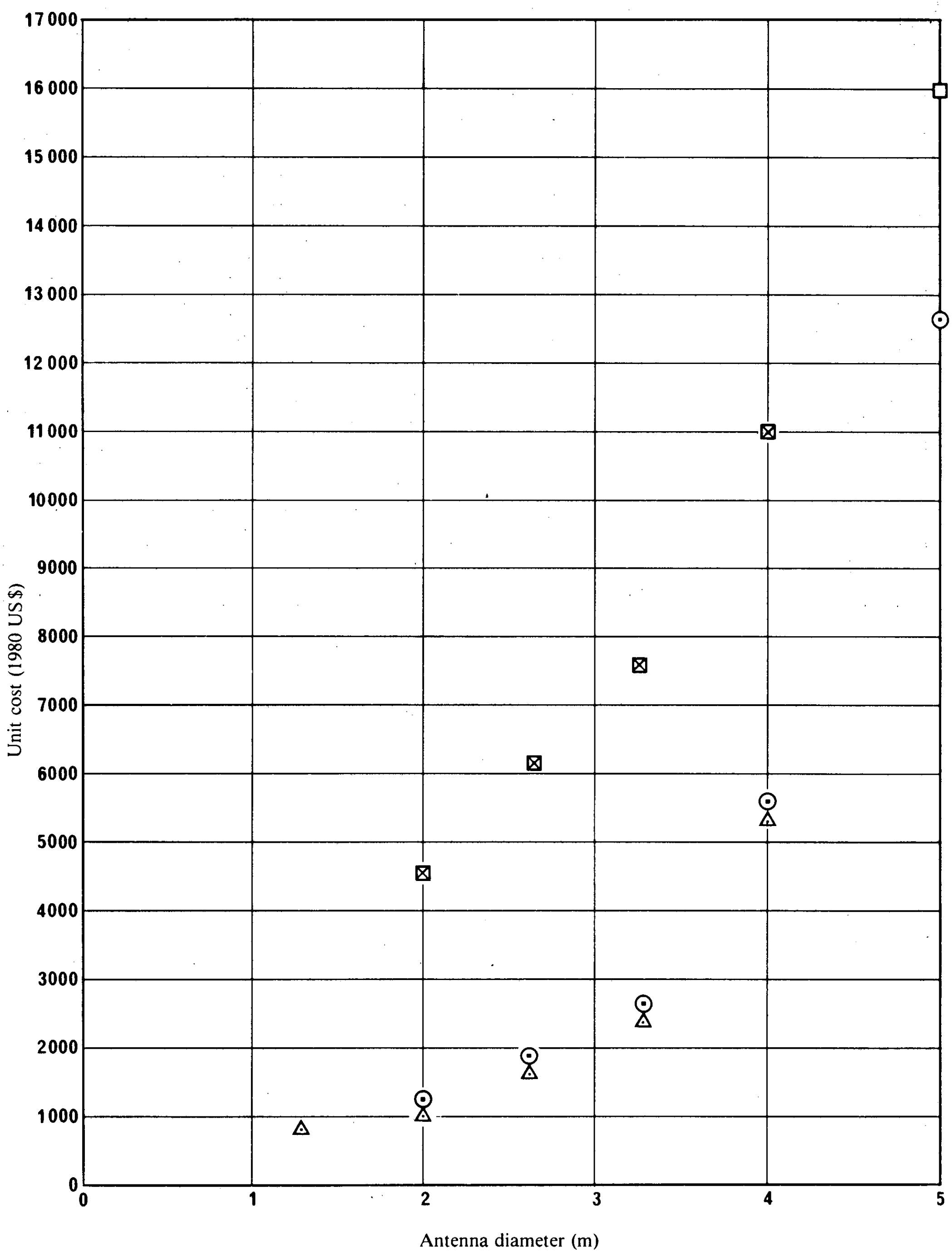

FIGURE 4-8 – *Antenna cost data from 1980 catalogue (USA)*

△ 12.2-12.35 GHz standard

⊙ 1.9-2.3 GHz standard

× 12.2-12.35 GHz high performance

□ 1.9-2.3 GHz high performance

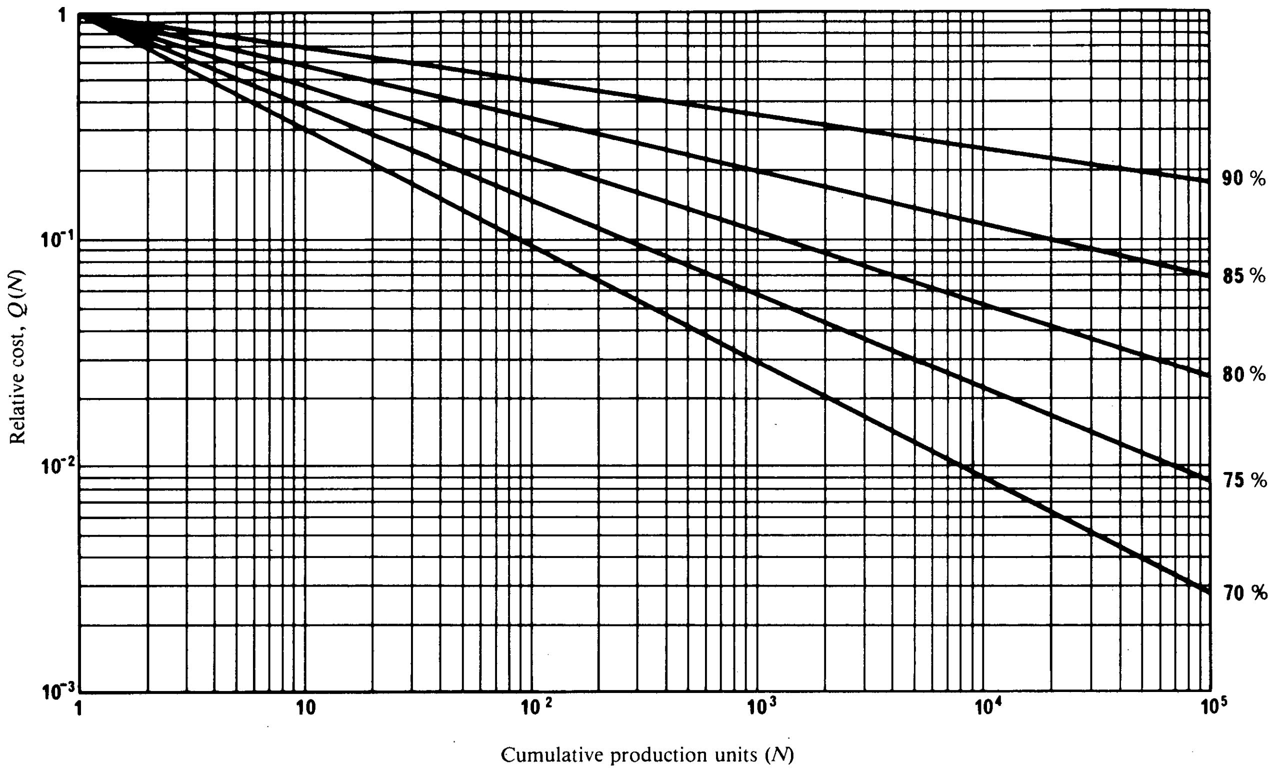

FIGURE 4-9 – *Learning curves*
(Learning factor L of 0.7 to 0.9)
$Q(N) = L^{\log_2 N}$

3.5.3.5 *Receiver costs*

Receiver costs will decrease because of increasing standardization of circuitry and use of integrated circuits. About an 85% learning curve is appropriate in planning receiver costs. Eventually, low noise RF amplifiers will be incorporated into the receiver, obviating the need for an external LNA. This should allow a 10% to 20% saving over the cost of separate units.

3.5.3.6 *Cost example*

The following two tables illustrate large quantity earth terminal cost estimation using the learning curves and average receiver and antenna costs from Table 4-VI and Fig. 4-8.

TABLE 4-VIIa – *Estimated costs for a 12 GHz ground terminal design*

Quantity	Antenna cost (\$) (1) (D = 1 m, G = 39.5 dB) 90 % learning curve	Receiver cost (\$) (noise figure = 3.5 dB) 85 % learning curve	Total terminal unit cost (\$)
1	750	3 000	3 750
100	375	1 020	1 395
1 000	262	600	862
10 000	188	345	533
100 000	127	198	325

(1) Standard performance.

TABLE 4-VIIb – *Estimated costs for a 2.6 GHz ground terminal design*

Quantity	Antenna cost ($) ($D$ = 2 m, G = 32 dB)	Receiver cost ($) (noise figure = 3 dB)	Total terminal unit cost ($)
1	2 000	750	2 750
100	1 000	255	1 255
1 000	700	150	850
10 000	500	86	586
100 000	340	50	390

3.5.4 *Background of recent 4 GHz technology*

3.5.4.1 *Antennas*

Low values of operational satellite e.i.r.p. in the 4 GHz band require that antennas of at least 3 m in diameter be used together with LNAs in the 100 K to 120 K temperature range. Until recently, demand for earth terminals was low and there was a small number of manufacturers producing high quality, solid reflector antennas. This type and size of antenna requires a strong mount which brought the price of antennas plus mount into the $10 000 to $20 000 range. A significant contributor to cost for this type of antenna was the difficulty of shipping such a bulky object.

As the demand for lower cost terminals grew, alternative designs appeared on the market. As a solution to the shipping problem, there are now several antenna types whose reflector can be broken down into several sections. Others are available in even more basic kit form.

An example of a unique approach is an inverted umbrella type of erectable antenna which uses a metallized mylar reflector surface and weighs less than 10 kg. The disadvantage of this approach is that it cannot be rigidly mounted to withstand much wind.

Another solution to the transportation and mounting problem is the use of low cost spherical antennas. These antennas are generally built using a flexible grid of metal or wooden strips covered with metal mesh. Adjustment screws are provided at many points on the surface. Being spherical, the surface is adjusted at the site using a piece of string equal to the radius of curvature. These antennas usually employ an F/D (F: focal length (m) and D: antenna diameter (m)) ratio of around 1.5 in order to approximate the surface of a parabola. While the approximation is not perfect and results in some gain penalty, the large F/D ratio allows a fairly wide scanning range. Antenna positioning is not critical since the focal point can move up to 20° away from the perpendicular to the centre of the reflector.

Although there is probably some performance loss as well as side-lobe increase in the less expensive antennas, the performance loss can be easily made up by a slight increase in diameter.

Innovations in the antenna area have resulted in a price range of from below $500 to over $10 000 for essentially the same amount of gain. The interesting thing is that all these antennas have their own market.

Most of the techniques developed at 4 GHz will be applicable at 2.6 GHz and prices should be similar. At 12 GHz, however, where surface tolerance requirements are more severe and smaller antennas will be required, the main candidates will most likely be solid surface parabolic with prime focus, or offset fed reflectors in low side-lobe applications. This will keep the price range smaller and prices higher because some of the low cost techniques discussed are not as applicable for high surface tolerance antennas.

3.5.4.2 *Receivers*

As discussed in the antenna section, US 4 GHz satellite reception requires an LNA of 100 K to 120 K with a 3 m antenna. The 120 K LNA has developed into an industry standard and is available for under $1000. LNAs are also available at 80 K and 100 K temperatures but current GaAs FET yields and required alignment procedures substantially raise the cost of LNAs which have temperatures below 120 K.

Industry consensus is that LNA prices have temporarily reached a "plateau" because of GaAs FET prices and such labour intensive activities as alignment and machining of the housing. Improved yields in GaAs FET manufacturing are needed to produce a price breakthrough in LNAs. Another cost saving approach is to combine the LNA and first down converter into one package, to be mounted at the antenna. Such a unit will soon be available as a standard component.

Demand for television receive-only (TVRO) terminals has had a similar effect on receiver costs as in the area of antennas. There has been a general price reduction, although the market is still supporting a wide range of prices. Established manufacturers are selling industrial standard receivers to the cable TV industry in the $2000 to $3000 price range, while mostly new manufacturers have come up with less expensive receivers below $1000.

Step 6

3.6 *Communication sub-system and spacecraft power*

While many factors influence spacecraft weight and cost, spacecraft prime power has historically been shown to have the greatest effect. Broadcasting satellites are generally power limited. Presently this limitation is around 2 kW for a 1000 kg satellite and is expected to be in the 3-5 kW range with near term advanced solar panel technology for this satellite weight class [Cuccia, 1980]. The accurate estimation of spacecraft power is therefore very important.

Since the communications payload is the primary power consumer it is the key to spacecraft power estimation. In this step, communication sub-system RF power is first estimated, then spacecraft power is estimated from communication sub-system RF power.

3.6.1 *Communication sub-system RF power*

Given some value of required e.i.r.p.*, RF power will depend on the size of the service area and number of channels. Service area size determines the antenna beamwidth and gain that can be used. In order to cover the service area efficiently a shaped beam may be employed. The beam shape may range from elliptical to a complex shape which can be formed from a set of adjacent smaller beams. The power savings which result from using many small beams to cover a complex service area are illustrated in Table 4-VIII.

A set of world maps is provided in Annex 4-V for service area coverage planning *. Circular beams, as well as other shapes, project without distortion on these maps.

Given the required e.i.r.p. and beamwidth, it is possible to compute the required RF power per beam by subtracting antenna gain from and adding circuit losses to e.i.r.p. The relationship between antenna gain in dB and beamwidth for an elliptical beam is given by:

$$G = 10 \log [27\,000/A \cdot B] \tag{13}$$

where A and B are the -3 dB beamwidths along the major and minor axes of the ellipse in degrees. For a circular beam this expression reduces to:

$$G = 10 \log [27\,000/\theta^2] \tag{14}$$

where θ is the -3 dB beamwidth in degrees.

Circuit losses are typically around 1.5 dB but can vary up to $\pm$ 0.5 dB or more around this value depending on the amount of switching and cable or waveguide lengths in the transmission circuitry.

* In the case of 12 GHz broadcasting satellites in Regions 1 and 3, consult Appendix 30 to the Radio Regulations.

Required RF power (P_0), summed over all the beams is then given by the following expression:

$$P_0\,(\mathrm{dBW}) = \sum_{i=1}^{N} [e.i.r.p._i\,(\mathrm{dBW}) - G_i\,(\mathrm{dB}) + L_{ci}\,(\mathrm{dB}) + 10 \log M_i] \qquad (15)$$

where:

M_i : number of television channels in each beam,

G_i : antenna gain for each beam, and

L_{ci} : transmitter circuit losses for each beam.

Note that spacecraft antenna gain will in general not be uniform in the direction of every part of the service area. This must be taken into account in the computation of the RF power.

3.6.2 *Total spacecraft power*

Given communications sub-system transmitter output (RF) power the following relationship from Annex 4-II can be used to estimate spacecraft power:

$$BOL\ Power = 1.05 \times \frac{TRFP/PAEFF + 220 + K + 50 \cdot N}{(EOL/BOL) \cos 23.5^\circ} \quad \mathrm{W} \qquad (16)$$

where:

BOL : beginning of life

EOL : end of life; and EOL/BOL is normally 0.75 (seven year life)

TRFP : total RF power (W)

PAEFF : power amplifier efficiency

K : 0.2 ($TRFP$ – 200) when $TRFP$ > 200 W, zero otherwise

N : number of batteries (see Annex 4-II).

This relationship is plotted in Fig. 4-10 for two values of power amplifier efficiency (2 batteries assumed).

TABLE 4-VIII – *RF power versus number of composite circular beams*

Spacecraft antenna		Power required per beam (dBW)		Approximate number of beams required for US coverage	Amount of TWTA power required for full US coverage (dBW)	
Gain (dB)	3 dB beamwidth (degrees)	e.i.r.p. 60 dBW	e.i.r.p. 55 dBW	7.83×10^6 km^2 area	e.i.r.p. 60 dBW	e.i.r.p. 55 dBW
36	2.5	24	19	6	1507	477
38	2.0	22	17	8	1268	401
41	1.5	19	14	13	1032	326
42	1.25	18	13	16	1009	319
44	1	16	11	25	995	315
44.8	0.9	15.2	10.2	30	993	314
45.7	0.8	14.3	9.3	35	942	298
47	0.7	13	8	42	840	265
48.4	0.6	11.6	6.6	53	768	242
49.9	0.5	10.1	5.1	77	770	249
51.8	0.4	8.2	3.2	100	660	208
53	0.35	7	2	120	600	190

Step 7

3.7 *Spacecraft weight*

Spacecraft weight has historically been found to be the key parameter in estimating spacecraft cost. A parametric model for estimating spacecraft weight is presented in Annex 4-II. This model, based on [Melachrino and Baker, 1980], derives the weights of the spacecraft and its constituent sub-systems using communication sub-system weight and power as inputs. A procedure for estimating communication sub-system weight and power is given in Annex 4-III.

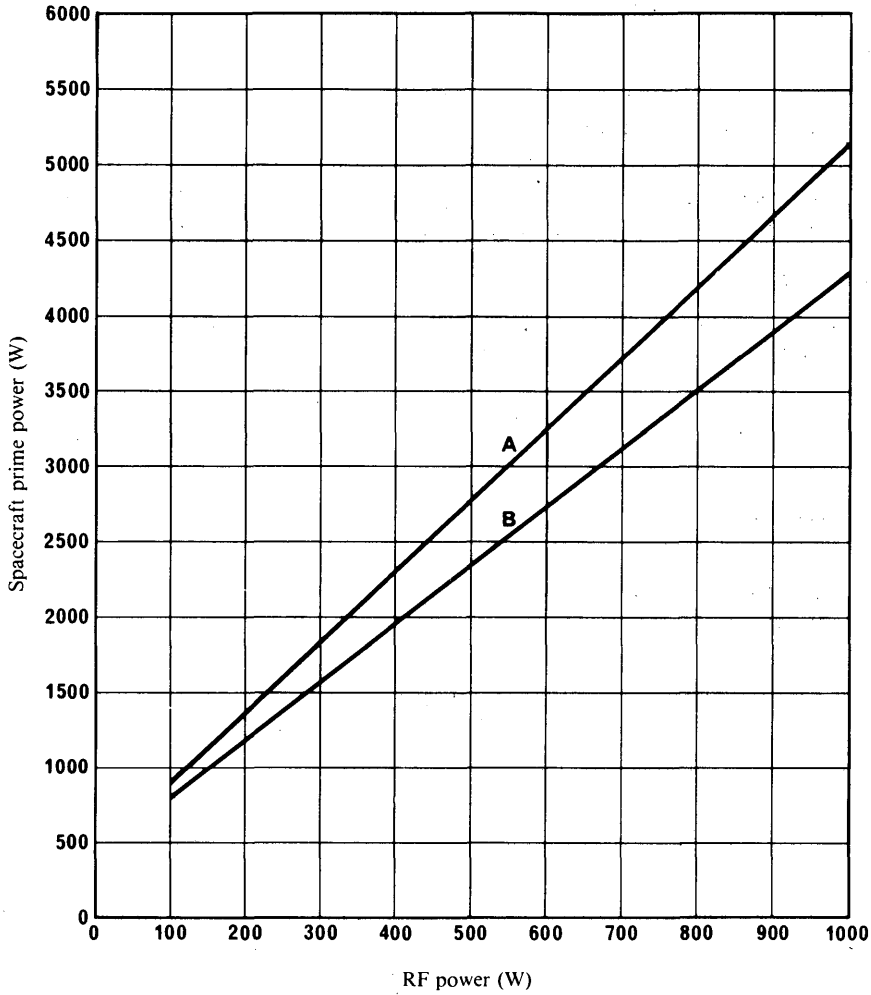

FIGURE 4-10 – *Spacecraft power versus RF power*

Power amplifier efficiency:

Curves A: 33 %
B: 40 %

3.7.1 *Techniques for simplified weight estimation*

In some cases the user may wish to make an estimate of spacecraft weight without working through a detailed procedure. A parameter that is sometimes used for such an estimate is spacecraft prime power. However, the user should realize that the accuracy of this simplified approach is limited since factors such as payload complexity which also impact weight are not fully taken into account.

Nevertheless, an initial estimate of spacecraft weight can be derived for broadcasting satellites from the data plotted in Fig. 4-11. The data points are representative of published paper designs and points derived by working through the procedure of Annex 4-II. Very little actual design data, except for BSE, is available since so few broadcasting satellites have been built to date.

The published spacecraft design characteristics used in Fig. 4-11 are listed in Table 4-IX, while the characteristics derived from Annex II are listed in Table 4-X. The two parameters varied in generating the latter data points are RF power and percentage earth solar eclipse protection. The entire range of 0 to 100% eclipse protection is shown for each point design. The weight estimation model of Annex 4-II uses a battery of 23 kg for each increment of 1000 W required during eclipse. For the low RF power designs, one such battery is sufficient to supply all housekeeping needs and give 100% eclipse protection. For the higher RF power spacecraft, a number of batteries are needed and the effect of this on spacecraft weight is evident.

A line curve fit of the form A_p^B, where p is the spacecraft beginning of life prime power in kilowatts, can be drawn through the data points as shown in Fig. 4-11. This curve can then be used to estimate spacecraft weight.

TABLE 4-IX – *Published BSS spacecraft designs*

Spacecraft	RF power (W)	Communications sub-system weight (kg)	BOL power (W)	RF power eclipse protection (%)	Spacecraft weight (kg)
FACC 1(1)	400	136	1956	100	623
FACC 2(2)	600	182	2732	100	776
FACC 3(1)	1000	273	4360	50	1066
TRW 1(2)	600	128	2656	0	643
TRW 2(2)	950	299	4330	25	1179
TRW 3(2)	2000	384	8300	25	1539
BSE	200	65	1000	—	350
TV-SAT/TDF-1	780	167	3400	—	1060

(1) See Report 812. Weight includes some residual liquid ascent stage hardware.

(2) See [Cohen, 1981]. Published EOL power converted to BOL power by factor of 1.33.

TABLE 4-X – *Spacecraft designs using Annex 4-II**

Case	RF power (W)	Communications sub-system weight (kg)	Beginning of life (BOL) power (W)	Maximum RF communications power eclipse protection (%)	No. of batteries	Spacecraft weight (kg)
1	200	65	1180	100	1	338
2A	400	136	1956	50	1	500
2B	400	136	2028	100	2	548
3A	600	182	2733	25	1	611
3B	600	182	2805	100	2	659
4A	1000	273	4286	0	1	845
4B	1000	273	4358	50	2	893
4C	1000	273	4430	100	3	941
5A	2000	384	8170	0	1	1175
5B	2000	384	8242	25	2	1224
5C	2000	384	8386	50	4	1320
5D	2000	384	8458	75	5	1369
5E	2000	384	8530	100	6	1417

* Design assumptions:

Total Δv required:	500 m/s
Fuel specific impulse (I_{sp}):	220 s
Pitch axis accuracy:	0.05°
Communications power (other than PA):	50 W
Power amplifier efficiency:	40 %
Solar array:	60 W/kg
Battery:	66 Wh/kg, 80 % DOD (23 kg/battery)
RF power:	design variable
Eclipse protection:	design variable – 0, 25, 50, 75, 100 %

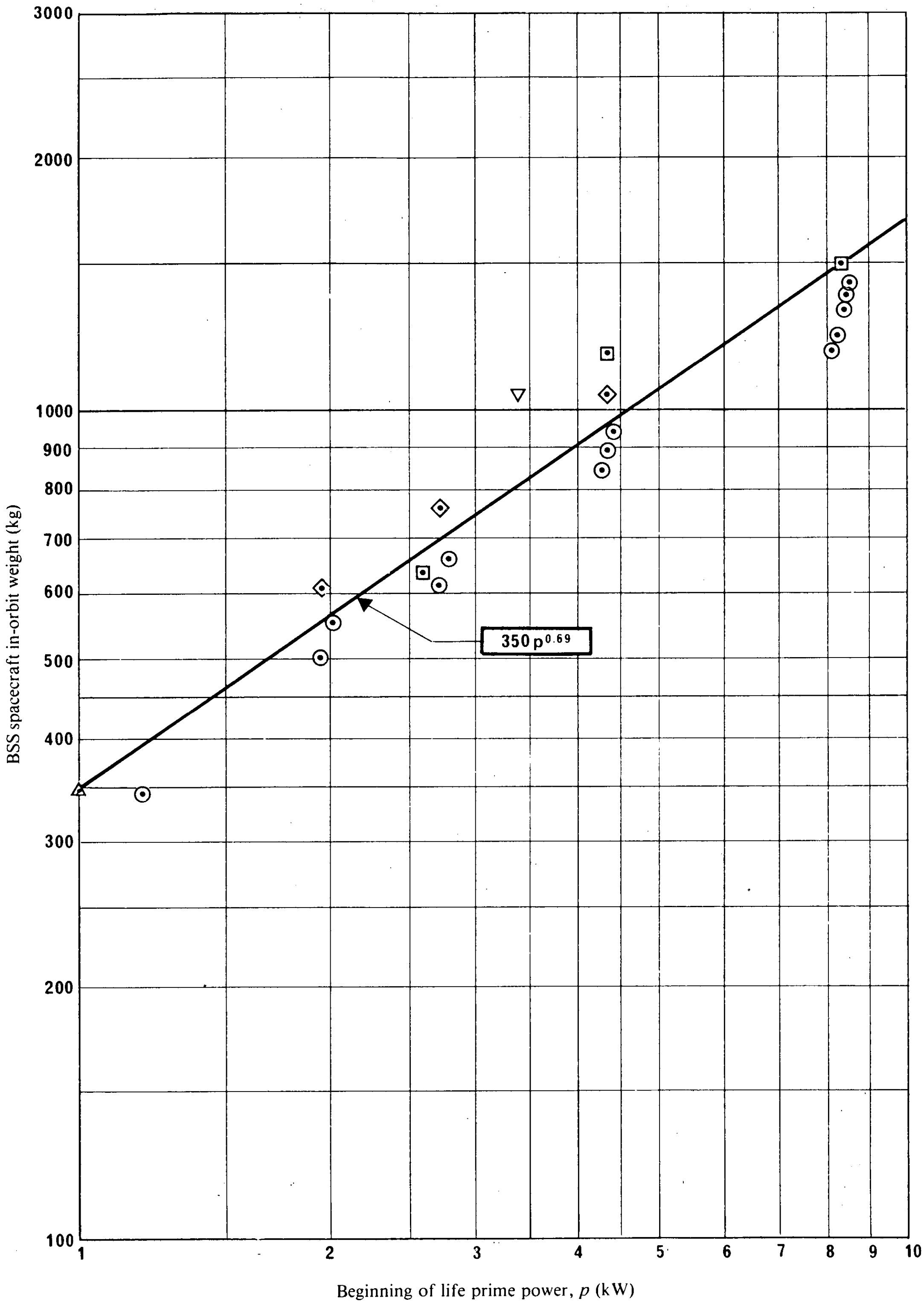

FIGURE 4-11 – *Spacecraft in-orbit weight versus prime power*

△ BSE
▽ TV SAT/TDF-1
⊡ TRW
◇ FACC
⊙ Annex 4-II

Step 8

3.8 *Satellite cost*

The most direct method of satellite cost estimation is to define the requirements of each sub-system, then estimate sub-system development and manufacturing costs and add the costs of system engineering, spacecraft integration, management and profit.

Unless the system designer is part of a satellite manufacturing organization, this type of approach is not practical, nor is it in most cases necessary during early system phases. For this reason several cost estimating approaches have been developed which yield various degrees of insight into spacecraft cost and its sensitivity to certain spacecraft parameters. Two of these methods will be described in order of increasing complexity. Since the simpler model cannot handle subtle design variations, the user will have to make a decision as to which method suits his requirements.

The first method uses the Defense Communications Agency (DCA) cost estimation model based on total spacecraft weight. The second method uses the Ford Aerospace and Communications Corporation (FACC) cost model which requires spacecraft sub-system weights as an input.

3.8.1 *The DCA cost model*

In 1978, an algorithm was generated for the estimation of the costs of communication satellites by DCA [1978]. This algorithm, based on satellite weight, is plotted for both recurrent and non-recurrent costs in Fig. 4-12 and includes the known costs of many medium satellites, showing the excellent correlation involved. These costs are based on the following equations where C_N and C_R are the non-recurrent and recurrent costs respectively and W is the satellite weight in kilograms. The non-recurrent cost includes development cost of a protomodel spacecraft.

$$C_N = 4.145 \times 10^4 \, W^{1.15} \tag{17}$$

$$C_R = 6.40 \times 10^4 \, W^{0.93} \tag{18}$$

These curves were developed by Professor David Staelin and Dr. R. Harvey [MIT, 1979].

3.8.2 *The FACC cost model*

One of the most detailed models to estimate satellite costs was that developed by the US Air Force several years ago [SAMSO, 1978]. Its use requires a knowledge of the weights of the sub-systems, primary powers and a variety of other characteristics.

In 1978-1980, M. Baker, Jr. and S. Melachrino of Ford Aerospace Communications Corporation devised a computer program for estimating spacecraft weight and cost based on a modified version of the SAMSO spacecraft cost model. This computer program has been designed to provide systems engineers with a tool to estimate spacecraft sizes and costs, and to determine the effect of increasing or decreasing communications capability on spacecraft size and cost when performing system level definition and trade-offs. The model is limited to 3-axis stabilized spacecraft.

In this model, the estimates of spacecraft sub-system weights and power are rearranged to fit the SAMSO cost estimating relationship (CER) parameters. Basic cost estimates at the sub-system level are generated using an FACC-modified version of the SAMSO CER [Fong *et al.*, 1977; Rohwer *et al.*, 1975]. Weighted complexity factors are then generated and applied to the basic estimates to arrive at the cost estimates for the spacecraft. Both non-recurrent costs and recurrent (first unit) costs are determined including management and support, prototype refurbishment (where required). Profit and on-orbit incentive costs are included.

This program includes a flow chart and is described in detail in Annexes 4-II and 4-IV on a sub-system-by-sub-system basis. Annex 4-II explains the weight model and outlines the method for estimating the overall spacecraft weight and the weights of the constituent sub-systems. Annex 4-IV explains the cost model for which the inputs are, in part, weights of the spacecraft sub-systems as derived in Annex 4-II.

Step 9

3.9 *Launch vehicle cost*

3.9.1 *Background*

Placing a spacecraft into geostationary orbit involves three steps. The first step is to launch the spacecraft into a low earth orbit of about 100-160 nautical miles altitude. This step is accomplished by either using expendable rockets or the space transportation system (STS). The second step is to go from the low earth orbit to a synchronous transfer orbit. This task is accomplished by using a perigee kick

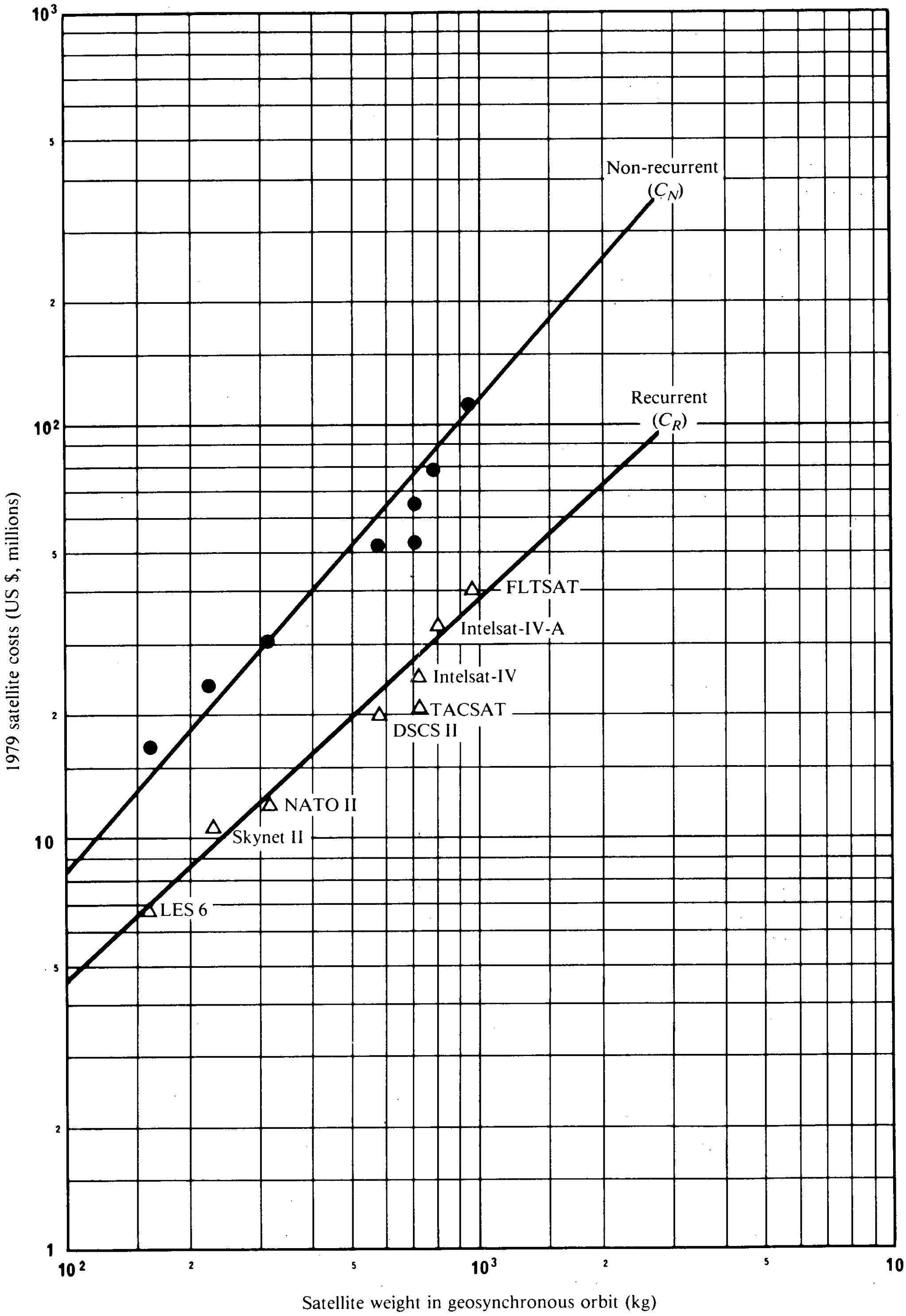

FIGURE 4-12 – *Spacecraft cost versus weight*

$$C_N = 4.145 \times 10^4\ W^{1.15}$$
$$C_R = 6.40 \times 10^4\ W^{0.93}$$

motor (PKM). This synchronous transfer orbit has approximately the same apogee as the final geostationary orbit (about 36 000 km altitude) but is inclined with respect to the equatorial plane at an inclination angle of transfer orbit, about 27°, for example, when the satellite is launched from the Eastern Test Range of the USA. The final step in the journey is to move the spacecraft from the transfer orbit to the synchronous equatorial orbit. For this an apogee kick motor (AKM) is used. From this discussion it is clear that the spacecraft, the PKM, and AKM comprise the total payload for the vehicle leaving the Earth for the low earth orbit. The spacecraft plus the apogee kick motor are the payload for the perigee kick motor, and finally the spacecraft is the payload for the apogee kick motor. The total launch cost should include the cost of the launch vehicle to the low earth orbit as well as the cost of the apogee and perigee kick motors.

3.9.2 *Costs of expendable vehicles (excluding AKM and related costs)*

On May 30, 1980, an STS Users Conference was held at Cape Kennedy by NASA at which the new costs of the two Delta vehicles and the Atlas/Centaur were disclosed (see Table 4-XIa).

TABLE 4-XIa – *Expendable US launch vehicles (1984 launch)*

Item	Delta 3910	Delta 3920	Atlas/Centaur
Launch vehicle	$27.4 M(1)	$32.4 M	$58 M
Upgrade charge	$ 1.25 M	$ 1.25 M	
PAM-D including optional services	$ 4.0 M	$ 4.0 M	
Total cost	$32.65 M	$37.65 M	$58 M
Payload weight into synchronous transfer orbit (2)	1090 kg	1250 kg	2300 kg
Cost/kg into transfer orbit (inclination 27°)	$30 000	$30 120	$25 200

(1) M: million.
(2) Weight in geostationary orbit is about one-half of these values.

TABLE 4-XIb – *Information on the Ariane launch vehicle*

Item	Ariane 1	Ariane 2	Ariane 3	Ariane 4
Mass in transfer orbit (inclination 8° 5′)	1700 kg	2000 kg	2420 kg	3500 kg
Mass in geostationary-satellite orbit	970 kg	1140 kg	1380 kg	2000 kg
Date of operational availability	end 1981	end 1982	end 1982	1985
Cost for a single launching (full capacity) (1980 US $)	$42 M(1)	$43 M	$47 M	$50 M
Cost/kg into transfer orbit	$24 700	$21 500	$19 400	$14 300
Cost/kg into geostationary orbit	$43 300	$37 700	$34 000	$25 000

(1) M: million.

3.9.3 *Considerations of Shuttle launch costs*

The Space Shuttle's total capacity in weight and volume is much greater than that required for most geostationary-satellite systems. The STS together with the IUS, which consists of both an apogee and a perigee kick motor, will be able to place up to 2250 kg into geostationary orbit. NASA has established a pricing policy that permits the purchase of a part of the Space Shuttle capacity, with the price for sharing the capacity as set forth in the NASA Space Transportation System Reimbursement Guide, JSC-11802 dated May, 1980.

A shared-flight user will pay a percentage of the dedicated-flight-price. The price for all payloads is based on launch weight or length as shown in the payload sharing nomographs of Fig. 4-13. These nomographs are explained below:

- to calculate a weight load factor, the user should divide the payload weight (including the weight of the spacecraft, the weight of apogee and perigee kick motors, flight kit, support equipment, etc.) by the total Shuttle payload weight capability at the desired inclination. Two standard orbit inclinations are offered to users for flights originating from the Eastern Test Range (Kennedy Space Center launch);

- to calculate an approximate length load factor, the user should divide the payload length (including upper stages, airborne support equipment, rational clearance, etc.), plus 15.2 cms nominal for dynamic clearance, by the length of the cargo bay, 1829 cms. The actual dynamic clearance will be used for final billing;

- to determine a charge factor, the user should now divide the load factor (length or weight, whichever is greater) by 0.75. However, the effective charge factor is never greater than 1.0;

- to determine the price for his payload, the user should multiply the price of a dedicated flight (plus a use fee, if applicable) by the calculated charge factor.

The dedicated flight price is \$18 million escalated for inflation plus \$4.3 million non-escalated. Escalation for inflation will be computed according to the Bureau of Labor Statistics index for the private business sector, all persons: productivity, hourly compensation, unit labour cost, and prices seasonally adjusted. For planning purposes, estimated inflation factors are given in Table 4-XII.

The cost of integrating the payload with the STS must also be included. This cost can be up to \$8 million depending on payload.

The approximate weights and lengths of the upper stages to be used with the STS are given below:

Stage	Weight (kg)	Length (cm)
IUS (PKM + AKM)	19 700	498
SUSS-A (PKM)(1)	5 600	231
PAM-D (PKM)(2)	2 950	211 (mounted sideways in STS bay)

(1) Weight into transfer orbit: 1970 kg.
(2) Weight into transfer orbit: 1360 kg.

TABLE 4-XII – *Planning inflation rates (NASA Shuttle)*

Date	Rate
January 1975 (Reference)	1.0
July 1979	1.45
1980	1.55
1981	1.66
1982	1.77
1983	1.90
1984	2.03
1985	2.17
1986	2.33
1987	2.49
1988	2.66
1989	2.85
1990	3.05

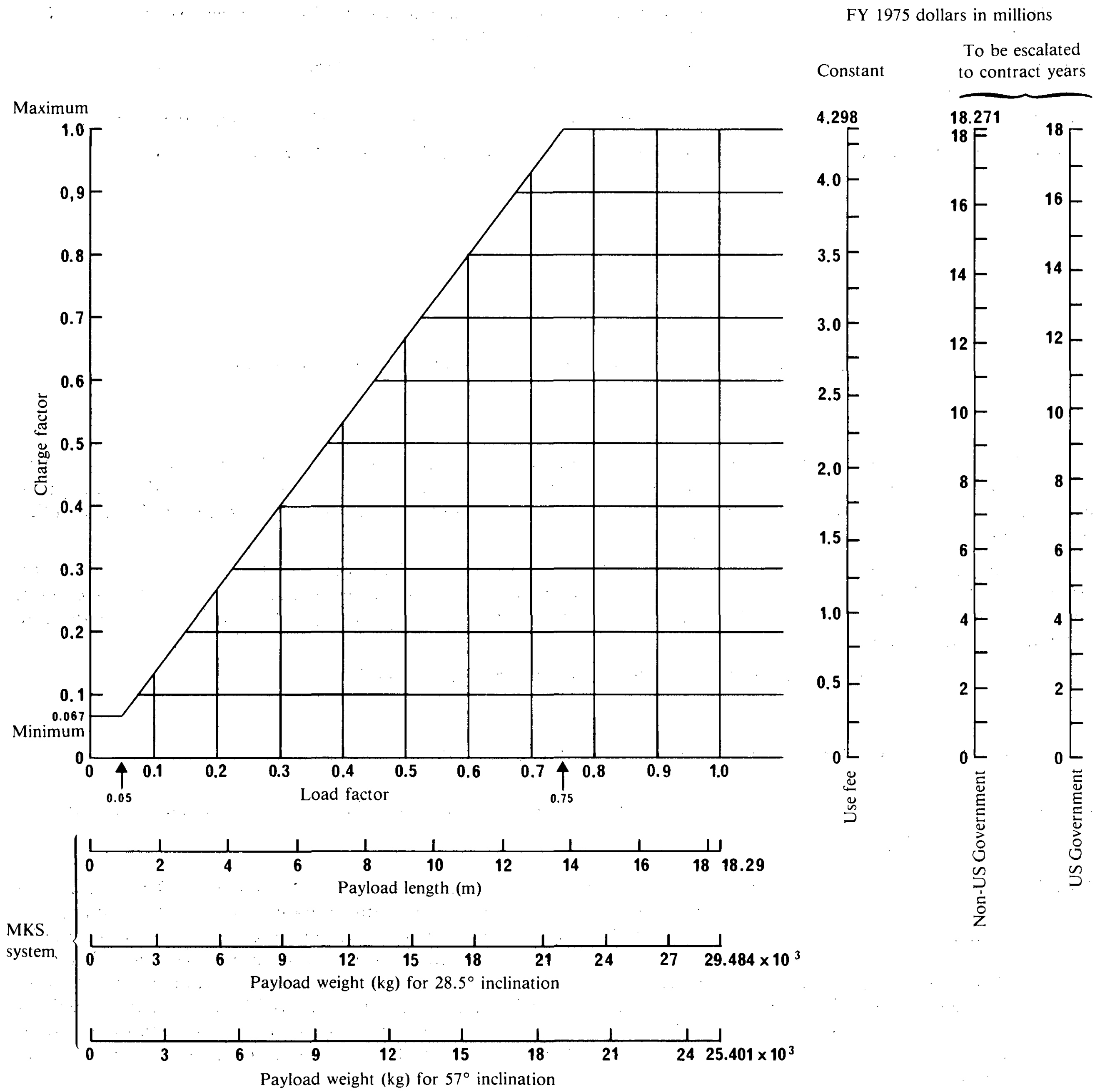

FIGURE 4-13 – *Payload-sharing nomograph (MKS system)*

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ANNEX 4-I

CALCULATION OF ATMOSPHERIC ATTENUATION DUE TO RAIN

Rain is one of the principal causes of signal attenuation on centimetric and millimetric wave propagation paths through the lower atmosphere. In designing a communication link it is necessary to provide a margin to compensate for this attenuation. The purpose of this Annex is to outline a step-by-step procedure for computing this rain margin for various link reliabilities.

Atmospheric attenuation due to rain can be neglected at 2.6 GHz but can be large at 12 GHz. This attenuation depends both on the rate of precipitation and the slant range through that portion of the atmosphere which is below the 0° C isotherm. Various models and methods have been proposed for calculation of the rain attenuation. The method outlined in this Annex is based on [NASA, 1980].

Information on this subject can also be found in Reports 563, 564 and 721.

1. Step-by-step computation of atmospheric attenuation due to rain

Step 1: Locate the region where the earth station is located on the map (Figs. 4-14 to 4-20) and determine the rain climate.

Step 2: Obtain the rain rate R_p from the rain rate distribution Tables 4-XIII to 4-XV inclusive. To illustrate the usage of these Tables, consider rain region H in Fig. 4-14. For a link reliability of 99% the parameter p in the second column of Table 4-XIII is 1% and the rain rate R_p (corresponding to p = 1%) is 12 mm/h. This means that in this region rain rate exceeds 12 mm/h only during 1% of an average year. Therefore, if in the design of the communication system sufficient margin is provided to compensate for rain attenuation caused by rain precipitation at a rate of 12 mm/h, the margin would be sufficient for 99% of the year when rain does not exceed 12 mm/h. The last two columns of these Tables give the total time of the year when rain rate exceeds the stated value and so could lead to signal degradation or a complete outage.

Step 3: Establish surface projected path length D by equation (19).

$$D = \begin{cases} (H(p) - H_0)/\tan\theta & \text{for } \theta \geqslant 10^\circ \\ E\,\psi & \text{for } \theta < 10^\circ \end{cases} \tag{19}$$

where E is radius of the Earth (8500 km) and

$$\psi = \sin^{-1}\left[\frac{\cos\theta}{H(p)+E}\sqrt{(H_0+E)^2\sin^2\theta + 2E\,[H(p) - H_0] + [H(p)]^2 - H_0^2} - (H_0+E)\sin\theta\right] \quad \text{radians} \tag{20}$$

θ : elevation angle from the ground station to the satellite which can be obtained from Fig. 4-21 for the relative longitude and latitude of the earth station with respect to the geostationary position of the satellite,

H_0 : the ground station height relative to the sea level,

$H(p)$: rain height as obtained from Fig. 4-22 for the given probability of occurrence p,

p : 100 − desired link reliability.

Step 3a: If D resulting from the last step is greater than 22.5 km, a new rain rate from Table 4-XIII must be calculated. If D is less than 22.5 km, step 3a should be skipped. In order to revise rain rate R_p to a new rain rate R_p' first calculate p' which is related to p by the expression:

$$p' = p \frac{22.5}{D} \tag{21}$$

where D is the projected path length as calculated in step 3. Then, from the rain distribution tables, find the new rain rate $R_{p'}$ for this p'.

The new rain rate R_p', and surface projected path $D' = 22.5$ km should be used in the next few steps.

Step 4: Determine parameters α and β from Table 4-XVI.

Step 5: Calculate the surface projected attenuation value, $A(R_p, D)$ from R_p and D of step 3 (or R_p', and D' of step 3a) $A(R_p, D)$ is given by equation (22) below:

$$A(R_p, D) = \begin{cases} \alpha R_p{}^{\beta} \left[\dfrac{e^{u\beta d} - 1}{u\beta} - \dfrac{b^{\beta} e^{c\beta d}}{c\beta} + \dfrac{b^{\beta} e^{c\beta D}}{c\beta} \right] & d \leqslant D \leqslant D' \\ \alpha R_p{}^{\beta} \dfrac{e^{u\beta D} - 1}{u\beta} & d > D \\ (H(p) - H_0)\, \alpha R_p{}^{\beta} & D = 0\,(\theta = 90^\circ) \end{cases} \tag{22}$$

where:

$$u = \left[\frac{\log_e b e^{cd}}{d} \right] \tag{23}$$

$$b = 2.3\,(R_p)^{-0.17} \tag{24}$$

$$c = 0.026 - 0.03 \log_e R_p \tag{25}$$

$$d = 3.8 - 0.6 \log_e R_p \tag{26}$$

Step 6: Adjust for height along a slant path.

$$L_R = \frac{A(R_p, D)}{\cos \theta} \qquad \theta \geqslant 10^\circ \tag{27}$$

where L_R is the rain attenuation in dB.

Example: Table 4-XVII gives an example for the required rain attenuation margin for 6 locations in the US and for link reliabilities of 99, 99.9 and 99.99%. Note that the margin increases rapidly as the desired link reliability increases.

Note from the CCIR Secretariat. – The rain climate regions shown in Figs. 4-14 to 4-20 inclusive have been changed in the most recent updating of Report 563, to which reference should now be made for actual rainfall data. However, these figures are retained without change in this PLEN/3 report for use with the illustrative examples in this Annex.

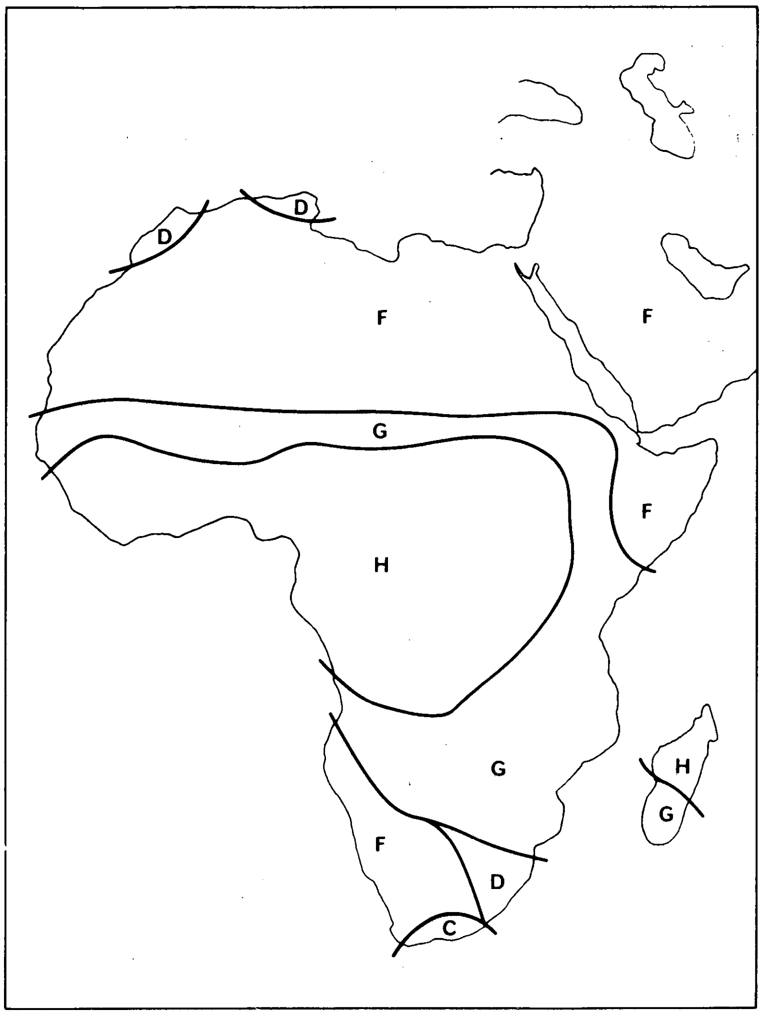

FIGURE 4-14 – *Rain climate regions for Africa*
(see Table 4-XIII)

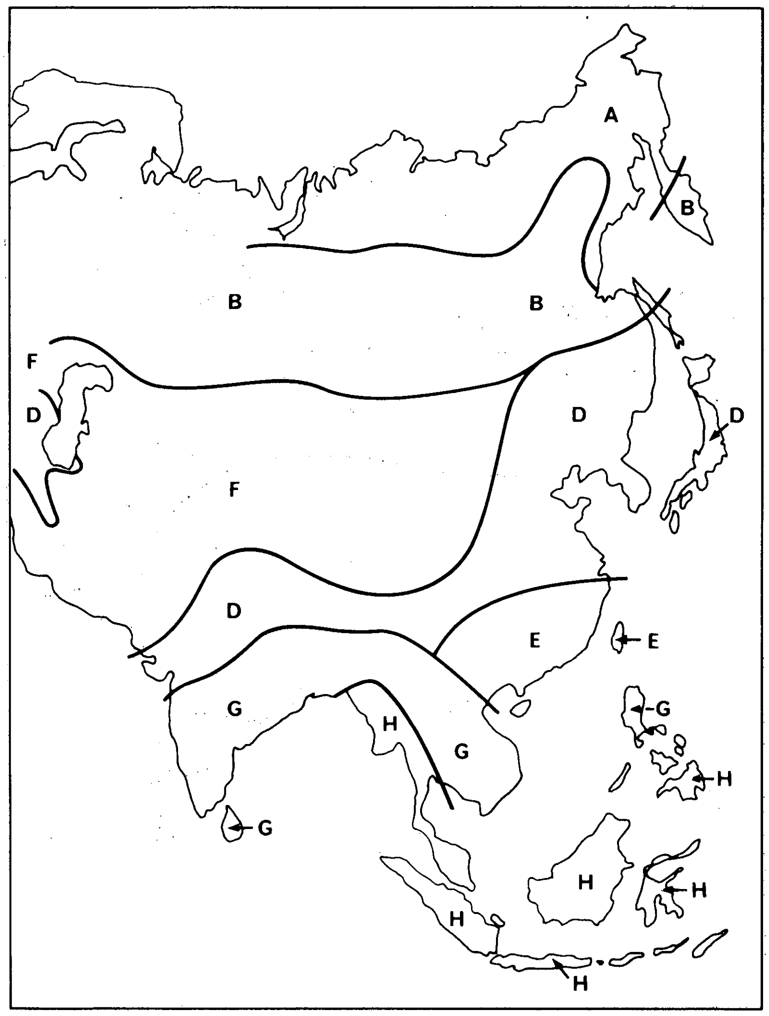

FIGURE 4-15 – *Rain climate region for Asia*
(see Table 4-XIII)

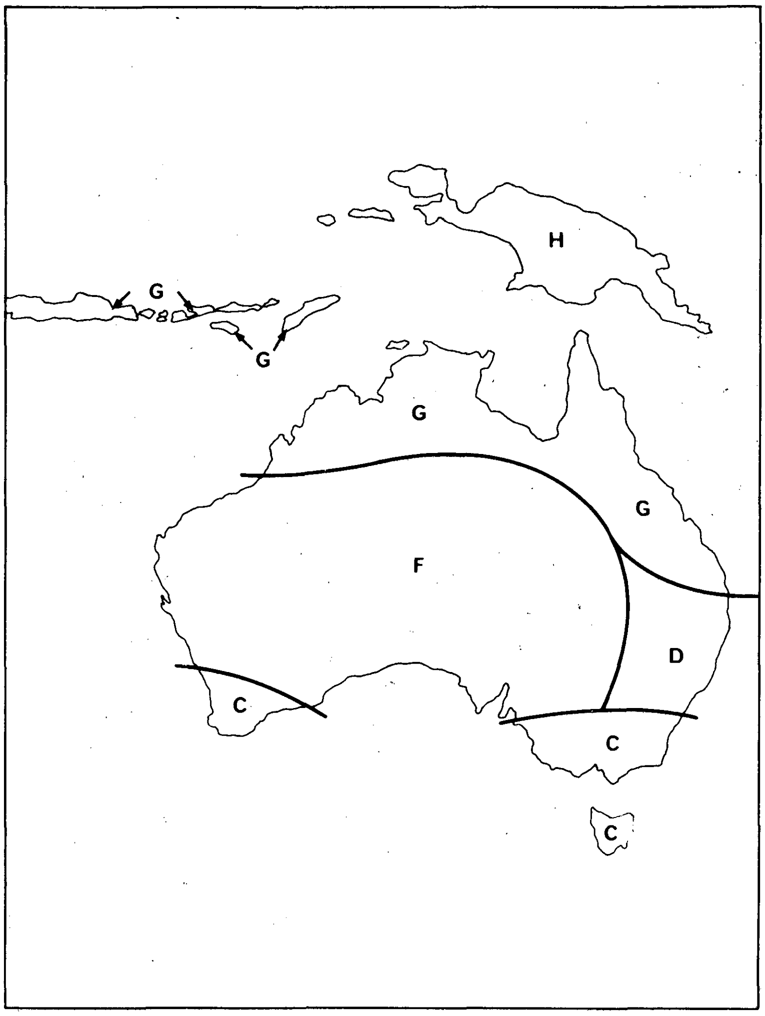

FIGURE 4-16 – *Rain climate region for Australia*
(see Table 4-XIII)

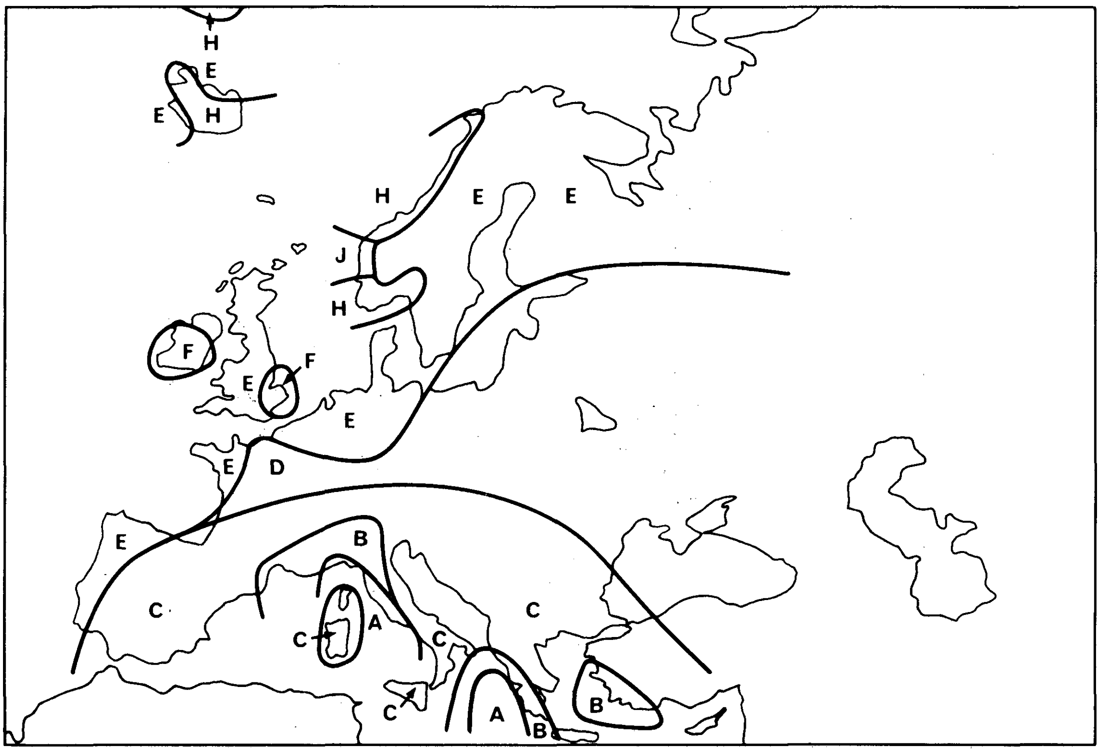

FIGURE 4-17 – *Rain climate region for Europe*
(see Table 4-XV)

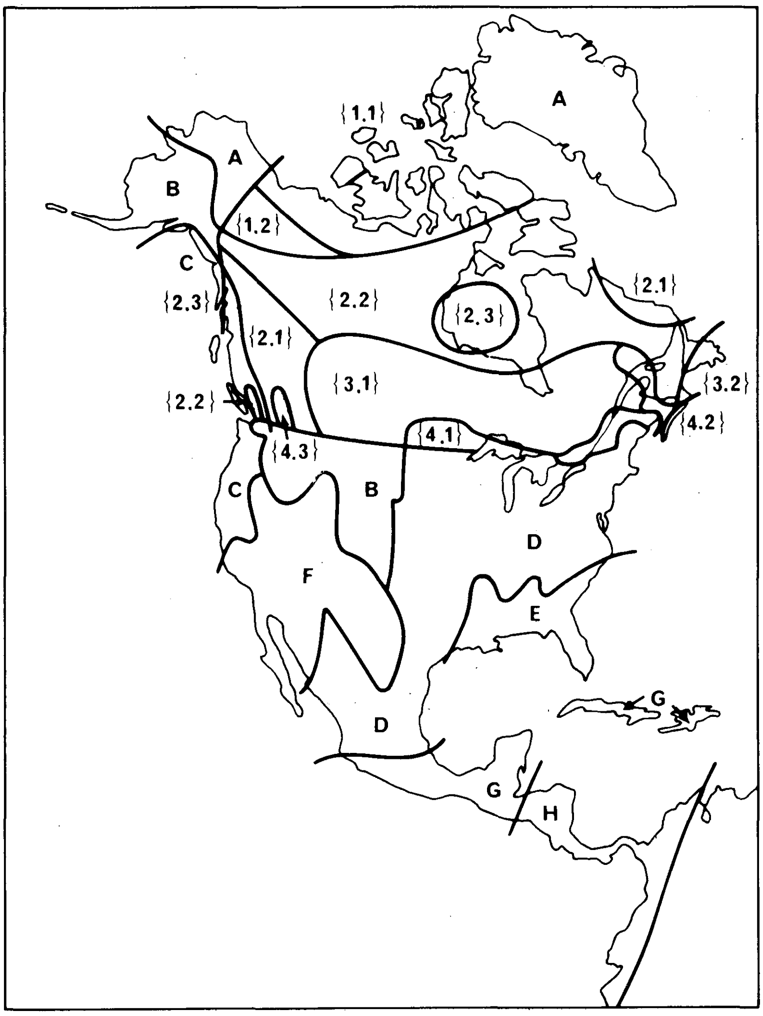

FIGURE 4-18 – *Rain climate regions for North and Central America* (see Tables 4-XIII and 4-XIV)

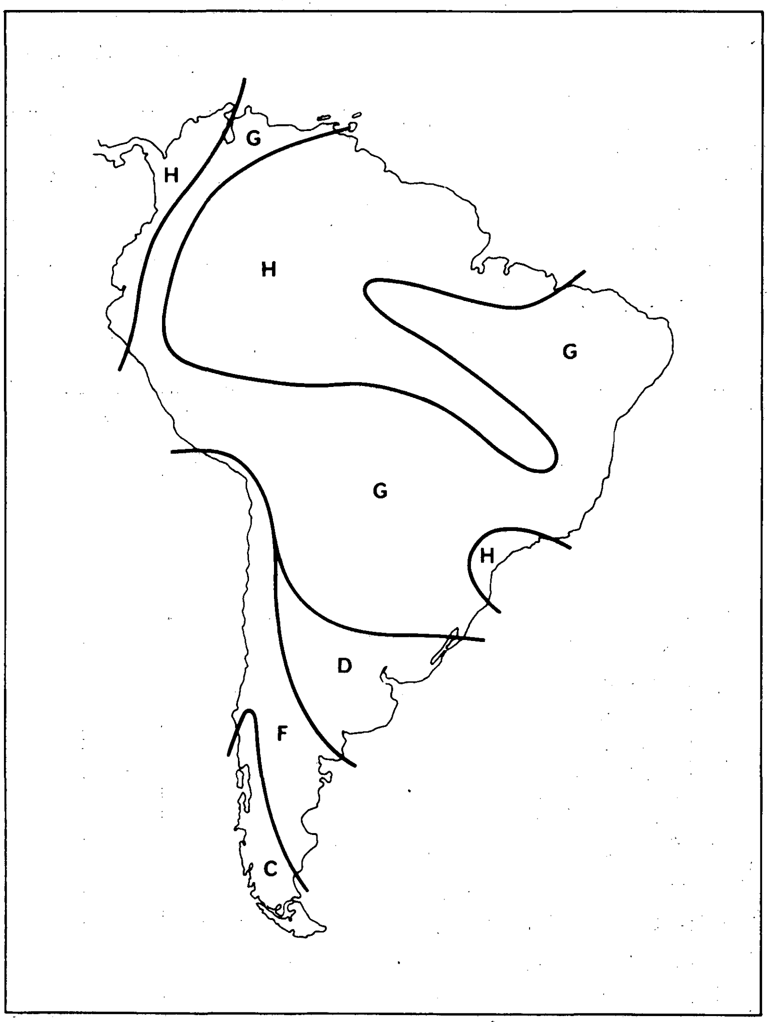

FIGURE 4-19 – *Rain climate region for South America*
(see Table 4-XIII)

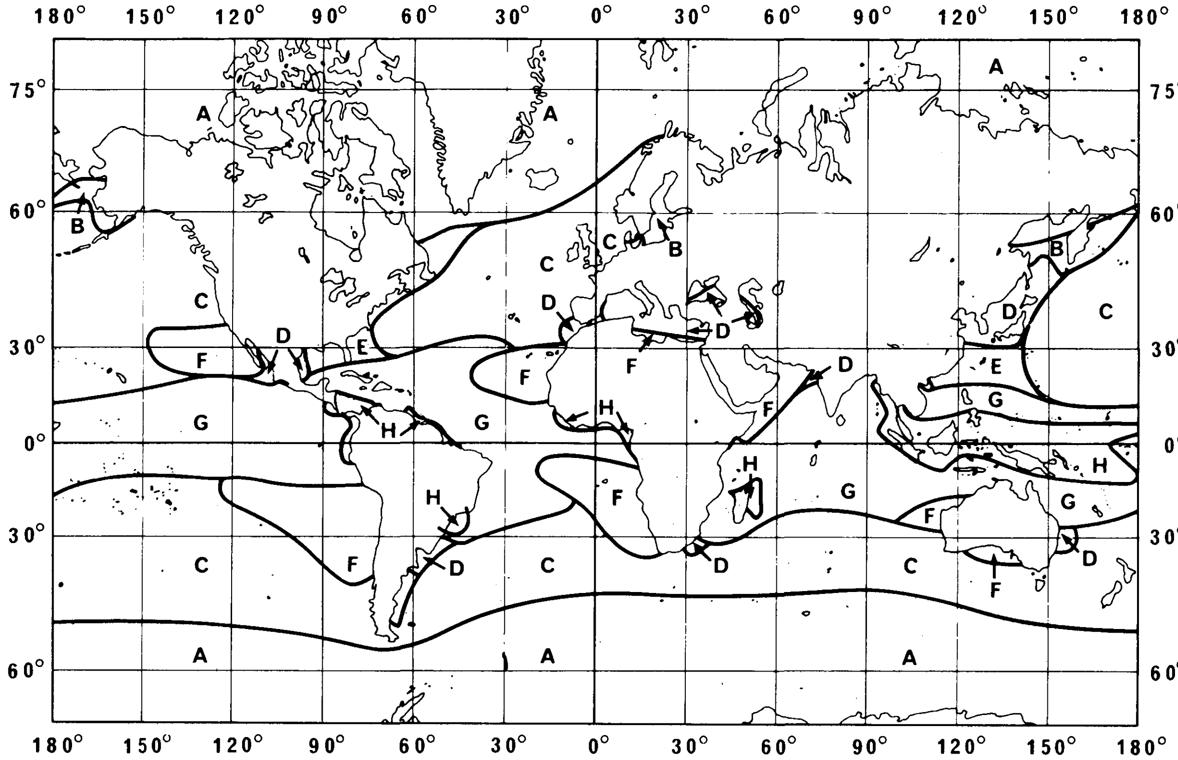

FIGURE 4-20 – *Rain climate regions for the oceans*
(see Table 4-XIII)

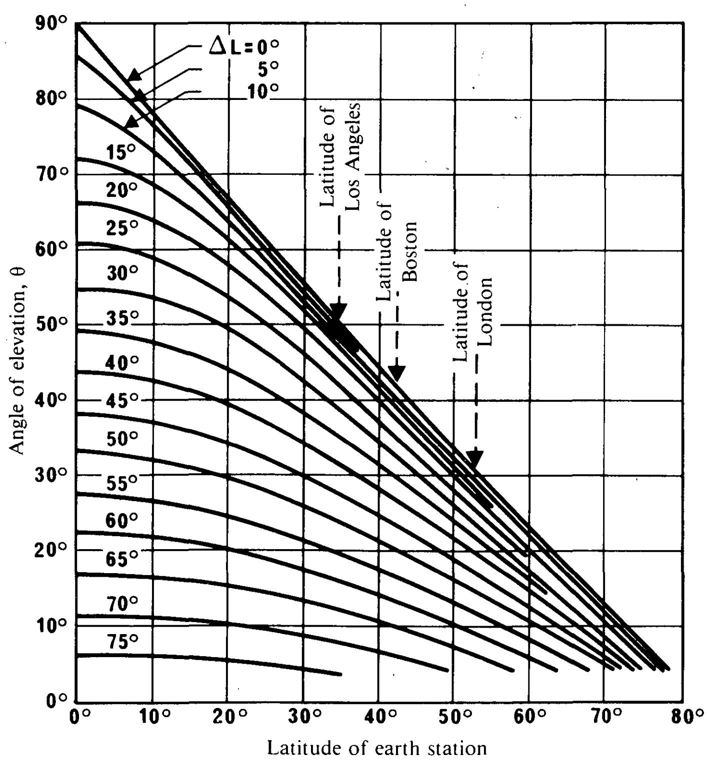

FIGURE 4-21 – *Angle of elevation to satellite as a function of latitude and relative longitude*

Δ *L:* difference between the earth station longitude and the satellite longitude

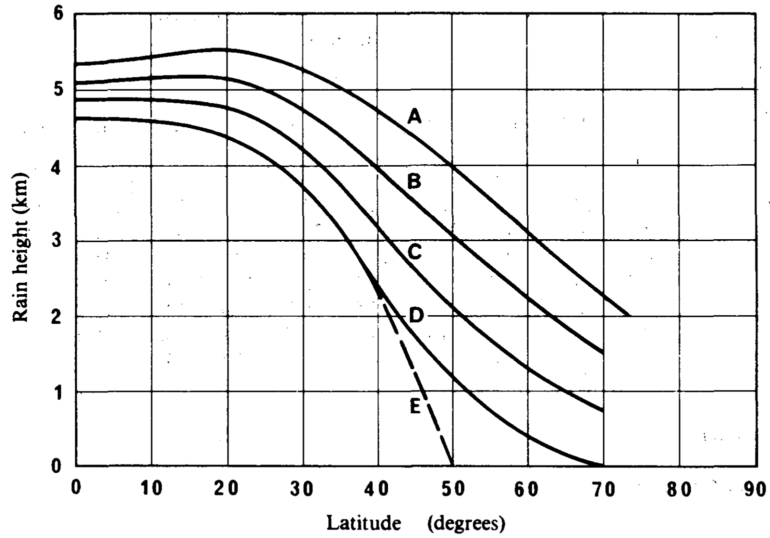

FIGURE 4-22 – *Rain height versus latitude φ (degrees) below which attenuation due to hydrometers is expected*

Curves A: probability of occurrence of associated rain intensity: 0.001 %
B: probability of occurrence of associated rain intensity: 0.01 %
C: probability of occurrence of associated rain intensity: 0.1 %
D: probability of occurrence of associated rain intensity: 1.0 %
E: includes rain and snow occurrences

TABLE 4-XIII – *Point rain rate (R_p) distribution values (mm/h) versus percentage of year rain rate is exceeded*

Link reliability (%)	p(1): percentage of year rain rate is exceeded	Rain rate R_p for various rain climate regions (mm/h)								Outage time	
		A	B	C	D	E	F	G	H	Minutes per year	Hours per year
99.999	0.001	29	58	78	108	165	66	185	253	5.3	0.09
99.997	0.003	17	36	52	78	132	43	141	202	15.8	0.26
99.99	0.01	10	20	28	49	98	23	94	147	53	0.88
99.97	0.03	6	11	14	29	66	11	60	103	158	2.62
99.9	0.1	3	5	7	15	35	5	32	64	526	8.77
99.7	0.3	1	2	4	7	15	2	17	34	1580	26.3
99.0	1.0	0.5	1	2	3	6	0.1	8	12	5260	87.66

(1) p = 100 – the desired link reliability.

Note. — This Table is to be used for Africa (Fig. 4-14), Asia (Fig. 4-15), Australia (Fig. 4-16), North and Central America excluding Canada (Fig. 4-18), South America (Fig. 4-19) and oceans (Fig. 4-20).

TABLE 4-XIV – *Point rain rate (R_p) distribution values (mm/h) versus percentage of year rain rate is exceeded*

Link reliability (%)	p[1]: percentage of year rain rate is exceeded	Rain rate R_p for various rain climate regions (mm/h)										Outage time	
		1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	4.1	4.2	Minutes per year	Hours per year
99.999	0.001	22	22	22	42	42	42	79	79	150	150	5.3	0.09
99.997	0.003	12	14	15	23	26	28	43	49	81	92	15.8	0.26
99.99	0.01	6.1	8.0	9.9	12	15	19	22	29	41	54	53	0.88
99.97	0.03	3.3	4.9	6.7	6.3	9.3	13	12	18	23	33	158	2.62
99.9	0.1	1.7	3.0	4.4	3.2	5.5	8.3	6.1	10	12	20	526	8.77
99.7	0.3	0.9	1.8	3.0	1.8	3.4	5.7	3.4	6.4	6.4	12	1580	26.3
99.0	1.0	—	1.1	2.0	0.9	2.0	3.7	1.8	3.8	3.3	7.2	5260	87.66

(1) p = 100 – the desired link reliability.

Note. — This Table is to be used for Canada (Fig. 4-18).

TABLE 4-XV – *Point rain rate (R_p) distribution values (mm/h) versus percentage of year rain rate is exceeded*

Link reliability (%)	p[1]: percentage of year rain rate is exceeded	Rain rate R_p for various rain climate regions (mm/h)									Outage time	
		A	B	C	D	E	F	G	H	J	Minutes per year	Hours per year
99.999	0.001	> 150	> 150	100	83	66	50	35	65	55	5.3	0.09
99.997	0.003	150	105	64	55	43	34	25	45	45	15.8	0.26
99.99	0.01	85	60	38	32	25	20	16	30	35	53	0.88
99.97	0.03	48	33	22	18	15	13	11	20	28	158	2.62
99.9	0.1	22	15	12	10	8	7	6	12	20	526	8.77
99.7	0.3	9	7	5	4	4	3	3	—	—	1580	26.3

(1) p = 100 – the desired link reliability.

Note. — This Table is to be used for Europe (Fig 4-17).

TABLE 4-XVI – *Values of* α *and* β *for a range of frequencies*

Frequency (GHz)	α	β
10	1.36×10^{-2}	1.150
11	1.73×10^{-2}	1.143
12	2.15×10^{-2}	1.136
15	3.68×10^{-2}	1.118
20	7.19×10^{-2}	1.097
25	0.121	1.074
30	0.186	1.043

TABLE 4-XVII – *Example of rain attenuation margins for 5 locations in the US and for various link reliabilities of 99, 99.9 and 99.99 %*

Location	Rain zone	Elevation above sea level (m)	Longitude west (degrees)	Latitude north (degrees)	Elevation angle to a satellite 95° W longitude (degrees)	Attenuation (dB) not exceeded during average year for given percentage of time					
						12.5 GHz			17.5 GHz		
						99 %	99.9 %	99.99 %	99 %	99.9 %	99.99 %
Portland, Maine	B	8	70	44	33.5	−0.1	−1.0	− 5.1	−0.3	− 2.3	−10.8
San Francisco, California	C	20	122	38	38.0	−0.4	−1.6	− 7.3	−0.8	− 3.5	−15.4
Chicago, Illinois	D	154	88	42	41	−0.3	−2.5	−10.2	−0.7	− 5.5	−21.4
Miami, Florida	E	3	80	26	56	−1.2	−7.5	−21.7	−2.5	−15.9	−44.8
Los Angeles, California	F	104	118	34	43.5	0.0	−1.2	− 5.8	0.0	− 2.6	−12.2
Seattle, Washington	C	3	122	48	29	−0.2	−1.4	− 6.9	−0.4	− 3.0	−14.6

REFERENCES

NASA [March, 1980] A Propagation Effects Handbook for Satellite System Design. ORI TR 1679. NASA Contract NAS5-25725.

ANNEX 4-II

SPACECRAFT WEIGHT ESTIMATION MODEL

The method for estimating spacecraft weight described in this Annex is based on a computer program developed by Ford Aerospace and Communications Company (FACC). The program is entitled "Spacecraft Parameter and Cost Estimation Model" and is described in [Melachrino and Baker, 1980]. It uses as its data base statistics taken from some 30 previously flown communication satellites. This program is applicable to 3-axis stabilized spacecraft only.

The program computes spacecraft cost as well as weight. The cost estimation aspects of this program are described in Annex 4-IV. The input to the FACC program is the weight and power of the communication sub-system. A procedure for the estimation of communication sub-system weight and power is given in Annex 4-III.

The output of the weight estimation part of the program consists of the spacecraft sub-system weights. The procedures for computing sub-system weights are given in block diagram form in the subsequent sections. These block diagrams may be used directly or, for users with access to a digital computer, the block diagrams may serve as a flow chart for writing a computer program.

1. Electrical sub-system weights

The weight of the electrical power sub-system on the satellite consists of three components. These components are solar array weight, battery weight and power processing equipment weight. This section outlines a systematic procedure to arrive at an estimate for the weight of the electrical power sub-system by calculating the weight of each constituent component. Before this can be done however, the power requirement of the spacecraft needs to be determined.

Figure 4-23 shows the block diagram for estimating power requirement during the eclipse. This power level is the major factor in determining the battery weight as outlined in Fig. 4-24. Figure 4-25 outlines the method for calculating beginning of life (BOL) power which is the determining factor in estimating solar array weight. Finally Fig. 4-26 suggests a method for estimating power conditioning weight. The weight of the electrical power sub-system is then the sum of the weights of the solar array, batteries and power conditioning equipment as obtained by Figs. 4-24, 4-25 and 4-26 respectively.

2. Structure sub-system weight

The block diagram of Fig. 4-27 shows the method for estimating the weight of the structure sub-system. The multiplier coefficients are based on statistical averaging of historical data.

3. Thermal sub-system weight

Figure 4-28 outlines the weight estimation model for the thermal sub-system.

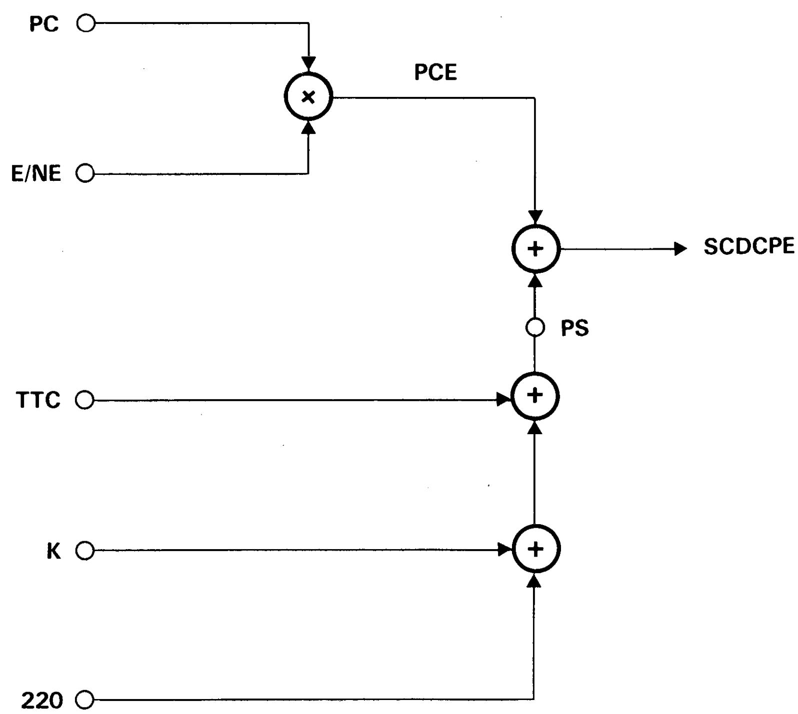

FIGURE 4-23 – *Spacecraft d.c. power during eclipse*

PC: communications sub-system d.c. power (Annex 4-III)

E/NE: ratio of communications eclipse power to non-eclipse power (PC)

TTC: TTC d.c. power
60 W if TTC has encryption
0 W if TTC has no encryption

PS: spacecraft d.c. power other than communications

K: spacecraft d.c. power = 0.2 (RF power —200) W*

SCDCPE: spacecraft d.c. power during eclipse

* (RF > 200 W, 0 otherwise)

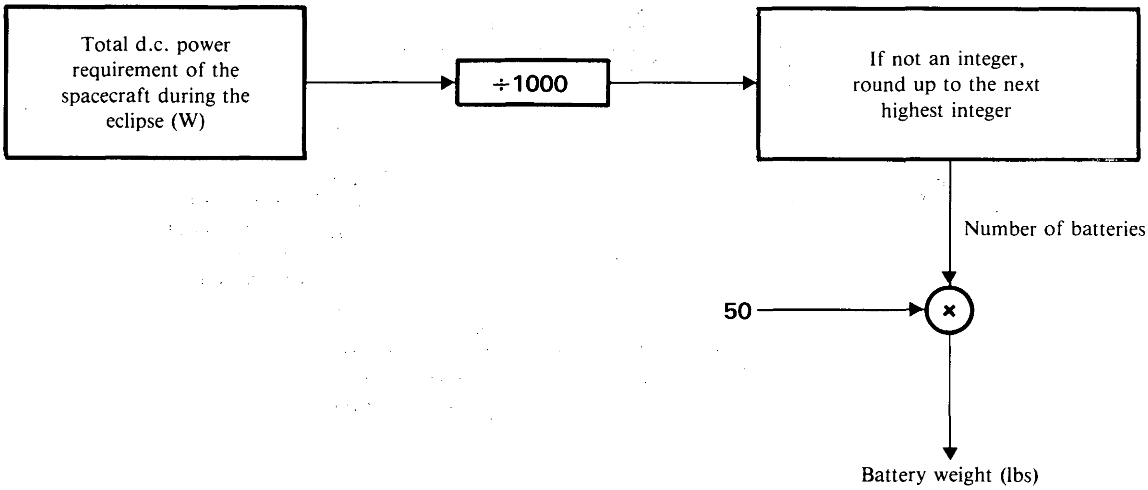

FIGURE 4-24 – *Battery weight*

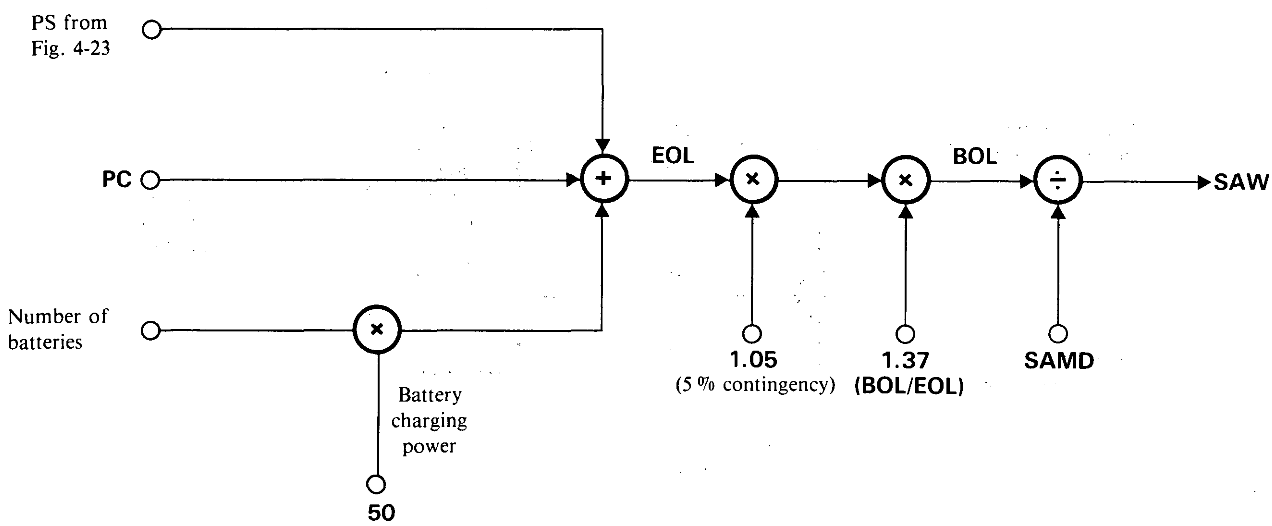

FIGURE 4-25 – *Solar array weight*

PS:	spacecraft d.c. power other than communications
PC:	communications sub-system d.c. power (Annex 4-III)
EOL:	end of life power
BOL:	beginning of life power
SAMD:	solar array mass density: 27.3 W per lb
SAW:	solar array weight (lbs)

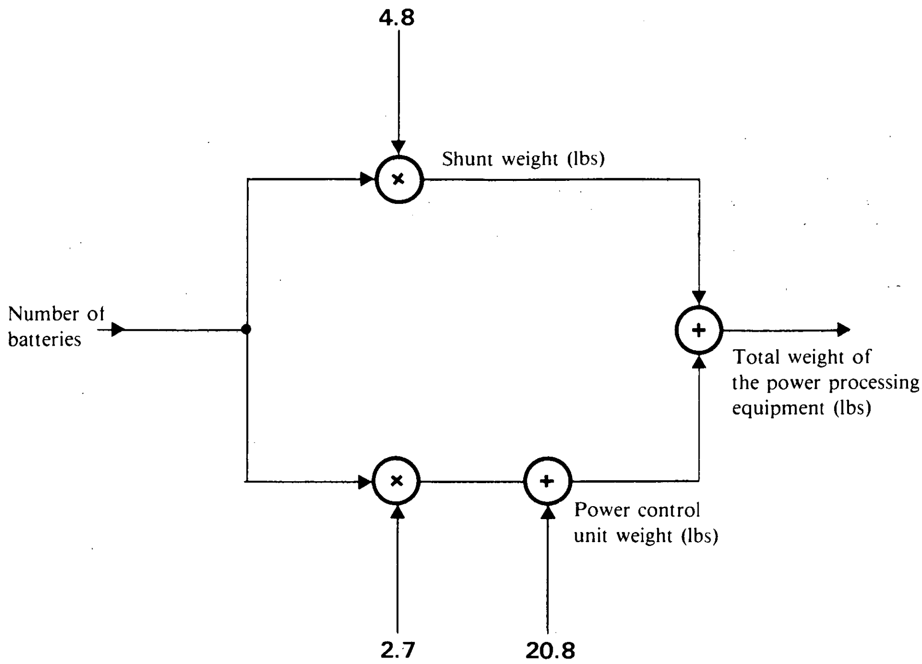

FIGURE 4-26 – *Weight of the power processing equipment*

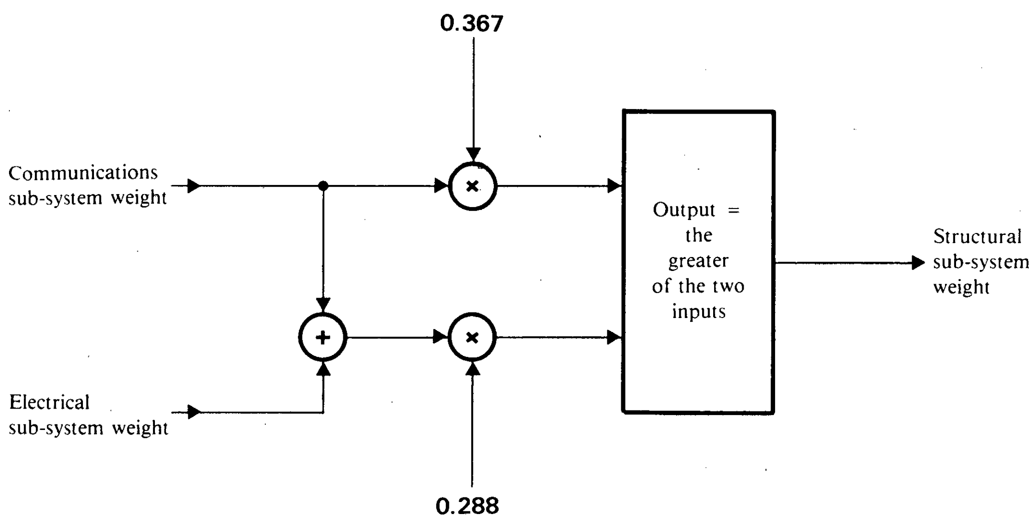

FIGURE 4-27 – *Model for estimating the structure sub-system weight*

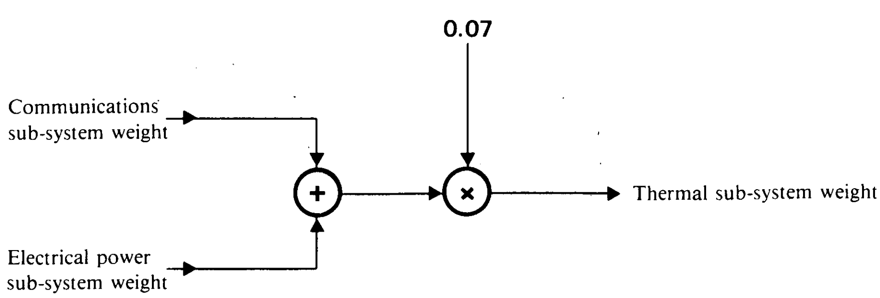

FIGURE 4-28 – *Model for estimating the thermal sub-system weight*

4. Tracking telemetry and control (TTC) sub-system weight

The weight estimate for this sub-system is based on Table 4-XVIII.

TABLE 4-XVIII – *TTC sub-system weight*

TTC sub-system weight	Comment
50 lbs (22.5 kg)	If TTC up link does not include either encryption or spread spectrum multiple access SSMA
80 lbs (36 kg)	If TTC up link includes encryption but no SSMA
110 lbs (50 kg)	If TTC up link includes encryption and SSMA

5. Attitude control sub-system weight

Table 4-XIX gives the weight of the attitude control sub-system for various pitch axis accuracies (PAA).

TABLE 4-XIX – *Attitude control sub-system weight*

Pitch axis accuracy (PAA)	3 × Communications sub-system weight	
	> 1300 lbs (590 kg)	< 1300 lbs (590 kg)
PAA > 0.1°	152 lbs (69 kg)	130 lbs (59 kg)
0.05° ≤ PAA ≤ 0.1°	172 lbs (78 kg)	152 lbs (69 kg)
PAA < 0.05°	207 lbs (94 kg)	187 lbs (85 kg)

6. Electrical and structural integration

Figures 4-29 and 4-30 give the weight estimate for the electrical and structural integration respectively.

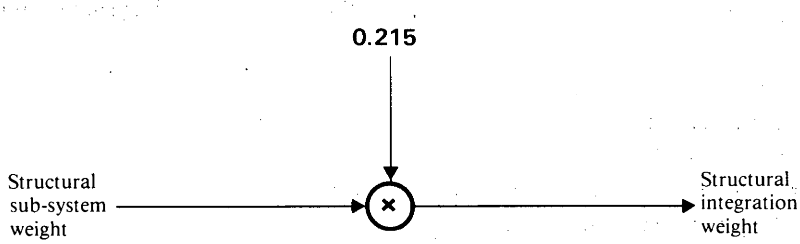

FIGURE 4-29 – *Model for estimating structural integration weight*

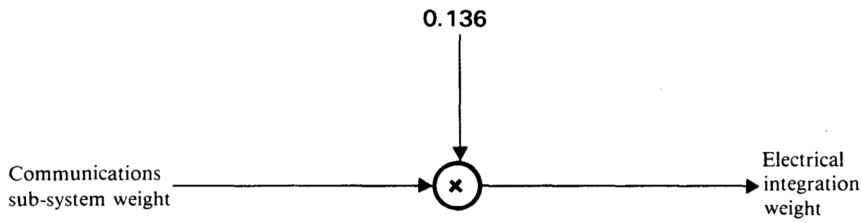

FIGURE 4-30 – *Model for estimating electrical integration weight*

Figure 4-30, p.152

7. On-board fuel weight and propulsion sub-system weight *

The amount of fuel to be carried in orbit by a spacecraft depends on several factors including the life of the mission, the weight of the satellite, the specific energy content of the fuel, etc. These parameters are related by:

$$M_{fuel} = M_{DSC}\left(e^{\frac{\Delta v}{I_{sp} \cdot g}} - 1\right) \tag{28}$$

where:

M_{fuel}: mass of the fuel,

M_{DSC}: dry weight of the spacecraft (i.e. the weight of the spacecraft after all the usable fuel has been spent),

I_{sp}: specific impulse of the fuel. I_{sp} is the indicator of the specific energy content of the fuel and its unit is seconds. An I_{sp} of 220 s is typical of monomethyl hydrazine liquid fuel,

g: Earth's gravitational acceleration = 9.8 m/s^2,

Δv: impulsive velocity increment.

A typical value for Δv for a 7 year geostationary mission is 500 m/s of which about 100 m/s is spent at the start of the mission for overcoming apogee kick motor firing dispersions, and placing the spacecraft at the assigned longitude in the geostationary orbit. Approximately 50 m/s is allocated to the north-south station keeping each year, and the yearly allocation to the east-west station keeping and attitude control are approximately 2 m/s and 8 m/s, respectively.

Using a Δv of 500 m/s and an I_{sp} of 220 s in equation (28) one gets:

$$M_{fuel} = 0.26\ M_{DSC} \tag{29}$$

The weight of the propulsion tankage and hardware is approximated to be about 10% of the weight of the fuel. This weight does not include the weight of the empty shell which may be left behind by the apogee kick motor, if it is integral with the spacecraft liquid propulsion sub-system. Summarizing the above discussion, Fig. 4-31 gives the block diagram for estimating the in-orbit fuel weight.

8. The overall spacecraft weight

The weight of the spacecraft is the aggregate sum of the constituent sub-systems which are:

- communications (Annex 4-III);
- electrical sub-system (Figs. 4-24, 4-25 and 4-26);
- structural sub-system (Fig. 4-27);
- thermal sub-system (Fig. 4-28);
- tracking, telemetry and control (TTC) sub-system (Table 4-XVIII);
- attitude control sub-system (Table 4-XIX);
- electrical and structural integration weight (Figs. 4-29 and 4-30);
- on-board fuel weight and propulsion hardware (Fig. 4-31).

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* The procedure for estimating the on-board fuel weight and the propulsion hardware weight as explained in this section is different from the procedure suggested by the FACC model.

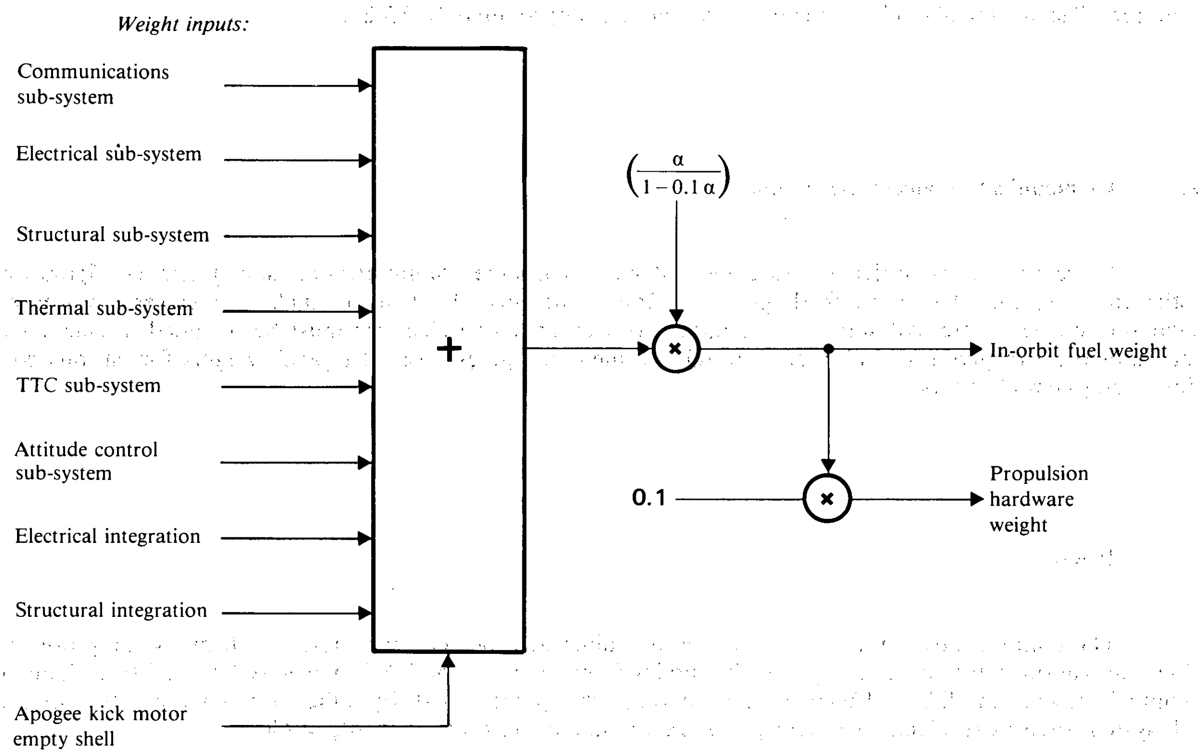

FIGURE 4-31 – *In-orbit fuel and propulsion hardware weight*

$$\alpha = \left(e^{\frac{\Delta v}{I_{sp}\cdot g}} - 1\right)$$

9. Apogee kick motor (AKM) weight

Using equation (28), a required $\Delta v = 1.8$ km/s and a fuel $I_{sp} = 284$ s, the AKM fuel weight is 0.91 times the on-geostationary orbit weight. Using 10% of the fuel weight as an approximation for AKM hardware weight, makes the AKM weight essentially equal to the satellite weight. Values of required velocity increment Δv and AKM fuel weight are directly related to the inclination angle of the transfer orbit and values mentioned above are for the launch from the Eastern Test Range of the USA. Therefore it is necessary to recalculate each value for the specific launch vehicle and site.

REFERENCES

MELACHRINO, S. J. and BAKER, M. W. Jr. [March, 1980] Spacecraft parameter and cost estimation model. Technical Memorandum TM-294, Ford Aerospace and Communications Corporation.

ANNEX 4-III

COMMUNICATION SUB-SYSTEM – WEIGHT AND POWER ESTIMATION

The communication sub-system consists of two major elements, the antenna and communication electronics.

1. Antenna weight

Antenna weight depends on the type, rigid or deployable, and on the diameter, which is determined by the narrowest beam required. The approximate relationship between antenna diameter and beamwidth, for an antenna efficiency of 0.55, is given by the following relationship:

$$D = 70.5\ \lambda/\theta \tag{30}$$

where D and λ (wavelength) are in the same units and θ is the -3 dB beamwidth.

Estimated antenna weight versus diameter is plotted in Fig. 4-32. The weight given includes the reflector and feed support, but not the feeds. The number of feeds depends on the number of beams or the beam shaping required. The weight of each feed can be estimated at approximately 0.5 kg.

2. Communication electronics weight

Since each communication satellite will have a unique communication sub-system configuration, weight estimation requires that a block diagram be drawn showing all elements such as receivers, power amplifiers, switching elements, etc. All stand-by redundant as well as active elements must be included. Element weights are then added up to give total sub-system weight. Table 4-XX gives a set of typical weights for various communication sub-system elements.

3. Power

The major contribution to communication sub-system power consumption will be by the power amplifiers. Communication sub-system d.c. power is obtained by dividing total RF power (§ 3.6.1 of this Chapter) by the assumed power amplifier efficiency, and adding the power used by other elements of the communication sub-system such as receivers. Receiver power requirements are given in Table 4-XX.

TABLE 4-XX – *Typical communication sub-system element weights*

Component	Unit weight (kg)	Unit power (W)
A. Receivers		
single conversion	1.1	5
dual conversion	1.5	6
B. Low level amplifier/driver	0.5	1
C. Power amplifiers		(33 % efficiency)
Solid state (2.6 GHz)		
0-5 W	1	
5-10 W	1.4	
Travelling wave tube amplifiers (TWTA)		(33 % efficiency)
0-5 W	1.1	
5-8 W	1.3	
8-10 W	1.5	
10-15 W	2.1	
15-20 W	2.7	
20-40 W	3.6	
40-80 W	4.3	
80-100 W	6.8	
100-200 W	9.1	
D. Input multiplexer	0.37/channel	
E. Output multiplexer	0.32/channel	
F. Switches	0.1-0.5 kg depending on complexity	

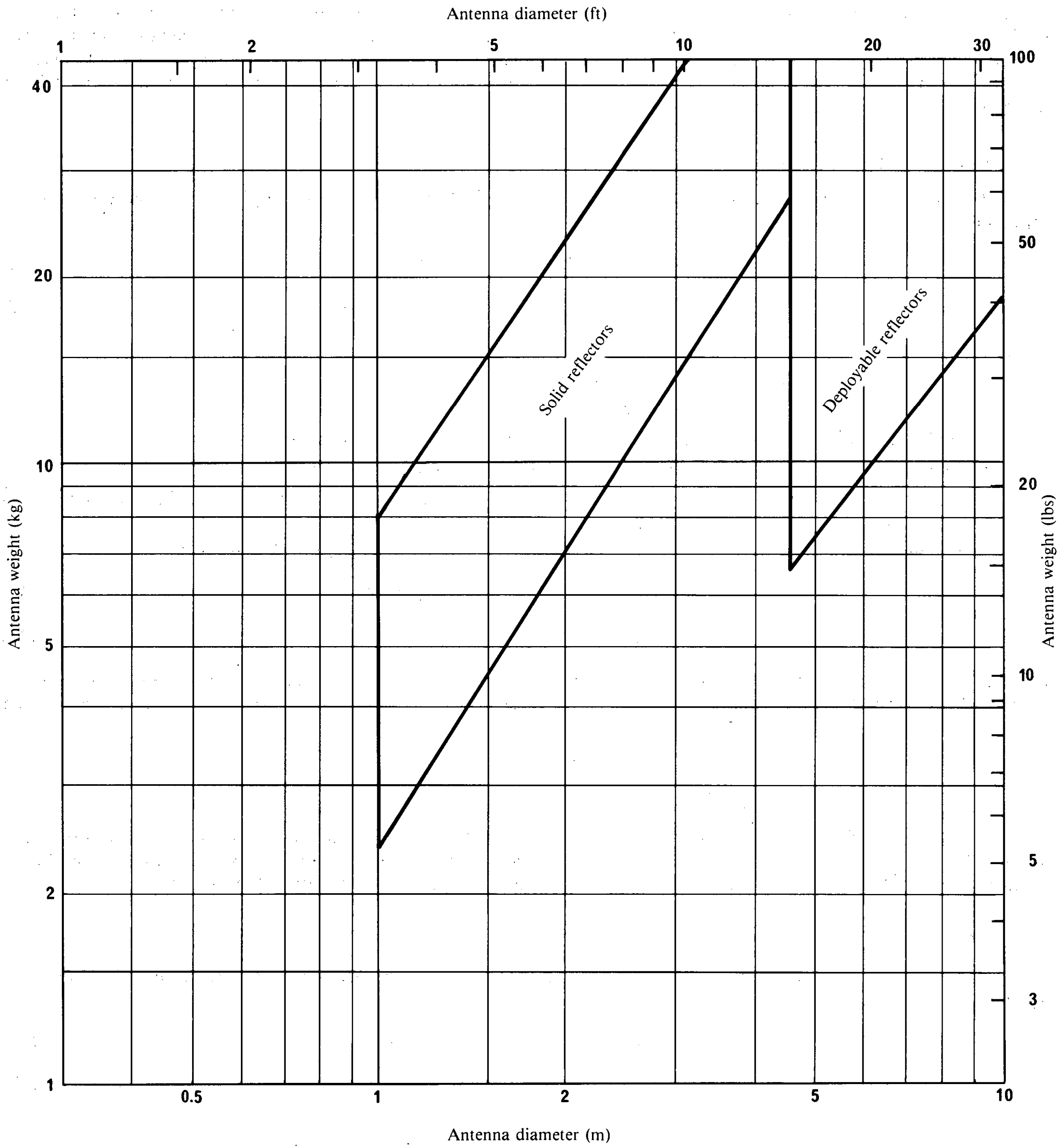

FIGURE 4-32 – *Antenna weight versus diameter*

ANNEX 4-IV

A SATELLITE COST MODEL

This Annex provides a detailed procedure for estimating communication satellite costs. The method is based on the FACC computer program [Melachrino and Baker, 1980].

Recurrent and non-recurrent costs are computed for each sub-system and are subsequently used to estimate the cost of the total program. The cost of each sub-system is derived, based on the complexity of the sub-system and its weight, as given by Annex 4-II. Both Annexes 4-II and 4-IV are presented in such a fashion that they can be used by users with no access to a digital computer. However, these Annexes can easily be used to write a computer program if a computer is accessible. In the following sections all the costs are in thousands of 1980 US dollars and the weights are in pounds.

1. Communication sub-system cost

The non-recurrent and recurrent costs of the communication sub-systems are given by equations (31) and (32) respectively:

$$CNR = CNWF[1375.6 + 199.6\ (0.67)^{\cdot}(CCP)] \qquad (31)$$

$$CR = CRWF[67.6\ (0.75)(CCP) - 91.9] \qquad (32)$$

where:

- CNR: communication sub-system non-recurrent cost,
- CR: communication sub-system recurrent cost,
- $CNWF$: communication sub-system non-recurrent weighted complexity factor,
- $CRWF$: communication sub-system recurrent weighted complexity factor,
- CCP: communication sub-system costing parameter (taken to be the weight of the communication sub-system. See Annex 4-III).

The weighted complexity factors $CNWF$ and $CRWF$ are given by equations (33) and (34) below:

$$CNWF = 0.52\ (CF + 0.39) + 0.48 \qquad (33)$$

$$CRWF = 0.56\ (CF + 0.29) + 0.44 \qquad (34)$$

The factor CF in equations (33) and (34) is the complexity factor for the communication sub-system which itself is the sum of the more basic complexity factors of various sections of the communication sub-system. CF is given by:

$$CF = \sum_{i=2}^{9} CLi \qquad (35)$$

where CLi are the basic complexity factors as given in Table 4-XXI. Note that the factor CF in equation (33) is obtained by summing the non-recurrent (NR) basic complexity factors of Table 4-XXI and the factor CF in equation (34) is obtained by summing the recurrent (R) basic complexity factors of Table 4-XXI.

2. TTC sub-system cost

The non-recurrent and recurrent costs of the TTC sub-system are given by equations (36) and (37) respectively.

$$TNR = TNWF[477.28 + 8.23\ (TCP)] \qquad (36)$$

$$TR = TRWF[48.28\ (0.75)\ (TCP) - 85.84] \qquad (37)$$

where:

- TNR: TTC sub-system non-recurrent cost,
- TR: TTC sub-system recurrent cost,
- $TNWF$: TTC sub-system non-recurrent cost weighted complexity factor,
- $TRWF$: TTC sub-system recurrent cost weighted complexity factor,
- TCP: TTC costing parameter (taken to be the weight of the TTC sub-system. See Table 4-XVIII of Annex 4-II).

The weighted complexity factors $TNWF$ and $TRWF$ are given by equations (38) and (39) below:

$$TNWF = 0.52\ (CF + 0.294) + 0.48 \qquad (38)$$

$$TRWF = 0.56\ (CF + 0.211) + 0.44 \qquad (39)$$

The factor CF in equations (38) and (39) is the complexity factor for the TTC sub-system which itself is the sum of the more basic complexity factors.

CF is given by:

$$CF = \sum_{i=1}^{5} TLi \tag{40}$$

where TLi are the basic complexity factors as given in Table 4-XXII.

3. Structure sub-system cost

The non-recurrent and recurrent costs of the structure sub-system are given by equations (41) and (42) respectively.

$$SNR = 1.346\ [759 + 66\ (0.66)\ (SCP)] \tag{41}$$

$$SR = 1.377\ [2.4 + 7.5\ (0.75)\ (SCP)] \tag{42}$$

where SCP in the above equation is the structure sub-system costing parameter which is taken to be the sum of the weights of the structure sub-system, thermal sub-system and the structural integration weight (see Figs. 4-27, 4-28 and 4-29 of Annex 4-II).

4. Attitude control sub-system cost

The non-recurrent and recurrent costs of the attitude control sub-system are given by equations (43) and (44) respectively.

$$ANR = ANWF\,[734.9 + 79.9\ (0.75)\ (ACP)] \tag{43}$$

$$AR = ARWF\,[25 + 40.9\ (0.8)\ (ACP)] \tag{44}$$

where:

- ANR: attitude control sub-system non-recurrent cost,
- AR: attitude control sub-system recurrent cost,
- $ANWF$: attitude control sub-system non-recurrent cost weighted complexity factor,
- $ARWF$: attitude control sub-system recurrent cost weighted complexity factor,
- ACP: attitude control sub-system costing parameter (taken to be the sum of the weights of the propulsion hardware and the weight of the attitude control sub-system. See Fig. 4-31 and Table 4-XIX of Annex 4-II).

The weighted complexity factors $ANWF$ and $ARWF$ are given by:

$$ANWF = 0.62\ (CF + 0.497) + 0.38 \tag{45}$$

$$ARWF = 0.50\ (CF + 0.296) + 0.50 \tag{46}$$

The factor CF in the above equations is the complexity factor for the attitude control sub-system which itself is the sum of the more basic complexity factors associated with the attitude control sub-system. CF is given by:

$$CF = \sum_{i=1}^{3} ALi \tag{47}$$

where ALi is given by Table 4-XXIII.

5. Electrical sub-system cost

The recurrent and non-recurrent cost of the electrical power sub-system is given by ER and ENR of equations (48) and (49) respectively.

$$ER = R1 + R2 \tag{48}$$

$$ENR = NR1 + NR2 \tag{49}$$

where:

$$R1 = 83.5\ (ECP1 \times ECP2)^{0.21128} \tag{50}$$

$$R2 = ERWF\,(40 \times ECP3/1000) \tag{51}$$

$$NR1 = 440.3 + 2.0 \times ECP2 \tag{52}$$

$$NR2 = ENWF\,(50 \times ECP3/1000) \tag{53}$$

TABLE 4-XXI – *Basic complexity factors for the communications sub-system*

Designation	Description	Basic complexity factor relationships related to highest communication frequency		
		< 15 GHz	15 to 56 GHz	> 56 GHz
*CL*1	Highest communications frequency			
1	< 15 GHz			
2	15 to 56 GHz			
3	> 56 GHz			
*CL*2	Highest power amplifier power at the highest frequency	*NR/R*	*NR/R*	*NR/R*
1	< 5 W	0.233/0.196	0.325/0.284	0.551/0.475
2	5 to 10 W	0.252/0.220	0.375/0.318	0.608/0.512
3	10 to 20 W	0.281/0.245	0.424/0.352	0.664/0.549
4	20 to 40 W	0.345/0.264	0.481/0.385	0.742/0.583
5	> 40 W	0.392/0.305	0.523/0.419	0.799/0.617
		NR	*R*	
*CL*3	Type of transponder			
1	Translating	0.100	0.109	
2	Regenerative	0.140	0.229	
3	Combination	0.245	0.355	
*CL*4	Number of active power amplifiers			
1	⩽ 10	0.067	0.073	
2	⩽ 50	0.086	0.080	
3	⩽ 100	0.112	0.088	
4	> 100	0.137	0.089	
*CL*5	Number of different frequency bands			
1	1	0.034	0.037	
2	2	0.035	0.037	
3	3	0.039	0.040	
4	> 3	0.040	0.041	
*CL*6	Number of receive/transmit antenna sets			
1	1	0.035	0.034	
2	2 or 3	0.039	0.039	
3	4 to 6	0.042	0.043	
4	> 6	0.047	0.049	
*CL*7	Most complex antenna coverage			
1	Earth	0.135	0.135	
2	Single spot: beamwidth ⩾ 1.0°	0.266	0.225	
3	Single spot: beamwidth < 1.0°	0.332	0.281	
4	Shaped: single beamwidth ⩾ 1.0°	0.380	0.230	
5	Shaped: single beamwidth < 1.0°	0.475	0.288	
6	Multiple spot single beamwidth ⩾ 1.0°	0.430	0.182	
7	Multiple spot single beamwidth < 1.0°	0.559	0.236	
8	Scanning ⩽ 7 beamwidths	0.662	0.212	
9	Scanning > 7 beamwidths	0.726	0.297	
*CL*8	Most complex antenna design			
1	Horn	0.100	0.100	
2	Single reflector	0.100	0.227	
3	Dual reflector	0.248	0.248	
4	Single lens	0.271	0.328	
5	Dual lens/phased array	0.448	0.542	
*CL*9	Number of feed elements in most complex antenna design			
1	1-10	0.100	0.102	
2	11-25	0.229	0.234	
3	26-50	0.458	0.455	
4	51-75	0.628	0.624	
5	76-100	0.798	0.794	
6	> 100	0.846	1.172	

NR: non-recurrent. *R*: recurrent.

TABLE 4-XXII – *Basic complexity factors for TTC sub-system*

Designation	Description	Non-recurrent (NR)	Recurrent (R)
$TL1$	Maximum TTC bit rate: CMD or TLM:		
1	$\leqslant 10^5$ bit/s	0.110	0.100
2	10^5 to 10^9 bit/s	0.199	0.154
3	$> 10^9$ bit/s	0.279	0.176
$TL2$	Total number of commands:		
1	$\leqslant 1000$	0.120	0.142
2	> 1000	0.144	0.183
$TL3$	Type of communications processing:		
1	None	0.303	0.304
2	Centralized	0.500	0.435
3	Distributed	0.583	0.483
$TL4$	Processing or TTC storage:		
1	None	0.151	0.152
2	$\leqslant 10^4$ bits	0.174	0.158
3	10^4 to 10^9 bits	0.210	0.182
4	$> 10^9$ bits	0.274	0.234
$TL5$	Processing memory:		
1	None	0.151	0.152
2	Magnetic core	0.160	0.160
3	Tape	0.165	0.165
4	Other	0.250	0.251

CMD: command.
TLM: telemetry.

Table 4-XXII, p.161

In the above equations, $ECP1$ to $ECP3$ are electrical power sub-system costing parameters. $ECP1$ is the sum of the weights of the electrical power sub-system and the electrical integration. The weight of the electrical power sub-system is the sum of the outputs of Figs. 4-24, 4-25 and 4-26 of Annex 4-II and the weight of the electrical integration is given by Fig. 4-30 of Annex 4-II. $ECP2$ is end of life power requirement (less the contingency) as given by block diagram, Fig. 4-25, Annex 4-II. $ECP3$ is the number of solar cells needed to produce the required beginning of life (BOL) power in watts and is given by equation (54).

$$\text{Number of solar cells} = \frac{\text{Bol power requirement}}{\text{Solar cell factor}} \tag{54}$$

The solar cell factor is taken to be 0.23.

$ERWF$ and $ENWF$ in equations (51) and (53) are the electrical power recurrent and non-recurrent weighted complexity factors. They are given by:

$$ENWF = 0.56\ (CF + 1.132) + 0.44 \tag{55}$$

$$ERWF = 0.52\ (CF + 0.836) + 0.48 \tag{56}$$

The factor CF in equations (55) and (56) is given by Table 4-XXIV.

6. Spacecraft programme cost

Once the recurrent and non-recurrent costs of various sub-systems have been determined one can cost the total spacecraft programme. The programme described in this section contains N spacecraft of which $N - 1$ are flight models and the other one is a prototype which can be refurbished to be a flight model. The various costs contributing to the total programme costs are:

– *total non-recurrent cost* =
  1.3 (sum of the non-recurrent costs of all the sub-systems)
– *first unit cost* =
  1.25 (sum of the recurrent costs of all the sub-systems)

– *prototype cost* =
1.25 (first unit cost)

– *research and development (R&D) cost* =
total non-recurrent cost – prototype cost

– *prototype refurbishment cost* =
0.2 (first unit cost) + 4500

– *flight model cost* =
(number of spacecraft – 1) (first unit cost)

– *in-orbit incentive cost* =
0.2 (total non-recurrent cost + flight model cost + prototype refurbishment cost)

– *total programme cost* =
total non-recurrent cost + flight model cost + prototype refurbishment cost + in-orbit incentive cost.

TABLE 4-XXIII – *Basic complexity factors for attitude control sub-system*

Designation	Description	Non-recurrent (NR)	Recurrent (R)
$AL1$	Attitude reference:		
1	Inertial or other	0.256	0.282
2	Celestial	0.357	0.321
$AL2$	Pointing control:		
1	Open loop	0.190	0.206
2	Closed loop	0.255	0.332
$AL3$	Pitch axis pointing accuracy:		
1	$> +1.0°$	0.294	0.302
2	$0.25°$ to $< 1.0°$	0.356	0.365
3	$0.1°$ to $< 0.25°$	0.482	0.429
4	$< 0.1°$	0.835	0.544

TABLE 4-XXIV – *Basic complexity factors for electrical power sub-system*

Designation	$TBPR$ [1] values	Non-recurrent (NR)	Recurrent (R)
1	$TBPR \leq 750$	0.432	1.978
2	$TBPR \leq 1250$	0.437	2.747
3	$TBPR \leq 1750$	0.442	3.846
4	$TBPR \leq 2250$	0.447	4.945
5	$TBPR \leq 2750$	0.452	6.044
6	$TBPR \leq 3250$	0.457	7.143
7	$TBPR > 3250$	0.462	9.066

(1) *TBPR*: end of life power requirement (W) (less the contingency margin. See Fig. 4-25, Annex 4-II).

REFERENCES

MELACHRINO, S. J. and BAKER, M. W. Jr. [March, 1980] Spacecraft parameter and cost estimation model. Technical Memorandum TM-294, Ford Aerospace and Communications Corporation.

ANNEX 4-V

COVERAGE AREA PLANNING
WORLD MAPS

This Annex includes a representative set of world maps drawn by the computer program WMAP [Calcomp, 1975]. Among the features of this program is the capability to project views of the Earth's surface onto a plane perpendicular to the viewer-Earth centre vector. Circular beams therefore project as circles on these maps.

Figures 4-33 to 4-40 inclusive show views of the Earth's surface from geostationary orbit at intervals of 45° longitude. If circular beams are used, required beamwidths can be computed graphically by drawing circles over the desired coverage area. Beam diameters in degrees can be scaled from the angular diameter of the Earth, which is 17.4°.

In selecting an initial orbital position a longitude of about 15° west of the centre of the service area provides good earth solar eclipse protection.

FIGURE 4-33 – *Satellite location 0° longitude*

FIGURE 4-34 – *Satellite location 45° E longitude*

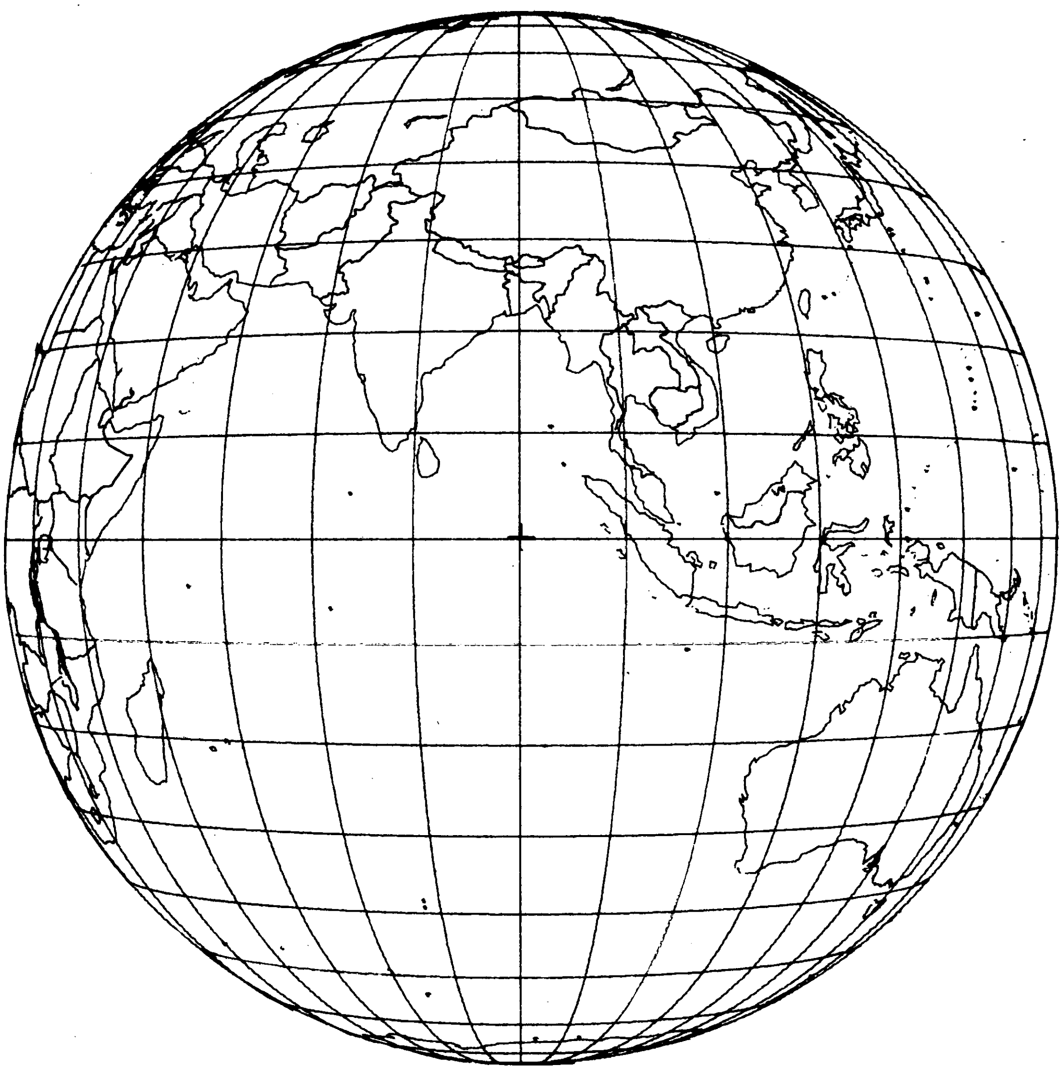

FIGURE 4-35 – *Satellite location 90° E longitude*

FIGURE 4-36 – *Satellite location 135° E longitude*

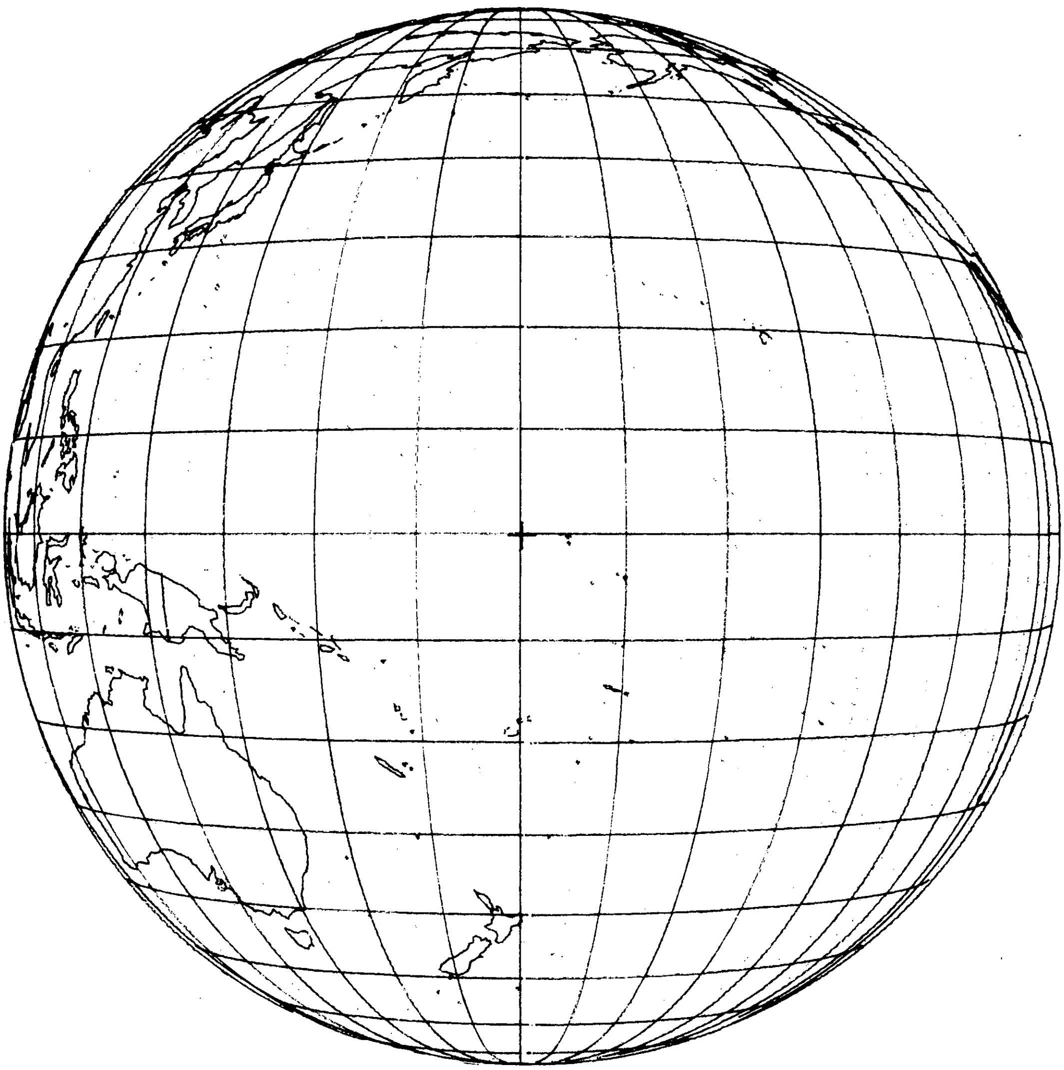

FIGURE 4-37 – *Satellite location 180° longitude*

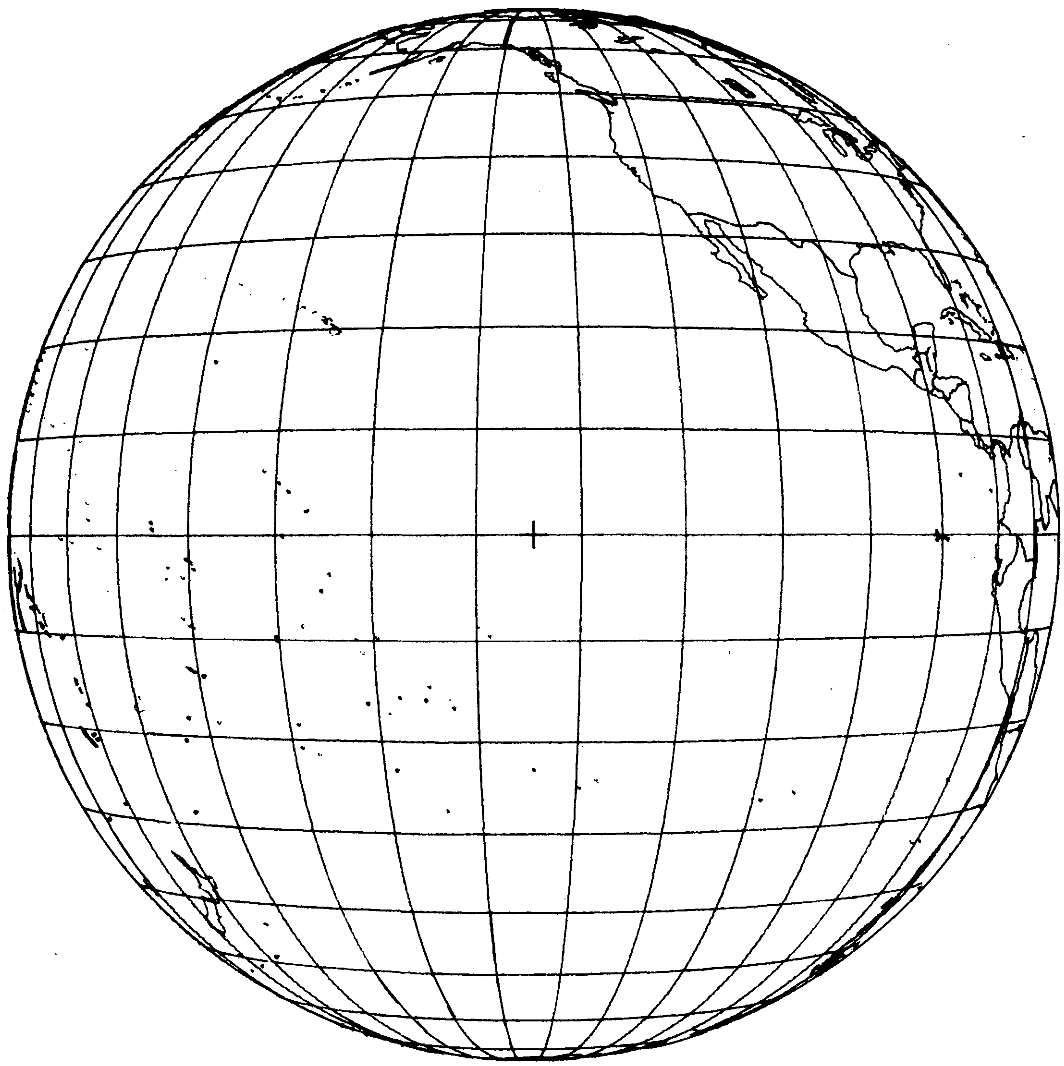

FIGURE 4-38 – *Satellite location 135° W longitude*

FIGURE 4-39 – *Satellite location 90° W longitude*

FIGURE 4-40 – *Satellite location 45° W longitude*

REFERENCES

CALCOMP [June, 1975] User's manual, Calcomp graphics functional software world map (WMAP) plotting software.

ANNEX 4-VI

EXAMPLE OF SYSTEM SYNTHESIS AND COSTING

A system synthesis and costing example is worked out in this Annex following the procedure of § 3 of Chapter 4.

1. Requirements

The example to be worked out is a single channel broadcasting satellite at 12 GHz for community reception with a coverage area of the contiguous United States.

2. Input parameters

- Number of earth terminals = 11 000
- Number of sound channels per video channel = 1
- Signal quality, S/N = 45 dB
- Television system M, FM modulation
- Bandwidth = 27 MHz
- Satellite location = 95° W
- Geographic location of earth terminals – throughout United States of America
- Earth station latitude and longitude – select worst case for elevation and rain
- Channels/beam = 1
- Number of beams: single shaped beam formed by 25 circular beams of 1°
- Service area: contiguous United States
- Link reliability = 99.9% of average year

3. Procedures

Step 1

3.1 *Required C/N_0* (§ 3.1, Chapter 4)

From Fig. 4-2, the required C/N_0 = 86.8 dBHz for S/N = 45 dB and RF bandwidth of 27 MHz. One sound sub-carrier at 6.8 MHz is included.

Step 2

3.2 *Total path loss* (§ 3.2, Chapter 4)

From Table 4-II, $L_{FS} = -205.8$ dB for Seattle which has an elevation angle of 29°.

From Table 4-III, for 99.9% link reliability, L_R ranges between -1.0 dB and -7.5 dB. Since the rain climate is so different over the service area, we will use 4 dB rain margin and require higher G/T terminals in high rain regions.

The design value of L_p is then $(-205.8 \ -4) = -209.8$ dB. We will require 4 dB higher G/T in certain high rain regions.

Step 3

3.3 *E.i.r.p. plus G/T* (§ 3.3, Chapter 4)

Because the spacecraft antenna gain is not expected to be uniform over the service area we will include a -3 dB factor for the edge of coverage area.

$$\begin{aligned} e.i.r.p. + G/T &= C/N_0 - L_p + K + 3 \text{ dB} \\ &= 86.9 + 209.8 - 228.6 + 3 \\ &= 71.1 \text{ dB} \end{aligned}$$

Step 4

3.4 *Selection of G/T, G and T* (§ 3.4, Chapter 4)

Select initial value of G/T = 16.1 dB(K^{-1}).

Then *e.i.r.p.* = 55 dBW

Select receiver with noise figure = 3.5 dB for all terminals.

Region 1: From Fig. 4-4, given 4 dB rain attenuation, T = 27.5 dBK
From Fig. 4-6, given T = 27.5 dBK and antenna diameter = 1.6 m (G_A = 43.6 dB),
G/T = 16.1 dB(K^{-1})

Region 2: From Fig. 4-4, given 8 dB rain attenuation, T = 28 dBK
From Fig. 4-6, given T = 28 dBK and antenna diameter = 2.8 m (G_A = 48.1 dB),
G/T = 20.1 dB(K^{-1})

Step 5

3.5 *Ground segment costs* (§ 3.5, Chapter 4)

Single unit costs from Table 4-VI and Fig. 4-8:

Receiver single unit cost for all terminals = \$3000
Antenna single unit cost for Region 1 (4 dB rain) = \$900 (1.6 m diameter)
Antenna single unit cost for Region 2 (8 dB rain) = \$2000 (2.8 m diameter)

Large quantity receiver costs 11 000 units using 85% learning curve (Fig. 4-9)
Cost = \$3000 (0.11) = \$330 each.

Antennas for Region 1, 10 000 units and 90% learning curve Cost = \$900 (0.25) = \$225 each.

Antennas for Region 2, 1000 units and 90% learning curve Cost = \$2000 (0.35) = \$700 each.

Total cost = 11 000 (330) + 10 000 (225) + 1000 (700) = \$6.58 million

Step 6

3.6 *Communication sub-system and satellite power* (§ 3.6, Chapter 4)

From Table 4-VIII required transmitted power for composite beams from 25, 1° beams and *e.i.r.p.* = 55 dBW, United States coverage:

transmitted power = 315 W (25 dBW)

Assuming 1.5 dB transmitting circuit losses:

P_0 = 25 dBW + 1.5 dB = 26.5 dBW

$TRFP$ = 447 W

Satellite power is taken from Fig. 4-10, assuming a power amplifier efficiency of 33%:

P_{Sat} = 2500 W

Step 7

3.7 *Satellite weight* (§ 3.7, Chapter 4)

Use the procedures of Annexes 4-II and 4-III to compute satellite weight. The required inputs are communication sub-system power and weight.

3.7.1 *Communication sub-system power* (Annex 4-III)

Communication sub-system power = 450/0.33 + 10 = 1374 W where 0.33 is the assumed power amplifier efficiency and 10 W is for other components in the sub-system.

3.7.2 *Communication sub-system weight* (Annex 4-III)

- Assume one 450 W power amplifier (PA) and one stand-by. Since Table 4-XX does not go to 450 W, PA weight is estimated to be 20 kg by extrapolation. PA weight = 2 × 20 = 40 kg.
- Assuming 2 receivers at 1.5 kg, receiver weight = 3 kg.
- Antenna size is computed from equation (30), beamwidth = 1°.

$$D = 70.5\ (0.025) = 1.76\ \text{m}$$

Since there are 25 feeds, the antenna weight is taken from the high side of the range shown in Fig. 4-32. W_A = 30 kg.

- Total communication sub-system weight = 40 + 3 + 30 = 73.
  Add 10% contingency = 73 + 7 = 80 kg (176 lbs)

3.7.3 *Electrical sub-system weight* (§ 1, Annex 4-II)

Assume 100% eclipse capability

- eclipse power = 1644 W (from Fig. 4-23)
- number of batteries = 2, weight = 100 lbs (45.35 kg) (from Fig. 4-24)
- solar array weight = (270 + 1374 + 100) (1.05) (1.37)/(27.3) = 91.9 lbs (41.7 kg) (from Fig. 4-25)
- power processing equipment weight = 35.8 lbs (16.25 kg) (from Fig. 4-26)

Total electrical sub-system weight = 100 + 91.9 + 35.8 = 227.2 lbs (103.3 kg)

3.7.4 *Structure sub-system weight* (§ 2, Annex 4-II)

From Fig. 4-27 structure sub-system weight is 116.1 lbs (52.62 kg).

3.7.5 *Thermal sub-system weight* (§ 3, Annex 4-II)

From Fig. 4-28 thermal sub-system weight is 28.2 lbs (12.8 kg).

3.7.6 *TTC sub-system weight* (§ 4, Annex 4-II)

From Table 4-XVIII, TTC sub-system weight is 50 lbs (22.7 kg).

3.7.7 *Attitude control sub-system weight* (§ 5, Annex 4-II)

From Table 4-XIX attitude control sub-system weight is 130 lbs (58.95 kg).

3.7.8 *Structural and electrical integration weights* (§ 6, Annex 4-II)

From Figs. 4-29 and 4-30 these weights are 25 lbs (11.34 kg) and 24 lbs (10.88 kg) respectively.

3.7.9 *In-orbit fuel weight* (§ 7, Annex 4-II)

From Fig. 4-31 this weight is given by:

$$\text{(Sum of sub-system weights)}\ (1 + 0.026)\ (0.207) = 776.5\ (1.026)\ (0.207) = 164.9 \text{ lbs } (74.7 \text{ kg}).$$

3.7.10 *Propulsion hardware weight* (§ 7, Annex 4-II)

This weight $= 0.1\ (164.9) = 16.5$ lbs (7.47 kg).

3.7.11 *Total spacecraft weight* (§ 8, Annex 4-II)

$$\text{Sum of all sub-system weights} = 776.5 + 164.9 + 16.5 = 957.9 \text{ lbs } (434.17 \text{ kg}).$$

Step 8

3.8 *Satellite cost* (§ 3.8, Chapter 4)

Using the procedures of Annex 4-IV, the sub-system non-recurrent and recurrent costs are derived.

3.8.1 *Communication sub-system* (§ 1, Annex 4-IV)

$$CNR = CNWF[1375.6 + 199.6\ (0.67)\ (CCP)] \quad \text{non-recurrent}$$

$$CR = CRWF[67.6\ (0.75)\ (CCP) - 91.9] \quad \text{recurrent}$$

where CCP is the weight of the sub-system = 176 lbs (80 kg).

$$CNWF = 0.52\ (CF + 0.39) + 0.48$$

$$CRWF = 0.56\ (CF + 0.29) + 0.44$$

The communication sub-system complexity factors are:

$CL1$	= 1			$f < 15$ GHz
		NR	R	
$CL2$	= 5	0.392	0.305	Power amplifier > 40 W
$CL3$	= 1	0.1	0.109	Translating transponder
$CL4$	= 1	0.067	0.073	< 10 power amplifiers
$CL5$	= 1	0.034	0.037	One frequency band
$CL6$	= 1	0.035	0.034	One receive/transmit antenna set
$CL7$	= 6	0.43	0.182	Beamwidth = 1°, multiple spot
$CL8$	= 2	0.1	0.227	Single reflector
$CL9$	= 2	0.229	0.234	25 feed elements
CF		1.387	1.201	(equation (35))

and therefore

$$CRWF = 1.275 \text{ and } CNWF = 1.404 \text{ (from equations (33) and (34))}$$

then

$$CNR = \$11.03 \text{ million}$$

and

$$CR = \$3.9 \text{ million}$$

3.8.2 *TTC sub-system* (§ 2, Annex 4-IV)

$TNR = TNWF[477.28 + 8.23\ (TCP)]$ non-recurrent

$TR = TRWF[48.28\ (0.75)\ (TCP) - 85.84]$ recurrent

where TCP is the weight of the sub-system = 50 lbs (22.7 kg).

$TNWF = 0.52\ (CF + 0.294) + 0.48$

$TRWF = 0.56\ (CF + 0.211) + 0.44$

The complexity factors are:

	NR	R	
$TL1 = 1$	0.11	0.1	Bit rate < 10^5 bit/s
$TL2 = 1$	0.12	0.142	Commands < 1000
$TL3 = 1$	0.303	0.304	No communications processing
$TL4 = 1$	0.151	0.152	No storage
$TL5 = 1$	0.151	0.152	No memory
	0.835	0.85	

$CF(NR) = 0.835$ for NR costs

$CF(R) = 0.85$ for R costs

so that:

$TNWF = 1.067$

and:

$TRWF = 1.034$

therefore:

$TNR = \$948\ 000$

and:

$TR = \$849\ 000$

3.8.3 *Structure sub-system cost* (§ 3, Annex 4-IV)

$SNR = 1.346\ [759 + 66\ (0.66)\ (SCP)]$ non-recurrent

$SR = 1.377\ [2.4 + 7.5\ (0.75)\ (SCP)]$ recurrent

where SCP is the combined weight of the structure, thermal, and structural integration sub-systems = 169.3 lbs (76.8 kg)

therefore:

$SNR = \$3.649$ million

$SR = \$0.488$ million

3.8.4 *Attitude control sub-system cost* (§ 4, Annex 4-IV)

$ANR = ANWF[734.9 + 79.9\ (0.75)\ (ACP)]$ non-recurrent

$AR = ARWF[25 + 40.9\ (0.8)\ (ACP)]$ recurrent

where ACP is the combined weight of the propulsion hardware and attitude control sub-system = 146.5 lbs (66 kg).

$ANWF = 0.62\ (CF + 0.497) + 0.38$

$ARWF = 0.50\ (CF + 0.296) + 0.50$

The complexity factors are:

	NR	R	
$AL1 = 1$	0.256	0.282	Inertial
$AL2 = 2$	0.255	0.332	Closed loop
$AL3 = 2$	0.356	0.365	< 1° pointing
	0.867	0.979	

$CF(NR) = 0.867$

$CF(R) = 0.979$

therefore:

$ANWF = 1.226$

$ARWF = 1.137$

and

$ANR = \$5.03$ million

$AR = \$2.547$ million

3.8.5 *Electrical sub-system cost* (§ 5, Annex 4-IV)

$ENR = 440.3 + 2\,(ECP2) + ENWF(ECP3/20)$	non-recurrent
$ER = 83.5\,(ECP1 \cdot ECP2)\,0.21128 + ERWF(ECP3/25)$	recurrent

$ENWF = 0.56\,(CF + 1.132) + 0.44$

$ERWF = 0.52\,(CF + 0.836) + 0.48$

From Table 4-XXIV, since BOL power is 1831 W

$CF(NR) = 0.447$

$CF(R) = 4.945$

therefore:

$ENWF = 1.34$

$ERWF = 3.486$

$ECP1$ is the sum of the electrical sub-system and electrical integration sub-system weights = 251.2 lbs (113.8 kg).

$ECP2$ is the end of life power requirement = 1831 W from Fig. 4-25.

$ECP3$ is BOL power/0.23 (equation (54)) = 10 869 number of cells.

therefore:

ENR = \$4.831 million

ER = \$2.828 million

3.8.6 *Spacecraft cost* (§ 6, Annex 4-IV)

(a) The spacecraft non-recurrent cost is 1.3 times the sum of the non-recurrent costs of the following sub-systems (in millions (M) of \$):

Communications		11.03
TTC		0.948
Structural		3.649
Attitude control		5.05
Electrical		4.831
	Total	25.508 × 1.3 = \$33.16 million

(b) The first unit cost is 1.25 times the sum of the recurrent costs of the following sub-systems (in millions (M) of \$):

Communications		3.9
TTC		0.849
Structural		0.488
Attitude control		2.545
Electrical		2.828
	Total	10.61 × 1.25 = \$13.2 million

(c) *Prototype cost*

= 1.25 (first unit cost)
= 1.25 (13.2)
= \$16.5 million

(d) *Research and development (R&D) cost*

= Total non-recurrent cost − prototype cost
= \$33.16 million − \$16.5 million
= \$16.66 million

(e) *Prototype refurbishment cost*

= 0.2 (first unit cost) + 4.5 million
= 0.2 (13.2 million) + 4.5 million
= \$7.14 million

(f) *Flight model cost*

= (number of spacecraft − 1) (first unit cost)
= (1) (13.2)
= \$13.2 million

Number of spacecraft = one flight unit plus prototype = 2 (*g*) *In-orbit incentive cost*

= 0.2 (total non-recurrent cost + flight model cost + prototype refurbishment cost)
= 0.2 (33.16 + 13.2 + 7.14)
= $10.7 million

(*h*) *Total spacecraft cost*

= total non-recurrent cost + flight model cost + prototype refurbishment cost + in-orbit incentive cost
= 33.16 + 13.2 + 7.14 + 10.7
= $64.1 million

Step 9

3.9 *Launch cost* (§ 3.9, Chapter 4)

From Step 7, the estimated weight of the spacecraft is 958 lbs (434.5 kg). The required launch vehicle is of the Delta 3910 class. From Table 4-XIa the launch cost is $32.65 million.

– At this point the total cost (T) of the spacecraft, launch and receiving terminals can be computed.

T =	64.1	Spacecraft
	32.65	Launch + AKM cost
	6.58	Receiving terminals
	$103.33	million + AKM cost

– This gives the cost for a system with e.i.r.p. = 55 dBW.

– Next select a higher value of G/T since space segment cost is so much greater than ground segment cost.

– Reiterate the procedure from Step 4 to get another cost point.

– Continue until total cost stops falling.

CHAPTER 5

COMMUNICATION-SATELLITE SYSTEMS

1. Introduction

Although this report deals with broadcasting-satellite systems, it is also considered useful to provide some information on telecommunication satellites, due to certain similarities in technology between the two types. Satellite networks have high operational flexibility and they provide wideband transmission channels. A multi-purpose satellite may be used for both broadcasting and communications.

2. Operational and traffic requirements

The use of communication-satellite systems in the world telecommunication network requires planning of the type and volume of traffic (i.e. telephony, telegraphy, facsimile, data transmission, television, etc.) to be accommodated, the routing of traffic, probable locations and capacities of earth stations, the interference/compatibility and the overall performance characteristics to be defined. The performance aspects of telephony, telegraphy and data transmission are matters for the CCITT and CCIR; standards for the transmission of television and sound signals are dealt with by the CMTT, while assessment and forecast of telecommunication traffic and its routing are matters for the World Plan Committee and the Regional Plan Committees to examine.

Satellite communication networks such as INTELSAT have made it possible for a world-wide international telecommunication network to expand at an ever-increasing pace. This is demonstrated by the growth in telecommunication capacity of the INTELSAT system from the initial "Early Bird" satellite (Intelsat-I) in 1965 which provided for 240 single destination circuits between Europe and North America to the present series of Intelsat-V satellites each capable of providing 12 000 circuits for single and/or multi-destination traffic plus two high quality television channels. The first of nine planned Intelsat-V satellites was launched in 1980. Communication satellites are not only capable of providing large groups of trunk circuits between major traffic centres, but can also provide access to remote points in the world, with a relatively low traffic density.

The Regional and World Plan Committee have considered plans to develop a world-wide telephone network employing both semi-automatic and fully automatic operation. The international circuits required for the plan will link the national networks throughout the world in a global telecommunication network. Communication satellites are important contributions to these facilities, especially in the linking of very long international circuits between continents. The programme envisaged earlier by the CCITT is a series of world switching centres, through which traffic is routed to its destination. Communication-satellite systems have made it possible to by-pass many of these switching points, thus resulting in improvement in the noise performance. At the same time the CCITT/CCIR have set up requirements and limits to be met by the communication-satellite facilities for this world-wide service.

INTELSAT has developed traffic models based upon requirements by type, path and loading and has proposed plans to meet traffic requirements through the Intelsat-V time frame and beyond. Planning is already advancing for future high capacity satellites of up to 40 000 circuit capacity. Currently, approximately 60% of the world's international trans-oceanic telecommunications is carried via the INTELSAT system.

Based on preliminary analysis of 1980 traffic data, the demand for international satellite circuits is expected to rise from approximately 15 000 circuits in 1980 to 30 000 circuits in 1984 in the Atlantic Ocean region (average annual growth of 19%), from approximately 5000 to 9500 circuits in the Indian Ocean region (average annual growth of 17.4%) and from approximately 2500 to 5000 circuits in the Pacific Ocean Region (average annual growth of 19%). This represents an average total circuit growth from 22 500 circuits in 1980 to 44 500 circuits by 1984 representing an average annual growth rate of 18.6% [ITU, 1980]. This traffic is supported by a ground segment consisting of approximately 239 earth stations comprising some 295 antennas.

The employment of frequency division multiple access (FDMA) techniques for a large volume of pre-assigned traffic and the rise in use of SPADE on a demand-assigned basis offer a very effective means of achieving these objectives.

Terrestrial telecommunication systems have an acceptable low probability of lost calls on an economical basis only when they are heavily loaded. However, the communication-satellite system achieves the same grade of service by establishing single or multiple circuits on demand between any destination in the system on a call-by-call (i.e. demand) basis.

3. Brief summary and references to relevant sections of the Radio Regulations and to Recommendations of the CCIR and the CCITT

A definition for the hypothetical reference circuit for systems in the FSS employing analogue transmission is given in Recommendation 352. The circuit can include one or more satellite-to-satellite links in the space portion and, for earth stations not connected in site diversity arrangement, will include one pair of modulation and demodulation equipment for translation from baseband to the radio-frequency carrier and from the radio-frequency carrier to baseband respectively.

The allowable noise-power in the basic hypothetical reference circuit for an active fixed-satellite system for frequency-division multiplex telephony is given in Recommendation 353.

A definition for a hypothetical reference digital path for systems using digital transmission in the fixed-satellite service is given in Recommendation 521. The digital path may comprise one or more satellite-to-satellite links and, for earth stations not employing site diversity, includes a pair of direct digital interface equipment, a pair of modem equipment (including time division multiple access equipment, if used), and IF/RF equipment at the transmit and receive earth stations respectively for translating from baseband to a radio frequency and vice versa.

The allowable bit error rates for the hypothetical reference digital path for systems in the fixed-satellite service using pulse code modulation for telephony are given in Recommendation 522.

Performance standards for television circuits designed for use in international connections are given in Recommendation 567.

The video-frequency bandwidth and permissible noise level in the hypothetical reference circuit for television signals in an active fixed-satellite system are given in Recommendation 354.

Frequency sharing between fixed-satellite systems and terrestrial radio services in the same frequency bands is dealt with in Recommendation 355.

The maximum allowable value of interference in a telephone channel of a fixed-satellite system, sharing the same frequency band with line-of-sight radio-relay systems, is given in Recommendation 356.

The maximum allowable value of interference in a telephone channel of a radio-relay system sharing the same frequency band as a fixed-satellite system is given in Recommendation 357.

The maximum allowable value of power flux-density at the surface of the Earth produced by a fixed satellite in the same frequency band shared with line of sight radio-relay systems is laid down in Nos. 2557, 2562, 2566, 2570, 2574, 2578 and 2582 of the Radio Regulations.

The determination of coordination distance and of auxiliary contours for fixed-satellite systems and terrestrial radio-relay systems sharing the same frequency bands is described in Appendix 28, Annexes I, II and III to the Radio Regulations.

Recommendation 446 stresses the necessity of using carrier energy-dispersal techniques for fixed-satellite systems in the shared frequency bands, in those systems using frequency modulation or digital modulation.

Reference radiation diagrams for the antennas of fixed-satellite earth stations, for use in interference studies, are given in Recommendation 465 and Report 391.

The pre-emphasis and de-emphasis characteristics for the fixed-satellite service, for telephony using frequency-modulation, are given in Recommendation 464.

The pre-emphasis and de-emphasis characteristics for a fixed-satellite service for television using frequency-modulation are set out in Recommendation 405.

Out-of-band noise measurement techniques (for telephony systems using frequency-division multiplex) during actual traffic in the fixed-satellite service are laid down in Recommendation 481.

CCITT Recommendation G.114 (Geneva, 1969) lays down the limits for connections for mean one-way propagation time.

CCITT Recommendation G.222 (Geneva, 1969) lays down the noise objectives for design of carrier transmission of 2500 km.

CCITT Recommendation G.223 (Geneva, 1969) gives the assumptions for calculation of noise in hypothetical reference circuits for telephony and the loading factors to be employed.

4. System figure of merit (G/T)

The reception of signals relayed from an orbiting or synchronous communication satellite involves a problem of sensitivity of a magnitude not encountered in conventional radio, television or trans-oceanic communications, mainly due to the long distances involved and to the practical limitations on the satellite transmit power capability.

In a conventional system, the concepts of noise figure and noise temperature are employed to determine the contribution of noise made by an amplifying system to a signal passing through that system. It is not only sufficient to recover the information, but a minimum quality must be met. In the event that the system sensitivity is less than that required to provide a minimal acceptable level of performance for the received signal, normally specified as a desired signal-to-noise ratio, or in terms of an effective error rate for digital signal transmission, either the bandwidth of the modulated signal must be reduced resulting in a reduction in channel capacity or the satellite transmit power must be increased. The receive earth station sensitivity or G/T is normally expressed in terms of the ratio of effective antenna gain with respect to a designated reference point (e.g. such as the input flange of the receive low noise amplifier), to the composite noise figure of the receive system referred to the same reference point. For example INTELSAT has set performance criteria in terms of a G/T recommendation for three types of standard high sensitivity earth stations. The characteristics of these earth stations are discussed in § 6.1.2 of this Chapter.

5. Frequencies

5.1 *Frequency allocations to the fixed-satellite service*

The Extraordinary Administrative Radio Conference (EARC) Geneva, 1963, was the first world conference to incorporate allocations for space services. Since then two subsequent World Administrative Radio Conferences, the WARC-ST-71, and most recently the WARC-79, have revised these allocations adding new allocations with consequent changes in certain existing allocations where necessary.

The bands allocated to the fixed-satellite service are shared with other services in accordance with the present Radio Regulations (see Table 5-I):

The bands of frequencies that are now being used for commercial communication services are:

– 4/6 GHz bands (3400-4200 MHz down link and 5725-7075 MHz up link).

  These bands were the first to be used by international and domestic satellite systems. Except for the STATSIONAR satellite network, these systems presently operate in the 3700-4200 MHz down link and 5925-6425 MHz up link portion of these bands. These bands are also allocated to the fixed and mobile services. Line-of-sight radio-relay systems make extensive use of these two bands, as these were allocated for long-distance radio-relay systems for national and international inter-connection prior to the advent of satellite communications. The CCIR has laid down recommendations to assist in effective use of these shared frequency bands.

– 11/14 GHz bands (10 700-11 700 MHz down link and 14 000-14 500 MHz up link).

  These bands are only commencing to be used by INTELSAT to provide international fixed satellite communications via Intelsat-V.

– 12/14 GHz bands (11 700-12 200 MHz down link and 14 000-14 500 MHz up link).

  The 12 GHz down-link band is allocated to the fixed-satellite service in Region 2 and on an exclusive primary basis in North America. Domestic satellite systems commenced operation in this band on a commercial basis with the Canadian Anik-B satellite in early 1979 followed by the United States' domestic satellite system SBS in 1981.

  A number of other domestic systems will soon start operation or are planned for this band.

  Studies have been initiated in still higher frequency bands most notably the 18-28 GHz band, to provide information on their suitability.

5.2 *Capacity of the various bands*

So far, the capacity of the bands used in the fixed-satellite service was strongly influenced by the characteristics of the satellites. The earlier series of satellites were limited in both power and bandwidth. Three effective ways of increasing satellite capacity are to add bandwidth through the use of new frequency bands or the re-use of existing frequency bands through polarization isolation or through spatial separation. All three techniques were employed to increase Intelsat-V satellite capacity to 27 transponders and a telecommunications capacity of approximately 12 000 two-way voice circuits plus two TV channels. Both 4/6 GHz and 11/14 GHz bands will be used with spatial separation applied to both bands and polarization isolation to be used in the 4/6 GHz band for a four-fold re-use of this band. In comparison, Intelsat-IV-A used 750 MHz of equivalent bandwidth whereas Intelsat-V effectively uses 2137 MHz of bandwidth.

TABLE 5-I – *Frequency bands allocated to the fixed-satellite service and shared with other services*

Frequency band	Allocation (FSS)	Comments
(MHz)		
2500-2535	Down link (Region 3)	
2500-2655	Down link (Region 2)	
2655-2690	Down link/up link (Region 2)	
2655-2690	Up link (Region 3)	
3400-4200	Down link	
4500-4800	Down link	
5725-5850	Up link (Region 1)	
5850-7075	Down link	
7250-7750	Down link	
7900-8400	Up link	
(GHz)		
10.7 - 11.7	Down link/up link (Region 1) Down link (Regions 2 and 3)	Up link limited to feeder links for BSS
11.7 - 12.3	Down link (Region 2)	
12.2 - 12.5	Down link (Region 3)	Limited to national and sub-regional system
12.5 -12.75	Up link/down link (Region 1) Down link (Region 3)	
12.7 - 12.75	Up link (Region 2)	
12.75- 13.25	Up link	
14.0 - 14.8	Up link	14.0-14.5 GHz may be used for feeder links for BSS by coordination 14.5-14.8 GHz: limited to feeder links for BSS.
17.3 - 17.7	Up link	Up links limited to feeder links for BSS
17.7 - 18.1	Down link/up link	
18.1 - 21.2	Down link	
27.0 - 27.5	Up link (Regions 2 and 3)	
27.5 - 31.0	Up link	
37.5 - 40.5	Down link	
42.5 - 43.5	Up link	
47.2 - 50.2	Up link	
50.4 - 51.4	Up link	
71.0 - 75.5	Up link	
81.0 - 84.0	Down link	
92.0 - 95.0	Up link	
102.0 -105.0	Down link	
149.0 -164.0	Down link	
202.0 -217.0	Up link	
231.0 -241.0	Down link	
265.0 -275.0	Up link	

5.3 *Flux density considerations*

In frequency bands shared between communication satellites and analogue angle modulated terrestrial radio-relay systems 1000 pW0p out of the total 7500 pW0p noise of a 2500 km hypothetical reference circuit of a terrestrial link has been allocated for interference, due to the aggregate of earth stations as well as the space segment of fixed-satellite systems.

The criteria for allocating interference from fixed-satellite systems into terrestrial radio-relay systems employing digital modulation is quite different with the controlling factor being the effect, on the bit error rate, of the system for a specified percentage of the time. However, limits on the allowable contribution remain to be allocated.

The limits for maximum power flux-density as laid down in the Radio Regulations as a function of frequency, are shown in Table 5-II.

When the power flux-density limits given for the 3-8 GHz frequency range are translated into terms of maximum e.i.r.p. from the satellite, assuming free-space loss conditions only, a figure of +11.5 dB(W/4 kHz) is obtained at the horizon, increasing to a maximum value of +20 dB(W/4 kHz) at the sub-satellite point. However, during most of the time the total energy from the satellite is not concentrated in any particular 4 kHz band but is spread over the bandwidth of the transponder, in a manner dependent on the method of modulation. Thus, under full load conditions, and, assuming wide-deviation frequency modulation, the total e.i.r.p. is distributed over the bandwidth of the transponder in a Gaussian fashion with a peak at the centre frequency (Report 384). For a typical 40 MHz transponder, this spreading reduces the effective flux density at the centre frequency by about 36 dB. Thus, assuming that full-load conditions prevail at all times, an e.i.r.p. of +47.5 dBW at the horizon would be permissible for every 40 MHz carrier. However, for both telephony and television, full-load conditions do not prevail all the time. Artificial energy dispersal is, therefore, resorted to, under conditions of light loading. Using optimum techniques, it is possible to achieve a flux density which is not more than 3.0 dB higher than that obtained with full load (Report 384). Thus, a maximum e.i.r.p. of +44.5 dBW is technically permissible.

The highest e.i.r.p. for any commercial operational fixed satellite in 1981 falls short of this figure. The above limitation on flux density therefore has not, so far, been a real hindrance. However, with progress in on-board power generating capacities and the use of narrow-beam antennas as mentioned earlier, values of e.i.r.p. higher than those permissible are well within the capabilities of satellite designers.

TABLE 5-II – *Limits of power flux-density*

Frequency range (GHz)	Limit of power flux-density (dB (W/m²))			
	$\theta \leq 5°$	$5° < \theta \leq 25°$	$25° < \theta \leq 90°$	Reference bandwidth
1.7- 2.5	−154	$-154 + 0.5\ (\theta - 5)$	−144	in any 4 kHz band
2.5- 2.69	−152	$-152 + 0.75\ (\theta - 5)$	−137	
3 - 8	−152	$-152 + 0.5\ (\theta - 5)$	−142	
8 -11.7	−150	$-150 + 0.5\ (\theta - 5)$	−140	
11.7-15.4	−148	$-148 + 0.5\ (\theta - 5)$	−138	
15.4-23	−115	$-115 + 0.5\ (\theta - 5)$	−105	in any 1 MHz band

Note. – θ is the angle of arrival of the wave (degrees above the horizontal).

6. International systems

6.1 *INTELSAT system*

6.1.1 *Space segment*

The characteristics of the space segment for the INTELSAT series of satellites are shown in Table 5-IV.

Intelsat-I, II and III satellites have been fully described in the literature. The Intelsat-IV satellite series, commissioned in March, 1971, provide a much larger capacity with 12 transponders. A total capacity of 3000 to 9000 high quality two-way voice circuits or 12 television channels is possible. There are two global transmitting antennas and two steerable spot-beam antennas each with beamwidths of 4.5°. The two so-called "spot" beams may be used to illuminate relatively small selected areas of the Earth as visible from an in-orbit spacecraft and a "global" beam illuminates the whole of the visible portion of the Earth. If these "spot" beams (with a higher e.i.r.p. than global beams) are directed towards an area of maximum traffic density, the result is approximately to double the number of circuits that can be obtained relative to that of a similar transponder associated with a "global" beam antenna. The spot beam feed horns can be moved mechanically under command from the ground, so that the area illuminated by them may be changed.

As can be seen from Table 5-IV, Intelsat-IV-A is a larger and higher capacity version of Intelsat-IV. Details of Intelsat-IV-A are to be found in [ITU, 1975].

The Intelsat-V is the latest and largest of the Intelsat series of satellites to be deployed. The first satellite was launched in December, 1980 and located at 338.5° E longitude over the Atlantic Ocean. Nine Intelsat-V spacecraft are planned to be built and put into service. Some of its major technical/operational characteristics are [Edelson *et al.*, 1977; Rusch *et al.*, 1978]:

- a number of transmit beam configurations consisting of a global, two hemispheric, and two zonal or regional beams at 6/4 GHz and two spot beams at 14/11 GHz. The zonal and hemispheric beams employ beam shaping to minimize power requirements and improve the spatial isolation to permit frequency re-use;
- dual orthogonal circular polarization employed at 6/4 GHz and linear polarization at 14/11 GHz;
- four-fold frequency re-use obtainable at 6/4 GHz by taking advantage of the spatial isolation afforded by the shaped beams and the orthogonal polarization isolation;
- 21 transponders at 6/4 GHz ranging in bandwidth from 36 to 77 MHz for a total usable bandwidth of 1357 MHz;

  6 transponders at 14/11 GHz ranging in bandwidth from 72 to 241 MHz for a total usable bandwidth of 780 MHz;
- cross-strapping arrangements permit interconnection of 14/4 GHz and 6/11 GHz links on board the satellite to meet varying traffic demands;
- a total capacity per satellite of 12 000 two-way telephone circuits plus two TV channels.

The later versions of Intelsat-Vs scheduled to be launched in 1982/83 will be equipped to provide limited maritime communication capability (ship-to-shore-to-ship).

Further details are given in Table 5-IV and in the references cited above.

6.1.2 *Ground segment*

The ground segment for the communication-satellite service of INTELSAT consists of three standard types of earth stations for operation with the Intelsat series of satellites. The Standard A and B type stations operate exclusively in the 6/4 GHz bands while the Standard C type station operates in the 14/11 GHz bands with Intelsat-V satellites.

Table 5-III summarizes the major characteristics of the three types of standard INTELSAT earth station.

TABLE 5-III – *Major characteristics of INTELSAT earth stations*

Characteristics	Station type		
	Standard A	Standard B	Standard C
Frequency band (receive/transmit) (GHz)	4/6	4/6	11/14
Antenna diameter (m)	29-32	11-13	16 (typical)
G/T (dB(K^{-1})) (f (GHz))	40.7 + 10 log (f/4)	31.7 + 10 log (f/4)	39 + 10 log (f/11.2) (typical) (1)

(1) For the Standard C the G/T is specified in terms of 39 dB(K^{-1}) plus attenuation and noise temperature increases that are predicted for a specified percentage of the time.

TABLE 5-IV – *Characteristics of Intelsat satellites*

Satellite	Intelsat-I	Intelsat-II	Intelsat-III	Intelsat-IV	Intelsat-IV-A	Intelsat-V*
Launch weight (kg)	68	118	288	1112	1515	1870
In-orbit weight (kg)	39	83	127	700	826	1020
Diameter (cm)	73	142	142	240	238	
Height (cm)	59	67	104	530	699	
TWT power output (W)	1 × 6	3 × 6	2 × 11	12 × 6.3	4 × 6.3 16 × 5.0	
Redundancy	Spare TWT Spare receiver	Spare TWT Spare receiver	No TWT spare	Spare TWT. Triple redundant front end		Double redundant receivers. No TWT redundancy
Available d.c. power (W)	45	81	106	565	600	1200
E.i.r.p. (dBW)	13	15.5	25.8	26.0(1) 37.0(2)	26.0(1) 32.0(2)	(4)
Beamwidth (degrees)	omni	toroidal	global	16(1) 4.5(2)	16(1) 4 × 14(3)	(5)
Transponders	2	1	2	12	20	(27 independent)
Bandwidth per transponder (MHz)	25	125	225	36	36	(6)
Total usable bandwidth (MHz)	50	125	450	432	720	2137
Polarization	linear	linear	circular	circular	circular	circular and linear
Voice circuit channel capacity	240	240	1200	4500(7)	6500(7)	12 000(7)
First launch of series	April, 1965	January, 1967	December, 1968	March, 1971	September, 1975	December, 1980

* 3-axis stabilized.

(1) Refers to global coverage antenna.

(2) Refers to narrow beam antenna.
Refer to the on-axis main lobe power for a single carrier saturated condition for each repeater.

(3) Hemispheric West and hemispheric East beams.

(4) Global 23.5 and 26.5 dBW.
Hemispheric 26.0 and 29.0 dBW.
Zone 29 dBW.
Spot 41.4 (East) and 44.4 (West).

(5) Global (receive/transmit) 22°/18°.
Hemispheric – shaped.
Zonal – shaped.
Spot – 1.6° (East); 1.8 × 3.2 (West) (transmit and receive).

(6) Global (6/4) 2-36 MHz, 1.41 MHz (1-36 MHz and 1-72 MHz shared with hemispheric).
Hemispheric (6/4) 6-72 MHz, 2-77 MHz, 2-36 MHz.
Zone (6/4) 8-72 MHz.
Spot (6/4) 2-77 MHz, 2-72 MHz, 2-241 MHz.

(7) Dedicated transponders for television not included.

The earth station mainly consists of a high sensitivity, high-gain fully steerable Cassegrain antenna with a diameter ranging from 11 to 32 m depending on the type of earth station, with its feed arranged for transmission of 6 and/or 14 GHz signals from the station and for reception of 4 and/or 11 GHz signals from the satellite.

Standard type A and type B stations which plan to operate with Intelsat-V must be equipped with a dual orthogonal polarized transmit and receive feed system.

The antenna is capable of manual and auto-track operation.

The power amplifier could be of the travelling-wave type having the entire bandwidth of 500 MHz for transmission of telephony and television or with klystron power amplifiers tunable over the 500 MHz bandwidth, with telephony and television transmissions using individual power amplifiers.

The transmitting chain consists of a baseband amplifier, an intermediate-frequency amplifier and a modulator, an up-converter for each and an exciter for each chain.

The receiving system consists of a low noise amplifier with an instantaneous bandwidth of 500 MHz in the 4 GHz band, followed by a chain of amplifiers, a set of frequency dividers, the output of each of which is down-converted, demodulated with the help of threshold extension devices to baseband and is fed on to the multiplex terminal for further signal processing.

INTELSAT systems are currently operating with an overall availability better than 99.8% and current technical improvements in earth-station equipment may raise this figure even closer to 100%.

By year end 1980, the ground segment of INTELSAT consisted of 295 antennas at 239 earth stations located in some 131 countries and territories.

6.2 *INTERSPUTNIK* [ITU, 1980; Borodich *et al.*, 1978] (Report 207)

The international communication satellite system INTERSPUTNIK is intended for television, telegraph and facsimile communications and also for the exchange of radio and television broadcasting programmes between the participating countries. The system was set up in 1971 by an inter-governmental agreement between nine member Socialist countries. At present there are ten member countries of INTERSPUTNIK. The system has been in regular operation since November, 1973 with the bringing into service of earth stations in the U.S.S.R. and Cuba.

INTERSPUTNIK leases transponders on satellites belonging to the U.S.S.R. Up until 1980 all the stations operated with Molniya-III type satellites with the following parameters:

Orbit (elliptical)	
– inclination	63° ± 2°
– apogee	40 000 km
– perigee	500 km
– period	12 hours
Frequency band	
– transmit	3650-3900 MHz
– receive	5975-6225 MHz
– total peak power	30 W
– maximum antenna gain	17.3 dB

The main feature of the service area provided by the Molniya satellites is that points in the northern hemisphere 180° apart can be linked up (for example, Cuba and Mongolia).

With the launching and bringing into service of the Statsionar type satellites in the 1978-79 time period the INTERSPUTNIK stations have transferred to operate with these geostationary satellites. As one of the ten member countries of INTERSPUTNIK, the U.S.S.R. leased six transponders on the Gorizont satellite in the Atlantic Ocean region to the organization with a further two transponders leased on the Gorizont satellite serving the Indian Ocean region. The transfer to the Statsionar satellites has led to an increase in the number of international transmissions.

The earth stations used in the INTERSPUTNIK system have the following parameters:

– total peak power	2 to 6 kW
– antenna gain:	
– transmitting	54.8 dB
– receiving	51.9 dB
– system noise temperature	100 K

Frequency modulation is used for colour television broadcasting by the SECAM-III-B system. The accompanying sound is broadcast by two different methods, time and frequency division multiplexing of the television channel. With TDM the sound signals are converted into a sequence of duration-modulated pulses located in the line-blanking intervals. With FDM of the television channel, the sound signal is organized by means of an FM sub-carrier above the television signal spectrum (7.5 MHz).

For telephone communications, frequency modulation is used with each carrier modulated by a single telephone channel (SCPC).

The quality standards of the telephone and television channels are in keeping with CCIR and CCITT Recommendations.

7. Regional systems

7.1 *MOLNIYA-1 system* [Fortushenko, 1965; Sviazizdat, 1965]

7.1.1 *Space segment*

The first satellite Molniya-1 was launched in an elliptical orbit on 23 April, 1965.

Spacecraft and initial orbit data

Altitude of apogee (km)	40 000 (above Northern hemisphere)
Altitude of perigee (km)	500 (above Southern hemisphere)
Inclination	65°
Approximate period	12 h
Transmitter power output	40 W
Satellite antenna gain	18 dB

(the antenna is automatically directed towards the Earth).

7.1.2 *Ground segment*

There are stations in Moscow and Vladivostok, separated by distances of about 7000 km. These stations have the following technical characteristics:

Transmitter	5 kW
Noise temperature of the receiving system (with antenna noise)	230 K
Type of operation	television, multi-channel telephony, telegraphy and facsimile services.

7.1.3 *Experimental results*

A large number of experimental and commercial telephone calls were made from Moscow to Vladivostok and *vice versa.*

The quality of the communication service was good. Transmission delay gave rise to no significant degradation.

Monochrome television transmission quality was adequate.

Colour television transmissions were made using the SECAM-III system from Moscow to Paris, and similarly from Paris to Moscow, through earth stations near Moscow and Pleumeur-Bodou (appropriate modifications were made to the equipment at Pleumeur-Bodou). The transmission showed quite satisfactory results.

7.2 *ORBITA distribution system* [Talizin *et al.*, 1967]

7.2.1 *System description*

The ORBITA distribution system is used for the transmission of central television programmes. It consists of one transmitting station, situated near Moscow, and a large number of receiving stations, located at distances of 3000-7000 km, over all the territory of the Soviet Union. Sound transmission is carried out by means of a special system of pulse-duration modulation within the limits of the back porch of the line-blanking pulses. The ORBITA system permits the transmission of colour television programmes using the SECAM system together with sound by means of the above-mentioned method, as well as newspaper pages and central broadcasting programmes either instead of the television signal or simultaneously with it.

7.2.2 *Satellites*

Molniya-1 satellites are used in the ORBITA system; their parameters are given above.

7.2.3 *Earth stations*

Earth stations have the following parameters:

Output power of the transmitter	5 to 10 kW
Diameter of transmitting antenna	25 to 12 m
Noise temperature of the receiver (with antenna noise)	100 K
Diameter of receiving antenna	12 m with an effective aperture of 79 m^2

7.2.4 *Results*

The ORBITA system has been in regular operation since November, 1967. The number of receiving stations in 1969 exceeded 30 and new stations are under construction.

Qualitative indices of television images at the output of the receiving earth station meet CCIR standards, except that of weighted r.m.s. noise which, in relation to the peak-to-peak video signal, is between 45 and 48 dB.

7.3 *MOLNIYA-II system*

At present, the MOLNIYA-II satellite system is in regular operation providing communication in the 4 and 6 GHz bands.

The first Molniya-II satellite was launched into a high elliptical orbit in 1971 to distribute colour and monochrome television programmes to the ORBITA-2 network and to transmit sound broadcasting programmes; it also provides multi-channel telephony in the multiple access mode and other types of message transmissions throughout the U.S.S.R. Quality parameters of the system conform to the appropriate CCIR Recommendations.

7.3.1 *Satellites*

Characteristics of the satellites in the MOLNIYA-II system are similar to those given for MOLNIYA-I.

7.3.2 *Earth stations*

In 1974, this system included 45 earth stations. The earth stations have the same characteristics as those given for the MOLNIYA-I earth stations, and are designed to operate with satellites in both the elliptical and the geostationary-satellite orbit.

7.4 *Satellite television distribution system MOSKVA* [Kantor *et al.*, 1980]

The satellite system MOSKVA is designed for television distribution in the territory of the U.S.S.R. The system is essentially a distribution type system for television programmes. However, in remote areas with very sparse population, the system is used for community reception and viewing of programmes. The service area of the MOSKVA system is small, covering the territory of 2-3 time zones in the Urals, Volga and Central Asia regions. The small dimensions of the service area are due to the use of a narrow-beam satellite transmitting antenna with an aperture of 5° × 5°. The system uses a transmitting earth station with a 12 m diameter antenna, one of the satellite channels of Statsionar-6 and simplified receiving earth stations with 2.5 m diameter antennas designed for community reception.

To improve the conditions of electromagnetic compatibility with terrestrial and satellite systems and to meet the standard for power flux-density on the Earth's surface, the MOSKVA system uses an energy dispersal method which reduces the spectral power density to the permitted value. Dispersal is effected by adding to the video signal a triangular signal with a frequency of 2.5 Hz. The small size of the receiving station considerably simplifies the licensing problem in view of the possibility of using the screening properties of natural obstacles, buildings and other structures.

The main parameters of the MOSKVA system are given in the following sections.

7.4.1 *Characteristics of the satellite network in the Earth-to-space direction*

Centre frequency	6000 MHz
RF bandwidth	34 MHz
Earth station transmitting antenna gain	55 dB
Satellite receiving antenna gain	19 dB
Receiving space station noise temperature	2500 K
Peak frequency deviation	± 15 MHz
Peak frequency deviation due to energy dispersal signal	± 4 MHz

7.4.2 *Characteristics of the satellite network in the space-to-Earth direction*

Centre frequency	3675 MHz
RF bandwidth	34 MHz
Peak power of satellite transmitter fed to satellite antenna	40 W
Satellite transmitting antenna gain	30 dB
Earth station receiving antenna gain	37.5 dB
Receiving earth station noise temperature	200 K
Video signal-to-noise ratio	53 dB

8. Domestic systems

A number of domestic satellite systems have been put into operation, beginning with the Canadian TELESAT system in 1973, the United States' WESTAR system in 1974, the United States' SATCOM system in 1975 and the United States' COMSTAR system in 1976.

A summary of the characteristics of these and other domestic systems in operation or soon to be in operation is given in this section.

8.1 *SBTS (Brazil)* [Embratel, 1980]

8.1.1 *System description*

The Brazilian satellite telecommunications system (SBTS) is based on utilization of leased Intelsat-IV-A F2 space segment capacity (see § 8.7 of this Chapter). The system is used for the distribution of television, telephony and data traffic, employing FDM-FM and SCPC/FM access/modulation techniques with transmit/receive earth stations at eighteen locations within the country since 1981.

8.1.2 *Space segment*

The system leases four hemispheric beam transponders on the Intelsat-IV-A F2 (Atlantic 3) satellite (transponders 5, 7, 9 and 11) with an estimate of five transponders required by year end 1982. Further information on this type of satellite is provided in Table 5-IV.

8.1.3 *Ground segment*

The earth station segment is comprised of one 15 m station designated TN3, and the remaining stations with 10 m diameter antennas. As of 1981 all but one of the earth stations provided transmit and receive capability with the station at Campo Grande used for receiving TV only.

TABLE 5-V – *Major characteristics of SBTS earth stations*

Earth station	Antenna diameter (m)	Main axis gain (dB)		G/T (dB(K^{-1}))
		6 GHz	4 GHz	
TN3	15	57.4	54.2	> 35.0 + 20 log f/4 (1)
Others	10	53.4	50.7	> 31.0 + 20 log f/4 (1)

(1) f: frequency (GHz).

8.2 *ANIK system (Canada)*

8.2.1 *System description*

The Canadian domestic satellite system is owned and operated by Telesat Canada for the purpose of providing reliable high-quality radio communication services to all parts of Canada.

The Canadian system is comprised of three 6/4 GHz satellite networks and three 14/12 GHz satellite networks. The 6/4 GHz satellites are located at 104° W, 109° W and 114° W longitude while orbit positions at 109° W, 112.5° W and 116° W longitude will be used for 14/12 GHz satellites. The nominal station-keeping tolerance for all satellites is ± 0.1°.

The maximum gross capacity of the TELESAT 6/4 GHz satellite networks is 34 560 telephone simplex channels for the Anik-A and B type satellites which increases to 95 040 telephone channels when the capacity of the Anik-D type satellite (6/4 GHz) is included. The 14/12 GHz Anik-C satellites, the first of which commenced operation in early 1983, have a gross capacity of 64 512 telephone channels.

Both analogue and digital modulation techniques are used in the TELESAT system. Analogue frequency modulation is used with baseband capacities ranging from 12 to 1320 telephone channels or one television signal with its associated audio and cue/control channels. The capacities of the 2Φ and 4Φ-PSK digitally modulated RF carriers range from 1 to 300 telephone channels.

The multiple access techniques used in the TELESAT system include both frequency division multiple access (FDMA) and time division multiple access (TDMA), with the former predominating at the present time.

The bandwidths, earth station e.i.r.p.s and satellite e.i.r.p.s of typical RF carriers in the TELESAT system are given in Tables 5-VI and 5-VII for the 6/4 GHz and 14/12 GHz bands respectively.

8.2.2 *Space segment*

The characteristics of the TELESAT Anik-A, Anik-B and Anik-D 6/4 GHz satellites are summarized in Table 5-VIII. Table 5-IX provides the characteristics of the TELESAT Anik-B and Anik-C 14/12 GHz satellites.

8.2.3 *Ground segment*

The number of earth stations in operation in 1981 in the TELESAT system was about 200 at 6/4 GHZ and 150 at 14/12 GHz.

Tables 5-X and 5-XI provide data on earth station antenna sizes, gains, system noise temperatures and the maximum e.i.r.p.s used at 6/4 GHz and 14/12 GHz respectively. The radiation patterns for TELESAT earth station antennas generally conform with the reference pattern of $G = 32 - 25 \log \varphi$ of Recommendation 465.

TABLE 5-VI – *TELESAT 6/4 GHz RF carrier transmission parameters*

Carrier	Band-width (kHz)	E.i.r.p. (dBW)	
		Earth station	Satellite
TV	36 000	81.0	36.0
1320 VC(1)	36 000	82.0	36.0
TDMA(2)	33 000	79.0	35.5
360 VC	15 000	68.5	29.5
Radio	200	65.0	16.0
SCPC(3) 2Φ – A	44	45.7	4.2
SCPC 2Φ – B	44	50.1	8.6
SCPC 2Φ – C	44	52.5	11.0
SCPC 4Φ – A	22	45.7	4.2
SCPC 4Φ – B	22	50.1	8.6
SCPC 4Φ – C	22	52.5	11.0
108 VC	7 500	67.1	26.2
12 VC	2 500	60.8	19.4
6.3 Mbit/s	6 100	61.8	20.6
4.2 Mbit/s	3 500	60.6	21.7

(1) VC: voice channels.
(2) TDMA: time division multiple access.
(3) SCPC: single-channel-per-carrier.

TABLE 5-VII – *TELESAT 14/12 GHz RF carrier transmission parameters*

Carrier	Bandwidth (kHz)	E.i.r.p. (dBW)	
		Earth station	Satellite
91 Mbit/s	50 000	83.0	48.0
TV (half transponder)	27 000	77.0	43.0(1)
TV (half transponder)	27 000	77.0	40.0(2)

(1) Spot beam; coverage: 1/4 Canada.
(2) Regional beam; coverage: 1/2 Canada.

TABLE 5-VIII – *Characteristics of Telesat 6/4 GHz satellites*

Usage	Anik-A	Anik-B	Anik-D
	Domestic	Domestic	Domestic
Satellite channels			
number	12	12	24
bandwidth (MHz)	36	36	36
e.i.r.p. (max.) (dBW)	36	39	39
Transmit antenna gain (max.) (dB)	30	30	30
Receive antenna gain (max.) (dB)	29	29	29
Noise temperature, T(K)	2000	1780	1000
Pointing tolerances (degrees)	± 0.5	± 0.2	± 0.2
Polarization	Single, linear	Single, linear	Dual, linear
Beam shaping	Yes	Yes	Yes
Frequency re-use	None	None	Dual polarization
Expected satellite life (years)	7	7	10
Single/multiple band	Single	Multiple	Single
Launch date for first satellite of each series	1972	1978	1982

TABLE 5-IX – *Characteristics of Telesat 14/12 GHz satellites*

Usage	Anik-B	Anik-C
	Domestic	Domestic
Satellite channels number bandwidth (MHz) e.i.r.p. (max.) (dBW)	 6 72 50	 16 54 51
Transmit antenna gain (edge of coverage area) (dB)	39	40
Receive antenna gain (max.) (dB) Noise temperature, T(K)	32 1080	37 1250
Pointing tolerances (degrees)	± 0.15	± 0.025
Polarization	Single, linear	Dual, linear
Beam shaping	Yes	Yes
Frequency re-use	None	Dual polarization
Expected satellite life (years)	7	10
Single/multiple band	Multiple	Single
Launch date for first satellite of each series	1978	1982

TABLE 5-X – *6/4 GHz earth station parameters*

Antenna diameter (m)	Gain (dB)		System noise temperature (K)		Maximum e.i.r.p. (dBW)
	Transmit	Receive	Minimum	Maximum	
30	63.0	59.5	140	—	83.0
10	53.5	50.5	80	140	83.0
8	52.0	48.5	140	445	82.0
4.6	46.5	43.7	175	—	72.0
3.7	43.1	41.5	175	—	55.1

TABLE 5-XI – *14/12 GHz earth station parameters*

Antenna diameter (m)	Gain (dB)		System noise temperature (K)		Maximum e.i.r.p. (dBW)
	Transmit	Receive	Minimum	Maximum	
8	59.0	57.0	158	—	83.0
4.6	54.5	52.8	418	—	79.0
1.8	—	44.5	600	—	—
1.2	—	41.0	600	—	—

8.3 *TELECOM-1 (France)* [ITU, 1980]

In 1979, the French Government decided to introduce a satellite telecommunication system referred to as TELECOM-1.

The first operational satellite was scheduled to be launched late in 1982 with a reserve satellite launched in the spring of 1983.

The system was scheduled to commence operation by mid-1983.

The system will perform two main tasks:

– set up company intra-links providing wide-band, high speed digital links between the various sectors of the enterprise. Six transponders in the 14/12 GHz bands will be used for this purpose employing TDMA access technique and small earth stations about 3 m in diameter;

– establish links with overseas departments routing telecommunication traffic between metropolitan France and the French overseas departments. Four transponders operating in the 6/4 GHz bands are planned to provide this service.

8.4 *INSAT-1 (India)*

8.4.1 *System description*

The Indian National Satellite System, INSAT-1, is a multipurpose system. It is planned to provide domestic telecommunication, meteorological, direct-TV broadcasting (community reception), radio networking and disaster warning services. The system consists of two identical satellites positioned in the geostationary orbit, INSAT-1A at 74° E ± 0.1 and INSAT-1B at 94° E ± 0.1 with the needed capability for all these services, together with matching facilities on the ground. INSAT-1A was launched in 1982. INSAT-1B is programmed to be launched in 1983. The principal elements of the space and ground segments are given below.

8.4.2 *Space segment*

– Twelve, 36 MHz wide telecommunication channels operating in 5935-6425 MHz (Earth-to-satellite)/3710-4200 MHz (satellite-to-Earth) frequency bands with 32 dBW (minimum), end of life (EOL) equivalent isotropic radiated power (e.i.r.p.) over the primary coverage area.

– Two, 36 MHz wide direct TV broadcast channels in 5855-5935 MHz (Earth-to-satellite)/2555-2635 MHz (satellite-to-Earth) frequency bands with 42 dBW (minimum) EOL e.i.r.p. each over the primary coverage area.

– A very high resolution radiometer (VHRR) to operate in visible (0.55 - 0.75 μm) and infra-red (10.5 - 12.5 μm) channels with minimum resolution of 2.75 km and 11 km respectively and full earth coverage full-frame image every 30 minutes, with option for sector scan under command. Associated data channel (800 kHz wide) at 4034.55 MHz (satellite-to-Earth).

– A data channel (200 kHz wide) operating at 402.75 MHz (Earth-to-satellite)/4038.1 MHz (satellite-to-Earth) for relay of meteorological, hydrological and oceanographic data from unattended land and ocean-based data collection platforms (DCPs) to a central location.

– Master control station on ground for tracking, telecommand/telemetry and control.

8.4.3 *Ground segment*

8.4.3.1 *Telecommunications*

- Five large earth stations (31.7 dB(K^{-1}));
- thirteen medium earth stations (25.7 dB(K^{-1}));
- * eleven remote area terminals (19.7 dB(K^{-1}));
- * four road transportable terminals (19.7 dB(K^{-1}));
- * two jeep transportable/air-liftable emergency communication terminals (19.7 or 17.5 dB(K^{-1}))

8.4.3.2 *Meteorology*

- A Meteorological Data Utilisation Centre (MDUC) for processing VHRR and DCP data;
- about 100 data collection platforms (DCPs) deployed all over the country, including some over ocean areas; and
- disaster warning receivers (for low level injected carrier in the 2.5 GHz band).

8.4.3.3 *Broadcasting*

- Earth-to-satellite channels (combined with telecommunication earth stations);
- direct reception television receivers: $G/T = 8.2$ dB(K^{-1}) (3.6 m diameter)
- receive only terminals for radio programme networking (low level injected carrier in the 2.5 GHz band): $G/T = 9$ dB(K^{-1}) (3.6 m diameter)

8.5 *PALAPA (Indonesia)* [ITU, 1980]

8.5.1 *System description*

The Indonesian system (SKSD) consists of two satellites with 12 transponders each and 40 earth stations having 10 m antennas. The system commenced operation in August, 1976.

In 1979 action was taken to expand and consolidate utilization of the system by:

- installing additional small terminals;
- re-allocation and provision for new FDM equipment;
- negotiating agreements with other ASEAN countries (Philippines, Thailand and Malaysia) to use the satellites.

8.5.2 *Space segment*

The space segment consists of two satellites operating in the 6/4 GHz band. Each satellite has 12 transponders. These satellites are very similar (same except for antenna coverage) to the characteristics of the Anik-A satellites given in § 8.2 of this Chapter.

A contract has been signed for two new satellites as replacements for the first generation satellites which reach their end of design life in mid-1983. The major characteristics of the replacement satellites are:

- 24 C-band RF channels each with 36 MHz usable bandwidth;
- linear, orthogonal polarization and interstitial channelling permitting frequency re-use;
- e.i.r.p. of 32-34 dBW over the entire ASEAN region;
- increased satellite sensitivity of approximately 2 dB.

8.5.3 *Ground segment*

- The initial ground segment consisted of 40 earth stations having 10 m antennas;
- additional small terminals have been added providing telephony and telegraphy channels via SCPC with demand assignment to locations that are difficult to reach via existing terrestrial facilities;
- during 1979, television receive only (TVRO) equipment was installed at 18 sites;

* For SCPC, companded FM operation.

- during 1980, expansion of several of the FDM-FM carriers was undertaken. Also earth station exchange interface equipments required to expand both the FDM and SCPC demand assignment networks is planned;
- modifications to the existing ground segment will be required to accommodate the new satellites to permit them to be fully utilized. Provision of these modifications is now under way.

8.6 *Domestic systems in the United States* [Satellite News, 1981; Satellite Systems Engineering Inc., 1980]

As of 1981, there were four domestic fixed-satellite systems in operation within the United States. They are referred to as COMSTAR, SBS (Satellite Business Systems), SATCOM and WESTAR. All systems except SBS operate exclusively within the 6/4 GHz bands. SBS operates exclusively in the 14/12 GHz bands.

The following sections briefly review the characteristics of each of these systems. Further details for each system are contained in the references.

8.6.1 *COMSTAR*

8.6.1.1 *System description*

The COMSTAR system is composed of three participants; AT&T Long Lines Department, GTE Satellite Corporation and Comsat General Corporation. The satellites are owned by Comsat with their entire capacity leased by AT&T. There are presently four satellites in orbit utilizing three orbital locations.

The system commenced operation in June, 1976 providing facilities for network telecommunication services to the 48 contiguous states (CONUS), Alaska, Puerto Rico and Hawaii. Private line services are also provided following the initial three year moratorium placed on the system.

There will be no follow-on satellites planned for the particular system as both AT&T and GTE will be implementing their separate systems referred to as the TELSTAR (AT&T) and GSTAR (GTE) series of satellites.

8.6.1.2 *Space segment*

Four satellites have been placed in orbit with the latest Comstar-D4 replacing Comstar-D1. Furthermore Comstar-D1 will be collocated with the Comstar-D2 satellite to function as one system. The major satellite parameters are listed below:

– spacecraft designation:	Comstar
– stabilization:	Spin
– number launched:	4
– launch vehicle:	Atlas/Centaur
– satellite mass (kg):	1520 (at launch); 811 (in orbit)
– primary power (W):	760 (BOL), 610 (EOL)
– design life (years):	7
– coverage:	CONUS, Alaska, Hawaii and Puerto Rico
– e.i.r.p. (dBW):	31-33
– G/T (dB(K^{-1})):	-8.8
– single carrier saturation flux-density (dB(W/m^2)):	-66.7, -72.7, -75.7, -81.7 (selectable)
– number of transponders:	24
– frequency band (GHz):	transmit 3.7-4.2 receive 5.925-6.425
– polarization:	linear, frequency re-use
– number of antenna beams:	4 transmit, 2 receive

8.6.1.3 *Ground segment*

There are ten major earth stations in the system not including the TTC station. The major characteristics of the AT&T four main stations are:

– frequency band (GHz):	4/6
– antenna diameter (m):	30
– figure of merit G/T (dB(K^{-1})):	42
– modulation:	FM
– transponder access:	SCPC (typical).

8.6.2 *SATCOM*

8.6.2.1 *System description*

The SATCOM system, owned by RCA Americom, commenced operation in November, 1973, using leased ANIK capacity. The various services provided by the system are:

- commercial communications offering private leased channels for voice, data and facsimile communications;
- video and audio services providing point-to-point and multi-point distribution of television, radio and news service programming. The industries served in this group include radio and television broadcasters, pay TV, CATV and publishing;
- government communication services via a network comprising more than 20 stations;
- Alascom services providing telecommunication services within Alaska and between Alaska and CONUS.

Both FDM-FDMA and SCPC techniques are used employing analogue FM and digital modulation techniques.

8.6.2.2 *Space segment*

The first SATCOM satellite was launched in December, 1975. As of year end 1980 there were two SATCOM satellites in orbit, SATCOM-I and SATCOM-II. Two more satellites are scheduled to be launched during 1981. At the present time, RCA Americom is leasing spare capacity on the Comstar satellite as an interim measure until SATCOM-III and SATCOM-IV are in operation.

Characteristics of the SATCOM satellites are:

– spacecraft designation:	RCA SATCOM
– stabilization:	3-axis
– number launched *:	3
– launch vehicle:	Thor Delta 3914
– satellite mass (kg):	907 (at launch); 461 (in orbit)
– primary power (W):	770 (BOL); 550 (EOL)
– design life (years):	8
– coverage:	CONUS, Alaska, Hawaii
– e.i.r.p. (dBW):	33, 26 (Hawaii)
– G/T (dB(K^{-1})):	-5; -10 (Hawaii)
– single carrier saturation flux density (dB(W/m^2)):	-80; -75 (Hawaii)
– number of transponders:	24
– frequency band (GHz):	receive 5.925-6.425 transmit 3.7-4.2
– polarization:	linear; frequency re-use
– number of antenna beams:	2 receive; 2 transmit.

8.6.2.3 *Ground segment*

RCA Americom owns and operates commercial earth stations near the major metropolitan centres within the USA. Also the company owns and operates a number of earth stations dedicated to government communication services. There are also a large number of privately owned TVRO earth stations for the distribution of television and radio programming services to more than 1500 CATV systems.

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* SATCOM-III launched in December, 1979, failed to achieve geostationary orbit.

TABLE 5-XII – *Major characteristics of RCA Americom stations*

Characteristics	Station description		
	Major commercial	Data service (DET 56)	US Govt. dedicated
Frequency bands (GHz)	4/6	4/6	4/6
Antenna diameter (m)	10-13	5	4.5-11.0
G/T (dB(K^{-1}))	30-33.4	22	22-32.4
Modulation type	FM, digital	56 kbit/s digital	FM-TV and digital
Access	FDMA, SCPC	FDMA	FDMA, SCPC

8.6.3 *WESTAR*

8.6.3.1 *System description*

The WESTAR domestic system, jointly owned by Western Union Telegraph Co., Fairchild Industries and Continental Telephone, commenced operation in 1974 with the launching of two satellites. As of 1981 there were three satellites in operation providing the following services:

– 1200 channel trunk message within CONUS employing FDM-FM modulation. Also multiple access message employing FDMA access with FDM-FM, digital or a combination of both modulation techniques;
– network distribution of television and radio programmes;
– provision of news media services;
– provision of private line voice/data links.

Western Union is also constructing the tracking and data relay satellite system (TDRSS) with the first launch scheduled for 1983. This NASA/Western Union shared system will provide NASA with improved tracking and communications capacity. Also these satellites, referred to as Advanced Westar, will represent the replacement satellites for the commercial services. The series of spacecraft call for four in-orbit, two of these providing NASA with TDRSS capabilities, one for Advanced Westar operations and one common spare.

The present system operates entirely in the 6/4 GHz bands while the Advanced Westar satellites will provide services in both the 6/4 GHz and 14/12 GHz frequency bands.

8.6.3.2 *Space segment*

There are three satellites presently in orbit with a further four (Advanced Westar series) scheduled to be launched during 1982-83. The following summarizes the characteristics of the Advanced Westar spacecraft.

Note. – The 6/4 GHz band characteristics of the Advanced Westar spacecraft are identical to the existing satellites except that the Advanced Westar has a slightly higher TWTA power output (5.5 W compared to 5.0 W).

– Spacecraft designation:	TDRSS
– Stabilization:	3-axis
– Number of satellites:	5
– Launch vehicle:	Shuttle
– Spacecraft mass (kg):	2000 (approx.) in orbit
– Primary power (W):	1700 EOL
– Design life (years):	10

	6/4 GHz band		11/14 GHz band
	CONUS	Alaska/Hawaii	7 switchable spot beams within CONUS
– Coverage:			
– e.i.r.p. (dBW):	33	26-28	42-50.3
– G/T (dB(K^{-1})):	−6	−13	−5.0 to 4.4
– Single carrier saturation pfd (dB(W/m^2)):	−80	−72	−78 (+3, −12)
– Number of transponders:	12		4 (satellite switched)
– Transponder bandwidth (MHz):	36		225
– Polarization:	linear		circular, linear
– Number of beams:	1 transmit 1 receive		7 transmit 7 receive

8.6.3.3 *Ground segment*

There exist seven Western Union earth stations located near major metropolitan centres within CONUS. In addition there are a large number of privately owned TVRO earth stations operating within the system.

Additional types of earth stations will be brought into service when the Advanced Westar commences operation.

TABLE 5-XIII – *Characteristics of Western Union stations*

Characteristics	Station description				
	Western Union	Large	Medium	Small	Thin route
Frequency bands (GHz)	6/4	14/12	14/12	14/12	14/12
Antenna diameter (m)	15.5	7-13	5-7	3-5	3
G/T (dB (K^{-1}))	37.0	—	—	—	—
Modulation	FM	← Digital TDMA →			
Access	FDMA/SCPC				
Capacity (1)	—	30-50	4-8	1	9.6-56 (kbit/s)

(1) Capacity in terms of channels of 1.544 Mbit/s per channel.

8.6.4 *Satellite Business Systems (SBS)*

8.6.4.1 *System description*

SBS is a specialized common carrier for communications which commenced operation in early 1981. The system offers integrated all-digital, high capacity private networks to business and government organizations within CONUS.

SBS is a jointly owned system consisting of Aetna Life and Casualty, COMSAT General Corporation and IBM.

Major features of the system include:

– fully integrated voice/data and image service offerings;
– all digital transmission;
– operates exclusively in the 12/14 GHz band thereby eliminating the need for frequency coordination and permitting earth stations to be located in proximity to the customers' premises;
– TDMA type of access with demand assignment and voice activation capability to optimize channel utilization.

There are presently three satellites in orbit.

8.6.4.2 *Space segment*

The main characteristics of the satellite are given below:

– Spacecraft designation:	SBS
– Stabilization:	spin
– Number of satellites:	3
– Launch vehicle:	Thor Delta/PAM 3910
– Spacecraft mass (kg):	900 (at launch); 546 (in orbit)
– Primary power (W):	900 (EOL) (deployable skirts)
– Design life (years):	7
– Coverage:	CONUS (shaped beam)
– e.i.r.p. (dBW):	40-43.7
– G/T (dB(K^{-1})):	+2 to −2 (adjustable on command)
– Single carrier saturation pfd (dB(W/m^2)):	−82 (for $G/T = -2$)
– Number of transponders:	10
– Transponder bandwidth (usable) (MHz):	43
– Frequency band (GHz):	transmit 11.7-12.2 receive 14.0-14.5
– Polarization:	dual linear
– Number of beams:	1 transmit, 1 receive.

8.6.4.3 *Ground segment*

The ground segment consists of three types of earth stations. Their major characteristics are given below:

– Station designation:	Manned	Remote 1	Remote 2
– Antenna diameter (m):	10	5	7
– G/T (dB(K^{-1})):	36.6	30.4	33.3
– Modulation:	digital	35-65 Mbit/s	QPSK
– Transponder access:	FDMA	FDMA	FDMA
– Number of stations: (as of year end 1980)	2		37 total remote

8.7 *INTELSAT leased systems* [Kelley, 1978; ITU, 1980]

INTELSAT began leasing satellite transponder capacity for domestic or special communications services in 1973. The relatively low cost of leasing satellite capacity combined with the use of small earth stations makes leasing economically attractive to many countries.

The major characteristics of the leasing arrangements are:

- the leases are provided from available spare capacity not being used for the provision of international services, on condition that they can be pre-empted if, in an emergency, the spare capacity is required for international services *;
- satellite capacity is leased in units of full transponders (36 MHz), half transponders (18 MHz) or one-quarter transponders (9 MHz). As of year end 1980, capacity was available for leasing on INTELSAT-IV spot and global beam transponders and on INTELSAT-IV-A global, hemispheric and spot beam transponders.

As of mid-1980 there were fifteen countries leasing capacity for domestic communications from INTELSAT with the total bandwidth leased of approximately 576 MHz or nearly the equivalent of one and one-half Intelsat-IV satellites. Figure 5-1 shows the rapid growth of INTELSAT leased systems over the 1975-1979 time period.

Further details are given in [Kelley, 1978].

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* INTELSAT is considering the provision of space segment capacity on a planned basis to meet the requirements of leased domestic services.

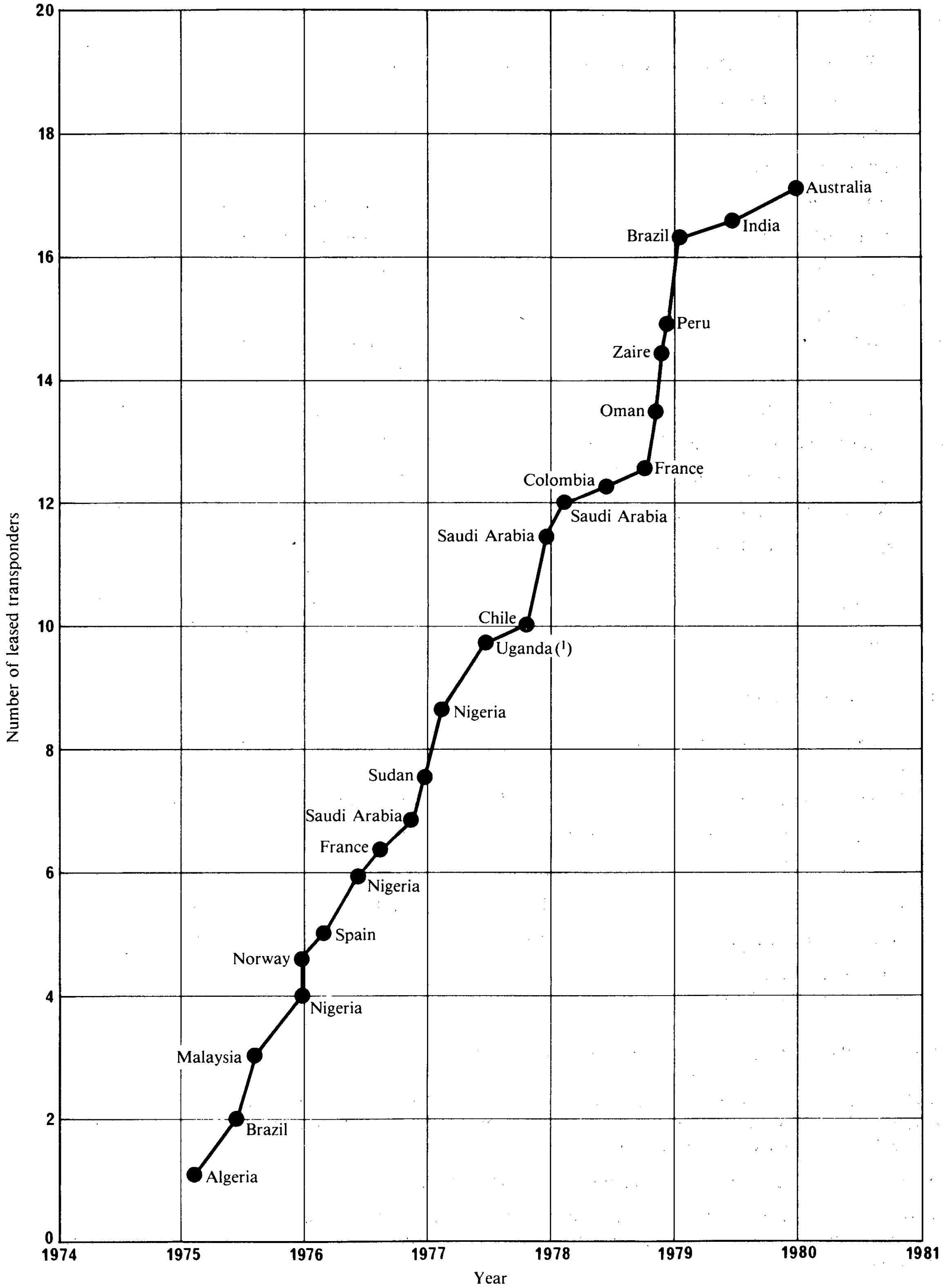

FIGURE 5-1 – *Growth of INTELSAT leased systems*

As of 31 December 1979

Capacity leased:	16 transponders
Number of countries:	16
Number of operational earth stations:	94
Number of channels:	10 TV video 5500 telephone/telegraph

(1) Terminated lease effective April 1979.

9. Experimental fixed-satellite service systems

9.1 *CS (Japan)* (see Report 207)

9.1.1 *Introduction*

In Japan, considering the increasing demands for domestic communications including emergency usages, the medium-capacity communications satellite for experimental purposes using 30 and 20 GHz bands, has been developed and various kinds of experiments are being conducted.

The CS was launched in December, 1977 and put into geostationary-satellite orbit. Transponders in the 30/20 GHz and 6/4 GHz bands and a multi-band shaped beam reflector antenna are on board. The coverage of the antenna is restricted to the Japanese territory. The characteristics are given in Tables 5-XIV and 5-XV.

Experimental items are measurements of on-board mission equipment characteristics, signal transmission characteristics and propagation characteristics, especially in the 30 and 20 GHz bands and satellite communication system operations.

9.1.2 *Space segment*

The characteristics of the satellite are given in Table 5-XIV.

TABLE 5-XIV — *CS satellite characteristics*

Mass in orbit	340 kg
Stabilization	Spin stabilized (90 rpm)
Orbital position	135° E
Station-keeping (N-S/E-W)	< ±0.1°
Number of transponders	2 (6/4 GHz) 6 (30/20 GHz)
Transponder bandwidth	200 MHz each
e.i.r.p. per transponder	29.8 dBW (4 GHz) 37.0 dBW (20 GHz)
Figure of merit (*G/T*) at edge of the coverage area	-8.1 dB(K^{-1}) (6 GHz) -4.5 dB(K^{-1}) (30 GHz)
Design life	3 years

9.1.3 *Ground segment*

Various types of earth stations are participating in the experiments. Their characteristics are summarized in Table 5-XV.

TABLE 5-XV – *Characteristics of earth stations in the CS system*

	KASHIMA Fixed-earth station		YOKOSUKA Fixed-earth station		SENDAI Fixed-earth station	Earth station for remote islands	Small transportable station		
							(Vehicle-mounted type)		(SCPC)
Frequency (GHz)	30/20	6/4	30/20	6/4	30/20	6/4	30/20	6/4	30/20
Diameter (m)	13.0	10.0	11.5	12.8	11.5(1)	11.5	2.7	3.0	2.0
e.i.r.p. (dBW)	94.1	74.2	92.7	91.0	92.5	81.0	75.0	66.0	56.3
Figure of merit (G/T) (dB(K^{-1}))	44.2	31.6	43.7	31.3	44.4	32.0	27.0	20.0	20.3

(1) Off-set Cassegrain antenna (11.5 × 14.5 m)

9.2 *SYMPHONIE satellite system*

The first Franco-German experimental Symphonie satellite was launched in 1974, by means of a Thor Delta 2914 launch vehicle. The second satellite was placed in orbit in 1975. Each of these two satellites contains four repeaters with a bandwidth of 80 MHz, and uses circular polarization in the 4 and 6 GHz bands. Experimental transmissions of telephony and television have been made. These included, for example: TDMA telephony, high-quality television, educational television, and several sound programmes using FDM-FM.

9.2.1 *Space segment*

Orbit:	geostationary
Repeaters:	4, each of 80 MHz bandwidth
Maximum e.i.r.p. (dBW):	30
Polarization:	circular
Antenna:	2 beams (Euro-African and American)

9.2.2 *Ground segment*

Transmitter output power (kW):	2
Antenna diameter (m):	16
G/T (dB(K^{-1})):	31.5

Additional experimental work, with a Symphonie satellite positioned at 49° E, was carried out by India under the project "Satellite Telecommunications Experimental Project (STEP)" during a two year period commencing June, 1977. The experiments included *inter alia* the following:

- television transmission with multiple audio channels,
- digital communications with multiple access for trunk telephony (14.0 and 10.7 m antenna diameter),
- integration of satellite derived circuits into the national automatic trunk telephone network,
- remote area communication using road transportable terminal (6.1 m antenna diameter),
- emergency communications using small air-liftable terminal (3 m antenna diameter).

9.3 *Ariane Passenger Pay-Load Experiment (APPLE)*

APPLE is the first 3 axis body-stabilized geostationary satellite with its own apogee propulsion system and attitude and orbit control capability designed and built by India. It was launched by ESA's Ariane (LO3) launch vehicle in June, 1981 and is positioned at 102° E. The satellite is being used for the following experiments:

- time division multiple access telecommunications,
- spread spectrum multiple access,
- small communications terminal,
- random access packet switching,
- television with multiple audio PCM,
- telemedicine,
- networking for sound broadcasting, etc.

9.3.1 *Space segment*

Stabilization:	3 axis body stabilized
In-orbit weight (kg):	380
Transponders:	one
Bandwidth (MHz):	40
Receive frequency (MHz):	6385
Transmit frequency (MHz):	4160
e.i.r.p. (max.) (dBW):	31.5
Antenna (m):	0.90 parabolic reflector
G/T (dB(K^{-1})):	-1.0
Polarization:	Orthogonal, linear; vertical receive and horizontal transmit

9.3.2 *Ground segment*

The ground segment associated with APPLE is summarized in Table 5-XVI.

TABLE 5-XVI – *Ariane passenger pay-load experiment (APPLE) – ground segment*

Antenna size (m)	14.7	10.7	6.1		3.0
Transmit power (W)	3000	3000	3000	20	20
E.i.r.p. (max.) (dBW)	86	85	84	60	54
G/T (dB (K^{-1}))	30	28.5	24	21	17

9.4 *European Orbital Test Satellite (OTS)*

The European telecommunication satellite OTS is an experimental spacecraft intended to test in space the techniques adopted for the future operational satellite ECS (European Communication Satellite). This satellite system will provide telephony transmissions and broadcasting programme distribution in Europe. The OTS satellite operates in the frequency bands of 11 and 14 GHz and carries four transponders. The frequency re-use technique is realized by using orthogonal polarization. Moreover, beacons operating with circular polarization allow propagation and depolarization experiments to be performed above 11.7 GHz.

TABLE 5-XVII – *OTS satellite characteristics*

Orbit Position	Geostationary 10° W
Model A Transponders E.i.r.p. (maximum) Polarization	 2 × 120 MHz (spot beam) 2 × 40 MHz (Eurobeam) Eurobeam: 37.9 dBW Spot beam: 47.4 dBW Linear
Model B Transponders E.i.r.p. Polarization Beacon	 2 × 5 MHz (Eurobeam) 30.7 dBW Circular 11.786 GHz

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* See also Chapter 2 References.

APPENDIX I

OTHER CONSIDERATIONS

1. Introduction

Broadcasting from satellites is now a reality. With terrestrial systems it is not possible, except in adjacent countries, for programmes emanating from one country to be received directly by television viewers in another country. The use of satellites for broadcasting television programmes generated a new awareness among administrations of the various issues that may arise when television programmes broadcast from a satellite might be more widely available to the television viewing public in other countries. These considerations have led the United Nations to study certain legal issues that will be posed by this technology.

2. Studies within the United Nations and other international organizations

2.1 *United Nations*

The United Nations is playing, through the Committee on the Peaceful Uses of Outer Space (COPOUS), a coordinating role for consideration of the general applications of satellite broadcasting.

The Legal Sub-Committee of the COPOUS, through one of its Working Groups on direct television broadcast satellites, is engaged in establishing the principles governing the use by States of artificial earth satellites for direct television broadcasting. This Working Group was first established in 1969 to study the technical feasibility of direct broadcasting from satellites and has, among other commitments, made a study of the implications of the development of direct broadcasting satellites from social, cultural, legal and other aspects. It also carried out studies relating to the possible time scale of direct TV broadcast service from satellites, the problem of spill-over of signals, responsibility of States and consultation and agreements between them, etc.

2.2 *International Telecommunication Union (ITU)*

The ITU has played a continuing and important role in formulating the technical recommendations, coordinating procedures and the coordinated use of the radio-frequency spectrum and geostationary-satellite orbit for the development of space communications including broadcasting from satellites.

The World Administrative Radio Conference for Space Telecommunications, Geneva, 1971 (WARC-ST-71), the World Administrative Radio Conference for Broadcasting Satellites, Geneva, 1977 (WARC-BS-77) and the World Administrative Radio Conference, Geneva, 1979 (WARC-79), have marked successively significant steps forward in the orderly development of satellite broadcasting. The important decisions of the WARC-79 relating to the broadcasting-satellite service and regulatory aspects are briefly recapitulated in the following sections.

2.2.1 *Regulatory aspects of the broadcasting-satellite service (BSS)*

The allocated frequency bands are given in Chapter 1.

2.2.1.1 *620-790 MHz band*

This band is allocated to the terrestrial services in the three Regions. However, a footnote to the Table of Frequency Allocations (No. 693 of the Radio Regulations), authorizes the use of this band by the BSS for television stations using frequency modulation, subject to the prescribed procedures. In accordance with RR 693, such stations shall not produce a power flux-density in excess of the value -129 dB(W/m^2) for angles of arrival less than 20° within the territories of other countries without the consent of the administrations of these countries. Also, according to Recommendation No. 705 of the WARC-79 providing sharing criteria on a provisional basis, the maximum power flux-density produced at the surface of the Earth within the service area of a terrestrial broadcasting station, for other angles of arrival, δ, shall not exceed:

$$\left.\begin{array}{ll} -129 + 0.4\,(\delta - 20) & \\ -113 & \end{array}\right\}\ \mathrm{dB(W/m^2)}\quad \begin{array}{l} \text{for } 20^\circ < \delta \leqslant 60^\circ \\ \text{for } 60^\circ < \delta \leqslant 90^\circ \end{array}$$

except with the agreement of the administrations concerned.

2.2.1.2 *2.50-2.69 GHz band*

The BSS in this band is limited to national and regional systems for community reception. The power flux-density at the Earth's surface, assuming free-space propagation conditions, shall not exceed the following values in any 4 kHz band (RR 761, 2561-2564):

$$\left.\begin{array}{l} -152 \\ -152 + 0.75\,(\delta - 5) \\ -137 \end{array}\right\} \mathrm{dB(W/m^2)} \quad \begin{array}{l} \text{for } 0^\circ < \delta \leqslant 5^\circ \\ \text{for } 5^\circ < \delta \leqslant 25^\circ \\ \text{for } 25^\circ < \delta \leqslant 90^\circ \end{array}$$

where the angle of arrival, δ, is above the horizontal plane.

In Region 1, this band is shared on a primary basis with terrestrial services. However, this band is also allocated to the fixed-satellite service (in addition to the terrestrial service) on a primary basis in Region 2 and partly in Region 3.

2.2.1.3 *12 GHz band*

In Region 1, the band 11.7-12.5 GHz is shared with terrestrial services.

In Region 2, the band 12.1-12.7 GHz is shared with the terrestrial and fixed-satellite (space-to-Earth) services. However, the Regional Administrative Radio Conference, in 1983, divided the band 12.1-12.3 GHz into two equal sub-bands, the lower of which is allocated to the FSS while the upper sub-band is allocated to the BSS (RR 841).

In Region 3, the band 11.7-12.2 GHz is shared with terrestrial services. The band 12.5-12.75 GHz is limited to community reception and is shared with the fixed-satellite (space-to-Earth) and terrestrial services. The power flux-density, produced by a station in the BSS, at the edge of the coverage area for 99% of the worst month shall not exceed -111 dB(W/m^2).

At present, a Plan exists for stations in the BSS in the bands 11.7-12.2 GHz in Region 3, and 11.7-12.5 GHz in Region 1. The provisions and the associated Plan are contained in Appendix 30 to the Radio Regulations. The same Appendix contains the procedure for modifications to the Plan.

A Regional Administrative Radio Conference (RARC) held in 1983 for Region 2, among other actions, adopted a plan for the BSS in the part of the 12 GHz band allocated to that service.

At present no Plan exists for the band 12.5-12.75 GHz in Region 3, nor is any conference for this purpose foreseen.

2.2.1.4 *Feeder links for the broadcasting-satellite service*

Feeder links for the BSS may, in principle, use any of the bands allocated to the fixed-satellite (Earth-to-space) service subject to the application of coordination procedure of Article 11 of the Radio Regulations. The WARC-79 identified certain bands for exclusive or preferential use by feeder links to broadcasting satellites. These are given in Chapter 3.

The WARC-79 also decided that the feeder links to broadcasting satellites operating in the bands 11.7-12.5 GHz in Region 1 and 11.7-12.2 GHz in Region 3 shall be operated in the bands 10.7-11.7 GHz, 14.5-14.8 GHz and 17.3-18.1 GHz, in accordance with the agreement and the associated plans to be adopted at a future administrative conference. Pending such agreements and the relevant plans, the advance publication, coordination and notification procedures of Articles 11 and 13 of the Radio Regulations remain applicable. In the application of these procedures, the administrations sharing the same orbital position in the Plan may conclude pre-coordination agreements among themselves in accordance with Resolution No. 101 of the WARC-79.

For Region 2, the Plan for feeder links to broadcasting satellites in the 12 GHz band was established by the RARC SAT-83, which drew up a detailed frequency assignment and orbital position plan for the BSS. The feeder links Plan is in the band 17.3-17.8 GHz.

For more details on compatibility of frequency bands for the BSS with shared services and feeder links for the BSS, reference may be made to texts in Chapter 3 of this report.

2.2.2 *Resolutions and Recommendations of the WARC-79* [ITU, 1979]

– The Conference confirmed WARC-ST-71 Resolution No. Spa2-2 as Resolution No. 507 according to which the stations in the BSS shall be established and operated in accordance with agreements and associated plans adopted by world or regional administrative conferences.

– The Conference adopted Resolution No. 33 relating to the bringing into use of space stations in the BSS prior to the entry into force of agreements and associated plans for the BSS.

- The Conference annexed to the Radio Regulations the BSS Plan adopted by the WARC-BS-77 for Regions 1 and 3 in the 12 GHz band and also adopted Resolution No. 701 for convening a regional administrative radio conference for the detailed planning of the BSS in the 12 GHz band and associated feeder links in Region 2. *
- The Conference adopted Resolution No. 503 relating to the coordination, notification and recording in the MIFR of frequency assignments to stations in the BSS in Region 2, in the interim period.
- The Conference adopted Resolution No. 101 concerning the drawing-up of agreements and associated plans for the feeder links to the BSS in the 12 GHz band under the Plan adopted by the WARC-BS-77 for Regions 1 and 3.
- The Conference adopted Resolution No. 100 relating to the coordination, notification and recording in the MIFR of assignments in the band 12.1-12.3 GHz to stations in the FSS with respect to stations in the BSS in Region 2.
- The Conference adopted Resolution No. 32 relating to the use of frequency assignments to terrestrial and space radiocommunication stations in the band 11.7-12.2 GHz in Region 3 and in the band 11.7-12.5 GHz in Region 1 so as to avoid harmful interference from terrestrial services to broadcasting-satellite stations operating in accordance with the WARC-BS-77.
- The Conference adopted Resolution No. 505 relating to the BSS (sound) in the frequency range 0.5-2.0 GHz.
- The Conference adopted the following Recommendations: Recommendation No. 506 relating to the harmonics of the fundamental frequency; Recommendation No. 508 relating to transmitting antennas for the BSS; Recommendation No. 101 relating to feeder links for the BSS and Recommendation No. 507 relating to spurious emissions in the BSS.

2.3 *United Nations Educational, Scientific and Cultural Organization (UNESCO)*

UNESCO is carrying out studies on regional broadcasting-satellite systems for informational, educational and cultural development. Major feasibility studies were carried out by the United Nations in cooperation with the ITU and the UNDP for a regional tele-education system for the South American region (1971-1973). Preliminary studies have also been undertaken by UNESCO in other regions of the world including the Arab States and Africa (in collaboration with the Economic Commission for Africa and the Pan-African Telecommunication Union). UNESCO was responsible for a major project begun in 1971 to train Indian personnel in the production and technical operation of television service, particularly as related to the training of personnel for the Indian Satellite Instructional Television Experiment (SITE, 1975-1976). UNESCO has also published the "Declaration of guiding principles" on the use of satellite broadcasting for the free flow of information, spread of education and for greater cultural exchange.

The International Commission for the Study of Communication Problems (Chairman, Sean MacBride), set up by UNESCO in 1977, has taken into account various facets of satellite-based broadcasting services and included them in its report published in 1980 [UNESCO, 1980]. As a follow-up of the study by the Commission, UNESCO has set up the International Programme for the Development of Communication (IPDC) the objectives of which are, among others: international cooperation in the field of information and communication, promoting in the developing countries creation or extension of infrastructures for the different communication sectors, strengthening cooperation and coordination with other specialized agencies, especially the ITU, providing advisory services in the field of communication development for optimum utilization of available resources, etc. The activities are to be coordinated by an Inter-Governmental Council and special funds are to be mobilized for achieving the objectives of the IPDC.

2.4 *UNESCO and the World Intellectual Property Organization (WIPO)*

UNESCO and WIPO are engaged in studies of the problems of copyright and neighbouring rights arising from direct broadcasting from satellites and the problems of legal protection against unauthorized use of satellite emissions.

2.5 *Applicability of international law*

A negotiating text has been prepared by the Legal Sub-Committee of COPOUS and the following view has been expressed on certain aspects of international law.

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* This Conference was held during 1983 for a period of 5 weeks.

Activities in the field of direct television broadcasting by satellite should be conducted in accordance with international law, including the Charter of the United Nations, the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies of 27 January 1967, the relevant provisions of the International Telecommunication Convention and its Radio Regulations and of international instruments relating to friendly relations and cooperation among States and to human rights.

The text also makes provision for:

- rights and benefits of States;
- international cooperation;
- peaceful settlement of disputes;
- State responsibility;
- duty and right to consult;
- copyright and neighbouring rights;
- notification to the United Nations;
- consultation and agreements between States.

3. Training for broadcasting-satellite services

For optimum operation of broadcasting-satellite services, it is essential to establish an efficient infrastructure for training the required personnel. The training needs for BSS differ from those in other space radiocommunication services in as much as that the maintenance of a large number of ground terminals is required. It should be recognized that training can only function in a satisfactory manner when it is part of, and based on, the fundamental policies of each responsible Government with regard to the relevant field. The training policy often depends on the more general issues of each country's national education and human resources development policies. Training should be regarded as productive investment resulting in personnel growth and development in improving higher satisfaction, higher efficiency and a better service to the general public.

Training is required to be imparted to various personnel in equipment as well as programme aspects of the BSS. This includes planning, installation, maintenance of equipment and programme development and other related aspects including management and working arrangements.

In the field of technical assistance in cooperation with the UNDP, UNESCO and other UN agencies, the ITU has been actively promoting training in space communications technology, with the objective of meeting the manpower demand in developing countries. The type of assistance is in the form of establishment and/or improvement of national or multinational training institutions, as well as in-service and on-the-job training, the organization of short-term specialist meetings and seminars, implementation of fellowships and exchange of training materials.

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APPENDIX II

FORMULAE AND EXPRESSIONS FOR MANUAL CALCULATIONS CONCERNING BROADCASTING-SATELLITE SYSTEMS

If the geographical coordinates of a point A on the Earth are φ (latitude) and $\Delta\lambda$ (longitude measured with respect to the sub-satellite point S'), then the great-circle distance between A and S' is given by the arc ψ of great circle S'A:

$$\cos \psi = \cos \varphi \cos \Delta\lambda \tag{1}$$

The azimuth Z of A, seen from S' is given by:

$$\tan Z = \frac{\sin \Delta\lambda}{\tan \varphi} \tag{2}$$

From these two equations we can deduce from the given geographical coordinates (φ and $\Delta\lambda$) the polar coordinates on the Earth's surface (ψ and Z) as follows:

$$\sin \varphi = \sin \psi \cos Z \tag{3}$$

$$\tan \Delta\lambda = \tan \psi \sin Z \tag{4}$$

The azimuth of the satellite, seen from point A, is given by:

$$\tan Z' = \frac{\tan \Delta\lambda}{\sin \varphi} \tag{5}$$

The elevation angle of the satellite, seen from the same point, is given by:

$$\tan \varepsilon = \frac{\cos \psi - \dfrac{R}{R + h}}{\sin \psi} \tag{6}$$

For the geostationary satellite:

$$R = 6378.16 \quad \text{km}$$

$$h = 35786.04 \quad \text{km}$$

thus:

$$\tan \varepsilon = \frac{\cos \psi - 0.15127}{\sin \psi} \tag{6a}$$

The angle, δ, between the line connecting the satellite and the centre of the Earth and the line connecting the satellite and the point A, for the geostationary satellite, is given by:

$$\tan \delta = \frac{0.15127 \sin \psi}{1 - 0.15127 \cos \psi} \tag{7}$$

The distance d between the satellite and point A, for the geostationary satellite, is given by:

$$d = 35786.04 \sqrt{1 + 0.41999\,(1 - \cos \psi)} \quad \text{km} \tag{8}$$

If the distances between the satellite and two points A and B on the Earth are respectively d_A and d_B, then the straight line joining A and B is:

$$d_{AB} = 9020.08 \sqrt{1 - \cos \psi_A \cos \psi_B \cos (\Delta\lambda_B - \Delta\lambda_A) - \sin \psi_A \sin \psi_B} \quad \text{km} \tag{9}$$

The angle between the lines joining the satellite and the points A and B, respectively, is given by:

$$\cos \varphi_S = \frac{d_A^2 + d_B^2 - d_{AB}^2}{2\, d_A d_B} \tag{10}$$

For two satellites S_1 and S_2, spaced on the geostationary orbit by an angle $\lambda_{S2} - \lambda_{S1}$, the distance between them, measured along a straight line, is:

$$d_S = 59629.18 \sqrt{1 - \cos (\lambda_{S_2} - \lambda_{S_1})} \quad \text{km} \tag{11}$$

If ($\lambda_{S2} - \lambda_{S1}$) is sufficiently small,

$$d_S = 735.9\,(\lambda_{S_2} - \lambda_{S_1}) \quad \text{km} \tag{11a}$$

The angle between the lines connecting a point A on the Earth and the satellites S_1 and S_2 is given by:

$$\cos \varphi_{SS} = \frac{d_{S_1}^2 + d_{S_2}^2 - d_S^2}{2\, d_{S_1}\, d_{S_2}} \tag{12}$$

where d_{S1} and d_{S2} are obtained from equation (8). The values of $\Delta\lambda$ in equation (2) are based respectively on the sub-satellite points corresponding to the satellite S_1 (for the distance d_{S1}) and the satellite S_2 (for d_{S2}).

The distance between the two satellites measured along the arc along the geostationary orbit is given for all angular separation of satellites by:

$$d_{SS} = 735.904\,(\lambda_{S2} - \lambda_{S1}) \qquad \text{km} \tag{11b}$$

The gain G (dB) of an antenna, referred to an isotropic source, is given, for a circular aperture D (m), at a frequency f (GHz) by:

$$G = 20 \log D + 20 \log f + 17.87 \qquad \text{dB} \tag{13}$$

The corresponding beamwidth 2δ (-3 dB) is:

$$2\delta = 21/Df \qquad \text{degrees} \tag{14}$$

The free-space loss L between two isotropic sources separated by d (km), at a frequency f (GHz), is:

$$L = 92.442 + 20 \log f + 20 \log d \qquad \text{dB} \tag{15}$$

For the sub-satellite distance for the geostationary orbit:

$$L_0 = 183.576 + 20 \log f \qquad \text{dB} \tag{15a}$$

The additional loss for a point different from the sub-satellite point for a geostationary satellite, is:

$$\Delta L = 10 \log [1 + 0.41999(1 - \cos \psi)] \qquad \text{dB} \tag{16}$$

If a receiving antenna at the sub-satellite point has an effective area of 1 m^2, the (spreading) loss between the satellite and the antenna is independent of the frequency, and is:

$$L_{0(1\ m^2)} = 162{,}066 \qquad \text{dB/m}^2 \tag{17}$$

For an effective isotropic radiated power (e.i.r.p.) equal to P (dBW) and for the sub-satellite point, the power flux-density is:

$$pfd_0 = P - 162.066 \qquad \text{dB(W/m}^2) \tag{18}$$

The relationship between the power flux-density and the field strength E at the receiving point is:

$$E = pfd + 145.763 \qquad \text{dB}(\mu\text{V/m}) \tag{19}$$

The relationship between the e.i.r.p. and the field strength is:

$$E = P - 16.303 \qquad \text{dB}(\mu\text{V/m}) \tag{20}$$

When $d \neq h$ (that is, all other points):

$$pfd = P - 162.066 - \Delta L \qquad \text{dB(W/m}^2) \tag{18a}$$

The noise power in an effective bandwidth b (Hz), with a temperature t (K) is:

$$p_n = k\, t\, b \tag{21}$$

If k (Boltzmann's constant), t and b are expressed in logarithmic units ($B = 10 \log b$, and $T = 10 \log t$) and b in MHz:

$$P_n = -168.6 + T + B \qquad \text{dBW} \tag{21a}$$

The relationship between the noise temperature t_n and the noise factor f is, for an ambient temperature t_0:

$$t_n = t_0\,(f - 1) \tag{22}$$

and

$$f = (t_n/t_0) - 1 \tag{23}$$

If the antenna noise temperature is t_A (K), and if the noise temperature of the receiving system (apart from the antenna) is t_n (K), the total system noise temperature is:

$$t_s = t_n + t_0 (f - 1) \qquad \text{K} \tag{24}$$

If there is an element with attenuation l at a temperature t_l, between the antenna and the receiver, the total system noise temperature becomes:

$$t_s = t_l (1 - l) + t_0 (f - 1) + l\, t_A \qquad \text{K} \tag{24a}$$

Expressed in logarithmic units:

$$T_S = 10 \log t_s \qquad \text{dBK} \tag{25}$$

The loss in antenna gain, due to ageing and the weather can be given by a factor m ($m < 1$). If the coupling element between the antenna and the receiver has an attenuation l, the usable antenna gain is:

$$g_r = g\, m\, l \tag{26}$$

or, expressed in logarithmic units:

$$G_R = G - M - L \tag{26a}$$

where G is the antenna gain as given in equation (13), $M = 10 \log m$, $L = 10 \log l$.

If $t_l = t_0$, the g/t factor is:

$$g/t = \frac{g\, m\, l}{t_0 (1 - l) + t_0 (f - 1) + l\, t_A} \tag{27}$$

or, in logarithmic units:

$$G - T = 10 \log (g/t) \qquad \text{dB} \tag{27a}$$

where:

p_t : transmitter power (W),

g_t : transmitter antenna power gain (isotropic),

g : receiver antenna power gain (isotropic),

l : propagation attenuation, i.e. the ratio between transmitted and received power as given in equation (15),

the received power is given by:

$$p_c = \frac{p_t\, g_t\, g}{l} \qquad \text{W} \tag{28}$$

or, in logarithmic units:

$$P_c = P_t + G_t + G - L \qquad \text{dBW} \tag{28a}$$

Taking account of all the transmission effects, and with b in MHz the ratio between the received carrier and the noise power (carrier/noise ratio) will be:

$$P_c - P_n = P_t + G_t + (G - T) - L - B + 168.6 \qquad \text{dB} \tag{29}$$

or:

$$P_c - P_n = e.i.r.p. + (G - T) - L - B + 168.6 \qquad \text{dB} \tag{29a}$$

For all points other than the sub-satellite point, the attenuation will increase by ΔL (equation (16)). Depending on the elevation angle for the point considered, it will be necessary to add the atmospheric attenuation ΔL_a (see Report 215). The carrier/noise ratio is then:

$$P_c - P_n = e.i.r.p. + (G - T) - 20 \log f - \Delta L - \Delta L_a - B - 14.916 \qquad \text{dB} \tag{30}$$

with f in GHz and B in MHz, for practical reasons. For f in MHz, this, of course, becomes:

$$P_c - P_n = e.i.r.p. + (G - T) - 20 \log f - \Delta L - \Delta L_a - B + 45.084 \qquad \text{dB} \tag{30a}$$

If the cross section of the satellite antenna beam is circular or is an ellipse having a major axis which, when projected on to the service area on the Earth coincides with the azimuth of the satellite, measured from the boresight point, the boundary of the service area may be calculated by an approximate method. The accuracy of this is greater as the size of the beam becomes smaller.

The minor axis of the boundary ellipse is given by:

$$b/2 = d \tan \delta \qquad (31)$$

where d is the distance from the service area (boresight) measured along the beam axis (equation (8)).

The direction of the major axis at the boresight point corresponds to the azimuth of the satellite seen from this point and is given in equation (5). The ratio between the major axis a and the minor axis b is given, for the same conditions, by:

$$a/b = \operatorname{cosec} \varepsilon \qquad (32)$$

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