XVII A.P.
DÜSSELDORF
21.5-1.6 1990
CCIR

XVIIth PLENARY ASSEMBLY
DÜSSELDORF, 1990

INTERNATIONAL TELECOMMUNICATION UNION

REPORTS OF THE CCIR, 1990

(ALSO DECISIONS)

ANNEX TO VOLUMES X AND XI – PART 2

BROADCASTING-SATELLITE SERVICE (SOUND AND TELEVISION)

CCIR INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

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BROADCASTING-SATELLITE SERVICE (SOUND AND TELEVISION)

(Study Groups 10 and 11)

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SECTION 10/11B: SYSTEMS

REPORT 215-7

SYSTEMS FOR THE BROADCASTING SATELLITE SERVICE (SOUND AND TELEVISION)

(Question 2/10 and 11, Study Programme 2A/10 and 11)

(1963-1966-1970-1974-1978-1982-1986-1990)

1. Introduction

This Report describes the essential elements of broadcasting-satellite system design and their relationships. The object of the Report is to assist the system designer, frequency planner, and spacecraft and earth-station engineer in their choice of system characteristics. Such choices, as is the case in the design of systems in general, are bounded by various constraints: limitations imposed by the state of international agreement and, most important, by considerations of system economics.

Other relevant information on the systems aspects of the broadcasting-satellite service are given in the Recommendations and Reports listed below;

- Terminology
  Recommendation 566
- Television broadcasting systems
  Recommendation 650, Reports 1073 and 1074
- Sound broadcasting systems
  Report 955
- High definition television broadcasting systems
  Report 1075
- Feeder links
  Report 952
- Modulation, multiplexing and coding
  Recommendation 651, Reports 632, 953 and 954
- Transmitting and receiving antennas
  Recommendation 652, Report 810
- Earth receiving equipment
  Report 473
- Satellite technologies
  Report 808
- Interservice frequency sharing
  Report 634

2. Major system parameters

There are different ways to approach the selection of system parameters. One method is given in this section.

As a first step, decide on system input factors. That is, the desired quality for various percentages of time, the number of channels (including the number of accompanying audio programme channels) and the area of coverage on the Earth. The subject of quality of reception is discussed in greater detail in § 3.

2.1 Factors affecting choice of orbit and of orbital position in the GSO

2.1.1 General

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 the (broadcast service area) 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 for broadcast recieving installations.

2.1.2 Geostationary satellite orbit (GSO)

The geostationary satellite orbit (GSO, altitude 35786 km above the equator) has been chosen for most existing and planned broadcasting satellite systems. It permits 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).

2.1.3 Inclined orbits

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 Annex I (see Table XI).

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.

2.1.4 Choice of orbital position in GSO

The following factors shall be considered in choosing an orbital position in the GSO:

- receiving antenna elevation angle within the broadcasting service area;
- effect of the eclipse due to the moon.

(Generally, orbital position of the broadcasting satellite is chosen about 20 to 40 degrees westward from the centre of the broadcasting service area to overcome eclipse blackout during service time.)

2.2 Frequency of operation

2.2.1 General

In selecting a frequency band for a broadcasting-satellite system, the choice obviously is constrained not only to the frequency allocations established in the Radio Regulations for the broadcasting-satellite service, but by other factors such as current or planned use of certain frequencies shared with other services within the desired area of coverage, or in areas subject to interference from the system being planned (e.g., see Report 634).

The principal propagation effects to be taken into account are attenuation, due to atmospheric gases and rain, and depolarization.

2.2.1.1 Attenuation

Atmospheric attenuation is due mainly to rain and cloud attenuation. It varies with frequency, angle of elevation and local climate. It can be closely extended from a rain attenuation model.

Measurements that have been carried out in Europe*, Japan, Malaysia, Australia, United States and France are described in Annex II. The values of attenuation not exceeded during 99% or 99.9% of the worst month are listed in Table I.

Table I. - *Worst-month attenuation observed in different locations and at frequencies from 11.6 to 30 GHz*

Location of measurements	Frequency (GHz)	Elevation angle (deg)	Attenuation (dB) not exceeded during given fraction of worst month	
			99 %	99.9 %
Europe*	11.5	20 to 45	1.1	3.3
France (Paris)	11.6 and 11.8		1.8	4.0
France (Brittany)	11.6 and 11.8		1.5	3.4
Japan (12 locations)	12	30 to 60	2.4	6.9
Malaysia (Klang)	12	corrected to 45	1.7	8.7
Australia (Darwin)	12.75	50	6	16
Australia (Sydney)	12.75	53	1	20
USA (Maryland)	11.70	29.5	<1	5.4
USA (North Carolina)	11.70	36	1	1.8
"	20	36	1.5	11.0
"	30	36	2.4	19.5

* Measurements done by the European Space Agency (ESA) in certain countries of Western Europe.

The rain attenuation model based on rain fade statistics corresponding to 1% of the worst month has been applied to both feeder-link and down-link planning for the 12 GHz broadcasting-satellite service as described in Appendices 30 (Orb 85) and 30A of the Radio Regulations. (See Report 723 for a method of estimating worst-month statistics from annual statistics.)

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

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* Measurements done by the European Space Agency (ESA) in certain countries of Western Europe.

For any frequency f(GHz), other than 11.5 GHz, an approximate value for 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:

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

Measurements can be corrected with respect to elevation angle by using the cosecant law [CCIR, 1978-82a].

Little data on rain attenuation is available for tropical rain climates. More measurements are required in these areas above 11.6 GHz to provide a useful body of data.

2.2.1.2 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)

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

where A is the atmospheric attenuation, in decibels.

Actual measurement statistics have been analyzed in Report 564 where a more detailed equation taking into account the influence of frequency and elevation angle can be found.

A more detailed discussion of depolarization effects due to precipitation can be found in Report 814, Annex 5 of Appendix 30 (ORB-85) of Radio Regulations and Appendix 30A.

2.2.2 Effect of additive radio noise

Additive radio noise ———— is produced from both natural and man-made sources (power lines, electrical apparatus, automobile ignition systems). Figure 1 indicates typical noise levels associated with these sources, and shows that in the lower part of band 10 and in the greater part of band 9 a minimum of noise is introduced depending upon the conditions. It should be noted however that, while many measurements of impulsive noise level have been made, evaluation of these data is as yet incomplete . Therefore, the noise levels shown in Figure 1 must be considered as provisional.

At present, limited information on the subjective aspects of impulsive noise is available [Pacini *et al.*, 1971]. There is insufficient knowledge regarding the dependence of man-made noise on the angle of arrival, polarization, frequency, height of antenna, etc., to make adequate engineering analyses of the levels likely to be present at the terminals of the receiving antenna.

In addition to the noise sources indicated in Fig. 1, a significant increase in noise level can occur for short periods when the Sun is within the antenna beam, if narrow-beam receiving antennas (beamwidth less than about 5°) are used. For geostationary satellite orbits, these periods occur in the day-time for a few consecutive days in spring and autumn. The noise temperature and the angular size of the quiet solar disc is observed at 12 GHz as about 12 000 K and 0.6° of arc, respectively. Examples of solar inteference to small antennas are described in Annex III obtained by the experiments with the medium-scale broadcasting-satellite for experimental purposes, (BSE) of Japan.

2.3 Required margin

The choice of frequency and the desired quality for various percentages of time dictate an operating margin (see Report 811) which depends both on the attenuation statistics applicable to the broadcasting service area and on the values of carrier-to-noise power ratio corresponding to the signal quality objectives and the modulation parameters of the signal and the receiver.

In the case of frequency modulation it is necessary to keep the carrier-to-noise ratio above the threshold for as high as possible a percentage of time (usually 99.9%) and also to achieve a given signal-to-noise ratio objective for a specific percentage of time (usually 99%). Thus it is necessary to choose a margin above threshold such that both requirements are met simultaneously. This margin should include the atmospheric loss and other terms not specifically included in the power budget. Provision should be made in the required value for *G/T* for atmospheric effects on system temperature.

Table I gives examples of the margins for atmospheric loss for the European broadcasting area, part of the USA, Australia, Japan and Malaysia.

Note. – In the case of the operational Japanese broadcasting-satellite BS-2a, the time statistics of carrier-to-noise ratio exceeding 14 dB for 99% of the time and exceeding 10 dB for 99.95% of the time for a period of seven months including the worst months of June and July for rain attenuation, were obtained. The results are shown in Table II.

Table II – *Time statistics of received C/N ratio measured over the period of 12 May-24 December, 1984*

C/N ratio (dB)	14.0	12.0	10.0	8.0
Time percentage exceeded above *C/N* ratio (%)	99.0	99.9	99.95	99.98

Frequency:	11.996 GHz
Receiving antenna:	75 cm in diameter (gain: 37.6 dB)
Receiver noise figure:	3.0 dB
Effect of feeder link on down-link *C/N* ratio:	0.2 dB
Accumulated rainfall during the period:	710 mm
Measurement site:	Tokyo (rain climatic zone M)

The report of JIWP 10-11/3 [CCIR, 1986-90a] pointed out a need of studying alternative criteria for determining appropriate margins for high definition television (HDTV) signals which may require higher carrier-to-noise ratios than conventional television signals and may operate in frequency bands where attenuation margins are higher than in the 12 GHz bands.

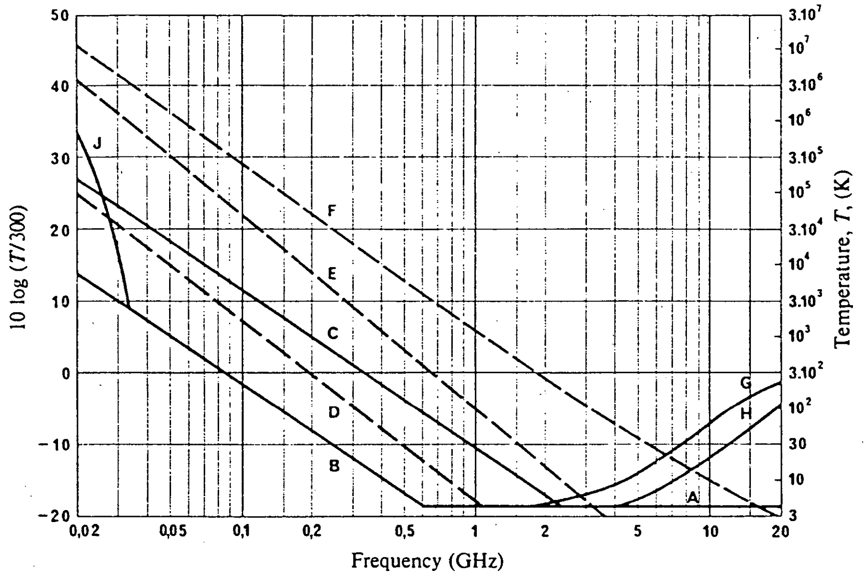

FIGURE 1 – *Noise temperature from natural and man-made sources*

Note. – This graph should be extended to 100 GHz and curves G and H should be projected according to the best available data, so as to include performance predictions for the 40 and 80 GHz broadcasting-satellite service allocations. It is realized that curve E is in conflict with Fig. 1 of Report 258 for frequencies up to 250 MHz. Therefore, curve E and, as a result, curve F, should be treated with caution. Administrations and the appropriate CCIR Study Groups are requested to study and submit data.

Curves A: Cosmic noise background (Report 205).

B: Minimum cosmic noise (Report 205).

C: Maximum cosmic noise (Report 205).

D: Typical man-made noise in "rural" area (omnidirectional receiving antenna (Report 670, Fig. 3).

E: Typical man-made noise in "urban" area (omnidirectional receiving antenna) (Report 670, Fig. 3).

F: "Urban" noise, adjusted for a directional antenna orientated at angles of elevation greater than 45: noise discrimination equal to one half the gain of the antenna (in dB) is assumed with a gain of 8 dB at 20 MHz and 25 dB at 2500 MHz.

G: Typical noise due to rainfall and atmospheric absorption for 0.1% of the time: temperate latitudes: angle of elevation 30°.

H: Typical noise due to rainfall and atmospheric absorption for 1% of the time: temperate latitudes: angle of elevation 30°.

J: Night-time atmospheric noise (Report 322).

2.4 Modulation and required bandwidth

The transmission of radio signals by satellite normally use a modulation method that involves a power-bandwidth trade-off. Satellites to date have generally been power rather than bandwidth limited and have, therefore, usually used FM. AM, while having a significantly narrower bandwidth, requires so much more power that it has not been competitive. FM also has the advantage of being a constant envelope signal and is, therefore, not as sensitive to transponder amplitude non-linearities.

Report 632 discusses details of the modulation methods used for satellite systems including a comparison of FM with digital modulation techniques.

2.4.1 *Television broadcasting using frequency modulation*

The required RF bandwidth, b, for video combined with an audio FM sub-carrier is approximated by the following equation:

$$b = D_{b(p-p)} + 2f_b$$

where $D_{b(p-p)}$ is the peak-to-peak deviation of the carrier by the composite baseband signal and f_b is the composite baseband bandwidth.

System performance for video baseband signals only is discussed in § 3.2. Artificial energy dispersal, a technique useful to facilitate sharing with other services whose signal energy is confined to bandwidths much smaller than those required for FM analogue transmission (as is the case for the BSS) would increase the bandwidth occupied by the signal from the satellite. (A requirement to employ artificial energy dispersal of 600 kHz on all transmissions serving Regions 1 and 3 is incorporated in the Radio Regulations, Appendix 30. Energy dispersal is also required in some circumstances on transmissions serving Region 2.) Other details are discussed in §2.4.4and are given in Report 631.

In the 12 GHz band, laboratory tests have shown that for frequency-modulation transmission of a 625-line colour television signal accompanied with sound transmitted by a frequency-modulation sub-carrier, a good compromise was obtained between the transmitter bandwidth and the quality of the signal for a radio-frequency bandwidth of about 25 MHz.

Some tests carried out in Japan ——— have shown that in the transmission of frequency-modulated television signals accompanied by sound signals in a single channel, using a multiplexed frequency-modulation sub-carrier at 4.5 MHz, satisfactory results can be obtained with a bandwidth of 23 MHz. Moreover, advantage can be taken of over-deviation to transmit six supplementary sound signals of medium quality, by means of a second subcarrier using frequency modulation and time-division-multiplexing by pulses.

The bandwidth occupied by a signal from a broadcasting satellite must be increased to accommodate one or more sound channels. Typically this increase is a quite small percentage of the bandwidth required for the video alone. The radio-frequency channel width of the satellite transmitter must also be larger than the occupied bandwidth to account for both transmitter frequency instability and to keep adjacent channel interference to acceptably small values.

The increase in bandwidth to accommodate both sound channels and guard bands is of the order of 10% of the radio-frequency bandwidth, b.

Further details on the signal characteristics, bandwidth requirements and system performance for the baseband signals being considered for future satellite broadcasting systems are given in Report 1075.

2.4.2 *Sound broadcasting*

For sound broadcasting, both FM and digital modulation are considered.

Modulation methods and required bandwidth are indicated in Report 955 and Report 1228. ——— The systems described in Report 955 are intended for use in bands 7 and 9 for portable, mobile and fixed radio receivers. The systems described in Report 1228 ——— are intended for the broadcasting-satellite service in the 12 GHz band, generally for fixed reception.

2.4.3 Frequency deviation and pre-emphasis

Planning of the broadcasting-satellite service has been based on the use of pre-emphasis characteristics given in Recommendation 405. However this does not preclude the use of other pre-emphasis characteristics, provided that the use of such characteristics does not cause greater interference (Radio Regulations, Appendix 30 (ORB-85) (Annex 5, § 3.1.3)). ——— [D'Amato and Stroppiana, 1979] illustrate the results of an investigation carried out in order to optimize the pre-emphasis characteristic. All the factors affecting the signal quality (threshold noise visibility, spurious amplitude modulation, distortions, sound-on-video and video-into-sound crosstalk) have been taken into consideration. The experimental data support the use of the current CCIR recommended pre-emphasis characteristic for broadcasting satellites.

The pre-emphasis specifications for the signal formats recommended for use with future broadcasting satellite systems are given in a Special Publication of the CCIR [CCIR, 1988].

[CCIR, 1974-78a] considers a technique for improving the video signal-to-noise ratio on an FM satellite link by optimizing the frequency deviation and the pre-emphasis characteristic simultaneously. Further studies are required to establish the applicability of this technique to the broadcasting-satellite service.

2.4.4 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 11, 14.5 to 14.8 and 17 GHz bands (Earth-to-space) are limited to feeder links for the BSS. **Worldwide plans for feeder-link assignments in the 14 and 17 GHz bands were developed at RARC-83 and WARC-ORB 88, and are given in Appendix 30A of the Radio Regulations.)**

In principle, 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.

In practice, the amounts of energy dispersal to be used in connection with **the assignments in the 12 GHz down-link Plans and the 14 and 17 GHz feeder-link Plans are given in Appendices 30 (ORB 85) and 30A respectively.**

2.4.5 Preservation of d.c. component in frequency modulators

In order to obtain the maximum utilization of the available bandwidth by either monochrome or colour signals, the centre frequency of the carrier modulated by a video signal should be preserved (e.g. by preservation of the d.c. component in the frequency modulator), especially in satellite circuits which operate under constraints of power and bandwidth.

The centre frequency can be constrained to correspond to the mid-point of a pre-emphasized peak white video signal [AuBC, 1983].

If the centre frequency is not preserved, then not only could system performance be impaired, but signals could be radiated outside the assigned channel bandwidth during periods of rapid changes in luminance, thus creating the possibility of interference to second adjacent channels. More restrictive filters, with all their limitations, would then be required at the output of the modulator to suppress these out-of-band signal components.

In the case of transmissions employing multiplexed analogue components (MAC), the pre-emphasis characteristic likely to be employed will attenuate low video frequencies only slightly. Therefore it is even more important for such systems to preserve the centre frequency corresponding to the central value of the video signal [CCIR, 1988].

2.5 *Satellite e.i.r.p. and earth receiver figure of merit (G/T)*

2.5.1 *Optimizing satellite e.i.r.p. and earth receiver figure of merit*

In any satellite communication system there are usually trade-offs to be made between satellite and ground terminal cost and complexity, therefore one of the key trade-offs involves the e.i.r.p. of the satellite as a function of the figure of merit (*G/T*) of the ground terminals. With all other system parameters unchanged, e.i.r.p. and G/T can be varied as long as their sum remains constant. Figure 2 shows graphically the sum of *e.i.r.p.* and figure of merit, in the case of 12 GHz systems with a minimum S/N of 45 dB, for various bandwidths and minimum C/N ratios. No losses other than the free space loss are included. Analogous results can be obtained in the case of other frequency bands or other minimum S/N ratios.

The available satellite e.i.r.p. per channel for a given satellite transmitter output power depends on the transmitting antenna gain corresponding to the required coverage area. High e.i.r.p. satellite designed to provide several television channels to large geographical service areas are currently difficult to implement because of the high primary power required.

Other system options available for decreasing the required e.i.r.p. are to use modulation methods which require less power, or to obtain sufficient video compression so that digital modulation techniques become power effective (see Report 631).

Determining the effects of increasing the antenna size of receiving earth stations is fairly straightforward, since gain as a function of size is well known and antenna cost data are available. Practicality (mounting, wind loading, etc.), particularly for home (individual) use, must also be considered. Further information is given in §3 of Report 473.

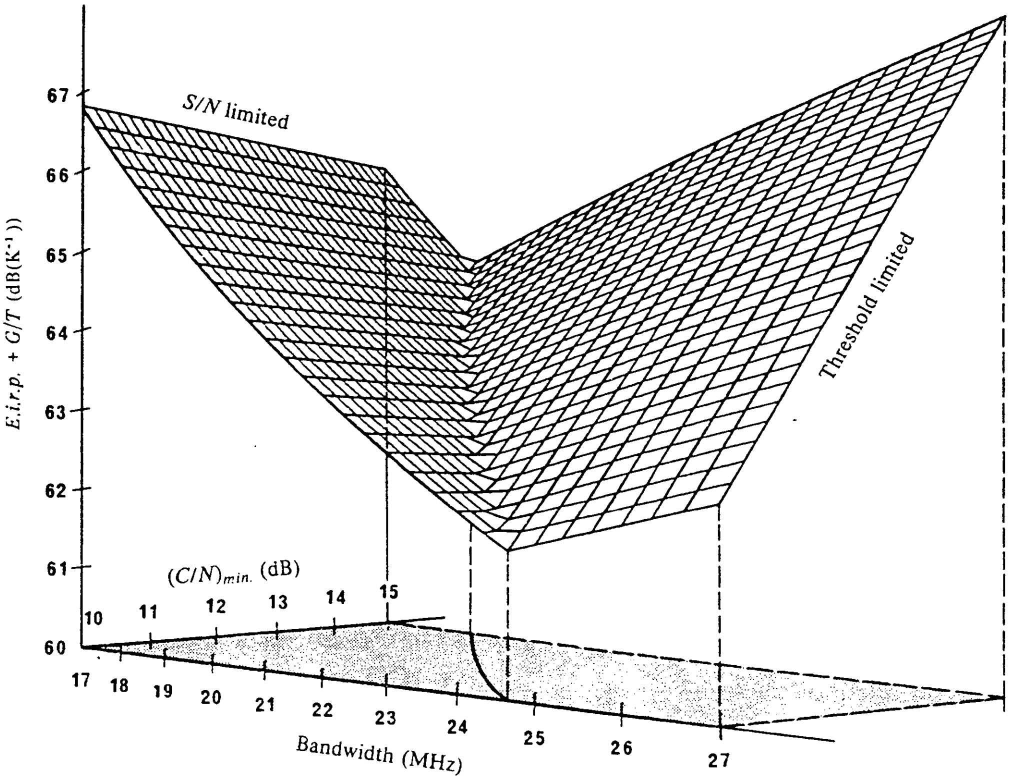

FIGURE 2 – *Parametric surface for the determination of the optimum bandwidth (minimum video S/N = 45 dB)*

2.5.2 *System calculation formulae*

The relationship between satellite e.i.r.p. and earth-station figure of merit is:

$$C/N_d = e.i.r.p. - L_{FS} + G/T - 10 \log kB - L_A - L_R \qquad \text{or}$$
$$e.i.r.p. = C/T + L_{FS} + L_A + L_R - G/T \qquad \text{dB}$$

where:

C/N_d: minimum acceptable carrier-to-noise ratio (dB);

C/T: carrier-to-noise temperature ratio of the space-to-Earth path, (dBW(K^{-1}));

e.i.r.p.: equivalent isotropically radiated power from the satellite towards a point on the edge of the required service area (dBW);

k: 10 log Boltzmann's constant (dB(WK^{-1} Hz^{-1}));

L_{FS}: free space path loss on the space-to-Earth path (dB)
$= 20 \log 4\pi R/\lambda$ (where R is the distance and λ is the wavelength measured in the same units);

L_A: path loss due to clear air absorption (dB);

L_R: fade level due to rain (dB);

G/T: minimum, degraded value of the receiver figure of merit (dB(K^{-1}));

B: noise bandwidth of an individual channel (Hz).

The required satellite e.i.r.p. can be converted into required satellite transmitter output power, P_S, if the satellite antenna gain, G_T is known:

$$P_S = e.i.r.p. - G_T \qquad \text{dB}$$

The half-power beamwidth θ_0 can be determined once satellite antenna gain is specified:

$$\theta_0 = \sqrt{27\,843/G_T} = 225(\lambda/\pi D)$$

where G_T is the antenna gain expressed as a ratio and D is the diameter of the antenna expressed in the same units as λ, the wavelength. An antenna aperture efficiency of 55% has been assumed.

Determination of exact coverage area on the ground is complicated because of the difficulty of determining the intersection of the satellite antenna beam with the spherical surface of the earth. For beams directed near the sub-satellite point, a 1.5° beam produces a coverage area with a diameter of about 1000 km. The same beam directed towards higher latitudes, or towards areas far removed in longitude from the sub-satellite point will cover a much larger area on the surface of the Earth [Ostrander, 1967; Sollfrey, 1966].

The following relationship exists between the magnitudes of field strength and power flux-density.

The straightforward conversion between the unit of field strength, E, (dB(μV/m)) and power flux-density Φ, (dB(W/m^2)) is:

$$\Phi = E - 145.8$$

There are several additional useful relationships:

- the noise power in a 1 MHz bandwidth is −144.0 dBW at a noise temperature of 290 K,
- 1 μV e.m.f. in a 75 Ω source corresponds to an available power of −144.8 dBW,
- 1 μV e.m.f. in a 50 Ω source corresponds to an available power of −143.0 dBW.

The relation between the e.i.r.p. of a geostationary satellite and the power flux-density at the surface of the Earth is:

$$\text{power-flux density} = \text{e.i.r.p.} - \text{spreading loss} + B - W - X$$

where:

power-flux density	is in dB(W/m^2) in the reference bandwidth B
e.i.r.p.	is in dBW
B (reference bandwidth) (See Note 1)	is in dBHz
W (actual signal bandwidth)	is in dBHz ($W > B$)

X is a factor, in dB, which takes into account the uniformity of the signal spectrum over its bandwidth W. X ranges from 0 dB when the signal spectrum is flat, to ($B - W$) dB when the signal bandwidth $W \leqslant B$.

For the point on the Earth at latitude $\varphi°$ and relative longitude (sub-satellite point = 0°) $\lambda°$ and with $\cos \Delta = \cos \lambda \cos \varphi$, we obtain the following relationship:

Angle Δ (degrees)	spreading loss, dB(m^2) (See Note 2)
0 (sub-satellite point)	162.1
80	163.4

For an angle of elevation ε, with $\tan \varepsilon = (\cos \Delta - 0.1513)/\sin \Delta$, we obtain the following relationship:

Angle ε (degrees)	spreading loss, dB(m^2) (See Note 2)
0	163.4
90	162.1

Note 1. – The reference bandwidth has various values. For space research, it is 1 Hz; for the fixed-satellite service it can be 4 kHz, or 1 MHz, depending on the characteristics of the terrestrial service with which a band is shared. When the emission of a satellite is not uniformly distributed over its necessary bandwidth, the limit on power flux-density is usually construed to apply to the "worst" reference bandwidth.

Note 2. – The e.i.r.p. (dBW) minus the spreading loss in dB(m^2) is equal to the power flux-density (dB(W/m^2)), atmospheric loss not included.

The foregoing formulae are typical of those used in connection with the planning of broadcasting satellite and feeder link frequency assignments in the 12 and 14/17 GHz bands respectively.

3. Quality of reception

3.1 *General considerations*

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 Report 405. **The recommended method for assessing the quality of television pictures is given in Recommendation 500.**

It seems to be important to determine the overall performance of the entire system and then define appropriate specifications of components, such as satellite repeaters and home receivers, in the form of target values. Table III of this Report shows typical major parameters of components used in the satellite broadcasting system, and it mainly deals with the least preferable quality determined at the edge of the service area for planning purposes. As satellite broadcasting is capable of delivering a high quality TV signal comparable to that of the studio to the general public, it is practicable to set a higher quality standard.

TABLE III — *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.

The television signal transmission standard for the hypothetical reference circuit (2500 km) shown in Recommendation 567 may be considered as a reference. Target performance for the part of the satellite broadcasting chain which is to replace the terrestrial broadcasting chain is shown by example in Table IV. In practice, the appropriate overall target performance should be established by giving consideration to its achievability for each component and by individually investigating the distribution ratio so that the total required cost is minimized. Report 405, Annex II indicates that there is a possibility of another law of addition to find overall impairment distribution between different items. Account may also be taken of the above consideration. Further study on this matter is invited.

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 IV – *Example of the major television transmission characteristic allocations for a composite video system*

Item	Overall characteristics	Allocation to the receiving equipment (1)	Distribution factor	Law of addition (4)
Continuous random noise ratio ($dB_{p-p/r.m.s.}$) (2)	53	48/54 (3)	0.9	2
Periodic noise ratio:				
Power supply hum ($dB_{p-p/p-p}$)	35	–/41	0.5	2
Single frenquency ($dB_{p-p/p-p}$) (more than 1 kHz)	55	–/58	0.5	2
Differential gain (%)	10	10/6	0.5	1.5
Differential phase (deg.)	5	5/3	0.5	1.5
Short time overshoot (%)	15	–/8	0.5	no law
Steady-state characteristics:				
Gain/frequency (dB) (500 kHz – 4.2 MHz)	± 1	± 1.0/± 0.6	0.5	1.5
Delay/frequency (ns) (500 kHz – 4.2 MHz)	± 100	–/± 60	0.5	1.5

(1) Values shown are: minimum standard/target performance.
Minimum standard means that this is a minimum acceptable standard anywhere within the service area.
Target performance means that this is an objective for good quality achievable within the service area.

(2) Signal-to-random noise ratio includes all sources of random noise not only from the front end but also from the IF stage and video amplifiers.

(3) The WARC-BS-77 indicated 14 dB C/N for 99% of the worst month at the edge of the service area. This figure indicates an expected value for 50% of the time in the main part of the service area.

(4) Overall performance D_t can be calculated by using sub-system performance D_i and law of addition p as follows:

$$D_t = \left[\sum_{i=1}^{n} (D_i)^p\right]^{1/p}$$

3.2.1 *Video transmission*

A method of calculation of signal-to-noise ratio after demodulation for frequency modulation television signals is given by

$$S/N = C/N + 10\log\{3(D_{p\text{-}p}/f_v)^2\} + 10\log(b/2f_v) + k_w \qquad \text{(dB)}$$

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)

$D_{p\text{-}p}$: 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 V).

For example, in Table VI, the video signal-to-noise ratio is evaluated using the equation given above, assuming a C/N of 14 dB, and a frequency deviation due to video of 12 MHz peak-to-peak (see Appendix 30 of the Radio Regulations), where the highest video frequency for the system in use, f_v, is taken from Report 624 and the combined de-emphasis and weighting improvement factor, k_w, is taken from Table V.

TABLE V – *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.

Examples of the applicable video noise weighting reduction factor are given in Table V. For further details, see Report 637.

TABLE VI - *Typical video signal-to-noise ratios*

System	f_v (MHz)	k_w (dB)	S/N (dB)
M	4.2	13.8	45.5
B and G	5.0	16.3	46.1
D, K and L	6.0	18.1	45.9
I	5.5	12.9	41.7

3.2.2 *Audio transmission*

The unweighted signal-to-noise ratio of accompanying audio channels, which consist of FM sub-carriers located above the video baseband, is determined by the following equation:

$$S/N_a = 10 \log \left[\frac{3}{4} \left(\frac{b}{f_a} \right) \left(\frac{D_s}{f_s} \right)^2 \left(\frac{D_a}{f_a} \right)^2 \right] + \left(\frac{C}{N} \right) + k_a$$

where:

S/N_a : audio channel r.m.s. signal to r.m.s. noise ratio (dB);

D_s : peak deviation of the main carrier by the sub-carrier (MHz);

D_a : peak deviation of the sub-carrier by the audio (MHz);

f_s : frequency of the sub-carrier (MHz);

f_a : highest audio frequency (MHz);

C/N : pre-detection carrier-to-noise ratio (dB);

k_a : combined improvement factor due to pre- and de-emphasis for the audio channel (dB). (See CMTT Report 496, Table II, for improvement factors corresponding to various audio channel baseband bandwidths);

b : pre-detection RF bandwidth (MHz) defined by the equation in §2.4.1.

The audio signal-to-noise ratio (after demodulation) is evaluated in Table VII using the equation given above, assuming the same C/N of 14 dB and frequency deviation by the composite baseband signal which is approximated to be the deviation due to the video signal, of 12 MHz peak-to-peak.

The following system values are applied:

- Peak deviation of the subcarrier by the audio (D_a) at the subcarrier frequency (f_s) : 15 kHz
- Combined improvement factor (k_a) due to pre- and de-emphasis for the predetection RF bandwidth (b) as defined in §3.2.1, but using composite baseband parameters.[1] : 9 dB
- Peak deviation (D_s) due to a sound sub-carrier amplitude equal to about 30% of the total peak-to-peak deviation of the carrier[2] : 1.8 MHz

Examples of the audio signal-to-noise ratio value which can be expected are given in Table VII.

TABLE VII - *Typical audio signal-to-noise ratios*

System	D_a (MHz)	f_s (MHz)	b (MHz)	S/N (dB)
M	0.025	4.5	21	49.7
B and G	0.050	5.5	23	54.4
D, K and L	0.050	6.5	25	53.3
I	0.050	6.0	24	53.8

---

[1] See Report 496, Table II, white noise conditions.

[2] See Report 632.

3.2.3 *Combined video and audio*

Other combined video and audio modulation schemes, such as video with multiple audio FM sub-carriers or with digital audio modulation are described in Reports 632, 1073 and 1074. Additionally, Report 632 gives subjective results of picture and sound quality as a function of carrier-to-noise ratio.

3.3 *Influence of standards for television*

To provide a television broadcasting-satellite service, the following may be considered:

- to take into account the specific needs of the broadcasting-satellite service as given in Recommendation 650 and Report 1073;
- to match exactly the existing standards as employed for terrestrial broadcasting in the geographic area of interest;
- to provide a receiving device to convert the satellite signal into one usable by a standard receiver;
- to provide a receiver designed specifically for the broadcasting-satellite service.

3.4 *Influence of the feeder link*

The overall carrier-to-noise ratio is related to the feeder-link carrier-to-noise ratio and the down-link carrier-to-noise ratio by a relationship which must include the two following factors [CCIR, 1978-82b]:

- the transfer characteristic of the satellite transponder,
- the statistics of rain attenuation on the feeder links and down links.

For example, to limit an impairment of the carrier-to-noise ratio, C/N, of the down link to 0.5 dB, owing to the presence of the feeder link in case of simultaneous fading due to rain attenuation on both links, a C/N of 24 dB is required in the feeder link. Both values, 14.5 dB and 24 dB, are calculated for 99% of the most unfavourable month at all points within the service area.

Where small fixed or transportable feeder-link terminals are to be employed, it may be desirable to make $(C/N)_u$ somewhat smaller in order to keep the power and cost of the feeder-links within reasonable bounds and to reduce the interference of the feeder-link transmissions into nearby terrestrial microwave links. Further details of this partitioning of link noise contributions are given in Report 952.

Feeder links, including their importance in planning, are considered in detail in Reports 561 and 952.

4. **System examples**

The tables in this section give, purely as illustrative examples, the parameters of broadcasting-satellite systems, using a geostationary satellite of a type that might be possible in the future. It will be observed that some of the examples call for transmitter powers greater than those likely to be practicable for many years. Furthermore, these examples do not take into consideration frequency sharing with other services. However, the parameters of these examples might be modified to correspond to other possibilities which demand less satellite power.

Note. – Examples given are for the bands allocated by the World Administrative Radio Conference, Geneva, 1979. Attention is drawn to the fact that different assumptions are made in the various examples, particularly regarding the reception quality, the receiving installation (noise factor, antenna size) and the area served as determined by the transmitting antenna beamwidth. For this reason, caution must be exercised when comparing the transmitter powers, etc., indicated in the tables.

The way in which the values given in the tables for the transmitter power in the satellite may be modified, if adjustment is made to any of the assumed parameters, is summarized below:

- assuming the use of a transmitting antenna beam of circular cross section, halving the beamwidth will permit a reduction of power by 6 dB. Doubling the beamwidth will require 6 dB more power.
- an increase in the signal-to-noise ratio, made in order to achieve better quality, will require a corresponding increase (in decibels) in the transmitter power. Similarly a decrease will permit an equivalent decrease in the power, but with frequency modulation, the deviation and radio-frequency bandwidth have to be lowered, if the region of the threshold of the discriminator is approached;
- an increase in the factor of merit of the receiving system will lead to a reduction (by an equal amount in decibels) of the transmitter power required and vice versa.

Thus the examples, modified as desired, can serve to indicate the conditions that would be required to enable the public to receive broadcast programmes whose technical quality would be comparable at all times with that of the services provided in the conventional way by a network of terrestrial transmitters.

These examples derive the field strength required for certain stated receiver characteristics. Other assumptions can be made which deal with colour television systems which will result in different required field strengths, and different requirements for satellite e.i.r.p. The object of all of these examples is to establish a reasonable range of satellite power output requirements for a broadcasting-satellite service.

4.1 *Television broadcasting*

Tables VIIIa and VIIIb present examples of community reception and individual reception television systems, respectively, with different frequencies.

Television broadcasting standards for satellite broadcasting are described in Recommendation 650 and Report 1073, and descriptions about multiplexed analogue component techniques are given in Report 1074.

4.2 *Sound broadcasting*

Table IX presents ——— 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 Report 632). Some sound channels could also be associated with television programmes, additional to the sound channel transmitted as proposed in §4.1.

In Germany (Federal Republic of) a digital satellite radio system (DSR) designed for the emission of 16 stereophonic digitally encoded sound programme channels has been in operation since 1989. The use of other systems is under consideration. The detailed descriptions of these systems are given in Reports 955 and 1228.

Report 955 presents the results of studies of satellite sound broadcasting systems operating in other bands for individual reception.

4.3 *High definition television*

Descriptions of HDTV systems and examples of link parameters for HDTV signals using broadcasting satellites in various frequency bands are given in Report 1075.

TABLE VIIIa - *Examples of community reception television system parameters*

Parameter	1	2	3	4	5	6	Remarks
1. System							
Frequency of carrier (GHz)	0.7	2.6	12	12.5	22.75	42	Note 7
Approximate equivalent rectangular bandwidth (MHz)	19	20	27	24	40	40	Note 1
Carrier-to-noise ratio before demodulation (dB)	16	15	16	14	11	11	Note 1
Additional noise of feeder link (dB)	0.5	0.5	0.5	0.5	0.5	0.5	
Required C/N (dB)	16.5	15.5	16.5	14.5	11.5	11.5	
2. Receiving installation							
Figure of merit, G/T (dB(K $^{-1}$))	-4.4	5.9	16.5	14.7	11.6	11.5	Note 2
System noise temperature(K)	750	750	500	500	1100	1500	
Antenna diameter (m)	3.4	3	1.8	1.4	0.8	0.5	
Required PFD at the edge of beam area (dB(W/m^2))	-116.5	-116.2	-111.3	-111.6	-104.1	-98.7	Note 6
3. Propagation							
Spreading loss (dB)	162.4	162.4	162.4	162.4	162.4	162.4	Note 3
Additional attenuation for propagation (dB)	0	0	0	0	2.0	2.0	Note 4
Rain attenuation for 99% of the worst month (dB)	0	0	1.0	1.0	4.0	8.0	Note 4
Required e.i.r.p. from satellite at edge of beam area (dBW)	45.9	46.2	52.1	51.8	64.3	73.7	
4. Satellite transmitter							
Antenna beamwidth (deg.) at -3 dB points	1.4	1.4	1.4	1.4	1.4	1.4	Note 5
Antenna diameter (m)	23.0	6.2	1.3	1.3	0.7	0.4	Note 5
Antenna gain (dBi)	38.5	38.5	38.5	38.5	38.5	38.5	Note 5
Loss in feeders, filters, joints, etc. (dB)	1.0	1.0	1.0	1.0	1.0	1.0	
Required satellite transmitter power (dBW)	8.3	8.6	14.6	14.3	26.8	36.2	
(W)	6.8	7.3	29	27	480	4200	

TABLE VIIIb - *Examples of individual reception television system parameters*

Parameter	7	8	9	10	11	Remarks
1. System						
Frequency of carrier (GHz)	0.7	12	12.5	22.75	42	
Approximate equivalent rectangular bandwidth (MHz)	19	27	24	40	40	Note 1
Carrier to noise ratio before demodulation (dB)	16	14	14	11	11	Note 1
Additional noise of feeder link (dB)	0.5	0.5	0.5	0.5	0.5	
Required C/N (dB)	16.5	14.5	14.5	11.5	11.5	
2. Receiving installation						
Figure of merit, G/T ($dB(K^{-1})$)	-14.0	6.0	10.0	7.5	9.5	Note 2
System noise temperature (K)	-	1100	750	1100	1500	
Antenna diameter (m)	-	0.8	1.0	0.5	0.4	
Required PFD at the edge of beam area ($dB(W/m^2)$)	-107.0	-102.8	-106.9	-100.0	-96.7	Note 6
3. Propagation						
Spreading loss (dB)	162.4	162.4	162.4	162.4	162.4	Note 3
Additional attenuation for propagation (dB)	0	0	0	2	2	Note 4
Rain attenuation for 99% of the worst month (dB)	0	1	1	4	8	Note 4
Required e.i.r.p. from satellite at edge of beam area (dBW)	55.4	60.6	56.5	68.4	75.7	
4. Satellite transmitter						
Antenna beamwidth at -3 dB points (deg.)	1.0	1.0	1.0	1.0	1.0	Note 5
Antenna diameter (m)	32.0	1.8	1.8	1.0	0.5	Note 5
Antenna gain at the edge of service area (dBi)	41.4	41.4	41.4	41.4	41.4	Note 5
Loss in feeders, filters, joints, etc. (dB)	1.0	2.0	2.0	3.0	3.0	
Required satellite transmitter power (dBW)	15.0	21.2	17.1	30.0	37.3	
(W)	32	130	50	1000	5400	

Notes to Tables VIIIa and VIIIb:

(1) Required bandwidth and carrier-to-noise ratio depend on the modulation method and signal quality.

(2) Values are "usable figure of merit" according to the definition given in Annex I of Report 473-4. 55% efficiency and 1 dB pointing error are assumed for calculation of antenna gain, which is usually better than the indicated value, especially below the 12.5 GHz band because of the improvement of the receiver noise temperature and antenna efficiency.

(3) Satellite elevation angle is assumed as 40°.

(4) Rain attenuation should be corrected by using the appropriate value for each climate zone.

(5) Antenna beamwidth should be adjusted to the size of service area. Antenna diameter and gain will be changed accordingly.

(6) The PFD values given here are based on calculations intended to satisfy the required C/N for the satellite broadcasting system and will be required for 99% of the worst month.

(7) The carrier frequency shown in Columns 5 and 10 (22.75 GHz) is an example of the mid frequency of the band allocated to the broadcasting-satellite service in Regions 2 and 3.

5. Other applications to existing and new services

It is agreed as a basic premise that the introduction of these transmissions within a television channel must not create additional interference to other systems nor require additional protection over that required for the standard application of the broadcasting-satellite service, e.g. television transmission.

5.1 *Broadcasting of data in a frequency-modulated television channel*

It is now possible to envisage the use of certain television signal lines for broadcasting data in the broadcasting-satellite service.

The introduction of these new signals should not alter the characteristics of the television channel, the interference levels or the criteria for sharing with other services, as defined by the WARC-BS-77.

A study carried out in France showed the possibility of using this new broadcasting service within the satellite broadcasting channel. ———————— This service uses a system of digital modulation made up in the baseband of an NRZ binary signal frequency limited to the video band. The bit rate is about 6 Mbit/s. The 6.5 MHz sound sub-carrier of the television signal may or may not be superimposed on this signal.

5.2 *Interactive connection*

New and innovative applications of the broadcasting-satellite service in the community reception mode were investigated in the United States and Canada using the Applications Technology Satellite-6 (ATS-6) [IEEE, 1975] and the Communications Technology Satellite (CTS-Hermes). Examples of such applications include distribution of educational, medical, informational and other specialized material, for example, to schools, hospitals and community centres. A more detailed discussion of these applications including examples of particular applications are given in [CCIR, 1974-78b]. Many of these applications are considered to fall within the definition of community reception (Radio Regulations, No. 124).

A number of the applications also had associated with the broadcasting satellite transmission, a return communication connection – for example, to permit students in a classroom to interact with the remote instructor. In some cases this return or "interactive" link utilized satellite transmission. It is expected that the majority of such interactive links will consist of one or more sound channels.

TABLE IX. - *Examples of system parameters for sound broadcasting for individual reception*

Parameter	1	2	3	4	5	6	Remarks
1. System			Note 6	Note 6			
Frequency of carrier (GHz)	12	12	12	12	12	12	
Type of modulation	FM	FM/FM	4-PSK	4-PSK	4-PSK	4-PSK	
Sound frequency bandwidth (kHz)	15	15	15	20	15	15	
Sampling frequency (kHz)			32	48		32	
Number of sound channels	1	12	48	24	96	32	Note 1
Coding law			14/10 NIC	linear 16bit	ADM Note 7	16/14 float. point	
Transmission bit rate (Mbit/s)			24.6	24.6		20.48	
Approximate equivalent rectangular bandwidth (MHz)	0.18	22	27	27			
Carrier to noise ratio before demodulation (dB)	19	14	15.1 Note 2	15.1 Note 2		Note 3 82 (C/No)	
Additional noise of feeder link (dB)	0.5	0.5					
Required C/N (dB)	19.5	14.5	15.6	15.6			
2. Receiving installation						Note 8	
Figure of merit (dB(K^{-1}))	4	4	12.0			3.0	
Required PFD at the edge of beam area (dB(W/m^2))	-118	-103	-110.3			-103	
Received C/N (dB)			16.4				Note 4
C/No (dB)						85	Note 5
3. Propagation							
Spreading loss (dB)	162.4	162.4	162.4			162.4	
Additional attenuation for propagation (dB)	0.5	0.5	0.2			0.5	
Rain attenuation for 99% of the worst month (dB)	1.5	1.5	2.0			2.0	
4. Satellite transmitter							
Antenna beamwidth (deg.)	1.4	1				1.6x0.7	
Antenna gain (dB)	38	41	37			40.9	
Loss in feeders, etc. (dB)	1	1	2.5			2	
Transmitter power (dBW)	10	23	20			23.6	
(W)	10	200	100			230	
E.i.r.p. from satellite at edge of beam area (dBW)	47	63	54.5			62.5	

NIC: Near Instantaneous Companding.

(1) Monophonic channels.

(2) *C/N* for Nyquist bandwidth required to obtain BER of 10^{-7} (before error correction).

(3) For a BER of 10^{-3} (before error correction) corresponding to an excellent sound quality.

(4) *C/N* obtainable with a receiver having Nyquist bandwidth. Difference between required *C/N* and received *C/N* may be assigned as a margin in receiver design. In the case of 27 MHz bandwidth necessary for the reception of television signal, *C/N* will be about 14 dB with parameters given in this table.

(5) The margin between received and required C/N_0 may be used to further reduce the antenna size.

(6) These are possible system parameter variants based on the sound channel transmission used in the system described in § 2.3 of Report 1073. This system also specifies parameters in the first column of this table which conform to Recommendation 651.

(7) Equivalent to use of adaptive delta modulation (ADM) coding described in Report 953.

(8) Corresponding to a 40 cm dish for sound-only reception.

5.3 *Conditional access broadcasting*

A new application of the broadcasting-satellite service is the distribution of selective-access television programmes. This has led the French Administration to study a baseband scrambling technique which meets this requirement [CCIR, 1978-82c].

If the signal subject to scrambling is to remain in conformity with the characteristics of the 625-line standard, the scrambling system selected must retain the line structure of the television picture. The vertical components of the picture must therefore be destroyed so that even if absolute secrecy is not ensured the picture is sufficiently complex to discourage any attempt at deciphering.

This is achieved by introducing transformations in each television line following a pseudo-random sequence moving at the line pulse rate and initiated by each field.

The target receiver(s) is selected by means of keys (known as "service keys") comprising words of 18 bits which determine the pseudo-random sequence.

The equipment which has been under study for some years has been developed into integrated systems for use on analogue (CCD) or digital circuits which permit effective scrambling of the picture.

5.4 *Integrated service digital broadcasting*

Developments of digital technology in the field of broadcasting permit digital information to be transmitted either exclusively or in association with the main signal. A broadcasting-satellite channel is an appropriate medium for this purpose. Its high transmission quality and capacity is suitable for integrated use of various kinds of information to keep high flexibility and efficiency. It is necessary to take into account not only possible compatibility among all broadcasting media but also between other communication services and packaged media.

Study Programme 2N/10-11 decides to study the determination of the technical composition of services and specification of the technical parameters for ISDB so as to permit highly flexible and efficient operation using a broadcasting satellite television channel and to faciliate the design of cost effective systems. (See Report 1227).

6. Additional functions for broadcasting and spacecraft operations

6.1 *Narrow-band cueing channels*

In an operational system using transportable feeder-link stations, a need may be identified for independent SCPC type cueing channels transmitted using the same satellite transponder as the related television signal. A minimum of two of these narrow-band SCPC channels would seem to be necessary for cueing and talk-back. Since the antennas of the feeder-link stations are likely to be larger, these SCPC channels would be transmitted at lower power in order to limit the in-band intermodulation. The transmission of these cueing channels needs to be further studied as to the possibility of accommodating them within the Plans and the possible impact on the quality of transmission.

6.2 *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 service functions to be provided are summarized in Table X.

TABLE X – *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

[*] **Measurements made on the TDF-1 satellite have shown that a boresight error circle of 0.01 degree radius can be achieved in the pointing of the transmitting antenna through RF sensing of a ground beacon [CCIR, 1986-90b].**

While it may be desirable to use part of the broadcast frequency assignments for TTC services exclusively, it may not be feasible to do so from the operational and technology viewpoint. This implies that for certain phases during the lifetime of any broadcasting satellite, different frequency bands may have to be used.

The assignment of specific spacecraft service channels within the broadcast down-link and feeder-link frequency bands will have to be performed in close consultation with the broadcast channel frequency and polarization assignments to ensure compatibility with technological constraints and system operation constraints. Moreover, such assignments will have to be compatible with the broadcast transmissions and must not cause non-permissible interference into other services which share these frequency bands. These considerations suggest that appropriate sharing criteria may have to be developed. More detailed information on the accommodation of spacecraft service functions within the guardbands of the broadcasting-satellite service is contained in Report 1076.

REFERENCES

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[1974-78]: **a.** 11/419 (France); **b.** 11/396 (USA)

[1978-82]: **a.** 10-11S/117 (Japan); **b.** 10-11S/175 (Canada); **c.** 11/265 (France)

[1986-90]: **a.** 10-11S/8 (JIWP 10-11/3); **b.** 10-11S/139 (France)

ANNEX I

VISIBILITY TIME FOR THE SATELLITE

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 XII 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.

TABLE XI - *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.

In the example of TABLE XII, 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.

TABLE XII — *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

ANNEX II

MEASUREMENTS OF ATMOSPHERIC ATTENUATION AND DEPOLARIZATION AT FREQUENCIES OF INTEREST TO THE BROADCASTING-SATELLITE SERVICE

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 XIII. For system planning, it is proposed to use the median values, corresponding to the worst month in an average year.

TABLE XIII — *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 XIV. While the data presented should be regarded as provisional, they may be considered useful until more precise data become available.

TABLE XIV – *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

The values in Japan in Table XIV 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 [CCIR, 1978-82a].

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 Centre by monitoring the beacon on the Communications Technology Satellite (CTS). Measurements commenced at Greenbelt, Maryland in June 1976 and were completed in the fall of 1979. The elevation angles to CTS from Greenbelt and Rosman are 29.5 and 36 degrees respectively.

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

Table XV summarizes the results of these measurements for the two worst months of the measurement period.

TABLE XV — *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 [CCIR, 1978-82b]. 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.

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.

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CCIR Documents

[1978-82]: **a.** 10-11S/117 (Japan); **b.** 10-11S/13 (France)

ANNEX III

EXAMPLES OF SOLAR INTERFERENCE TO A SATELLITE BROADCASTING SYSTEM AS MEASURED DURING THE BSE EXPERIMENT

Figure 3 shows the degradation of carrier-to-noise ratio due to solar interference to the receiving system with a 1.6 m antenna and frequency of 12 GHz, bandwidth of 27 MHz, receiver noise of 650 K and antenna efficiency of 55%.

Maximum degradation due to solar interference is 6.7 dB and the longest time of degradation exceeding 1 dB is 8.4 min. Accumulated time of degradation is 32.8 min. through one period of interference.

For antennas of other sizes, maximum degradation, maximum duration of degradation and accumulated degradation time are as shown in Table XVI.

TABLE XVI

Antenna diameter (m)	Maximum degradation (dB)	Maximum duration (min)	Cumulative duration (min)
1.0	3	9.8	53.3
2.5	7	5.8	17.5
4.5	8	4.0	8.6

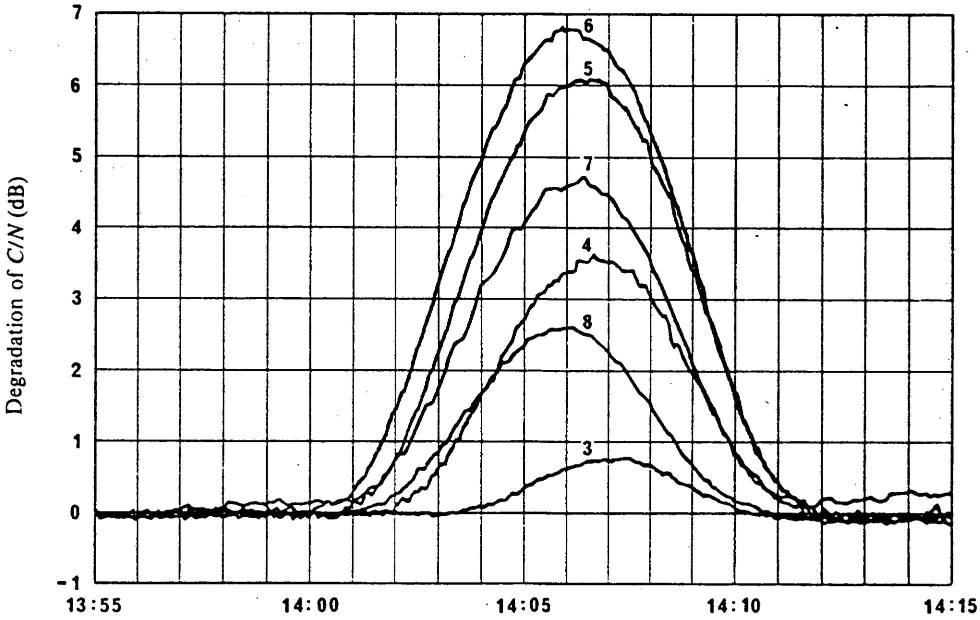

FIGURE 3 – *An example of solar interference to a receiving system with an antenna of 1.6 m diameter, measured in BSE experiment, during one solar interference period*

(Numbers adjacent to curves refer to the dates in March, 1980 on which the measurements were taken)

REPORT 1073-1

TELEVISION STANDARDS FOR THE BROADCASTING-SATELLITE SERVICE

(Question 2/10 and 11, Study Programme 2F/10 and 11)

(1986-1990)

1. Introduction

The present Report briefly describes in a comparative manner the basic characteristics of some of the systems which have been developed for television transmission with sound and data services for satellite broadcasting. Recognizing that there are advantages in reducing the number of modulation methods and the differences in the characteristics of these modulation methods, the basic parameters of each system were used to produce tables which stress the similarities between systems. Only fully specified systems adopted, or being seriously considered for adoption, by at least one administration, were considered in these tables. The detailed specifications of these systems are contained in a separate CCIR publication (Specifications of transmission systems for the broadcasting-satellite service).

Special considerations should be given to those systems that have adopted the general principle of time-division multiplexing since it permits an improvement in the quality of the signals by eliminating, in particular, the problems of intermodulation and cross-colour. A time-division multiplex structure also permits subsequent compatible introduction of further services or further improvements to the quality of the basic services. For example, wide-screen aspect ratio pictures can be transmitted. Displays of the 4:3 type can present the most interesting portion of the picture, selectable by a digital data signal. Further details are given concerning these improvements to the vision signal in Report 1074.

All systems described in this Report apply digital techniques for the sound (and for the data) in order to utilize to the greatest possible extent the capacity made available by the channels defined by the WARC-BS-77 and the RARC SAT-83, taking into account if necessary the need for direct translation on distribution networks with narrower bandwidths. The use of a sound/data multiplex (associated with the service-identification system) making available the capacity required, and at the same time the maximum flexibility, is also a very important asset. Possibilities of scrambling the signal for secure transmission and controlled reception are increasingly viewed as an important feature of such systems.

This Report presents a short summary of the main features of each of the fully specified systems considered. It is followed by tables listing values for the main characteristics of each system.

2. Summary description of the systems

2.1 *MAC/packet family*

The MAC/packet family of standards has three members all suited to satellite broadcasting: C-MAC/packet, D-MAC/packet and D2-MAC/packet. These systems have been optimized under different constraints and meet the various broadcasting-satellite service requirements in the 12 GHz band when the 625 line standard is used with a satellite channel of 27 MHz bandwidth.

The systems incorporate the following common features:

- time division multiplexing;
- MAC picture coding, with the capacity for extended aspect ratio (see Report 1074);
- packet multiplexing for sound and data;
- digital high and medium quality sound coding and error protection method (see Recommendation 651 and Report 632);
- service identification and conditional access systems with video and audio scrambling [CCIR, 1986-90a, b].
- full channel digital mode, when the area of the television frame normally reserved for the MAC vision signal (and its blanking interval) is replaced by data burst (see Report 1228).

The clock frequencies used in these three systems have simple relationships with the sampling frequencies of the digital studio standard defined in Recommendation 601.

This close relationship between these systems allows for the development and introduction of receivers capable of functioning with all of the standards.

2.1.1 *C-MAC/packet*

The C-MAC/packet system was, in part, developed to provide a high data channel capacity.

The particular features of the C-MAC/packet system are:

- the use of an RF time division multiplex wherein the carrier is frequency modulated by analogue picture signals during a certain fraction of line duration and 2-4-PSK modulated during the remainder of the line duration by a multiplex conveying several sound channels, synchronization and data signals;
- the capacity of the sound/data multiplex is about 3 Mbit/s, equivalent to eight high quality sound channels of 15 kHz bandwidth with near instantaneous 14/10 bit companding (protected by one parity bit per sample). The spare data capacity can be used for other services.

The C-MAC/packet system was adopted by the United Kingdom in 1983 and by Finland, Iceland, Norway and Sweden in August 1984* for broadcasting-satellite services.

2.1.2 D-MAC packet

The D-MAC/packet system was, in part, developed to provide both a high data channel capacity and a single baseband interface to other transmission and distribution media.

The particular features of the D-MAC/packet system are:

- a baseband time division multiplex in which the analogue picture signals are combined with duobinary encoded digital sound, synchronization and data signals;
- the capacity of the sound/data multiplex is about 3 Mbit/s, equivalent to eight high quality sound channels of 15 kHz bandwidth with near instantaneous 14/10 bit companding (protected by one parity bit per sample). The spare data capacity can be used for other services;
- the single baseband representation of the time division multiplex signal is frequency modulated for satellite broadcasting.

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* The adoption was also supported by the Administration of Denmark.

The D-MAC/packet system has been under further investigation by experts of a number of organizations and has been shown to be also suitable for satellite broadcasting.

As a result of these developments, the United Kingdom now intends to use the D-MAC/packet system for broadcasting-satellite services.

2.1.3 *D2-MAC/packet*

The D2-MAC/packet system was, in part, developed to provide a single baseband interface to other transmission and distribution media.

The particular features of the D2-MAC/packet system are:

- a baseband time division multiplex in which the analogue picture signals are combined with duobinary encoded digital sound, synchronization and data signals;
- the capacity of the sound/data multiplex is about 1.5 Mbit/s, equivalent to four high quality 15 kHz sound channels with near instantaneous 14/10 bit companding (protected by one parity bit per sample). The spare data capacity can be used for other services;
- the single baseband representation of the time division multiplex signal is frequency modulated for satellite broadcasting.

The Federal Republic of Germany and France have adopted the D2-MAC/packet system for operational use with their broadcasting-satellite services (TV-SAT and TDF-1)* when implemented.

2.2 *B-MAC systems*

Two closely related implementations of the B-MAC system have been developed for 525 and 625 line applications. Both systems are well suited to use in broadcasting-satellite service applications in the 12 GHz band using either 24 MHz or 27 MHz channelling.

The B-MAC signal is a baseband time division multiplex comprising analogue picture signals combined with a four (or two) level data burst containing digital sound, synchronization and data information.

Vision signal coding is performed using the same time compression factors as the C-MAC/packet and D2-MAC/packet systems. The clock frequencies of 625/50 and 525/60 B-MAC systems are the same multiples of the relevant line scan frequencies to permit use of the same integrated circuit devices for both systems. In the 525 line version the clock frequencies are simply related to the NTSC sub-carrier frequency, facilitating simple transcoding to NTSC. Both B-MAC systems can be configured to permit transmission of pictures with 16:9 aspect ratios.

The B-MAC systems provide a total data capacity of about 1.6 Mbit/s. This can be used to provide six high quality 15 kHz audio channels using adaptive delta modulation which features error concealment and parity protection (see Report 953); alternatively these channels may be configured as 204 kbit/s data channels. A utility data channel makes use of spare capacity in the data multiplex.

Included in the B-MAC structure is a conditional access system based on line translational scrambling for video, and data encryption for digital audio. Because of the high degree of commonality between the 625 and 525 line B-MAC systems it will be possible to develop a single receiver capable of receiving either B-MAC system.

The B-MAC system provides a single baseband interface to other transmission and distribution media.

The 625 line B-MAC system has been adopted in Australia for the Homestead and Community Broadcasting-Satellite Service (HACBSS) which commenced operation in October 1985.

The 525 line B-MAC system is under active consideration by the Direct Broadcasting Satellite Association and the Advanced Television Systems Committee in the United States and also by Canada.

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* Direct broadcasting 12 GHz band satellites of the Federal Republic of Germany (TV-SAT) and of France (TDF-1)."

2.3 *Digital sub-carrier/NTSC system*

In this system a digital sub-carrier is frequency multiplexed with the conventional NTSC vision signal. It has been developed for use in the broadcasting-satellite service.

The vision parameters of the system are based on those of system M/NTSC described in Report 624, thus the system is compatible with the terrestrial vision standard.

The sound/data signals are carried on a 5.73 MHz sub-carrier using differential 4-phase shift keying. This sub-carrier, together with the vision signal, frequency modulates the main carrier. The data capacity of the system is about 2 Mbit/s. This can provide four 15 kHz high quality audio channels using 14/10 bit near instantaneous companding, or two 20 kHz very high quality channels through the use of 16 bit linear coding. An additional data channel is also provided in both cases. Both schemes use BCH (63,56) coding error protection.

This system was adopted by the Japanese Administration in 1982 for use with its operational broadcasting-satellite service. This service commenced operation in May 1984 using BS-2a; it conforms to the WARC-BS-77 Plan.

Detailed specifications have been defined for the data channel, the capacity of which varies from 224 to 1 760 Kbps depending on the mode of sound transmission. A packet multiplexing scheme is used for the data channel (see Report 954, section 4.1) [CCIR, 1986-90c].

TABLE I – *Vision/data multiplex structure*

Parameter/System			MAC PACKET SYSTEMS			B-MAC (625 line)	B-MAC (525 line)	Digital sub-carrier/ NTSC
			C	D	D2			
General parameters	1.1	Modulation frame frequency (Hz)	25				29.97	
	1.2	Number of lines per picture (frame)	625				525	
	1.3	Line frequency (Hz)	15 625				15 734	
	1.4	Number of time increments per line	1 296			1 365		–
	1.5	Nominal reference clock frequency (MHz)	20.25			21.328	21.477	–
Multiplex structure	1.6	Multiplexing principle	**Radio frequency**	Baseband				Sub-carrier
	1.7	Vision coding	Time multiplexed analogue components					Composite (1)
	1.8	Nominal transmitted vision bandwidth (MHz)	8.4 (2)			7.5 (2)	6.3 (2)	4.5
	1.9	Nominal vision amplitude (V peak-to-peak (3))	1.000					
	1.10	Data coding	**See § 4.2 of Table IV**	**Duobinary**		Quaternary/binary (4)		See § 4.2 of Table IV
	1.11	Symbol rate (Mbaud)	**20.25**		10.125	7.11	7.16	2.048
	1.12	Occupied data spectrum (MHz)	**Not applicable**	**10.0**	5.0	7.11 (5)	7.16 (5)	1.2
	1.13	Nominal data amplitude (V peak-to-peak) (3)	**Not applicable**	**0.800**	0.800	0.770		See Table IV
	1.14	Number of bits per symbol	1			2/1 (4)		1

TABLE I *(continued)*

	Parameter/System	MAC PACKET SYSTEMS			B-MAC (625 line)	B-MAC (525 line)	Digital sub-carrier/ NTSC
		C	D	D2			
Multiplex structure	1.15 Instantaneous bit rate (Mbit/s)	20.25		10.125	14.22/7.11 (4)	14.32/7.16 (4)	2.048
	1.16 Multiplex description (6)	Flexible (7)			Rigid		–
	1.17 Basic frame multiplex configuration	See Fig. 1					–
	1.18 Basic line multiplex configuration	See Fig.2(a)	See Fig.2(b)	See Fig. 3	See Fig. 4		–
Reference signals	1.19 Synchronization principle	Digital code word					Vision: (1) Data: digital code word
	1.20 Clock recovery	Recovered from data			10 cycle (20 symbol) reference burst on each line		–
	1.21 Line synchronization	6 bit word			Not applicable		(1)
	1.22 Frame synchronization	64 bit word in line 625			1 131 symbols in line 2 (8)		16 bits/data frame
	1.23 Reference level for video and data clamping	Constant level			Average level of 20 symbol (binary) reference burst in HBI		Vision: (1) Data: irrelevant
	1.24 Clamp period (µs)	0.75			2.81	2.79	Vision: (1) Data: irrelevant
	(number of clock periods)	15			60		
	1.25 AGC reference level (V) (3)	± 0.500 relative to clamp level on one line per field in the VBI			−0.500 relative to clamp level on one line per field in the VBI		–

Footnotes to Table I

(1) The system is based on baseband characteristics of the M/NTSC system (see Report 624).

(2) In each case this bandwidth is below the limit imposed by the sampling frequency (see Report 1074).

(3) All voltages are measured with respect to a 75 Ω load.

(4) Two data coding implementations are possible. Firstly a quaternary system with 2 bits per symbol and secondly a more rugged binary code.

(5) Before transmission, the spectrum is intentionally bandwidth-limited by 6.3 MHz filtering.

(6) The multiplex structure may be compatibly reconfigured for full field data.

(7) By description of each component in terms of time increments and line numbers in line 625.

(8) This is line two of the B-MAC format, equivalent to PAL line 625.

TABLE II – *Vision coding*

	Parameter/System	MAC packet C, D, D2	B-MAC (625 line)	B-MAC (525 line)	Digital sub-carrier/ NTSC
General video parameters	2.1 Scanning method	Left to right, top to bottom			
	2.2 Active lines per frame	574		483	
	2.3 Spare lines per frame (available for additional services and test signals)	47	21/38 (1)		24
	2.4 Interlace ratio	2 : 1			
	2.5 Aspect ratio	4 : 3 (2)			4 : 3
	2.6.1 Assumed gamma of display 2.6.2 Overall gamma	2.8 1.2		2.2 1.0	
	2.7 Primary colour chromaticities: Red: Green: Blue:	x y 0.67 0.33 0.21 0.71 0.14 0.08			
	2.8 Chromaticity coordinates for equal primary signals $E'_R = E'_G = E'_B$	Illuminant D_{65} $x = 0.313$, $y = 0.329$			Illuminant C $x = 0.310$, $y = 0.316$
	2.9 Luminance signal equation	$E'_Y = 0.299\ E'_R + 0.587\ E'_G + 0.114\ E'_B$			
	2.10 Colour difference signal equations	$E'_R - E'_Y = 0.701\ E'_R - 0.587\ E'_G - 0.114\ E'_B$ $E'_B - E'_Y = -0.299\ E'_R - 0.587\ E'_G + 0.886\ E'_B$		$E'_I = -0.27\ (E'_B - E'_Y) + 0.74\ (E'_R - E'_Y)$ $E'_Q = 0.41\ (E'_B - E'_Y) + 0.48\ (E'_R - E'_Y)$	

TABLE II *(continued)*

	Parameter/System	MAC packet C, D, D2	B-MAC (625 line)	B-MAC (525 line)	Digital sub-carrier/ NTSC
Luminance	2.11 Number of clock periods	696	750		Not applicable (3)
	2.12 Compression ratio	3 : 2			
	2.13 Nominal sampling frequency (MHz)	13.500	14.219	14.318	
	2.14 Uncompressed bandwidth (MHz) (nominal)	5.6 (4)	5.0 (4)	4.2 (4)	4.5
	2.15 Reference black level (V) (5)	−0.500 relative to clamping level			Not applicable (3)
	2.16 Transmitted luminance signal equation (V) (5)	$-0.500 + E'_Y$			
	2.17 Amplitude range (V peak-to-peak) (5)	From −0.500 to +0.500			
Chrominance	2.18 Number of clock periods	348	375		
	2.19 Compression ratio	3 : 1			
	2.20 Sampling frequency (MHz)	6.750	7.109	7.159	
	2.21 Uncompressed bandwidth (MHz) (nominal) (6)	2.4	2.1		
	2.22 Zero chrominance reference level (V) (5)	0.000 relative to clamping level			
	2.23 Transmitted chrominance signal equations (V) (5)	$E'_{DB} = 0.733\,(E'_B - E'_Y)$ $E'_{DR} = 0.927\,(E'_R - E'_Y)$	$E'_{DB} = 0.694\,(E'_B - E'_Y)$ $E'_{DR} = 0.926\,(E'_R - E'_Y)$		

TABLE II *(continued)*

	Parameter/System	MAC packet C, D, D2	B-MAC (625 line)	B-MAC (525 line)	Digital sub-carrier/ NTSC
Chrominance	2.24 Amplitude range (7) (V peak-to-peak) (5)	From −0.500 to +0.500			Not applicable (3)
	2.25 Sequential transmission	E'_{DB} transmitted on odd active lines of each field E'_{DR} transmitted on even active lines of each field			
	2.26 Vertical pre-filtering (8)	Filter parameters left to choice of broadcaster	0.25, 0.5, 0.25		
	2.27 Coincidence between luminance and chrominance	Chrominance is transmitted one line before associated luminance			
Scrambling process	2.28 Scrambling process for conditional access	Double cut component rotation or single cut line rotation	Line translation		Under consideration

(1) The lesser figure pertains to a full conditional access system.

(2) The systems can also provide for an aspect ratio of 16 : 9.

(3) The system is based on baseband characteristics of the M/NTSC system (see Report 624).

(4) This bandwidth may be extended to approach the Nyquist bandwidth (e.g. to accommodate a 16 : 9 aspect ratio).

(5) All voltages are measured with respect to a 75 Ω load.

(6) This bandwidth will be limited in the encoder by a filter designed to minimize ringing.

(7) The chrominance signals accommodate 75% saturation and 100% amplitude colour bars.

(8) A 0.5, 0, 0.5 filter should be used in the receiver.

TABLE III – *Data multiplex structure*

	Parameter/System	C-MAC/packet D-MAC/packet	D2-MAC/packet	B-MAC (625 line)	B-MAC (525 line)	Digital sub-carrier/ NTSC
General data parameters	3.1 Useful data burst (bits/line)	2 × 99 (¹)	99	102/51 (²)		–
	3.2 Type of multiplex	Packet		Continuous		Continuous for sound, packet for data
	3.3 Organization	2 × 82 packets of 751 bits/frame (¹)	82 packets of 751 bits/frame	6 channels of 203 kbit/s plus one channel of 62.5 kbit/s	6 channels of 204.5 kbit/s plus one channel of 62.9 kbit/s	Data frame comprising 32 columns of 64 bits each
	3.4 Mean data rate (Mbit/s)	3.08 (³) (2 × 2 050 packet/s)	1.54 (³) (2 050 packet/s)	1.59	1.60	2.048
	3.5 Scrambling (for conditional access)	By addition of mod. 2 of pseudo-random binary sequence at data channel level synchronized on modulation frame		Not disclosed		Under consideration

TABLE III *(continued)*

<table>
<tr><th colspan="2">Parameter/System</th><th>C-MAC/packet
D-MAC/packet</th><th>D2-MAC/packet</th><th>B-MAC
(625 line)</th><th>B-MAC
(525 line)</th><th>Digital sub-carrier/
NTSC</th></tr>
<tr><td rowspan="7">Sound coding</td><td>3.6 Audio sampling frequency</td><td colspan="2">32 kHz for high quality (HQ)
16 kHz for medium quality (MQ)</td><td colspan="2">Basic audio rate
(for high quality)</td><td rowspan="4">32 kHz
or
48 kHz</td></tr>
<tr><td></td><td colspan="2"></td><td>203 kbit/s</td><td>204.5 kbit/s</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="2">Step size control</td></tr>
<tr><td></td><td colspan="2"></td><td>7.8 kbit/s</td><td>7.9 kbit/s</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="2">Emphasis control</td><td></td></tr>
<tr><td></td><td colspan="2"></td><td>7.8 kbit/s</td><td>7.9 kbit/s</td><td></td></tr>
<tr><td>3.7 Audio pre-emphasis</td><td colspan="2">CCITT Recommendation J.17</td><td colspan="2">Adaptive</td><td>50/15 μs</td></tr>
<tr><td></td><td>3.8 Audio coding method</td><td colspan="2">Linear 14 bit/sample (L)
or
near instantaneous 10 bit/sample (I)
Coding range: 5 levels</td><td colspan="2">Adaptive delta modulation
(see Report 953) (4)</td><td>14/10 near
instantaneous
or
16 bit linear</td></tr>
<tr><td></td><td>3.9 Protection</td><td colspan="2">Protection range: 2 levels
1 – first level by 1 parity bit per sample;
or
2 – second level by 5 bit Hamming code per sample</td><td colspan="2">2.33 bits per 13 bit block</td><td>BCH (63,56),
SEC, DED</td></tr>
<tr><td></td><td>3.10 Packet rate per monophonic or stereophonic channel (packets/s)</td><td colspan="2"><table>
<tr><th></th><th>MQ mono</th><th>HQ mono</th><th>HQ stereo</th></tr>
<tr><td>I1</td><td>253</td><td>503</td><td>1 003</td></tr>
<tr><td>L1</td><td>336.3</td><td>669.7</td><td>1 336.3</td></tr>
<tr><td>I2</td><td>336.3</td><td>669.7</td><td>1 336.3</td></tr>
<tr><td>L2</td><td>447.4</td><td>891.9</td><td>1 780.8</td></tr>
</table></td><td colspan="3">Not applicable</td></tr>
<tr><td></td><td>3.11 Identification of coding method</td><td colspan="2">Explicit by interpretation blocks</td><td colspan="2">Not applicable</td><td>Control code</td></tr>
<tr><td></td><td>3.12 Maximum number of high quality monophonic audio channels</td><td>8</td><td>4</td><td colspan="2">6/3 (2)</td><td>4 (15 kHz)
or
2 (20 kHz)</td></tr>
</table>

TABLE III *(continued)*

	Parameter/System	C-MAC/packet D-MAC/packet	D2-MAC/packet	B-MAC (625 line)	B-MAC (525 line)	Digital sub-carrier/ NTSC
Service identification	3.13 Service identification data location	1 line per frame in VBI and data channel 0 of packet multiplex		2 lines per frame in VBI		Under consideration
	3.14 Service description data organization	Data groups, commands and parameters carried by packets		Not applicable		
Conditional access	3.15 Control of descrambling	Control word for initialization of pseudo-random binary sequence		Not disclosed		Under consideration
	3.16 Secret information	Authorization keys per service Distribution key per subscriber		Not disclosed		
	3.17 Entitlement checking and management	Encrypted control words and authorization keys are broadcast in the data multiplex		Not disclosed		
	3.18 Addressing rate (addresses/h)	150 000 per kbit/s		1 000 000		
	3.19 Maximum number of addresses	64 × 10^9		256 × 10^6		
Data Broadcasting	3.20 Teletext coding	CCIR Teletext Systems A,B [CCIR, 1986-90d]				
	3.21 Protection	Protection range: 2 levels 1- CRC within teletext data block (2 teletext data blocks/packet) 2- CRC within teletext data block plus (24,12) Golay code FEC overall (1 protected teletext data block/ packet)				
	3.22 Identification of coding method	Set by parameter (DCINF) in the Service Identification channel				

(1) In assembling the packet multiplex, two data bursts can be utilized as a single entity.

(2) Two data coding implementations are possible: firstly a quaternary system with 2 bits per symbol and secondly a more rugged binary code.

(3) The multiplex structure may be compatibly reconfigured for full field data.

(4) Report 795 contains a description of a sound system under development in the United States which transmits four channels of directional information in two discrete channels using adaptive delta modulation for sound coding.

TABLE IV – *Modulation parameters*

	Parameter/System	C-MAC/packet	D2-MAC/packet D-MAC/packet	B-MAC (625 line)	B-MAC (525 line)	Digital sub-carrier/ NTSC
Modulation parameters	4.1 Nominal channel bandwidth (MHz)	27		24		27
	4.2 Data signal modulation	2-4-PSK	FM			4Φ-DPSK-FM
	4.3 Vision signal modulation	FM				FM
	4.4 Polarity of frequency modulation	Positive				
	4.5 Reference level frequency position	Exactly centred in channel				–
	4.6 DC component	Preserved				a.c. coupled
	4.7 Frequency deviation (MHz/V)	13.5		16.5	17.5	17.0 (¹)
	4.8 Pre-emphasis characteristic	E1(³) $= H(f) = A \dfrac{1 + jf/f_1}{1 + jf/f_2}$				CCIR Recommendation 405
	4.9 Pre-emphasis parameters A:	0.7071				
	f_1 (MHz)	0.84		1.87		
	f_2 (MHz)	1.50		3.74		
	4.10 Energy dispersal (kHz)	600 Triangular frame synchronous waveform				
	4.11 Sub-carrier frequency (MHz)	Not applicable				5.7272 (²)
	4.12 Frequency deviation of main carrier by sub-carrier (MHz)	Not applicable				± 3.25

(¹) This refers to video only deviation, i.e. without the sub-carrier.

(²) The sub-carrier frequency has been determined to be 8/5 times the nominal colour sub-carrier frequency considering the margin of the filter characteristics to avoid mutual interference between picture and PSK signal, and others.

(³) In addition to E1, a non-linear emphasis may be used for the MAC/packet family, see Report 1074, section 3.4.1.

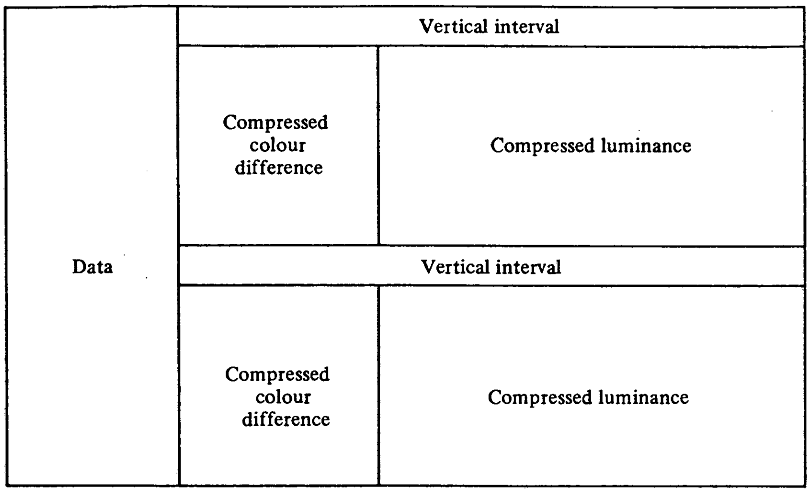

FIGURE 1 – *Basic TDM frame configuration*

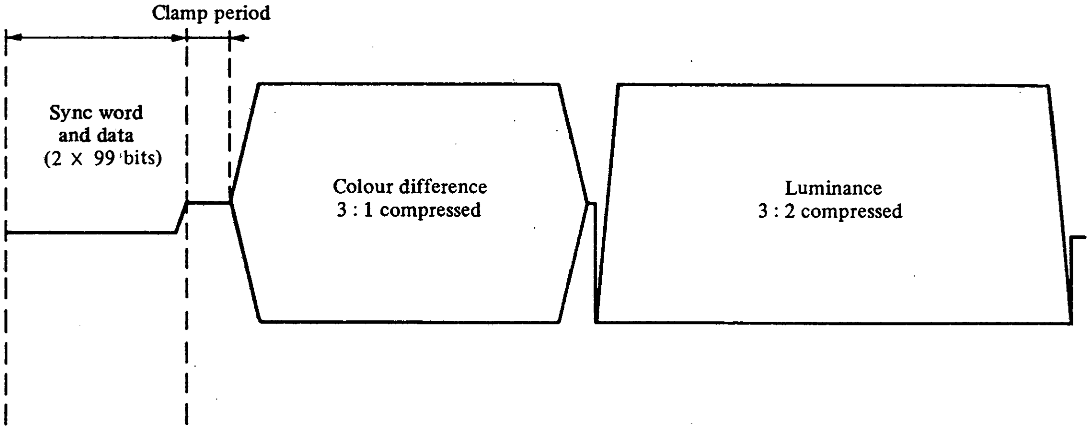

FIGURE 2(a) – *C-MAC/packet signal waveform (unscrambled)*

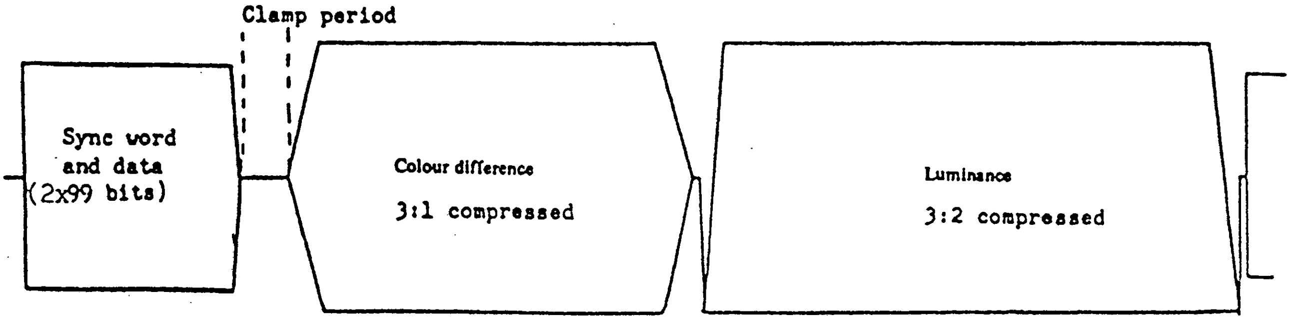

FIGURE 2(b) - D-MAC/packet signal waveform (unscrambled)

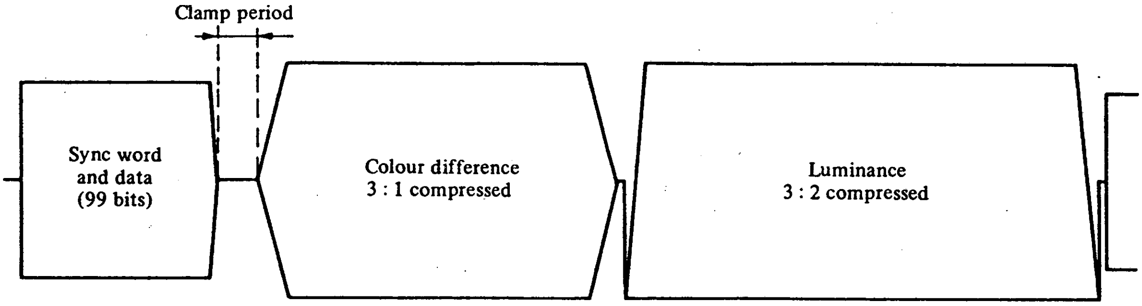

FIGURE 3 – *D2-MAC/packet baseband signal waveform (unscrambled)*

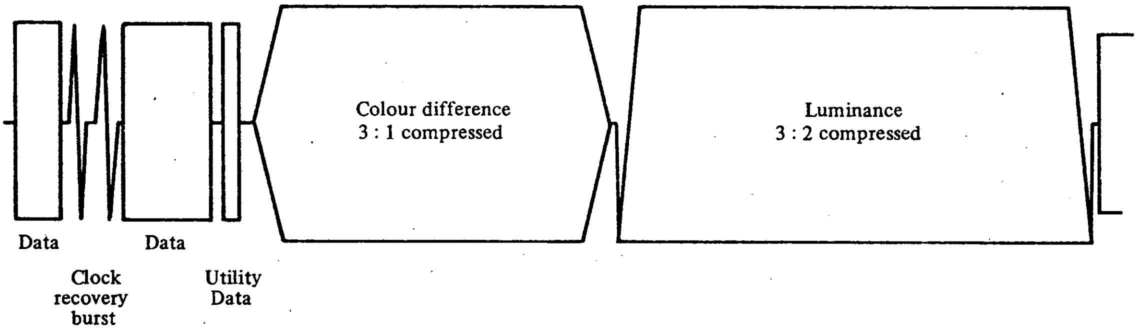

FIGURE 4 – *B-MAC signal waveform (unscrambled)*

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CCIR Documents

[1986-90]: **a**. JIWP 10-11/3-116 (France); **b**. JIWP 10-11/3-117 (United Kingdom); **c**. 10-11S/119 (Japan); **d**. JIWP 10-11/5 CP36 (EBU).

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[1982-86]: 10-11S/127 (CCIR); 10-11S/154 (IWP 10-11/3); 10-11S/164 and Addendum 1 (EBU); 10-11S/165 and Addendum 1 (EBU); 10-11S/170 (France); 10-11S/179 (France); 10-11S/178 (USA); 10-11S/182 and Addendum 1 (France, Germany (Federal Republic of)); 10-11S/193 (Australia); 10-11S/204 (Japan).

REPORT 1074-1

SATELLITE TRANSMISSION OF MULTIPLEXED ANALOGUE COMPONENT (MAC) VISION SIGNALS*

(Question 2/10 and 11, Study Programme 2F/10 and 11)

(1986-1990

1. Introduction

In 1977, the World Administrative Radio Conference established the Plan for satellite broadcasting in Regions 1 and 3, for the 12 GHz band. It was assumed at that time that television would use a conventional composite baseband signal, such as PAL or SECAM, with an analogue sub-carrier for the associated sound. However, the Plan does not preclude the use of other systems. Likewise, the Plan developed at the RARC SAT-83 for Region 2 assumed the use of conventional composite television signals such as NTSC with analogue sound sub-carriers but considerations were given to new systems resulting in allowance in the Plan for the use of such new systems as long as the interference criteria are still met.

Since that time, broadcasters have shown an increasing interest in providing an improved service. For example, there has been an agreement on a studio standard for digital video signals using separate components rather than composite coding.

Following this agreement intensive studies by certain organizations have led to the development of the new analogue component coding method intended for satellite transmission known as multiplexed analogue components (MAC).

The transmission of component signals would enable the viewer to obtain more benefits from future all-digital studios than if composite coding were retained for the transmission. Moreover, there is a tendency to provide a component interface to the domestic receiver and to magnetic tape recorders. These developments present an opportunity to create common standards for the broadcasting-satellite service (BSS) (see Report 632).

Several improved 625-line vision systems suitable for the BSS have been studied by the EBU; objective and subjective measurements have been made on a system using component signals, together with comparative measurements on conventional PAL and SECAM systems.

Based on this work, the EBU experts have developed a family of systems in which the vision signal is conveyed by the time-compressed component method. All the members of this family are suitable for satellite broadcasting. They are known as the C-MAC/packet system, the D-MAC/packet system and the D2-MAC/packet system and are described in Report 1073.

Similar studies of improved vision systems for the BSS in Canada and in the United States have led to the development of different 525 line and 625 line MAC systems using the B-type sound multiplex. The results of this work were treated at length in the RARC SAT-83 [CCIR, 1982-86a]. One of these systems (B-MAC) is described in Report 1073.

This Report describes the general characteristics of MAC systems, gives reasons for the choice of parameters for the 625-line and 525-line MAC vision systems, discusses future enhancements to such systems, and considers vision scrambling methods.

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* The information contained in Report 1074 should also be used to harmonize the information in other related CCIR Reports, Recommendations and publications on BSS systems.

2. General characteristics of MAC systems

2.1 *The limitations of composite coded signals as applied to the BSS*

The composite signals used in conventional television (NTSC, PAL, SECAM) were designed 30 years ago. The designs were optimized for AM transmissions and for compatibility between monochrome and colour receivers. This led to the inclusion of a colour sub-carrier in the upper part of the luminance band such that the colour information is "band shared" with the high frequency luminance information. It is the presence of this colour sub-carrier that creates the most noticeable limitations of composite coded signals which are cross-luminance, cross-colour susceptibility to FM noise and differential gain and phase.

An inherent feature of an FM system is that the demodulated noise power density increases as the square of the baseband frequency. Thus, when conventional television coding is used in the satellite channel, the chrominance signal is subject to more noise per unit bandwidth than the luminance signal. In the chrominance demodulation process, the high frequency noise is transformed into noise of lower frequency which is subjectively more disturbing. The net effect of this is to create an imbalance between the noise characteristics of the luminance and chrominance channel, such that colour difference noise is the dominant impairment at low values of C/N [Lucas and Windram, 1981].

Another feature of satellite transmissions of FM television signals is that the characteristics of the FM noise changes when the system is operated below FM threshold. These conditions may be the result of weather conditions and/or a misaligned antenna. In conventional television systems the de-emphasis network transforms this noise into long black and white streaks which are subjectively annoying and difficult to conceal. Furthermore, the presence of the colour sub-carrier reduces the FM threshold of the system and can cause intermodulation distortion with the sound signals.

With conventional receivers the effects of cross-colour and cross-luminance are such as to limit the effective bandwidths of the luminance and colour-difference signals to relatively low values (to around 3.5 MHz and 1 MHz respectively in the PAL system and for the NTSC system to around 3.2 MHz and 0.6 MHz). Cross effects can be reduced in receivers incorporating comb filters and field stores. In the case of still pictures cross effects can largely be eliminated and the luminance bandwidth is only constrained by the presence of the sound sub-carrier. With moving pictures, however, the reduction in cross effects is more limited and requires more complex storage mechanisms and motion adaptive filtering algorithms.

It was for all of the above reasons that the new component coding system (MAC) was devised. MAC has been designed to match the characteristics of the FM channel and to provide the basis for future developments.

2.2 *The MAC signal*

In the MAC vision coding system the luminance and one of the two colour-difference signals of the active line are separately time-compressed and placed in sequence within the line to form a time division multiplexed analogue component signal. The two time-compressed colour-difference signals are transmitted on alternate lines so as to minimize the necessary compression ratios of all signals and so improve noise performance [Lucas and Windram, 1981].

On reception the luminance and colour-difference signals are reconstituted by the use of line stores in the decoder. This method enables the noise impairments to be distributed appropriately between the chrominance and luminance to give improved performance under weak signal conditions. Cross effects are removed completely.

Time compression of the vision signals results in a proportionate increase in the video bandwidth required to pass the signal. However, the spectral width of the FM signal is a function of both frequency and amplitude of the baseband signals and this can be used to accommodate a time-compressed signal. The absence of a colour sub-carrier reduces the deviation at high modulating frequencies which allows the bandwidth of the baseband vision signals to be increased.

For a constant video bandwidth signal time compression in the coder followed by time expansion in the decoder results in an increase in the noise power at the receiver signal outputs. To a first approximation the noise power increases as the cube of the compression ratio.

It is clear from these considerations that particular care should be taken to minimize the compression ratios used in the design of MAC systems. In general however, MAC systems can be designed to have superior noise performance to conventional television systems employing the same vision bandwidths [Windram *et al.*, 1983a]. In this context the advantages of the MAC system are particularly strong when the C/N ratio is at or below FM threshold because the MAC de-emphasis network causes only short horizontal streaks which are subjectively less disturbing than those in conventional systems. Furthermore, the threshold noise streaks do not spread to adjacent picture elements and so concealment methods may readily be applied.

2.2.1 Multiplexing aspects

Several variants of the MAC format have been developed to an advanced stage: C-MAC/packet, D-MAC/packet, D2-MAC/packet, B-MAC type systems. Development work on another variant, A-MAC, has been dropped. The main difference relates to the way in which the digital sound/data signals are multiplexed with the MAC vision signal.

In the C-MAC/packet system the sound and data signals are inserted into the line blanking interval of the modulated video signal at RF in the form of a digitally-modulated carrier. At the transmission point time division multiplexing is carried out at intermediate frequency, switching between frequency modulated video and digitally-modulated sound and data in such a way as to maintain continuity of phase in the transmitted RF carrier.

In the case of the D-MAC/packet system and the D2-MAC/packet system developed by the EBU and the B-MAC systems developed in Canada and the United States, the sound and data signals are carried in the line blanking interval at baseband as digital signals. For these systems, the signal spectrum for the audio/data signal can be recovered at baseband from the output of the video phase-locked loop demodulator discriminator.

A MAC/packet signal (C, D, D2) using a compressed video bandwidth of 8.4 MHz has been shown to meet the WARC-BS-77 requirements for interference in practical tests (see Report 634). Measurements on interference aspects for the B-MAC system indicated that the co-channel interference criterion of the RARC SAT-83 is met (see Report 634).

2.2.2 Vision aspects

With C-MAC/packet and B-type sound multiplex (D-MAC/packet, D2-MAC/packet, B-MAC) the absence of sub-carriers allows the bandwidth of the baseband video signals or the deviation to be increased: the possibility of increasing the compressed video bandwidth to around 11 MHz is supported by evidence from interference tests on a system known as extended PAL [Shelswell, 1982; Rhodes, 1985].

Further work is required to confirm the upper limits of baseband obtainable with C-, D- or D2-MAC/packet systems. Nevertheless, it is likely that uncompressed video bandwidths of greater than 7 MHz for the luminance and greater than 3 MHz for the colour-difference signals will be obtainable. Such wider bandwidth transmissions may be needed in the future to obtain the higher resolution required for large screen displays. In this situation larger antennas and/or techniques such as noise reduction would be employed.

A further feature of C-, D- or D2-MAC/packet systems is the facility to signal changes in the boundaries between the digital signal and the vision signal; and between the vision signal and the field blanking interval. Proposals have been made to use this facility to transmit pictures of wider aspect ratio.

Techniques for obtaining extended definition signals of wider aspect ratio with MAC systems are further discussed in § 3 and 4 of this Report.

The MAC waveform is also very suited to vision scrambling for conditional access purposes (see § 5). Such scrambling methods require a simple means of rearranging the vision blocks. The separation of the components in a time division multiplex facilitates this. The de-scrambling would be easily accomplished in the line stores of the MAC decoder without the need for additional circuitry.

The problem of compatibility with existing receivers is similar whether MAC or conventional television coding is used. In either case new outdoor and indoor units of comparable overall complexity are required. In the MAC case, however, many receivers will need a composite coder in the indoor unit.

2.2.3 Summary

MAC systems offer many advantages over conventional systems. These include:

- the elimination of cross-colour and cross-luminance;
- improved horizontal luminance and colour-difference resolution;
- an overall improvement in subjective noise;
- reduced distortion and intermodulation;
- more efficient use of the transmission channel;
- facilitates vision scrambling for conditional access;
- potential for higher definition and wider aspect ratio pictures;
- retains high capacity digital sound/data transmissions.

3. Reasons for the choice of parameters for the MAC vision system used in the C-, D- and D2-MAC/packet systems defined in Report 1073

This section gives background information on the parameters for the particular MAC vision system described in Report 1073.

In specifying the vision characteristics for the MAC system, many decisions concerning the time multiplexing and the band shaping had to be made. For example:

- the best order for transmitting the colour-difference and the luminance components;
- line simultaneous or line sequential transmission of the colour-difference signals;
- the optimum bandwidth and levels for the luminance and colour-difference signals taking into account the requirements for horizontal resolution and noise;
- vertical resolution;
- the time compression of the luminance and colour-difference signals;
- the pre- and de-emphasis characteristic;
- picture quality;
- scrambling for conditional access;
- compliance with the WARC-BS-77;
- scope for future enhancements.

Most of the above characteristics are mutually dependent, so compromises had to be found.

3.1 *Luminance and colour-difference bandwidths*

The reference for the luminance and colour-difference bandwidths chosen was the 4:2:2 digital studio standard (see Recommendation 601), which uses sampling frequencies of 13.5 MHz and 6.75 MHz for luminance and colour-difference signals respectively. The maximum baseband bandwidths available with the 4:2:2 standard therefore are about 6 MHz and 3 MHz respectively.

Noise is closely related to the bandwidths of the luminance and colour-difference signals. In the MAC system, the vision noise performance is additionally affected by the time compression. To a first approximation the noise power, for a given compressed signal bandwidth, is proportional to the cube of the compression factor.

It is clear from these considerations that particular care must be taken in order to reduce the noise of colour-difference signals, which are compressed twice as much as the luminance signal. It was originally decided that the nominal maximum amplitude of the colour-difference signals (corresponding to 100% saturation) should be 1.3 V peak-to-peak. However, in order to permit the use, in the future, of an uncompressed chrominance bandwidth of > 2 MHz it was decided to limit the signal to an amplitude of 1 V peak-to-peak. This limit is considered acceptable, since it corresponds to a displayed saturation of about 96%, and it is rarely exceeded in natural pictures.

Since the maximum amplitude of colour-difference signals is the same as for luminance and the compression ratio is twice that for luminance, the maximum possible bandwidth for colour-difference signals is in principle half that of luminance. This limit can be approached at the transmitting end. However, in order to reduce overshoots, which can cause unacceptable impairments on colour-difference signals, the bandwidth of these signals must be further reduced, in the receiver, by means of a slow roll-off filter (e.g. of Bessel type).

The design of the receiver filters is left to manufacturers. It is likely that, in case of high-field strength signals, the colour-difference bandwidth which is in practice achievable at the receiver will be about 2 MHz (about 1/3 that of luminance). Because of the properties of the human eye, this bandwidth is more than adequate for natural pictures and just sufficient for some extremely critical electronically generated pictures (e.g. captions with small-size letters). A further bandwidth reduction could be desirable in the case of noisy signals, and in this case, the use of Gaussian or Bessel type filters with a 3 dB bandwidth of about 0.9 MHz has been suggested.

In order to provide some more detailed information on the relationship between noise and bandwidth, the noise power density has been calculated as a function of the frequency, taking account of the compression factor and the pre- and de-emphasis. The results demonstrate the significant rise in noise level as the frequency is increased. If the results are weighted by a characteristic having a time constant $\tau = 0.2$ µs (see Recommendation 451), the weighted noise density characteristic is as shown in Fig. 1, which includes the effect of pre-emphasis (see § 3.4). Here it is assumed that the luminance signal and the colour-difference signals are weighted equally. The curves at higher frequencies are relatively flat and indicate a good match between the characteristics of FM noise and visual perception of noise.

The visibility of noise on the screen may differ from that predicted theoretically because of failure of the constant luminance principle and because of physiological effects (the eye has different sensitivities to noise in the two colour-difference channels). By a suitable choice of the colour-difference axes, the subjective effects of chrominance noise might be decreased, but the improvement is not expected to be greater than about 1 dB. A further small noise improvement can be gained for the colour-difference signals by using vertical averaging at the receiver (instead of repeating a single line).

The influence of pre- and de-emphasis on noise is discussed in § 3.4.

3.2 *Choice of sequence of analogue component signals and of compression ratio*

The luminance component and the two colour-difference components must be transmitted sequentially and time compressed. It is necessary to decide whether both colour-difference signals should be transmitted during each line, or transmitted sequentially on alternate lines. The order in which the components are transmitted must also be decided.

In selecting the compression ratios, a compromise has to be found between the signal-to-noise ratio, interference constraints, transparency to the digital studio standard (taking account of the need to maintain a simple receiver design) and the simplest sharing of the active line time period of 52 µs. Independently of whether line sequential or line simultaneous transmission of the colour-difference signals is used, the last two factors suggest that the ratio of the luminance compression factor (Y) to the colour-difference compression factor (X) should be 0.5, the same sampling frequency being used for both compressed components. Moreover, the sum of the parts of the shared time should be equal to unity.

For sequential transmission of the colour-difference components, the following two equations are thus obtained:

$$\frac{Y}{X} = 0.5 \text{ and } \frac{1}{X} + \frac{1}{Y} = 1.$$

Hence, we obtain $X = 3$ and $Y = \frac{3}{2}$.

For simultaneous transmission of the colour-difference components, the equations become:

$$\frac{Y}{X} = 0.5 \text{ and } \frac{2}{X} + \frac{1}{Y} = 1.$$

We then obtain $X = 4$, $Y = \frac{4}{2}$.

As indicated in § 2.2, the decompressed noise power varies as the cube of the compression factor K, so the loss in the signal-to-noise ratio is equal to 30 $\log_{10} K$ (dB). It follows that the best noise performance is achieved if the compression ratios are kept at minimum.

The figures clearly show that in a system where both the colour-difference components are transmitted on the same line, the degradation in the luminance and colour-difference noise is 3.7 dB compared with the situation where the colour-difference signals are transmitted sequentially.

Moreover, time compression results in a proportionate increase in the bandwidth which must be accommodated within the FM channel. Thus to avoid additional interference caused by the increased maximum modulation frequency for simultaneous transmission of both colour-difference components, the deviation would have to be reduced, and this would lead to a further loss in the signal-to-noise ratio of about 2 dB and about 4 dB for the colour-difference and luminance signals respectively. Overall noise degradations of more than 5 dB appeared unsatisfactory, so the colour-difference signals are transmitted line sequentially with compression ratios of 3/2 for luminance and 3/1 for the colour-difference signals.

Regarding the order of transmission of the various components, the colour-difference component is transmitted before the luminance component. No strong reasons can be found why a different order would offer advantages affecting the complexity of the receiver. The colour-difference signal is transmitted first because it was thought that low frequency distortion would be most visible in the colour-difference signals. The latter should therefore be closest to the clamping reference at the start of the line.

3.3 *Considerations of vertical and horizontal resolution for the luminance and colour-difference signals*

For discussing this problem it is helpful to convert the vertical resolution, usually defined in cycles per picture height, to an equivalent horizontal resolution in MHz.

For a 625/50/2 : 1 system with a 4 : 3 aspect ratio, the Nyquist limit of 143.75 cycles per picture height (C/PH) (575 active lines/4) gives an equivalent horizontal checkerboard frequency of 3.7 MHz. This limitation is due to interlace flicker.

The potential luminance resolution however is equivalent to 7.4 MHz and this can be obtained by a progressive scanning in the vertical direction by using vertical pre- and post-filtering techniques. Account must be taken of this possible improvement when considering the necessary frequency response, to provide a good balance between the vertical and horizontal resolution.

By dropping alternate lines of the colour-difference signals, the potential vertical resolution of the chrominance information is halved with respect to luminance. The Nyquist limit of 71.87 C/PH corresponds to an equivalent frequency of 1.85 MHz. To reduce the alias components which are produced within the original signal spectrum by this procedure, the colour-difference signals must be vertically pre-filtered. This may further restrict the resolution depending on the type of filter used. If a simple line averaging filter (1,1 filter) were used for example, it would cause a loss of 3 dB at 1.85 MHz, while with a 1,2,1 filter, the loss would be 6 dB. The total response however also depends on the type of post-filtering in the receiver. In combination with a 1,2,1 pre-filter at the transmitter, a 1,2,1 post-filter in the receiver (which is recommended for a normal size of display) would result in additional restriction and a theoretical total response of -6 dB at 1.34 MHz.

This vertical resolution is lower than the maximum horizontal resolution which is obtained with low-noise signals (about 2 MHz). However, it is likely that more sophisticated pre-filtering techniques, particularly those based on field stores possibly accompanied by the corresponding post-filtering, could improve the chrominance vertical resolution so as to obtain the best possible balance between the resolution in the two directions.

It can therefore be concluded that sequential colour transmission gives a reasonably well balanced resolution in the horizontal and the vertical directions, and there is scope for further improvement by the use of more advanced processing.

3.4 *Choice of emphasis characteristic*

For the MAC system, the use of large amounts of pre- and de-emphasis to reduce distortion (as with composite signals) becomes unnecessary. However, emphasis is useful to give improved noise and interference performance taking account of the requirements of the WARC-BS-77 Plan.

When considering emphasis, account must be taken of the effect of threshold noise. The use of de-emphasis causes the threshold spikes to appear as streaks on the screen. The resulting impairment depends on the number and amplitude of the spikes, together with the length of the disturbance. The use of time decompression causes the streaks to be stretched by the compression factor.

The use of pre-emphasis is beneficial in reducing the amplitude and the number of spikes but it has the effect of increasing the length of the spikes. Subjective tests indicate that with a suitable choice of the pre-emphasis characteristic, the beneficial effects more than compensate for the negative effects.

In principle, the use of pre-emphasis could cause distortion due to the 27 MHz bandpass filtering and also truncation noise. This effect can be limited by a careful choice of the pre-emphasis characteristic.

The emphasis characteristic must be chosen as a compromise between the conflicting effects mentioned above. Computations and informal subjective assessments have been carried out by some EBU members with two networks [CCIR, 1982-86b]. The characteristics of the network, which is specified for the MAC/packet family of systems in Report 1073, are given in Table I.

The possibility is not excluded that, as a result of further studies, a slightly different, but compatible, characteristic will be proposed in order to optimize the performance.

The low frequency insertion loss of the MAC pre-emphasis network is only 3 dB. Therefore it is highly desirable that the video signal is d.c. restored at the input of the FM modulator.

3.4.1 The E7 compatible non-linear pre/de-emphasis network example for the MAC/packet family

In addition to the linear pre-emphasis characteristic E1 for the MAC/packet family described in Table I, a non-linear pre-emphasis network E7 (see Annex I) may also be used. E7 should be applied only to the vision signal, not to the data burst. The effect of its application is a subjective improvement in picture quality equivalent to a 3 dB increase in carrier to noise ratio of the received signal. E7 is a non-linear pre/de-emphasis which has been designed to provide noise and interference improvement without any threshold degradation. E7 is a frequency dependent instantaneous compander system. It is compatible in the sense that it has no effect at low video frequencies, so the deviation sensitivity of the FM signal is not affected. E7 may be implemented in either analogue or digital form, and both examples are specified below for both the pre- and de-emphasis networks. Both examples specified below meet the WARC-BS-77 Plan, when used in addition to E1 pre-emphasis. All pre-emphasis networks used for the MAC/packet family should be upwards compatible with HD-MAC described in CCIR Report 1075.

3.5 *Picture quality*

Subjective tests on picture quality at different carrier-to-noise ratios were made by the EBU and showed that the MAC* quality was always better than PAL or SECAM.

In considering the sharpness of a vertical colour transition, however, MAC is inferior to PAL because of the interpolating filters used on transmission and on reception in order to reduce the alias components which are produced by the line sequential colour transmission. These alias components, which exist in the SECAM system, may be very annoying with vertically-moving electronically-generated patterns (e.g. red captions on a black background), if they are not suppressed to an insignificant level by suitable filtering [Windram and Morcom, 1983].

As to signal-to-noise ratio, even at high *C/N* values some noise is visible in strongly saturated coloured areas. This noise is subjectively lower for MAC than for PAL or SECAM.

Subjective tests have also proved that the requirements in the WARC-BS-77 Plan referring to co-channel and adjacent-channel interference are met for unscrambled as well as for scrambled MAC signals (see Report 634).

Also, at lower *C/N* values the performance of the system is always better than the existing composite systems, even with extended threshold demodulation. The pictures are more acceptable, as the threshold streaks are much shorter, due to the smaller amount of de-emphasis and the shorter time constants.

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* In the system used for these tests, the 3 dB bandwidth for luminance was 5.6 MHz and for colour-difference signals was 1.6 MHz.

TABLE I – *Characteristics of pre-emphasis networks for MAC signals*

System	A_0 (dB)	A_∞ (dB)	f_z (MHz)	f_p (MHz)	f_p/f_z	S/N lum. (dB)	S/N col.-diff. (dB)
C-MAC D-MAC D2-MAC	−3	2.04	0.84	1.5	1.786	42.23	43.59
B-MAC	−3	+3	1.87	3.74	2		

A_0: low frequency gain

A_∞: high frequency gain

f_z: zero frequency

f_p: pole frequency

S/N lum.: weighted luminance signal-to-noise ratio corresponding to $C/N = 14$ dB (weighting network: Recommendation 451; bandwidth: 6 MHz)

S/N col.-diff.: weighted colour-difference signal-to-noise ratio corresponding to $C/N = 14$ dB (weighting network: Recommendation 451; receiver filter Gaussian with 6 dB point at 1.3 MHz).

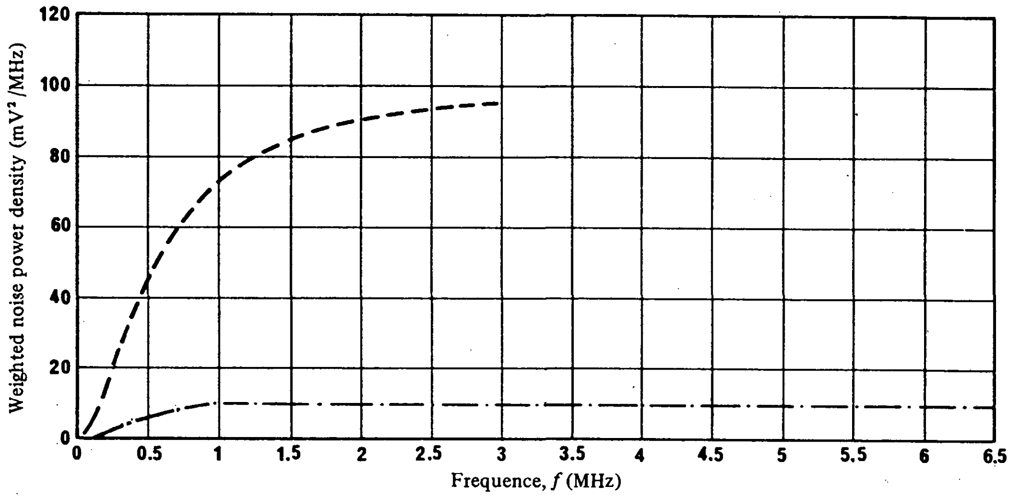

FIGURE 1 – *Colour-difference and luminance signals weighted noise power density*

Weighting filter : Recommendation 451

Pre-emphasis : network used for C-, D- and D2-MAC/packets

– – – – – – – Colour-difference signal

–·–·–·– Luminance

The ordinate scale is such that the area below the curves, expressed in dB with respect to 1 mV², provides the weighted signal-to-noise ratios corresponding to $C/N = 14$ dB

Note. – The curves for colour-difference noise assume that the two colour-difference noise powers add equally. It should be noted that the subjective effect of noise for each colour-difference channel is a complicated function of hue, saturation and luminance.

3.6 *Future enhancements*

When defining a new system for satellite broadcasting, it is important not to preclude any future enhancements that might be foreseen.

The following enhancements may be possible; some of them have not yet been tested experimentally but it should be possible to implement them with the proposed signal format.

3.6.1 *Improved resolution of the luminance and the colour-difference signals*

This might be achieved by increasing the compressed video bandwidth from 9 MHz to about 12 MHz which would result in an increase in horizontal resolution of 33%. It has yet to be confirmed that this would not cause unacceptable interference.

Another approach could be to use pre- and post-filtering to convey additional horizontal information as folded energy within the existing baseband. However, signals conveying this folded energy for picture enhancement may require compromises in design between receivers with post-filters which make use of this information and normal receivers [Tonge, 1982].

Techniques for improving the vertical resolution by pre-filtering prior to transmission and post-filtering using line and field stores in the receiver are described in reports by [Tonge, 1983; Long, 1983; Windram and Tonge, 1983]. It appears that an increase in (effective) vertical resolution of 100% is possible with still pictures. This resolution is reduced however at higher vertical/temporal frequencies.

3.6.2 Aspect ratio

The flexible format of the MAC/packet family coding scheme and the high data rate of the C- and D-MAC/packet systems provide the possibility to introduce compatible wider aspect ratio pictures. The use of TDM control to reduce the width of the digital sound burst (to a value sufficient to carry one stereo signal only) enables additional luminance aspect ratio information to be transmitted. The additional corresponding chrominance signals are sent in the field interval as shown in Figure 2 and described in [Windram et al., 1983b].

Further studies have led to the definition of an alternative approach for a wider aspect ratio with C-, D- and D2-MAC/packet systems. This approach makes use of the normal picture TDM components to provide a 16:9 aspect ratio picture and leaves the digital data capacity unchanged. A 4:3 picture can then be extracted from the 16:9 wide-aspect-ratio picture for display on conventional monitors. For the same baseband signal bandwidth this would give a slightly lower resolution due to the different decompression factor, but the system bandwidth for future receivers can be increased to compensate this effect. [Shelswell, 1982; CCIR, 1982-86 d, e, f, g].

Receivers with incorporated frame stores will be able to process this additional information for wider aspect ratio displays.

The 4 : 3 pictures are undisturbed by the process and are suitable for normal receivers.

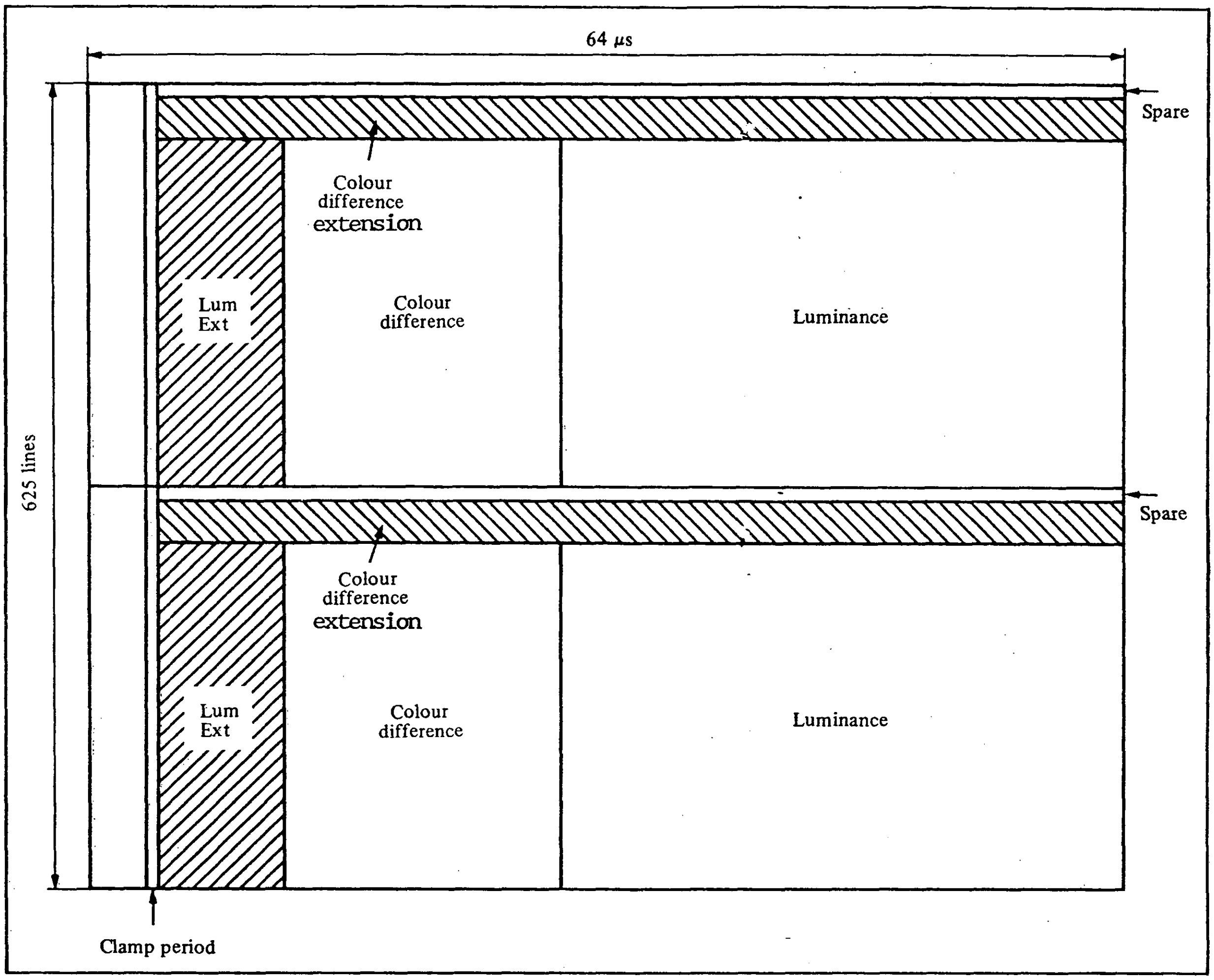

FIGURE 2 – *Proposed use of transmitted frame for extended MAC*

Note. – Shaded areas used for video extensions.

3.6.3 *Vision multiplexing at line and field rate*

The use of TDM control in the MAC/packet family of systems and the use of frame storage in receivers provides the basis for a variety of transmission formats. Some possibilities are under study [CCIR, 1982-86c].

Further studies are also being carried out on a second set of compression ratios, as well as on an alternative approach for a wider aspect ratio in the C- and D2-MAC/packet systems. This approach leaves the digital data capacity unchanged and provides a compatible 4:3 picture by using a new set of expansion ratios (for the same baseband signal bandwidth this would give a slightly lower resolution, but the bandwidth can be increased) [Shelswell, 1982; CCIR, 1982-86d, e, f, g].

3.6.3.1 *Multiplexing at field rate*

The principle of the method is shown in Fig. 3a. In this figure the content of line periods is represented in horizontal direction, whereas in vertical direction the sub-division during a field period is visualized.

During a number of line periods per field only the luminance information (the *Y* signal) is transmitted whereas during other line periods only colour-difference signals, in compressed form, are transmitted. The resulting picture will show the maximum horizontal resolution, as determined by the channel bandwidth, and an aspect ratio higher than normal. Methods aimed at the improvement of the vertical resolution are under study.

3.6.3.2 *Multiplexing at line and field rate*

An approach in which the methods at line rate and at field rate are combined is shown in Fig. 3b.

The time interval Y is reserved for the transmission of the luminance information. The interval c_a may contain one or two colour-difference signals; the same holds for the interval c_b. The boundaries between the time intervals are indicated by the lines a, b, d and e.

The advantage of TDM control is that it provides great flexibility to alter the boundaries between the sound and video and the luminance and colour-difference signals. This flexibility offers the possibility of increased aspect ratio, enhanced television, stereoscopic television and full field data transmission. It should be noted however, that many of the advantages referred to will require the use of a receiver incorporating a picture store.

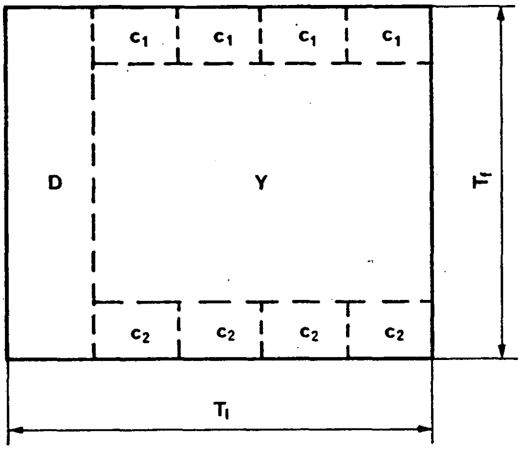

FIGURE 3a – *Multiplexing at field rate*

T_f: field period

T_l : line period

D : sound + data + sync.

c_1 : 1st colour-difference signal (e.g. U)

c_2 : 2nd colour-difference signal (e.g. V)

Y : luminance signal

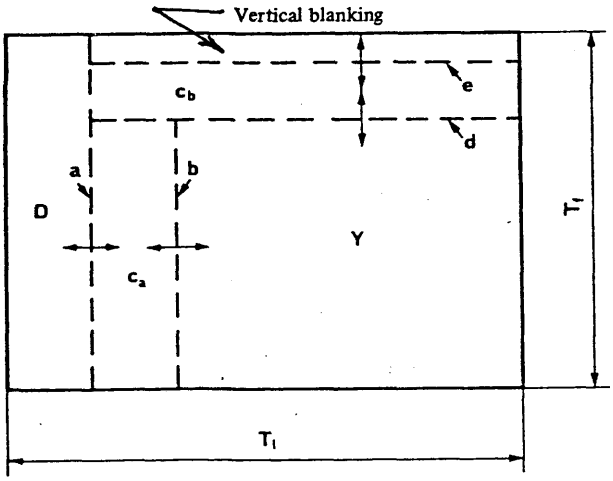

FIGURE 3b – *Multiplexing at field and line rate*

T_f: field period

T_l : line period

D : sound + data + sync.

c_a : 1st colour-difference signal (e.g. U)

c_b: 2nd colour-difference signal (e.g. V)

Y : luminance signal

3.6.4 *HDTV* (see also Report 801)

To avoid aliasing in the processes for extending vertical resolution in a single WARC channel, pre-filtering is used. The pre-filtering process involves discarding high frequency vertical/temporal information. This may not be of first order importance subjectively because the eye is less sensitive in this area [Tonge, 1982; Fujio *et al.*, 1982]. Filters can be implemented which preserve the high frequency vertical/temporal information for transmission in a second channel. The use of two WARC channels in this way should enable the achievement of nearly the full quality of an HDTV studio standard.

3.6.5 *Stereoscopic television*

A second WARC channel could be used to carry additional information to permit stereoscopic television [CCIR, 1982-86b]. In this case both channels may carry similar compatible extended definition signals. These signals are combined in the receiver to produce the stereoscopic display. Further study is required.

4. Reasons for the choice of parameters for the MAC vision system used in the B-MAC systems defined in Report 1073

Detailed specifications for the B-MAC systems were set to meet the following characteristics:

- operation in a 24 MHz channel with a nominal C/N of 14 dB;
- improved picture quality compared with existing 525-line systems;
- multiple high quality digital sound channels;
- data broadcasting capability (such data also to be used for sychronizing);
- encryption with individual addressability capability;
- potential for future enhancements;
- possible compatibility with high definition television.

B-MAC systems for both 525 and 625 lines have been developed in the United States and Canada. A similar system called B-TMC for 525 lines is under development in the United States. These systems are described in [CCIR, 1982-86h, i].

4.1 *B-MAC*

In the B-MAC systems the vision signal closely resembles the vision format of the MAC/packet family. The same compression factors are used, however the clock frequencies differ. Like the MAC/packet family, B-MAC transmits the luminance and chrominance information within the active line time. The colour-difference signals are sequentially transmitted on alternate lines. In B-MAC, the clock frequencies are even integer multiples of the NTSC colour sub-carrier frequency. The luminance sampling frequency of 14.32 MHz permits a luminance bandwidth up to 6.4 MHz using straightforward techniques. Chrominance bandwidth is limited by the Nyquist criteria. These bandwidths can be used to transmit wide-screen pictures on 525-line standards in a way which is compatible with the receivers, now in use, which have 4:3 aspect ratio screens. The wide-screen aspect ratio which makes this compatibility possible is 16:9 or 4:3 of the standard aspect ratio. Changing transmitted aspect ratio from 16:9 to 4:3 requires changing the clock frequencies for time decompression from $1365F_h : 910F_h : 455F_h$ to $1365F_h : 682.5F_h : 341.25F_h$. Selection of the portion of the 16:9 picture to be displayed on the 4:3 screen is controlled by an instruction transmitted digitally within the field blanking interval. The full bandwidth potential of B-MAC (6.4 MHz) requires about 3 dB greater C/N for the same *weighted* S/N with respect to that required for 4.2 MHz uncompressed luminance bandwidth.

B-MAC employs line translational video scrambling and digitally encrypts the audio/data with individual or group receiver addressability.

In this system, the vertical and horizontal synchronization information is transmitted in digital form using high redundancy error correction schemes, thus providing very robust synchronization signal recovery. This system has been demonstrated as being capable of maintaining synchronization at C/N values down to 2 dB so that reliable synchronization can be maintained during periods of high noise such as are typical of satellite transmissions under adverse weather conditions and/or antenna misalignment. Only one line of the vertical blanking interval is used to transmit the synchronization information; the remaining lines of the vertical blanking interval of the MAC signal can be used for other services such as teletext, additional vision information, etc.

A new emphasis network is proposed for these signals as the degree of emphasis necessary for NTSC is not optimum for component signals. The optimum MAC pre-emphasis characteristic has shorter time constants and less low frequency insertion loss as shown in Table I. Such a network improves performance at or below threshold, while at the same time the impulses induced by threshold noise are less subject to stretching. The resulting overall subjective picture quality improvement when the MAC signal operates under conditions of low C/N is considered to be one of the most significant attributes of the MAC system.

The MAC signal should be designed so that during adverse conditions the vision signal fails first followed by the synchronization. This follows the practice in terrestrial broadcasting. FM threshold is reached at about 10 to 11 dB C/N. Synchronization in MAC systems remains even at 2 dB C/N or less.

4.2 *Dual aspect-ratio B-MAC*

The B-MAC format has a potential for extension to extended definition transmissions. It carries an interlaced picture with the associated sound, synchronization and conditional access addressability data. The B-MAC systems can transmit either 4:3 aspect ratio or wide-screen 16:9 pictures [Rhodes and Lowry, 1985]. Viewers can view a 4:3 picture of very high quality (effective luminance bandwidth 4.8 MHz) on conventional 4:3 aspect ratio screens. Viewers having a 16:9 display can obtain wide-screen pictures. The increased luminance baseband bandwidth of 6.4 MHz will provide the same horizontal resolution on 16:9 displays as on basic displays of 4:3 aspect ratio. In the near future, advanced displays are expected which can de-interlace the transmitted signal for improved picture quality. A de-interlaced wide-screen picture (each frame is repeated twice) can be expected to approach the quality of a higher line-rate transmission system. Further studies, particularly concerning motion detection, will be required.

5. Scrambling for conditional access

It is a requirement in conditional access that the vision and sound signals should be scrambled under the control of an encryption system. The principles of conditional access are discussed in Report 1079. Examples relevant to the broadcasting-satellite service are given in Table I and Annex II of that Report and in the special publication of CCIR (Specification of transmission systems for the broadcasting-satellite service). The following is a description of picture scrambling.

5.1 *Scrambling algorithm*

Tests have shown that a very high degree of picture scrambling can be obtained by methods which redistribute the picture elements in time. The existence of a line store in each domestic decoder suggests that this process is best done within each line, rather than by re-ordering complete lines within a frame. The latter process would require a frame store.

Double-cut component rotation and single-cut line rotation are methods of scrambling which can be applied to MAC systems and are capable of giving excellent performance provided that tolerances on line tilt, within the path of the scrambled signal, are adequately controlled.

These methods are members of a family of scrambling techniques which rely on the splitting and rearranging of the multiplexed component which make up the video line.

In the double-cut component rotation system, the chrominance and luminance components are separately rotated cyclically about their lengths by a pseudo randomly determined distance (Fig. 4b). This rotation distance will be governed by the output of a pseudo-random sequence generator which forms part of the encryption process.

In the single-cut line rotation system, the colour-difference component of each line is cut into two segments and the first segment is moved to the end of the line (Fig. 4c). The position of the cut point is determined by the output of a pseudo-random sequence generator.

Component rotation and line rotation appear to be very attractive for picture scrambling and it has been demonstrated that the scheme is capable of totally concealing a transmitted image and can easily be de-scrambled [Lodge, 1983].

Line translation scrambling has also been implemented and has the advantage of lower sensitivity to distortions in the signal path such as line tilt. In this method the transmitted line blanking period is varied in a pseudo-random manner and this has the effect, in an unauthorized receiver, of de-correlating lines in the picture and displacing parts of the active line outside the viewing area of the displayed picture. The scrambling effect is strong [Lowry, 1984]. A schematic description of line translation scrambling for 525-line B-MAC systems is shown in Fig. 5.

There are a number of other ways of modifying the signal to obtain a scrambling effect. The two methods which have been described are suitable for use with a MAC system. The line stores used for time decompression can also be used to de-scramble the picture.

Early standardization of the scrambling methods may be necessary to prevent a proliferation of black boxes around the domestic television receiver.

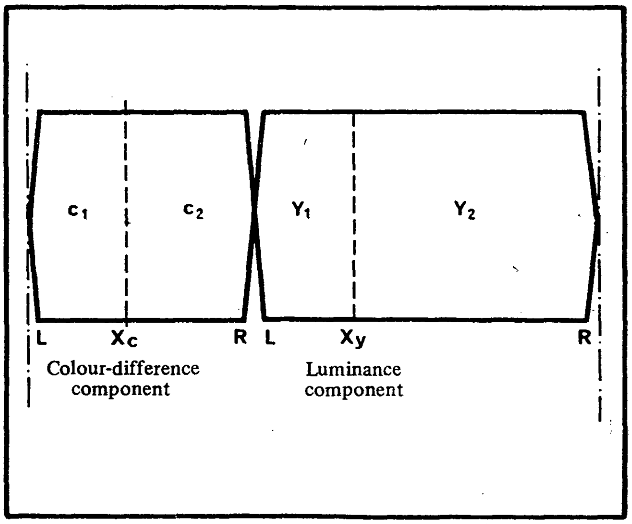

FIGURE 4a – *Normal MAC line*

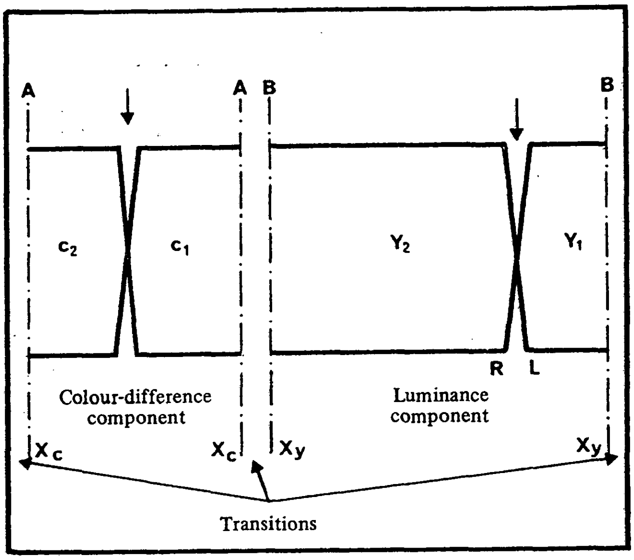

FIGURE 4b – *Double-cut component rotation scrambling*

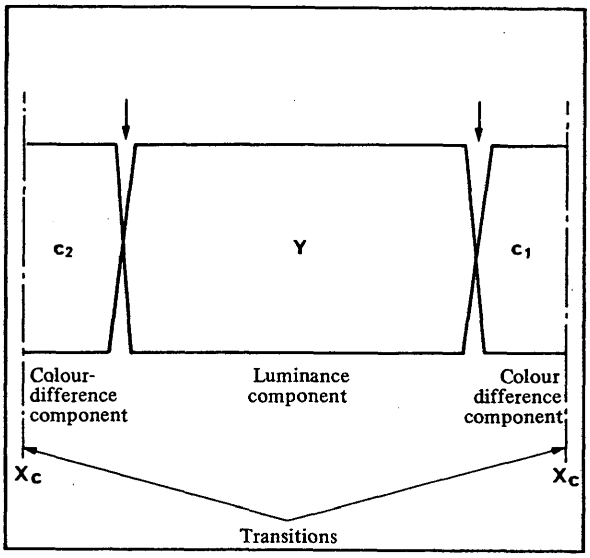

FIGURE 4c – *Single-cut line rotation scrambling*

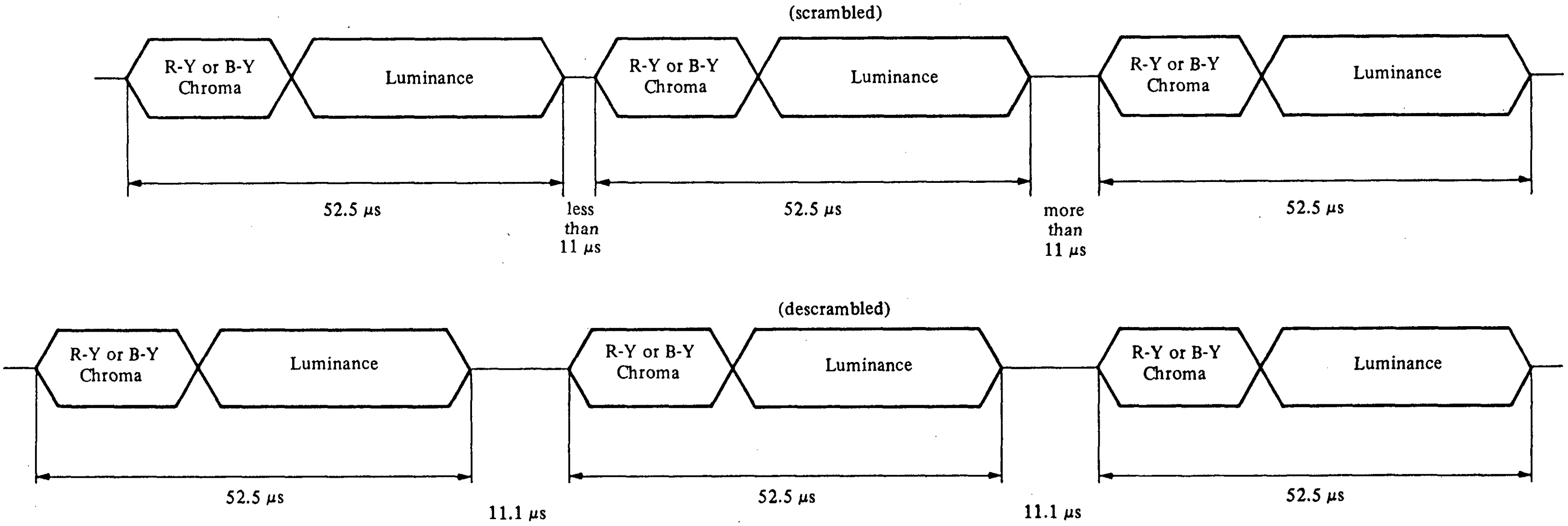

FIGURE 5 – *Line translational scrambling*

Note. – Averaged over any field, blanking time is constant. From line-to-line blanking time varies in a pseudo-random manner.

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CCIR Documents

[1982-86]: **a.** 10-11S/62 (Canada); **b.** 10-11S/39 (EBU); **c.** 10-11S/33 (Netherlands); **d.** 10-11S/170 (France); **e.** 10-11S/164 + Add. 1 (EBU); **f.** 10-11S/165 + Add. 1 (EBU); **g.** 10-11S/182 + Add. 1 (France, Germany (Federal Republic of)); **h.** 10-11S/178 (United States of America); **i.** 10-11S/193 (Australia).

ANNEX I

THE E7 PRE/DE-EMPHASIS CHARACTERISTICS*

1. E7 de-emphasis characteristic

1.1 *Analogue E7*

Referring to the block diagram of Fig. 6:

Delay element T

T = 0

Low-pass filter F

The transfer function is given by

$$\frac{1}{1 + j\, f/f_o}$$

where f = frequency
f_o= 2.0 MHz

Non-linear function N^{-1}

This is illustrated in Fig. 7

The output V_o of the non-linear function is related to its input V_i by the relationship:

$$V_i = \frac{V_o}{C} + \frac{1}{B} \ln \left[\frac{V_o + \sqrt{V_o^2 + (2AC)^2}}{2AC} \right]$$

A = 0.009
B = 19.80
C = 1.5642

This function has been specifically chosen because it can be simply implemented in analogue circuitry. [IBA, 1988].

Post filter

The E7 network is followed by a post filter. A 12 MHz (-3 dB) 3 pole Chebyshev (0.1 dB ripple) filter is suitable for this purpose.

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*It should be noted that the use of E7 is optional therefore its use must be signalled in the service identification codes of the MAC/packet family. If it is adopted universally, the signalling will not be necessary.Further studies on this question are needed, in particular to specify the signalling codes used in the service identification.

1.2 *Digital EZ*

It can be shown that the block diagram of Fig. 6 is functionally equivalent to the block diagram of Fig. 8, where F_1 is the complementary filter (high pass) to F, and the non-linear function is changed to become a new function, N_1. This is illustrated in Fig. 9.

The function is non-monotonic but can be easily implemented by means of a look-up table. The implementation of Fig. 8 is recommended because of its simplicity.

Sampling rate

20.25 MHz

Delay element T

T = 3 clock periods

High pass filter F_1

Phase response	:	linear
Magnitude response	:	Gaussian
-3 dB bandwidth	:	2.0 MHz

A 7-tap digital filter is used with the following coefficients:

$$C_0 = \frac{180}{256} \qquad C_2 = C_{-2} = -\frac{25}{256}$$

$$C_1 = C_{-1} = -\frac{58}{256} \qquad C_3 = C_{-3} = -\frac{7}{256}$$

These are scaled for unity a.c. gain

Non linear function N_1

If N^{-1} is described by $V_o = f(V_i)$,

where V_i = input
V_o = output

then N_1 is described by

$V_o = f(V_i) - V_i$ (see Fig. 9)

$f(V_i)$ cannot be specified in closed form, but can be evaluated from the relationship:

$$V_i = \frac{V_o}{C} + \frac{1}{B} \ln \left[\frac{V_o + \sqrt{V_o^2 + (2AC)^2}}{2AC} \right]$$

where A = 0.0111
B = 19.803
C = 1.5225

2. Pre-emphasis characteristics

2.1 *Analogue pre-emphasis*

The block diagram is shown in Fig. 10. The de-emphasis network shown corresponds to the characteristics of §1.1.

The gain G must be sufficiently high that the error e is small compared to the input signal for baseband frequencies up to 8.4 MHz. The output filter is 12 MHz (-3 dB) bandwidth low pass.

2.2 *Digital pre-emphasis*

The block diagram is shown in Fig. 11.

High-pass filter F_1

Clock rate	:	20.25 MHz
Phase response	:	linear
Magnitude response	:	Gaussian
-3 dB bandwidth	:	2.0 MHz

A 7-tap digital filter is used with the following coefficients:

$$C_0 = \frac{180}{256} \qquad C_2 = C_{-2} = -\frac{25}{256}$$

$$C_1 = C_{-1} = -\frac{58}{256} \qquad C_3 = C_{-3} = -\frac{7}{256}$$

These are scaled for unity a.c. gain.

Delay element T:

3 clock periods

Non-linear function N_1

As for de-emphasis (§1.1).

Non-linear function N_2

This function is described by the following equation:

$$V_o = V_i \frac{(1 - C)}{C} + \frac{1}{B} \ln \left[\frac{V_i + \sqrt{V_i^2 + (2AC)^2}}{2AC} \right]$$

where $A = 0.011$
$B = 19.80$
$C = 1.5225$

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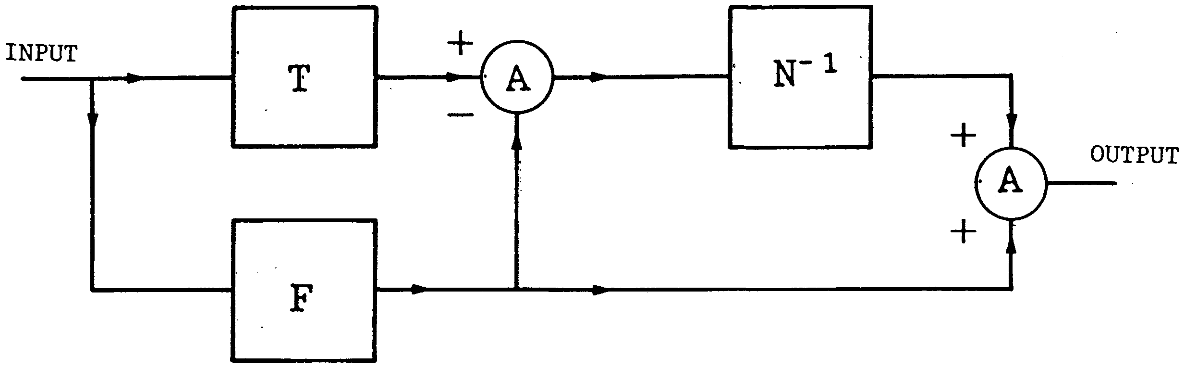
IBA, Experimental and Development report 141/88, *Compatible non-linear pre-emphasis for MAC signals*.



A : adder
T : delay element
F : low pass filter
N^{-1} : non-linear function

Figure 6 - E7 de-emphasis block diagram

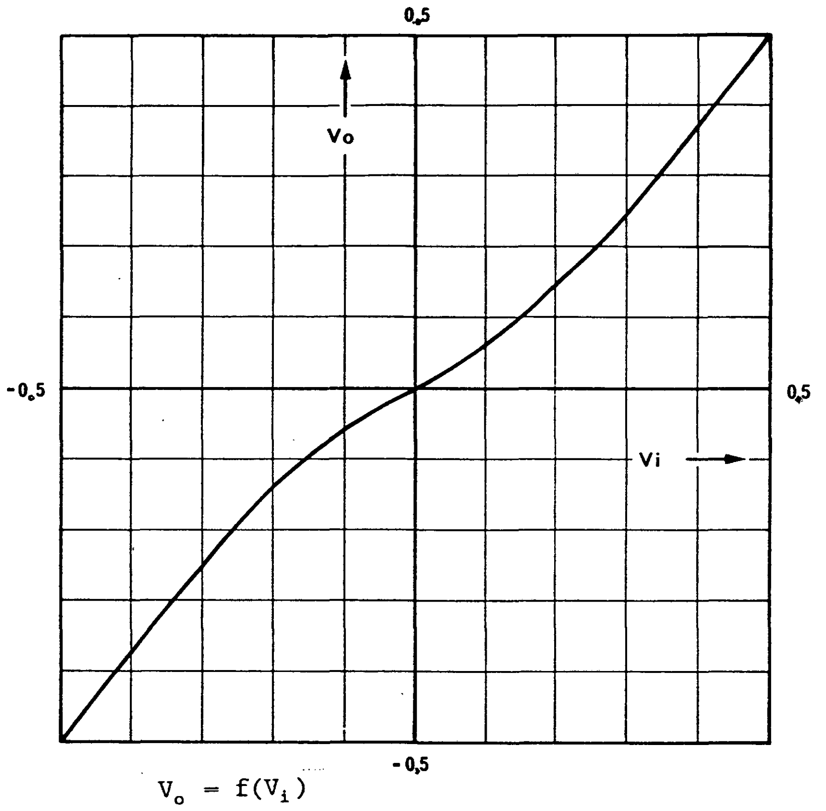
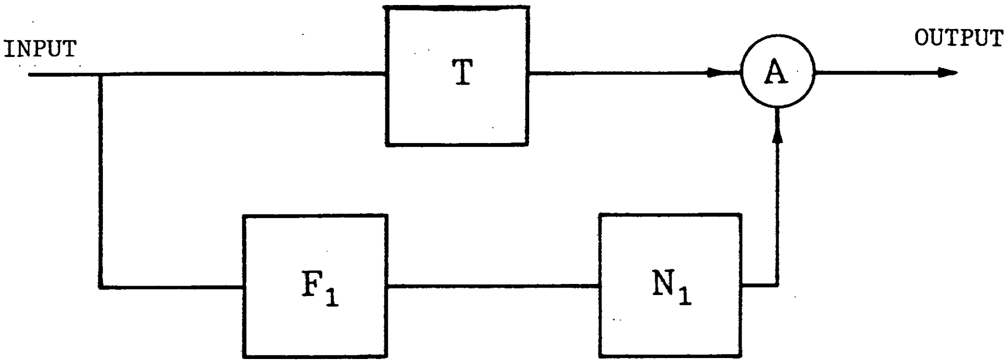
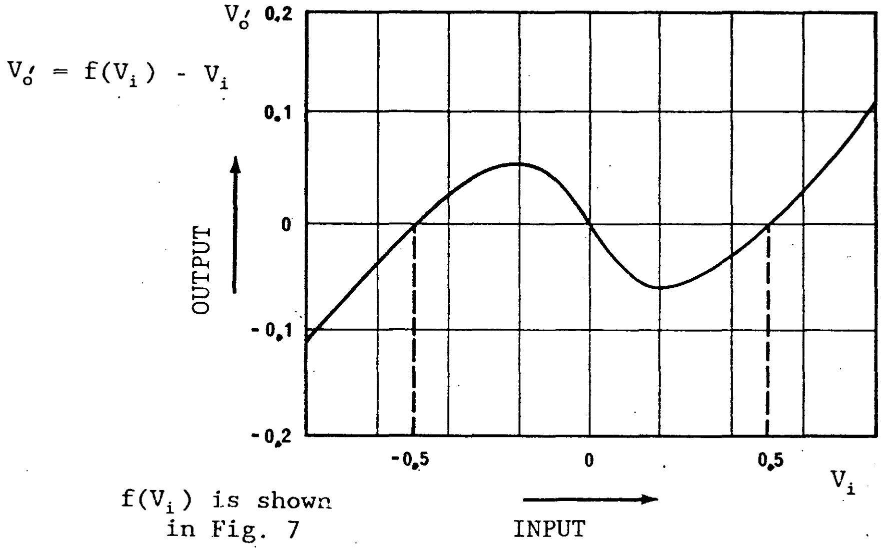


Figure 7 - Non-linear function N^{-1}



A : adder
T : delay element
F_1 : high pass filter
N_1 : non-linear function

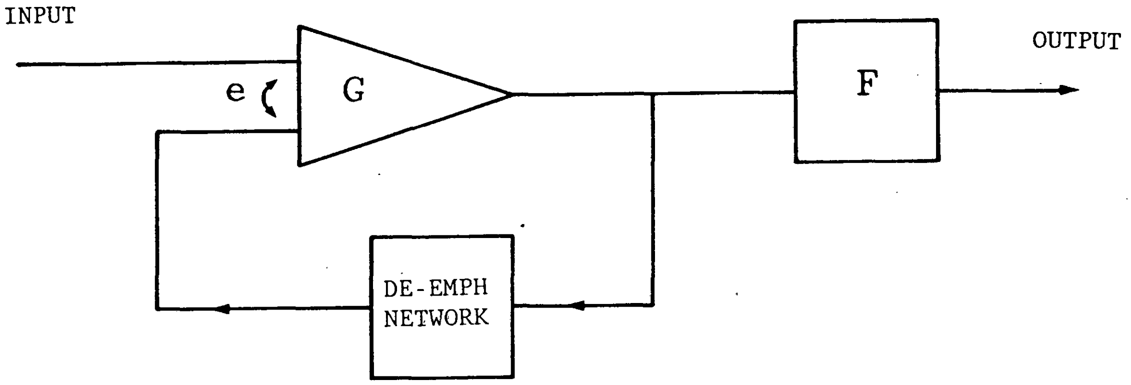
Figure 8 - Recommended de-emphasis implementation (digital)



$V'_o = f(V_i) - V_i$

$f(V_i)$ is shown in Fig. 7

Figure 9 - N_1 non-linearity



F : low pass filter
G : gain of amplifier $\gg 1$
e : error signal

Figure 10 - Analogue pre-emphasis configuration

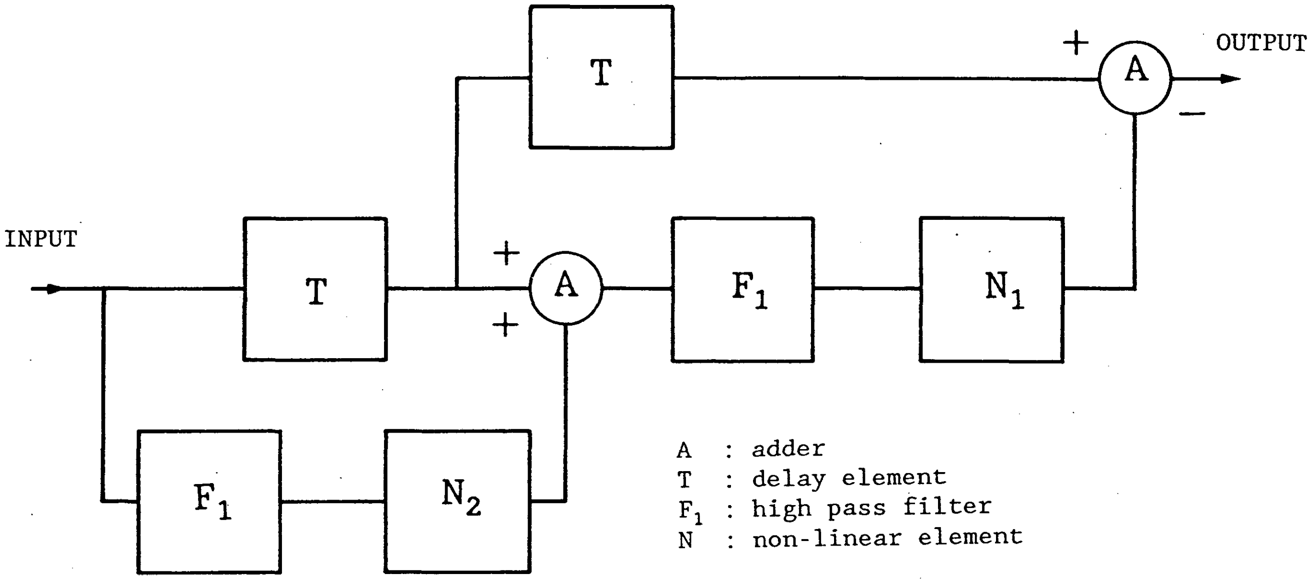


Figure 11 - Digital pre-emphasis configuration

REPORT 1075-1

HIGH DEFINITION TELEVISION BROADCASTING BY SATELLITE

(Question 2/10 and 11, Study Programme 2M/10 and 11)

(1986-1990)

1 Introduction

On the occasion of their fourth Inter-Union Conference in 1983, all the Unions representing the broadcasting organizations of the entire world were unanimous in their recommendation for the adoption of a set of common world-wide standards for high-definition television.

Additionally, at their fifth and sixth Inter-Union Conferences in 1986 and 1989, they were unanimous in recommending the provision of a single world-wide frequency allocation suitable for BSS in HDTV.

Report 801 gives information concerning general considerations, method of scanning, signal format of transmission, bandwidth reduction techniques and HDTV equipment.

Transmission systems for communications between broadcast centres are likely to be directly based on world-wide studio standards.

For satellite broadcasting of HDTV, standards with a modified format will be needed to allow for a good balance between very high picture quality, channel bandwidth suitable for HDTV and the complexity of the receiver. This balance has no unique solution and different proposed systems, both analogue and digital are described in this report.

Some administrations are considering the possible implementation of an HDTV BSS.

The CCIR has produced a Report to the second session of the WARC ORB 1988 in view of the possible consideration of a possible world wide frequency allocation to the BSS. It has also produced a Report at the extraordinary meeting of Study Group 11 on the subject of HDTV, with particular consideration of the question of a common world-wide standard. Most of the relevant material from these two reports has been integrated into this CCIR Report to present the current situation concerning HDTV systems, frequency bands and sharing problems.

2. Service availability and quality objective

The current CCIR studies are based on HDTV systems for which parameters will be optimized for viewing distance in the neighbourhood of three times picture height for a large screen display [CCIR, 1986-90a]. This will influence factors such as visibility of noise, interference and distortion. Objective figures are needed for the target values of these parameters. These objective figures are related to subjective impairments.

Two quality factors are considered necessary for satellite broadcasting of HDTV:

- good quality must normally be available;
- outage times should be severely limited.

The choice of quality objectives for HDTV is a sensitive issue because quality is the main feature of its viability. It is also considered unsatisfactory for the performance to fall below the equivalent of conventional TV systems. The viewer will be paying a premium for quality, both in the higher cost of the receiver, and in the programme costs.

The quality is related, depending upon the coding and modulation scheme, to the carrier-to-noise ratio which is a most important consideration in establishing an HDTV service. The WARC BSS Plans for conventional television are based on a carrier-to-noise ratio of 14 dB, corresponding to a quality grade of 3.5, achieved for 99% of the worst month.

Improvements in receiver technology have led to higher values of carrier-to-noise ratio being achievable as described in § 7. In the case of HDTV transmissions in the 12 GHz band, the target value of carrier-to-noise ratio should be in the order to 17 to 20 dB.

In the case of the other bands, the frequency deviation can be increased to compensate for noise impairment. However, this may lead to very wide bandwidth channels, with a possible increase in interference and distortion. Generally, considering the trade-off between spectrum efficiency and appropriate system characteristics, it may be desirable to set the target carrier-to-noise ratio at about 17 dB.

In the 12 GHz bands, the BSS Plans have stringent protection ratios so that interference, at worst, is just perceptible. Any HDTV signal in these bands will also have to respect this requirement. However, the sensitivity to interference may be different because of the different type of coding and changed viewing conditions. Also the effect of interference on digital signals may need to be treated differently. This is discussed further in § 11.

The effect of channel distortions on the quality of the received signal must also be included in the system design.

The main source of degradation to picture quality is caused by the increased levels of noise during times when the signal in attenuated by hydrometeors (see § 4). Careful attention must be paid to the question of trade-off between signal quality (carrier-to-noise ratio) and the time this is achieved or exceeded. Different trade-offs may be appropriate in different rain zones.

When considering availability objectives, not only must the percentage time the service is to be available be considered, but also the percentage of the service area that will be covered. Problems of clutter, physical geography and microclimates may lead to small but significant areas which cannot be guaranteed adequate quality. Differences in the HDTV television system performance, its baseband coding and modulation characteristics, as well as the frequency band and its propagation and sharing factors lead to new parameters being desirable (see Annex I).

3. Suitable and appropriate frequency bands

WARC ORB 1988, in its Resolution 521 resolved that the frequency range 12.7 - 23 GHz be considered for the choice of an appropriate band for wide RF band HDTV, and that while plans for the 11.7 - 12.7 GHz band can already be used for certain types of high definition television, studies should be continued on the long range future suitability of these bands for HDTV without prejudice to the existing plans in this band.

In this section there is a discussion of all the appropriate or available frequency bands, but with emphasis on detailed discussion of those frequencies identified by Resolution 521.

3.1 Available frequency bands

The following bands above 10 GHz are allocated to the BSS in Article 8 of the Radio Regulations:

12 GHz band:

the band limits are different in Regions 1, 2 and 3, and require slightly different receiver RF designs. The band was planned in 1977 for Regions 1 and 3 (27 MHz bandwidth channels) and in 1983 for Region 2 (24 MHz bandwidth channels).

With the possible exception of those countries in Region 2 whose assignments include all 32 channels, only certain transmission formats can be accommodated in the 12 GHz BSS Plans for Regions 1, 2 and 3. These Plans are not appropriate for the use of single channel wideband transmissions because of constraints on channel spacing and interference limits. More details can be found in § 6 of Report 631 on sharing.

23 GHz band:

from 22.5 to 23 GHz for Regions 2 and 3 subject to Article 14 of the Radio Regulations. It is not allocated to the broadcasting satellite service in Region 1.

The 23 GHz band is a possible worldwide band for HDTV broadcasting by satellite. However, use of that band for the BSS would be constrained by propagation factors and the need to share with the fixed, mobile and inter-satellite services also allocated to this band and to protect the radio astronomy service. This will be discussed in more detail in the next section.

42 GHz band:

from 40.5 to 42.5 GHz - worldwide allocation.

This band is allocated worldwide to the BSS with the terrestrial broadcasting service sharing the band on a permitted basis.

The rain attenuation is considerably greater than at lower frequencies.

Furthermore, high-power transmitting equipment and low-noise receiving equipment are not available for this band.

85 GHz band:

from 84 to 86 GHz - worldwide allocation

The 85 GHz band is allocated worldwide to the BSS, with the terrestrial fixed, mobile, and broadcasting services sharing the band on a "permitted" basis (see RR Footnote 913). This band is even less promising than the 42 GHz band from the point of view of propagation and technology.

3.2 Other suitable frequency bands

In general, at frequencies above 10 GHz, rain attenuation and rain depolarization increase with frequency. In addition, absorption is particularly large near the resonance frequencies of certain atmospheric gases. In particular, absorption is well above the generally increasing trend line near 22, 60 and 120 GHz. Since the attenuation above any of these frequencies is always greater than attenuation below them, the most suitable bands for space-to-Earth paths lie below 22 GHz.

Throughout the range from 1 GHz to about 22 GHz, attenuation in a completely dry atmosphere is low. Moreover, rain attenuation increases only slightly as the frequency is increased from 1 to 10 GHz. However, between 10 and 22 GHz, rain attenuation can increase by an order of magnitude for a given rain rate.

Although bands below 10 GHz would appear to be more suitable from the standpoint of their physical characteristics (rain attenuation and depolarization, coherence bandwidth, scintillation levels etc.) the bands between 10 and 22 GHz deserve first attention because of the need for large amounts of bandwidth to accommodate HDTV and the particularly difficult sharing situations that would be created in heavily used bands below 10 GHz.

P.f.d. limits are usually adopted to protect terrestrial systems from interference from space stations in the frequency bands shared on an equal basis by terrestrial and space (space-to-Earth) services. There are now no shared allocations to terrestrial and space (space-to-Earth) services in the frequency range 19.7-31 GHz with the exception of the band 22.5-23 GHz, which can be used by the BSS in Regions 2 and 3, subject to Article 14 of the Radio Regulations. Therefore no p.f.d. limits have been established in this frequency range. Studies have been carried out to establish the sharing requirements of some of the services in these bands. Details can be found in the CCIR Reports referred to in Section 12. An exhaustive study of all the bands referred to in Resolution 521 has not been carried out. Selective studies of some frequency bands have shown that there would be sharing difficulties to a greater or lesser extent over the whole frequency range identified in Resolution 521. Further studies are necessary.

4. Propagation factors affecting the use of these bands

This section summarizes the various propagation characteristics of the many frequency bands indicated in the previous section as possible bands for satellite emissions of HDTV.

A large number of models have been developed in the past to predict propagation effects on terrestrial and space-Earth links.

The CCIR has selected the method which showed the best compromise between accuracy and simplicity. This method is described in Report 564-3.

This method in its present form gives quite reasonable results, when compared with available data. However, measurements conducted in Japan indicate that this method tends to underestimate the losses and the difference corresponds to the estimated increased absorption during rain.

New European results tend to show that the ESA prediction is slightly better than the CCIR method when compared on an "rms error" basis. Nevertheless, it is felt that the predictions from the CCIR model are reasonably well founded for latitudes of about 30° and greater, but would tend to over-estimate the attenuation at lower latitudes.

4.1 Atmospheric absorption

Beyond about 8 GHz, the effects of the atmosphere on satellite transmission become non-negligible. Gaseous absorption is mainly attributed to the presence of water vapour in the atmosphere which causes absorption to increase with frequency in addition to the presence of absorption bands, the first one being centred at 22.8 GHz. The presence of oxygen results in absorption bands located around 60 and 120 GHz.

Figure 3 of Report 719-2 shows the level of absorption as a function of frequency and Report 564-3 gives the corresponding analytical model.

4.2 Rain attenuation

Rain is considered to be the most important source of attenuation on the space-Earth links. The various measurements of rain attenuation show that if the attenuation at 12 GHz is x dB, then at 20 GHz it is approximately 3.5x dB, at 30 GHz about 6x dB, and at 42 GHz about 8x dB.

The attenuation caused by rain is heavily dependent on the amount of precipitation at the specific location. Report 564-3 has defined different rain zones covering the globe so that appropriate precipitation levels can be used in the rain attenuation model.

For an average temperate climate (Europe), the figures in Table I may be given as estimates for the attenuation caused by rain, as a function of the frequency and the percentage of the worst month.

TABLE I

Estimated rain attenuation for average temperate climate

Frequency (GHz)	12		23		42		85	
Percentage (%) of worst month	99	99.9	99	99.9	99	99.9	99	99.9
Attenuation (dB)	1.5	4.5	4.5	13.5	11.6	35	19	57

Worst month statistics of attenuation in rain (Table II) were obtained using simultaneously passive radiometers at 12 GHz and 23 GHz for five years in Tokyo.

The values include absorption due to atmospheric gases as well as rain attenuation. The atmospheric absorption occupies approximately 0.1 dB and 2.8 dB at 12 GHz and 23 GHz, respectively [Ito, 1986].

TABLE II

Measured rain attenuation in Tokyo

Frequency (GHz)	12		23	
Percentage (%) of worst month	99	99.9	99	99.9
Attenuation (dB)	1.7	5.2	9.5	23.1

It has been shown that for frequencies above the 10 GHz band, much larger attenuation variations are sometimes experienced over rather small areas. These large attenuation variations over the region are the result of climatological and topographical differences and are often referred to as microclimates. They can create holes in the satellite footprint such that the -3 dB or -1 dB contour of the p.f.d. cannot be guaranteed over the whole of the central area.

Studies by the European Space Agency have shown that this problem can be ameliorated by using beam shaping of the satellite footprint to increase power flux densities in those areas likely to be most at risk.

A study of the fade durations statistics was conducted in Europe and it was found that fades of a duration of 10 seconds and longer contribute to 97-99% of total fading time. Bearing in mind the frequency scaling factors involved, one can assume that the fade duration distribution for fades of 6 dB and higher at 23 GHz and for 15 dB and higher at 42 GHz will have the same statistical characteristics.

For linear polarization, minimum rain attenuation occurs when there is an alignment between the polarization vector and the local vertical axis of the rain drops. Maximum attenuation occurs in the horizontal direction because falling rain drops are oblate. In the case of circular polarization, the vector is assumed to be at 45°, hence representing the in-between case for rain attenuation. Vertical polarization will produce a rain attenuation typically in the range of 75% to 95% of the rain attenuation produced by circular polarization.

The measurements of rain attenuation at 30 GHz were also carried out using a space diversity system (i.e., two space-Earth paths); an improvement in performance of about 4 dB for 0.1% of the worst month was obtained. It can be concluded that the use of the space diversity concept for the feeder links to the BSS working at these high frequencies might be a way to overcome high attenuation levels.

4.3 *Rain depolarization*

Rain-induced depolarization of a transmitted wave occurs as a result of the non-spherical shape of rain drops.

Even though circular polarization was adopted for the BSS at 12 GHz, a consideration of the type of polarization to be used at 23 GHz may be required so that the practical advantages of circular polarization can be compared with the lower rain attenuation and better cross-polar discrimination that can be obtained from linear polarization when it is close to local vertical or horizontal. This is even more true for the cases where frequency reuse is impossible due to very poor discrimination from the circular polarization.

In the case of linear polarization, an improvement over circular polarization of up to 15 dB in discrimination can be obtained if the polarization vector is close to the local vertical or horizontal. It should be noted that cross-polarization due to ice crystals at high frequencies (20-40 GHz) is still a largely unknown phenomenon and care therefore needs to be taken when considering the re-use of these frequencies by means of orthogonal polarization.

Depolarization for circular polarization can be predicted by the model described in Report 564-3. Recent measurement results were found to be in good agreement with predicted values. It should be noted that the semi-empirical formula given in Report 564-3 has not been tested for frequencies above 35 GHz.

Using the semi-empirical formula given in Report 564-3 (Geneva, 1986) relating cross polarization to attenuation, and taking account of the frequency, Table III can be drawn up for cross polarization.

TABLE III

Predicted cross-polarization isolation

Frequency (GHz)	12		23		42	
Percentage (%) of worst month	99	99.9	99	99.9	99	99.9
Available cross polarization isolation (dB)	30	20	25	15	24	13

Worst month statistics of rain repolarization were derived in Table IV by measuring the beacon signal from the CS at 19.5 GHz for six years in Kashima.

The values at 23 GHz and 42 GHz were scaled from the measurement at 19.5 GHz [Fukuchi, 1985].

TABLE IV

Measured and frequency-scaled cross-polarization isolation

Frequency (GHz)	19.5		23		42	
Percentage (%) of worst month	99	99.9	99	99.9	99	99.9
Available cross polarization isolation (dB)	28.3	20.2	26.8	18.7	20.9	12.8

4.4 Other propagation effects

Although the atmospheric impairments on radiowaves at frequencies above 20 GHz are dominated by rain effects, two other mechanisms, i.e., clouds and melting layers, may become increasingly important under certain conditions when going to higher frequencies.

Cloud effects on radiowave propagation can be described in terms of attenuation, scintillation and depolarization [CCIR, 1986-90b and c].

4.5 Propagation experiments in the frequency range up to 23 GHz

Space-based and terrestrial propagation measurements and experiments, up to 23 GHz and beyond, have been conducted for many years, and more are firmly planned.

The results of wholly terrestrial measurements and radiometer observations, both of which have been taken for many years over a wide range of frequencies and in many rain climatic zones are useful.

Space-based propagation measurements in this frequency range have been made using several spacecraft: SIRIO (18/12 GHz), ETS-V (30/20 GHz), TELE-X (18/12 GHz) and TDF-1 (18/12 GHz).

Additional data will be available from BS-B (18/12 GHz), TV-SAT (18/12 GHz), DFS/KOPERNIKUS (30/20, 30 GHz) and from the OLYMPUS (30, 18/30, 30/20 and 12 GHz) experimental satellite of ESA ———— and the ACTS (30/20 GHz) satellite of NASA (from 1992). These latter programs will provide information on the depth and duration of fades (signal attenuation) for small percentage of time, over a wide range of elevation angles, and in a variety of rain climatic zones. Feeder-link power control and small-scale earth station diversity will also be studied.

5. HDTV transmission techniques

5.1 General aspects

The important features of HDTV production systems as envisaged in Report 801 and relevant to the design of broadcasting systems are:

- spatial resolution in the vertical and horizontal directions of about twice that available with Recommendation 601;
- improvements in temporal resolution beyond that achievable with Recommendation 601 with no significant cost penalties;
- improved colour rendition;
- separate colour-difference and luminance signals;
- a wider aspect ratio with display on a large screen;
- multi-channel high fidelity sound.

The radio frequency bandwidth required is a function of the baseband bandwidth of the coded signal. Satellite systems are power limited and it is important that the spectral efficiency be optimized as far as possible.

The unprocessed HDTV signal is likely to require a baseband-width of around 60 MHz or a bit rate of over 1.2 Gbit/s if coded digitally [Shelswell and Dosch, 1986]. Such large spectrum demands are unlikely to be satisfied in existing or possible future bands and a significant amount of bandwidth compression must be applied. This leads to increased cost and complexity in system receiver design, and/or loss of quality; appropriate solutions must be found.

However, the use of a new frequency band could allow the future possibility of introducing an HDTV system of higher quality with a limited amount of bandwidth compression.

One feature which is highly desirable, although not absolutely necessary, is "downward compatibility". As defined in Report 801-3, a new emission standard is "compatible" with an existing emission standard if signals of the new standard can be received and displayed, without additional equipment, with receivers designed for the existing standard. The quality should be about the same as the quality when a signal of the existing standard is received. Examples of the existing downward compatible systems are given in section 6.

The following sections describe HDTV signal transmission techniques, leading to examples of transmission formats and their required radio frequency characteristics.

5.2 Video signal multiplexing

Multiplexing of luminance and colour-difference signals may be FDM or TDM, but TDM signals are less susceptible to FM noise and differential gain and phase when applied to BSS (see Report 1074). For this reason, most of the proposed HDTV transmission formats use a TDM scheme.

Compression ratios of luminance and chrominance are between 2:1 and 4:1. Colour-difference signals are multiplexed with the line-alternating method. Adoption of quasi-constant luminance processing is effective for reduction of the impairment caused by noise in the transmission path [Ninomiya, et al., 1987].

5.3 Bandwidth reduction techniques

Currently proposed HDTV studio standards have a video bandwidth or bit rate 4 to 5 times higher than the conventional analogue (Report 624) and digital standards (Recommendation 601). There is insufficient radio spectrum to permit a 4 to 5 fold increase in RF bandwidth and compression techniques which enable an HDTV signal to fit into a relatively narrower bandwidth channel, of the order of once or twice the width of those already planned in the 12 GHz bands, are required.

Sub-sampling is a widely used approach for bandwidth reduction of a signal by discarding some of the information present in the original signal without causing serious picture quality degradation. Diagonal or quincunx sub-sampling in the two-dimensional spatial domain is most common for this purpose. Temporal domain sub-sampling can be applied to the diagonal sub-sampling when further reduction of bandwidth is required for narrow-band transmission [Ninomiya, et al., 1987; Long and Stenger, 1986]. This method is called multiple sub-sampling or 3D sub-sampling. Linear sub-sampling can be used as a simple way to perform two-dimensional sub-band filtering. Also, the refresh rate of each sub-band can be made to differ, hence realizing a simple version of three dimensional sub-band coding [Tsinberg, 1989].

Line-column conversion (frame of field shuffling) is proposed for the purpose of increasing the vertical sampling rate combined with sub-sampling in case of using a rather small number of scanning lines such as 525- or 625-lines for transmission [Sauerburger, 1987; Iredale, 1986].

It is also possible using appropriate digital filters to reduce the number of lines in the transmission format (typically by 35% [Nishizawa and Tanaka, 1982]), by interface to sequential scan conversion. The principle is based upon the fact that particularly interlace scanning does not provide the full quality potential which can theoretically be attributed to the relevant number of lines [Long and Stenger, 1986].

Motion adaptive control of pre-and post-filtering and/or sampling structure can be applied for better picture quality. Motion compensation techniques may also be needed for the temporal interpolation of sub-sampled signals in case of uniform motion such as camera panning or tilting [Ninomiya, et al., 1987]. The effectiveness of motion compensation techniques can be further enhanced using more extensive digital assistance [Storey, 1986] to control the receiver. Motion detection and measurement are performed at the coder on the uncorrupted source signal and a digital motion control signal is transmitted with the compressed (analogue) video signal to select the decoding mode in the receiver. Most of the complexity is now moved to the broadcaster's transmitter which should assist with manufacturing lower cost , higher performance receivers.

For analogue transmission, further techniques can reduce the required channel bandwidth by applying appropriate pre-processing to the analogue video signal before frequency modulation. By allowing wider FM deviation for the useful components of the active part of the vision signal, it helps to reduce signal susceptibility to noise and interference. The main goal is to apply all possible measures before frequency modulation to reduce the difference between the peak and the average power of the signal and to produce a more symmetrical FM spectrum. The following measures can be applied:

- elimination of synchronization pulses, carriers and sub-carriers;
- subtraction of DC and low frequency signal content from the analogue signal with its digital encoding and transmission in the data multiplex;
- temporal pre-filtering (frame combing);
- instantaneous non-linear signal compression;
- time dispersion (chirp filtering);
- pre-emphasis.

As described in Report 1092 for digital HDTV transmission systems, additional compression techniques such as predictive coding (intra- and inter-field/frame DPCM), transform coding and entropy coding can be applied, as already with conventional digital television transmission (see also Report 1089).

The main challenge lies in reducing the necessary bit rate from about 1.2 Gbit/s (studio signal) to a rate suitable for satellite broadcasting. Hybrid DCT seems to be a promising procedure among various techniques. Adequate quality for both moving and still pictures has been reported achievable with a bit rate of about 120 Mbit/s [Kutka, R. and Waidhas, W., 1988]. Currently, real-time codecs for this technique are under development in various countries. A codec using inter-field DPCM with adaptive quantizing and 4-bit fixed length codes has been developed as described in Report 1092.

5.4 Sound and data multiplexing

Due to requirements of quality, capacity and flexibility, sound and data signals should be transmitted in digital form. In case of analogue transmission of vision signals, either baseband or RF TDM of digital sound and data can be used. The transmissible bit rate in the case of RF TDM is higher than that of the baseband TDM. For the sound system of HDTV, multi-channel systems such as 4-channel (3-channels for front and 1-channel for rear) or 5-channel (5-channel for front) systems as well as 2-channel (conventional stereo), have been proposed. Nevertheless, not all channels may need to be transmitted if a suitable matrixing were used in the receiver. The currently required bit rates are in the range from 1.35 to 3.4 Mbit/s, depending on the coding scheme and the error protection method used. In order to reduce the bit rate for sound, new coding schemes have been developed such as DPCM [CCIR, 1986-90d] while retaining a high sound quality. Even more efficient coding schemes such as sub-band coding [Theile, et al., 1987] are being developed and can reduce further the bit rate.

Sound coding schemes and their evaluation are discussed in Report 953.

According to CCIR Report 954-1 a certain amount of capacity for additional data should be provided, including that required for any digitally assisted television control signals.

5.5 Modulation techniques

Narrow RF-band HDTV signals intended for the operation in the 12 GHz band have to comply with the interference criteria on which the respective Plans are based. The service objective for the picture and sound should be met.

Wide RF-band HDTV signals for satellite broadcasting in the range 12.7 - 23.0 GHz require the use of suitable modulation and channel coding methods to cope with the difficult propagation characteristics existing throughout this part of the spectrum and which generally get worse at the higher end of this range.

5.5.1 FM modulation

Frequency modulation is usually used for the transmission of analogue BSS signals. The advantages of FM are its relative insensitivity to noise and interference compared with other analogue transmission methods, achieved at the expense of bandwidth. For television signals the bandwidth may be expressed empirically by a modified version of Carson's formula:

$$B = \alpha \Delta f_L + 2f_{max}$$

where: B : RF bandwidth (approximate) (MHz)

α : constant for a given system which depends upon the pre-emphasis used (in MAC and MUSE systems $\alpha \simeq 1$) [CCIR, 1986-90e] .

f_{max}: maximum video frequency (MHz)

Δf_L peak-to-peak frequency deviation caused by the low frequency vision components (MHz).

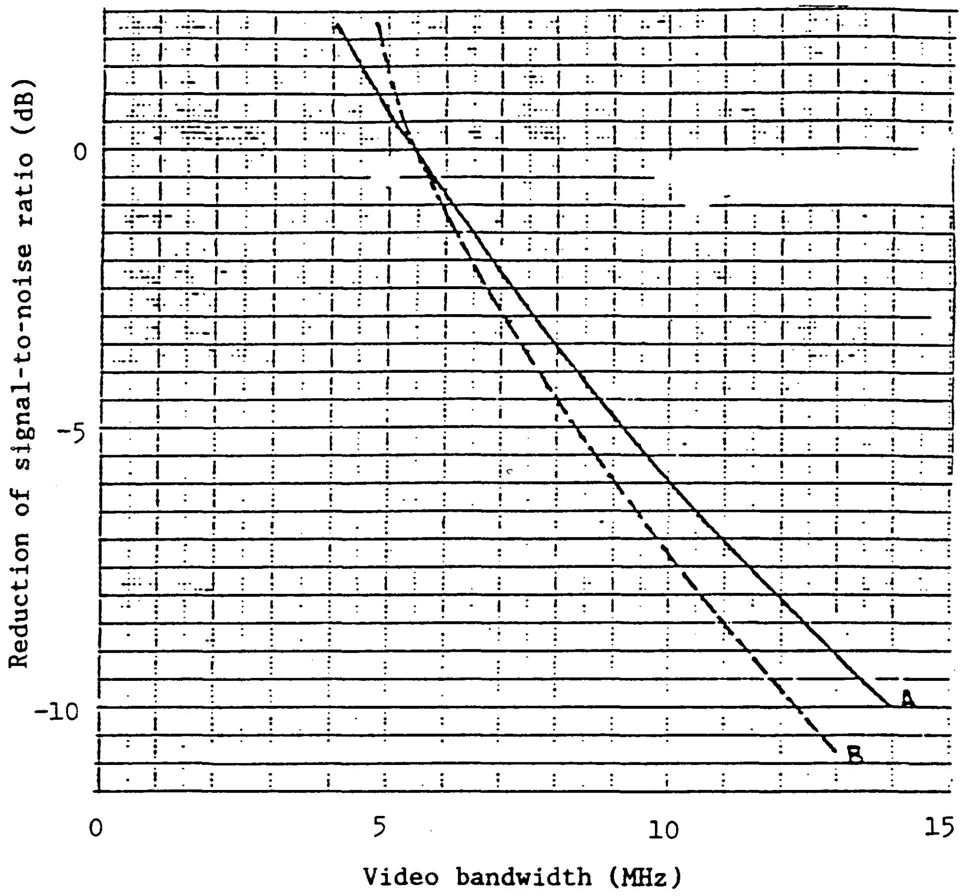


FIGURE 1 - Effect of increasing the video bandwidth on signal-to-noise ratio for FM transmission (MAC example)

Curve A: with CCIR unified weighting network (CCIR Recommendation 568)

Curve B: reduction of S/N unweighted.

Increasing the baseband width in a system to provide higher definition pictures has a significant effect on the available video signal-to-noise ratio, as illustrated in Figure 1.

Thus there is a need to increase the carrier-to-noise ratio when the bandwidth of the analogue transmission is increased.

In the 12 GHz band, the frequency deviation is restricted by interference constraints. Consequently for the transmission of an HDTV signal with about 10 MHz bandwidth, the carrier-to-noise ratio should be of the order of 17-20 dB.

In the case of the 20 GHz band, the frequency deviation can be increased to compensate for noise in the channel. However, this may lead to wide channel bandwidths, high levels of interference and distortion. For efficient use of the spectrum it may be desirable to set the target carrier-to-noise ratio at about 17 dB.

The bandwidth available may also be limited by interference restrictions if the channels overlap. There is no rule to predict acceptable levels of interference. Thus, the required channel spacing for a proposed system must be determined experimentally.

Existing FM systems employ linear fixed emphasis characteristics. But it is important to use more suitable emphasis characteristics in order to obtain a high signal-to-noise ratio. Non-linear emphasis is effective for this purpose [Ninomiya, et al., 1987] and adaptive emphasis may also be employed for the same purpose. DC preservation is necessary to utilize the given RF bandwidth effectively.

Threshold extension techniques (e.g., phase-lock loop or adaptive filter) can offer up to approximately 3 dB of threshold extension, which will decrease the outage time due to heavy rain in higher frequency bands.

5.5.2 Digital modulation

Taking into account the impact of digital technology on the broadcast field and on the consumer TV market, digital modulation could be the most appropriate technique for providing future single-channel wide RF-band HDTV broadcasting services.

Suitable methods of digital modulation are 4-PSK, 8-PSK, 16-QAM and possibly even 64-QAM, which give a range of trade-offs between power, bandwidth requirements and ease of sharing. Further study of their performance through a satellite channel is required, including the use of the non-linear transponder for non-constant envelope signals.

Laboratory investigations on a hardware satellite simulator have been carried out in Italy [Cominetti, Morello and Visintin, 1989] to evaluate the influence of the power amplifier (TWTA) non-linearities on the performance of three digital modems: QPSK, 8-PSK and 16-QAM. For different values of the TWTA output back-off (OBO), the E_b/N_o ratio, corresponding to a BER of 10^{-5}, has been measured. The following results, confirmed by computer simulations, were obtained:

QPSK can efficiently operate close to saturation (OBO = 0 dB, i.e. with maximum TWTA power; E_b/N_o = 12 dB). For 8-PSK, the optimum performance was found with 0.5 dB OBO (E_b/N_o = 17.3 dB). 16-QAM showed high sensitivity to non-linearities because of its inherent amplitude modulation and it is necessary to operate with about 7 dB OBO (E_b/N_o = 24 dB), giving very low power efficiency.

Studies [Shelswell and Dosch, 1986] indicate that a 27 MHz channel might support a maximum of between 60 and 100 Mbit/s depending upon interference effects and given a carrier-to-noise ratio of 20 dB. However, given the extremely high compression needed (> 10:1) to reduce the digital HDTV signal to this capacity, it is unlikely that an all-digital system can be achieved in a narrow RF-band channel.

QPSK or O-QPSK digital modulation allows operation at significantly reduced C/I conditions which are typically 10 dB lower than for conventional FM. Co-channel operation using orthogonal polarization can therefore be envisaged for the same service area. Furthermore, owing to the low sensitivity to interference from other digital signals, QPSK or O-QPSK would probably allow more spectrum/orbit efficiency in planning without the need for taking into account interference from adjacent orbit positions.

Because of this property overall spectrum efficiency with digital systems for a given band (i.e. the number of channels per service area) should at least be equal to that using an analogue FM wide-RF band system which needs only about half of the bandwidth for an individual channel but does not allow co-channel operation [Shelswell and Dosch, 1986; CCIR, 1986-90f].

Higher-order modulation schemes like 16-QAM, characterized by higher spectral efficiency than QPSK, require not only higher C/N values but also higher protection ratios, precluding co-channel operation using orthogonal polarization.

For a digital system, the overall HDTV service quality jointly depends on the performance of the picture coding algorithm and on the available margin against noise and interference, allowed by the RF-channel performance. The system optimization then requires a trade-off in the bit-rate allocation between "source video coding" and "modulation and channel coding" to achieve the highest picture quality with minimum outage times.

Studies for digital HDTV broadcasting are based on the inclusion of suitable forward error-correction and/or trellis modulation to ensure perfect picture quality for most of the time and useable picture quality up to a bit-error ratio of 10^{-3}.

6. Examples of HDTV transmission formats and their RF bandwidth requirements

Tables V(a) and V(b) give examples of HDTV transmission formats. The three examples (Table V(a)) are for transmission in the planned 12 GHz bands provided that the appropriate protection ratio requirements are shown to be met. These kinds of systems require extensive signal processing in order to allow the HDTV signal to fit into a single 24/27 MHz channel. However, for these systems the resolution in moving areas of the picture will be approximately one-half of the resolution for static pictures. In order to be free from these limitations it will be necessary to increase the video baseband bandwidth and consequently the RF bandwidth.

Other systems which can be carried in one 24/27 MHz channel have been partially demonstrated and others are still at various stages of development [CCIR, 1986-90g; Glenn, 1987; Iredale, 1986].

The four examples in Table V(b) require a wider bandwidth which could possibly be accommodated in the 23 GHz band (in Regions 2 and 3) or in a suitable new world-wide frequency band yet to be allocated.

The first and second columns (Table V(b) show the possibilities for various analogue systems (including MAC/packet compatible systems) intended to give good quality but their bandwidth requirements are such that they could only be implemented in a frequency band not subject to the planning constraints of the 12 GHz band. A band in the 20 GHz range suitable for wide RF bandwidth systems is therefore suggested.

TABLE V(a)

Characteristics of example narrow RF-band HDTV satellite broadcasting systems

Parameter	System N1 (MUSE)	System N2 (HD-MAC)	System N3(c)
Aspect ratio	16:9	16:9	16:9/4:3
Picture rate (Hz)	30	25(1)	59.94
Active lines/picture	1032	1152	720
Basic sampling frequency (MHz)	Y:45.55 C:14.85	54	75.6
Active samples/line:(4)			
luminance	1122	1440	1360
colour difference	376	720	340
Type of coding	analogue	analogue	analogue and digital
Compression method	motion-adaptive sub-sampling motion-compensation	motion-adaptive sub-sampling with motion compensation	adaptive sub-band coding
Maximum luminance band width (MHz)(2)	22	21	28.9
Maximum colour difference bandwidth (MHz)(2)	7	10.5	9.6
Luminance sub-sampling (horizontal)	3:1	2:1	-
Colour difference sub-sampling (horizontal)	4:1	2:1	-
Colour difference sub-sampling (vertical)	2:1	2:1	-
Luminance compression	12:11	3:2	8:1
Colour difference compression	48:11	3:1	-
Transmitted base bandwidth (MHz)(3)	8.1	10.125	6.0
Digital assistance (Mbit/s)	-	1-2	-
Coded video bit rate (Mbit/s)	-	-	90
Digital sound/data multiplex (Mbit/s)	1.35	1.5 or 3	-
Sound signal bandwidth (kHz)	20/15	15	15
Sampling frequency (kHz)	48/32	32	32
Number of sound channels	2/4	2/4 or 4/8	3
Coding/modulation method	DPCM/ternary	PCM/duobinary	To be specified
Companding law	15-to-8 (8 ranges) /16-to-11 (6 ranges)	Linear 14/ 14-10 NICAM	To be specified
Digital time compression	13.5:1	6.6:1	12.5:1
Error protection coding	included above	included above	To be specified
Symbol rate (Mbaud)	12.15 Ternary	-	11.2
Instantaneous bit rate (Mbit/s)	-	10.125/ 20.25(5)(6)	22.4
Type of modulation	FM	FM	FM
and deviation, ΔF_L (MHz)	10.2	9.55	To be specified
Required RF bandwidth(MHz)	27/24	27	27/24

TABLE V(b)

Characteristics of example wide RF-band HDTV satellite broadcasting systems

Parameter	System W1	System W2	System W3	System W4
Aspect ratio	16:9	16:9	16:9	16:9
Picture rate (Hz)	25$^{(1)}$	30	25$^{(1)}$	30
Active lines/picture	1152	1035	1152	1035
Basic sampling frequency (MHz)	54 or 72	Y:59.4 C:29.7	72	Y:74.25 C:37.125
Active samples/line:$^{(4)}$				
luminance	1440 or 1920	1536	1920	1920
colour difference	720 or 960	768	960	960
Type of coding	analogue possibly with digital assistance (DATV)	analogue	digital	digital
Compression method	motion-adaptive sub-sampling possibly with motion-compensation	motion-adaptive sub-sampling	sub-sampling and adaptive-predictive transform variat length coding	adaptive predictive DCT, block variable length coding
Maximum luminance and width (MHz)$^{(2)}$	21 or 24	27	21-24	30
Maximum colour difference bandwidth (MHz)$^{(2)}$	10.5 or 12	13.5	10.5-12	15
Luminance sub-sampling (horizontal)	2:1	2:1	3:2	none
Colour difference sub-sampling (horizontal)	2:1	4:1	3:1	none
Colour difference sub-sampling (vertical)	2:1	2:1	2:1	none
Luminance compression	3:2	25:22	8:3$^{(7)}$	8:1.33
Colour difference compression	3:1	50:11	8:2$^{(7)}$	8:0.67
Transmitted base bandwidth (MHz)$^{(3)}$	18	16.875	-	-
Digital assistance (Mbit/s)	up to 8	–	included in video bit rate	-
Coded video bit rate (Mbit/s)	-	-	127-147	12
Digital sound/data multiplex (Mbit/s)	1 to 4	2.7	2.5	3.072
Sound signal bandwidth (kHz)	≥ 15	20/15	To be specified	20
Sampling frequency (kHz)	≥ 32	48/32	To be specified	48
Number of sound channels	≥ 2/4	4	To be specified	4
Coding/modulation method	to be specified	DPCM/PCM	To be specified	PCM
Companding law	Linear 14/14-10 NICAM or to be specified	16-12/16	To be specified	none
Digital time compression	6.6 or 6:1	13.5:1	-	-
Error protection coding (Mbit/s)	included above	included above	10.5	about 12
Symbol rate (Mbaud)	-	24.3 ternary	-	-
Instantaneous bit rate (Mbit/s)	54$^{(4)}$ or 72$^{(4,5)}$	–	140-160	135
Type of modulation and deviation, ΔF_L (MHz)	FM or FM + 4 PSK family 9.55 to 18	FM 12-21	Digital (a) 4FSK (b) 8FSK (c) 16QAM	Digital (a) 4-PSK (b) 8-PSK (c) 16-QAM
Required RF bandwidth (MHz)	45-54	45-54	(a) 105-120$^{(8)}$ (b) 70-90$^{(8)}$ (c) 52.5-60$^{(8)}$	(a) 81 (b) 54 (c) 40

Notes to Tables V(a) and V(b)

(1) Display in an HDTV receiver would normally be after suitable up-conversion, for example 1250/100/2:1 (lines/field rate/interlace).

(2) Some loss of resolution will occur in moving areas of the picture, related to the nature and/or speed of motion. This will be much less for wideband systems.

(3) -6 dB point for overall transmission path.

(4) Source format.

(5) During digital transmission periods.

(6) Compatible with MAC/Packet family of CCIR Report 1073.

(7) Reduction in mean quantization accuracy, bits/sample.

(8) Shaping factor 1.5.

6.1 Narrow RF-band systems

6.1.1 System N1 (MUSE)

System N1 is the MUSE system developed in Japan for HDTV broadcasting using a single planned channel [Ninomyia, *et al.*, 1987; CCIR, 1986-90h].

The baseband signal bandwidth is 8.1 MHz. It uses 4:1 dot-interlaced sub-sampling which employs inter-field and inter-frame offsets.

Properties of the human visual system are effectively taken into the design. The technique of motion compensation is applied for the purpose of improving the effect of sub-sampling, in the case of uniform movement in the picture. Non-linear emphasis is applied to improve emphasis gain. Quasi-constant luminance processing is applied to reduce impairment caused by noise in the transmission path.

A detailed technical description is given in Annex II.

Digital transmission of the MUSE signal (System N1) is possible. For this purpose, a DPCM system has been developed with the total bit rate from 64 to 100 Mbit/s [CCIR, 1986-90j].

6.1.2 System N2 (HD-MAC)

System N2 is the HDMAC system currently being developed in Europe for use in the 12 GHz planned band [CCIR, 1986-90k, l, m and n].

This system has been designed to be compatible with the MAC/packet family of standards (see Report 1073 and the CCIR Special Publication: Transmission Systems for the BSS) and employs spectrum folding, sub-sampling and motion adaption to preserve the resolution of both static and tracket motion for high definition reception. After adaptive sub-sampling and filtering a 625-line MAC compatible signal is obtained for transmission. Adaptive filtering and display up-conversion are applied in the high definition receiver, using motion detection and vector measurement derived from the codes. Motion-adaptive control data is signalled to the receiver using DATV (digitally-assisted television) techniques [Storey, 1986].

Further details are given in Annex III.

In addition, digital transmission of the HD-MAC signal (System N2) at 140 Mbit/s has been demonstrated at IFA, Berlin in 1989 [CCIR, 1986-90o].

6.1.3 System N3 (North American systems)

The three systems described in this section are at various stages of development in North America for satellite emission in an NTSC (System M) environment.

6.1.3.1 System N3(a) (HDS-NA)

The HDS-NA system (High Definition System - North America) accepts either a 525-line progressive scan or a 1050-line interlace input signal. With the former input, it provides a luminance horizontal resolution of 500 lines per picture height (lines/ph) with 480 active lines delivered at a 59.94 Hz refresh rate. When a 1050-line interlaced source is used, the vertical resolution is nominally 680 lines. This system also provides four audio channels and conditional-access information. Satellite testing will begin in 1989. A more detailed description of this system is given in Annex IV, section 1.

6.1.3.2 System N3(b) (HDB-MAC)

The HDB-MAC (High Definition B-MAC) system is an outgrowth of the B-MAC system which is described in the CCIR special publication "Specifications of transmission systems for the broadcasting-satellite service".The HDB-MAC system employs a 525-line, 2:1 interlaced transmission, allowing simple conversion to NTSC for non-HDTV viewing. The system employs sub-Nyquist spectrum folding to trade diagonal resolution for increased horizontal resolution. This system allows for dual aspect-ratio transmission (16:9 or 4:3). The system provides six digital audio channels, a 63 kbit/s utility data channel, up to 600 rows per second of text data and a conditional access data channel. A more detailed description is given in Annex IV, section 2.

6.1.3.3 System N3(c) (SC-HDTV)

The SC-HDTV (Spectrum Compatible HDTV) system is the third system being developed in North America. It is a progressively scanned 59.94 Hz system employing sub-band video encoding and five transmission processing steps to provide the required enhanced signal-to-noise performance within a conventional baseband of 6 MHz bandwidth. FM satellite transmission efficiency is improved by allowing increased FM deviation for the most important components in the video signal and by increasing the symmetry of the modulated FM spectrum. A more detailed description of this system is given in Annex IV, section 3.

6.2 Wide RF-band systems

6.2.1 System W1

System W1 **is proposed as a development of HD-MAC for a wideband RF channel of up to twice the bandwidth of the existing planned channels. It would provide improved high-definition quality, possibly with a simplified receiver. There are two options, one based on 54 MHz sampling [Sauerburger, 1987] which would be compatible with System 2 HD-MAC receivers and one based on 72 MHz sampling [Storey, 1986] which would provide higher performance with much greater use of DATV, but is not completely compatible.**

6.2.2 System W2

System W2 is a non-compatible 60 Hz based system using 2-field offset sub-sampling. This system offers higher spatial resolution both for static and moving areas, compared to MUSE. The required RF bandwidth is between 45 and 54 MHz.

6.2.3 System W3

System W3 is an all-digital example which is not compatible with MAC/packet receivers, but retains compatibility at source with the CCIR Recommendation 601 625-line standard. Using 4-PSK modulation, the required bandwidth could be as high as 120 MHz, but if 16 QAM were used a RF bandwidth between 50 and 60 MHz is possible.

If the expected progress on bit-rate reduction techniques allows, without quality degradation, a further reduction in the video bit rate assumed in System N3 (Table V (b)), more powerful channel coding and modulation techniques may be adopted to increase the margin against noise and interference and to reduce the satellite power and outage times.

Studies carried out in Italy [Cominetti,Morello and Visintin, 1989] show that an HDTV system based on Hybrid DCT picture coding (at about 100 Mbit/s) and using 140 Mbit/s QPSK modulation, with rate 3/4 convolutional coding and soft decision Viterbi decoding, would allow a coding gain in the C/N ratio of about 5.2 dB with respect to System W3. The required RF bandwidth is 105 MHz, as for System W3.

6.2.4 System W4

System W4 is an all-digital example based on the combination of predictive coding and DCT for emission of 1125/60 studio signals. The total bit rate of this system is 135 Mbit/s. Using 4-PSK or 8-PSK modulation, the required RF bandwidths are 81 MHz or 54 MHz, respectively. However, RF bandwidth of about 40 MHz is possible using 16-QAM. This system can be applied for transmission using the H_4 level of the B-ISDN.

6.3 Downward compatibility

Following the definition of downward compatibility given in section 5.1, several approaches are possible.

One approach for compatibility between conventional television and high-definition television is two-channel transmission systems [CCIR, 1982-86a; Sauerburger and Stenger, 1984]. All signals necessary for receiving by conventional receivers are carried by one of the two channels. The other channel carries the additional information to permit reconstruction of the HDTV picture. However, there is now much interest in the development of HDTV formats which can be carried in a single channel.

In North America three systems are under consideration for satellite emission formats. They are based on a wide range of techniques for increasing resolution for a given channel bandwidth. Two of these proposed systems have versions suitable for terrestrial and satellite emissions and one system is intended exclusively for satellite emission. These systems have varying degrees of compatibility with existing NTSC receivers. Two are of the MAC type which result in a relatively simple converter for the picture information although the accompanying digital audio has to be extracted from the data multiplex. The third system which relies on video sub-band encoding was not intended to provide for a compatible NTSC signal and will require a more complex converter for NTSC display. Nevertheless, in all cases the field rate is the same as for NTSC and a simple relationship was preserved between the line rates of these three emission systems and the line rate of NTSC. This will allow for a much simpler conversion to NTSC.

In Europe, active studies are under way concerning HDTV systems which can be received compatibly by MAC/Packet receivers, with the normal quality of the latter signals. If the high-definition television signal possessed characteristics at the low frequencies of the spectrum identical to those of the existing MAC signals as in two of the examples of Table V compatibility between the two types of service will be possible.

[CCIR, 1986-90p] indicates that the choice in the European Community is for a system which is compatible with the MAC/packet family of transmission standards. Compatibility with the European DBS emission standard is considered vital for the commercial introduction of high definition television programmes, allowing consumers to see HDTV broadcasts on their conventional DBS sets and to make a choice of when to upgrade to HDTV. MAC/packet compatible HDTV (HD-MAC) was demonstrated at IBC Brighton, in 1988, and with further use of digital assistance techniques at IFA, Berlin, in 1989. Experts in Europe are confident that compatible HDTV can at least match the quality of non-compatible systems using similar bandwidth transmission.

With the development of consumer equipment to this HD-MAC standard, probably with displays operating at 100 Hz , the options for viewing DBS programmes will range from 4:3 PAL/SECAM and MAC to 16:9 MAC and HD-MAC.

The EBU [CCIR, 1986-90q] would support the HD-MAC system as described in Section 6.2.1 provided that it achieves an acceptable balance between HDTV and compatible MAC picture quality, provides full service continuity for data services, provides compatibility with the WARC-77 Plan and provides compatibility with MAC/packet receivers.

Although the MUSE system is not compatible with conventional TV systems, a MUSE to 525-line standards converter, intended for use with consumer receivers was developed and demonstrated. This is of small size (made up of four 20 cm by 30 cm circuit boards). The resultant 525-line picture converted with this converter has, on average, higher quality than the normal picture originated with NTSC standard, although it has some flicker at the edge, with less interference than that caused by the NTSC cross-colour. It has a simple circuit construction and it will be made available at a lower price by using LSI technology. The development of this MUSE to 525-line standards converter gave some prospect to HDTV broadcasting in the 1125-line systems which can be received utilizing conventional 525-line receivers.

7. Receiving equipment

7.1 Figure of merit

The figure of merit of the receiving equipment depends on the antenna gain and noise figure of the receiver, and it is calculated by the definition of usable figure of merit given in Annex I to Report 473, neglecting, however, the pointing loss, polarization effects and ageing.

There is a compromise to resolve the problems of using higher frequencies: if the antenna diameter is maintained constant, there is a rapid increase in the pointing accuracy needed. Whilst, if it is reduced in proportion to the wavelength, there is a severe reduction in antenna aperture. The choices given in Table VI are considered as possible examples for the satellite broadcasting system.

TABLE VI - Examples for antenna characteristics

Frequency (GHz)	12	23	42
Diameter (m)	0.9	0.9	0.5
Half power beamwidth (deg.)	1.9	1.0	1.0
Gain (dB) (η = 65%)	39.2	44.6	44.2

The most commonly accepted receiver noise figure in the 12 GHz band is between 1.3 and 4 dB. The figure-of-merit based on a 4 dB figure may be rather conservative and 1.8 dB would be more appropriate (see Report 473-4 (MOD F)).

A large number of low-noise amplification elements which can be applied for the 20 GHz range are being developed, with special interest in the HEMT (high electron mobility transistor). At 20 GHz using HEMTs, a single-element noise figure (NF) of 1 dB and amplifier NF of 2 dB have been achieved [Shibata et al. 1986]. A GaAs FET, on the other hand, has yielded at the same frequency a single element NF of 2 dB and amplifier NF of 3 dB [Handa et al. 1986]. A summary of the situation is given in Figure 2. The figure shows that the current status of the noise figure is 4 dB for the 20 GHz range and 7 dB for 42 GHz.

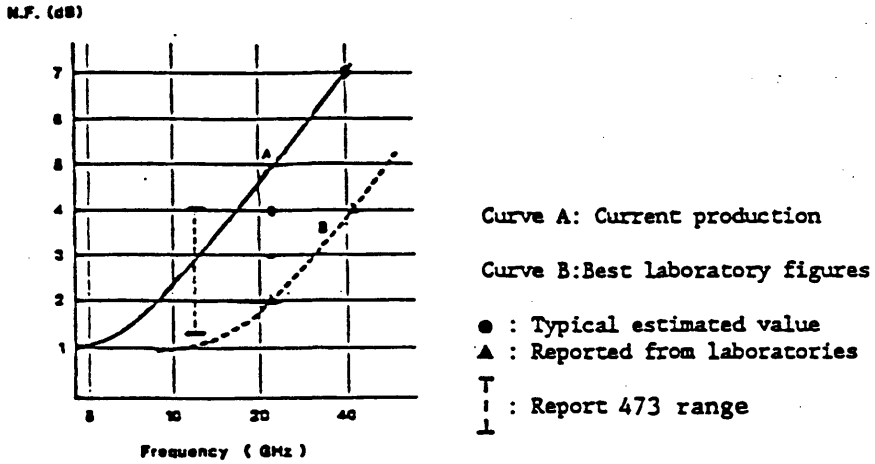


FIGURE 2 - Receiver noise figure performance as a function of frequency

It is noted that the effect of the noise increase due to rain attenuation should not be neglected for calculation of the figure of merit (see Report 473).

Results of figure of merit calculations based on the above conditions are given in Table VII.

TABLE VII

Example of figure of merit

Frequency (GHz)	12	23	42
Figure of merit (dB(K^{-1}))	14.1⁽¹⁾	17.0⁽²⁾	12.2
Noise figure (dB)	1.8	4	7

(1) A 16 dB(K^{-1}) figure of merit is expected assuming an antenna with a 1.0 m diameter and a 1.8 dB noise figure in clear sky.

(2) An 18 dB(K^{-1}) figure of merit is expected assuming 0.9 m diameter antenna and 4 dB noise figure in clear sky.

In addition to identifying the specifications of the receiving equipment for individual reception, there is also a need to characterize the equipment for community reception. In the case of the 23 GHz band, the size of the antenna for community reception will be in the range where automatic tracking might be required. Assuming a satellite station-keeping tolerance of ± 0.05°, a signal peaking accuracy of 0.1 dB at the time of installation and an allowed link degradation of 1 dB, and assuming the worst mispointing occurrence, the maximum size antenna that can be used without automatic tracking is 1.8 m. It is therefore suggested that the size of antenna for community reception be 1.8 m. The corresponding *G/T* would be 25 dB, with no allowance for mispointing and equipment ageing.

7.2 *Demodulator*

Whereas a conventional discriminator is commonly used, a threshold extension demodulator (phase-lock loop or adaptive filter, etc.) may also be used and offers up to approximately 3 dB of threshold improvement for FM systems.

For an overall digital signal, it is expected that the error performance can be improved by using complex decoding strategies.

7.3 *Decoder*

Low cost receivers are essential for HDTV satellite broadcasting to be popular. Most HDTV systems use digital processing employing frame stores in order to achieve a large scale bandwidth compression. The required number of logic gates would be several tens of thousands and necessary capacity of the store would be of the order of 10 Mbits.

Therefore the reduction of the receiver cost depends on how efficiently large-scale integration (LSI) can be introduced to signal processing. Recent trends towards larger capacity LSI stores, from 256 kbit to more than 1 Mbit, and towards digitization of conventional television receivers are expected to be a favourable impact on expediting the development of LSI circuits for HDTV receivers [CCIR, 1986-90r].

Recently, a total of 26 kinds of custom VLSIs have been developed for the MUSE decoder. Employing these VLSIs, the decoder can be built with 46 pieces of custom VLSIs. The size and the power consumption of the decoder is approximately 1/30th that of the prototype made with conventional ICs, and this represents a significant step forward to realize low cost MUSE receivers for home use[CCIR, 1986-90s].

7.4 Displays

A large-screen high-resolution display is necessary to provide the full benefits of HDTV viewing. For home use display a screen size of about 1.3 m (50 inches) in diagonal is a present target for development. Availability of such displays is a key factor in determining how rapidly HDTV will become popular.

Direct view cathode ray tubes (CRTs) of up to 1 m diagonal are currently available in addition to various front and rear projection displays which provide even larger images. For the home, gas discharge panels and liquid crystal colour displays are under development and would make the HDTV receiver much more practical.

Further information of the development of displays is described in Report 801.

7.4.1 Direct-View cathode ray tube displays

Direct-view displays using cathode-ray tubes (CRTs) with an aspect ratio of 16:9 and having diagonal length as large as 41 inches (66 to 104 cm) have been developed. The main problem with such large CRT displays is their weight, which can be as much as 170 kg.

In 1987, a 32-inch (80 cm) CRT was developed with a shadow mask of Invar steel. It attained a peak brightness of 230 cd/m^2 [CCIR, 1986-90t].

In the first designs, horizontal resolution of 1000 lines, or greater than 1400 picture elements per active line, and vertical resolution commensurate with 1250 total scanning lines were achieved, using phosphor dot pitches of around 0.3 mm and video bandwidths of about 60 MHz.

Operation at a line-repetition rate of 62 kHz was demonstrated to give 1250 lines progressive scanning at a 50 Hz field rate (1250/50/1:1) or 1250 lines. 2:1 interlaced scanning at 100 Hz field rate (1250/100/2:1) as options to eliminate interline flicker or large-area flicker.

Projection displays using CRTs have also been developed with screen sizes over 40 inches (1.0 m).

7.4.2 Front projection displays

Front projection is well developed and most practical for large displays. Front projectors may provide some of the first displays for use in the home. For television in cinemas, the most suitable technology is the use of light valves and Schlieren optics. These devices are available from several sources [CCIR, 1986-90u]

However, projection displays up to 3 m (118 inches) can be achieved with small CRTs for peak luminance figures in excess of 100 cl/m^2, and a screen gain of 13 [CCIR, 1986-90u].

A recent example is a front projector designed to provide a 250 cm (98 inches) diagonal 16:9 aspect ratio screen. This device has a peak luminance of 300 candela/m^2 and a screen gain of 10. The modulation transfer function provides 10% modulation at 1000TV lines [CCIR, 1986-90v and w].

7.4.3 The development of rear projection displays

Rear projection can provide large displays without commensurate increases in weight and overall volume of the receiver: desirable characteristics of receivers intended for home use. Highly stable receivers with overall dimensions suitable for home use have been developed with high brightness and contrast. The picture diagonal was 127 cm (50 inches) with a 16:9 aspect ratio and a 1250 line interlaced scanning system operating at a 50 Hz field rate (1250/50/2:1); the peak luminance of 400 cd/m^2 was nearly as high as that available with conventional 625-line receivers. Of perhaps more importance was the attainment of a stable and relatively high contrast ratio of 50:1.

7.4.4 Other HDTV displays under development

A solid-state light valve is being developed in the United States. An array of thin-film CMOS transistors laid down in the form of a television raster produces a 20-volt electrostatic deforming field. On top of the integrated circuit is a deformable layer and a reflective thin film.

A flat-panel display is desirable to make HDTV receivers more practical for the home and to encourage their use. The most practical way of realizing large displays that provide the fast operating speed required by HDTV is with gas-discharge devices. A 20-inch (50 cm) DC fast-discharge panel with internal memory has recently been fabricated as the first step towards the development of an HDTV flat-panel display. This study showed the possibilty of realizing even larger flat-panel HDTV displays. A 4-inch (10 cm) liquid crystal colour display using amorphous silicon TFTs has also been developed [CCIR, 1986-90x and y].

7.5 Examples of satellite broadcasting receivers

7.5.1 MUSE satellite receiver

For the reception of experimental HDTV satellite broadcasting in Japan, the same receiving antenna and outdoor unit as those used for existing satellite broadcasting with digital subcarrier/NTSC systems are being used.

The indoor unit is configured so as to be able to receive both digital subcarrier/NTSC and MUSE systems.

The FM detected MUSE signal is supplied to the MUSE decoder, where the dispersal signal is removed and de-emphasis is performed. The keyed AFC clamp pulse is supplied from the MUSE decoder to the indoor unit. For this purpose connecting terminals for the detected signal output and for the clamp pulse input are provided with the indoor unit.

The efficiency of the receiving antenna and the noise figure of the outdoor unit which are available in the current consumer market are 68% on average and 1.8 dB on average, respectively [CCIR. 1986-90z].

In September 1989 developments of prototypes of a MUSE receiver utilizing a series of custom VLSIs (see section 7.3) were announced.

The receivers are so designed as to receive those signals of the conventional VHF/UHF television, of Clear Vision (an enhanced quality television in Japan), and of Hi-Vision (HDTV in Japan) with a single equipment.

Most of them are capable of reproducing 3-1 Surround Sound (described in Report 1072) accompanied by the HDTV picture. Connections with VCRs and VDPs (Video Disk Players) have also been incorporated into their design in some cases [CCIR, 1986-89aa].

7.5.2 HD-MAC satellite receiver

The HD-MAC receiver includes an HD-MAC bandwidth reduction decoder (BRD) with possibly an optional upconverter to a field rate of 100 Hz. The BRD gives as output an Y, U, V signal on the 1250/50/2 standard with an aspect ratio of 16:9. The upconverter will output an 1250/50/2 signal.

The development of the HD-MAC receivers is based on the experimental decoder that was made for the demonstrated at the 1989 Internationale Funk-Ausstellung (IFA) in Berlin.

All receivers will be able to display conventional PAL/SECAM signals as well as MAC signals in both 4:3 and 16:9 aspect ratio [CCIR,1986-90ab].

Compatibility with the European BSS emission standard is considered vital for the commercial introduction of high definition television programmes, allowing consumers to see HDTV broadcasts on their conventional DBS sets and to make a choice of when to upgrade to HDTV. HD-MAC was demonstrated at IBC Brighton in 1988 and, with further use of digital assistance techniques (see Annex III and Report 801), at IFA Berlin in 1989 [CCIR, 1986-90ac].

In Berlin the HD-MAC signal was received from TV-SAT by a 90 cm parabolic antenna and a reconstructed signal was shown on several high definition displays.

An experimental surround sound system was added to the HD-MAC transmissions, utilizing the flexibility of the MAC/packet system and was reproduced along with a picture signal thereby enhancing the viewing experience of HDTV [CCIR, 1986-90o].

Conditional access systems have been developed suitable for the HD-MAC system. They comprise two separate parts: the scrambling and the access control system. The scrambling system is the process which makes unintelligible the components of a service (picture, sound and data).

This mechanism uses psuedo-random sequences which are periodically initialized by control words. The entitlement controller provides the data scrambler, implemented at the output of the packet multiplexer, and the MAC compressor with these control words. They are transmitted, in an encrypted manner, to the MAC/Packet decoder, via a packet channel [CCIR, 1986-90ad].

8. Satellite technology

It is important that the limitations of spacecraft technology are recognized. This section summarizes the results of studies into high-power amplifiers, output multiplexers, spacecraft antennas and the overall power requirements.

8.1 TWT

Travelling wave tubes are already available for space use at frequencies throughout the range being considered. Studies of both coupled cavity type devices and helix structures for the 20 GHz range indicate that an output power of 500 W, with an efficiency approaching 50%, is an achievable target within a timescale of 10 to 15 years. At 12 GHz, 400 W tubes are already available.

8.2 Multiplexer

Multiplexers for use at 12 GHz are well developed. Theoretical studies at frequencies around 20 GHz show that typical filter requirements can be met with acceptable insertion loss. However, multipacting would appear to provide a limit to the power handling capacity. Studies indicate that single filters should not normally be operated beyond about 225 W RF power at around 20 GHz. However, there are methods of power splitting between several filters allowing this limitation to be overcome.

8.3 Antennas

Shaped beam technology may be employed to efficiently cover the service area with perhaps only 1 dB variation in e.i.r.p. and to provide a geographical isolation capability not feasible with a simple beam. This may reduce interference outside the service area.

A study by the European Space Agency looked generally at the antenna performance achievable at around 20 GHz and concludes that shaped coverages supporting uniform EIRP are feasible. Regions of higher than average eirp (hot spots) to compensate for areas of abnormally high rainfall are also feasible. It is not possible to generalise about off-axis pattern and cross polar performance, since they are unique to each beam. In general shaping the coverage degrades cross polar and off-axis performance. Further work is required to accurately predict radiation pattern performance. It was concluded that only limited shaping could be achieved for the beam sizes studied, typically one third to one half the size of the UK, and simple ellipses may be preferable in many cases. If beam shaping is to be implemented then the shaped reflector approach is preferred since it affords greater directivity than a Multiple Beam Antenna (MBA). It should be noted, however, that if multiple coverages are required then only an MBA approach can achieve this with a single reflector.

8.4 Overall power requirements

The number of transponders which can be accomodated on board a satellite bus depend on their size and weight, the prime power available, the transponder efficiency and the ability to dissipate excess heat. Initial studies by the European Space Agency have provided estimates of the number of TWTs as a function of TWT power output. Efficiencies of 50% for the TWT and 90% for the electronic power conditioner have been assumed. Thermal analyses must be performed in more depth to establish more accurately the spacecraft capabilities. Two 500 watt or four 250 watt TWTs can be supported by the EUROSTAR 2000 class and four 500 watt or eight 250 watt TWTs can be supported by the OLYMPUS class spacecraft. In these cases, the available d.c. power is the limiting factor.

8.5 Experimental satellites

In order to develop the technology for exploiting the 20/30 GHz band several experimental payloads are available or will be available soon for various test transmissions, including experiments for future HDTV broadcasting by satellites in Europe.

In Europe, the satellite DFS-1 Kopernikus (Germany (Federal Republic of)) was launched in June 1989. Basically an operational telecommunication satellite it also carries a 30/20 GHz payload for test purposes (bandwidth 90 MHz, EIRP 52 dBW). It is planned to use this payload for wide RF band HDTV transmission experiments. Olympus, a European experimental satellite, provides a 20 W 30/20 GHz experimental payload of 700 Mhz of bandwidth (launched in July 1989). The transmission experiments including wide RF-band HDTV will be coordinated by the European Space Agency (ESA). In Japan, studies in an early phase include an experimental 20 GHz payload in the planned EDRT (Experimental Data Relay Transmission) satellite.

In conclusion, it can be said that, apart from the high-power satellite amplifier, all elements for future 30/20 GHz BSS satellites are available. It is predicted with confidence, however, that the required HPA output power will be available (using coupled cavity TWTs) and that the spacecraft bus can provide sufficient d.c. power to operate, say, 6 TWTs at 350 W RF output power.

9. Link budgets and satellite power requirements

The general equation for the power budget on the down link may be written as follows:

$$e.i.r.p._{transmit} = P_o + G_t + L_f$$

$$= PFD + L_s + A + \alpha$$

where:

$e.i.r.p._{transmit}$:	equivalent isotropically radiated power to the edge of the service area	(dBW)
P_o:	radio-frequency power at the output of the satellite transmitter	(dBW)
G_t:	maximum gain of transmit antenna = 41.4 dBi for 1^o beamwidth area (See §8)	(dBi)
L_f:	loss in the feeder and filters in the satellite	(dB)
PFD:	power-flux density requirement at the edge of service area $= C/N + \beta_u + k + B + 10 \log(4\pi/\lambda^2) - G/T$	(dB(W/m^2))
L_s:	spreading loss = $20 \log(4\pi d^2)$	(dB)
A:	rainfall attenuation (see §4)	(dB)
α:	atmospheric absorption	(dB)
C/N:	required carrier-to-noise ratio (see §2)	(dB)
β_u:	impairment due to feeder-link noise ≈ 0.5 dB	(dB)
k:	Boltzmann's constant = -168.6 (dB(W(MHz·K)$^{-1}$)	
B:	equivalent noise bandwidth (see §6)	(dB(MHz)
λ:	wavelength	(m)
G/T:	figure of merit of receiver (see §7)	(db(K)$^{-1}$)

An estimation of the e.i.r.p. requirements in each frequency band may be made using the values of Table VIII for spreading loss (L_s), wavelength factor (10 log $4\pi/\lambda^2$), atmospheric absorption (α) and rainfall attenuation (A) for temperate climates.

TABLE VIII

Comparison of required e.i.r.p. in different frequency bands

Parameter	12 GHz	23 GHz	42 GHz
L_s	162.5	162.5	162.5
10 log $\frac{4\pi}{\lambda^2}$	43.0	48.6	53.9
α	0.1	0.7	1.2
A	1.5	4.5	11.6
L_s + 10 log $4\pi/\lambda^2 + \alpha + A$	207.1	216.3	229.2
relative e.i.r.p. (dB)	0	+9.6	+22.1

It can be seen that on the above hypothesis of equal C/N, bandwidth and G/T, much higher e.i.r.p.s would be required for the higher frequency bands.

Examples of link budgets for the various types of transmission systems discussed in § 6 are shown in Table IX as well as a probable example for the 42 GHz band. It is clear that the 42 GHz band is not practicable. The powers required for the 23 GHz band are close to those predicted feasible (see section 8).

10. Subjective assessments and experiments of HDTV satellite broadcasting systems

For satellite broadcasting of high-definition television(HDTV) using a single channel in the 12 GHz band planned at WARC-BS 77, two systems have been developed: MUSE (Multiplex Sub-Nyquist Sampling Encoding) and HD-MAC (High Definition Multiplexed Analogue Components). Subjective assessment tests as well as experiments using actual DBS satellites have been conducted. Tests and experiments concerning wide RF band systems are still at an early stage.

TABLE IX

Examples of link budgets of HDTV satellite transmission

System		A	B	C	D
Category	Symbol	Narrow RF band[1] analogue	Wide RF band analogue	Wide RF band [2] digital	Wide RF band analogue
1. System					
Frequency of carrier (GHz)		12	23	23	42
Type of modulation		FM	FM	4 PSK	FM
Approximate equivalent rectangular bandwidth (MHz)	B	27(24)	54	70	125
Carrier-to-noise ratio[3] before demodulation (dB)	C/N	17(20)	17/22	17/22	17
Additional noise of feeder link (dB)	βu	0.5	0.5	0.5	0.5
Necessary C/N (dB)	$C/N+\beta_u$	17.5 (20.5)	17.5/ 22.5	17.5/ 22.5	17.5
2. Receiving installation					
Figure of merit[4] ($dB(K^{-1})$)	G/T	13 (16)	17/18	17/18	12
Required PFD at the edge of beam area (dBW/m^2)	pfd	-106.8	-102.1 /-97.1	-100.9 /-95.9	-88.2
3. Propagation					
Spreading loss (dB)	L_s	162.5	162.5	162.5	162.5
Additional propagation[5] losses (dB)	$A + \alpha$	1.6	5.2/ 0.7	5.2/ 0.7	12.8
Required e.i.r.p. from satellite at beam edge (dBW)	e.i.r.p.	57.7	65.6 /66.1	66.8 /67.3	87.1
4. Satellite transmitter					
Antenna beamwidth (deg)[6]		1.0	1.0	1.0	1.0
Antenna gain at the edge of service area (dB)	G_t	41.4	41.4	41.4	41.4
Loss in feeders, filters joints etc. (dB)	L_f	2.0	2.0	2.0	2.0
Required satellite (dBW) transmitter power	P_o	17.9	26.2/ 26.7	27.4/ 27.9	47.7
(W)		62	417 /468	550 /617	58900

Notes to Table IX

1) Values in brackets are for Region 2.

2) Noise bandwidth of 70 MHz and RF bandwidth of 105 MHz assuming a transmit bit rate of 140 Mbit/s, 2 bit/Hz modulation and a shaping factor of 1.5

3) The first value is the objective for 99% of the worst month; the second is for clear-sky where given.

4) The first value takes into account the increase in antenna temperature due to the rainfall assumed in note (5); the second value is the nominal clear sky G/T.

5) The earth-station elevation angle is asumed to be 40°. The first value corresponds to rain attenuation not exceeded for 99% of the worst month for average temperate climate in Europe as an example (see § 4). The satellite power should be adjusted to take into account the desired service time and propagation losses for the climatic zone under consideration. Where a second value is given this corresponds to the clear-sky propagation loss.

6) Antenna beamwidth should be adjusted to the size of service area. Antenna diameter and gain will be changed accordingly and the satellite output power will change according to the gain change.

10.1 Subjective assessments for narrow RF band systems

10.1.1 Effect of noise

Subjective assessment tests on the relationship between received C/N and picture/sound quality have been conducted. The experimental set-up for MUSE is illustrated in Figure 3. The received C/N ratio in a 27 MHz bandwidth was varied by adding noise to the frequency modulated MUSE signal, at 140 MHz.

The received picture and sound signals were evaluated using the five-grade impairment scale. Viewing and listening conditions used in the assessment tests are shown in Table X and Table XI (these conditions are basically based on Rec 500). The results of assessment tests are shown in Figure 4 and Figure 5. A subjective impairment of 4.5 corresponds to a carrier-to-noise ratio of 17.5 dB for the vision and 9.7 dB for the sound.

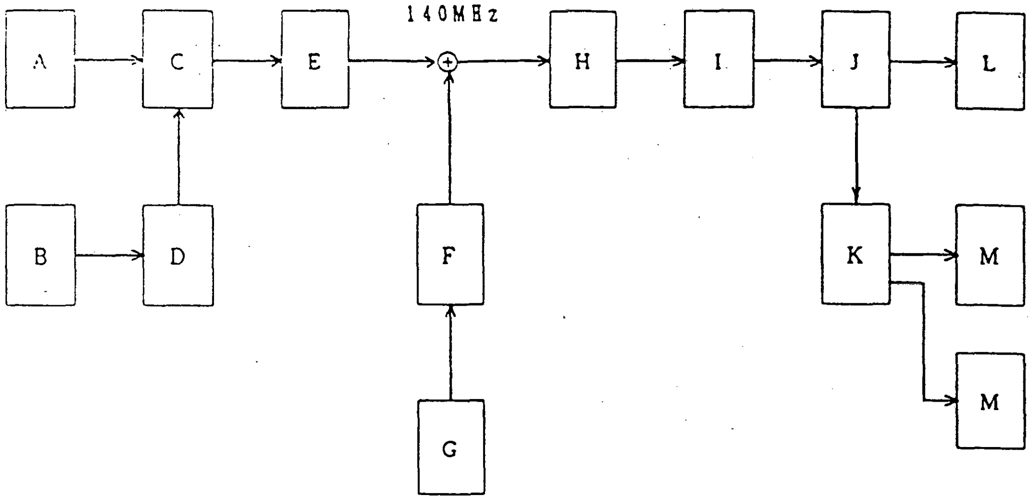


FIGURE 3 - Experimental set-up for subjective assesment tests

A: test slides
B: compact disk player
C: MUSE encoder
D: MUSE audio encoder
E: FM modulator
F: attenuator
G: noise generator
H: bandpass filter
I: demodulator
J: MUSE decoder
K: MUSE audio decoder
L: HDTV monitor
M: audio monitor

TABLE X

Viewing conditions

Test pictures	Test slides **Fruits, woman, canal scene, test pattern, colour bar**
Ratio of viewing distance to picture height	**3**
Picture monitor	**32" RGB monitor**
Peak luminance on the screen (cd/m^2)	**70**
Ratio of the luminance of the screen when displaying only black level in a completely dark room to that corresponding to peak white	**Approximately 0.01**
Room illumination	**low**
Grading scales	**Five-grade impairment scale**
Observers	**20 Non-experts**

TABLE XI

Listening conditions

Test sounds	3 kinds of test sounds piano, orchestra, speech
Maxixum sound pressure level (dbspl)	80
Background noise level (dbspl-A)	37
Grading scale	Five-grade impairment scale
Observers	24 Non-experts

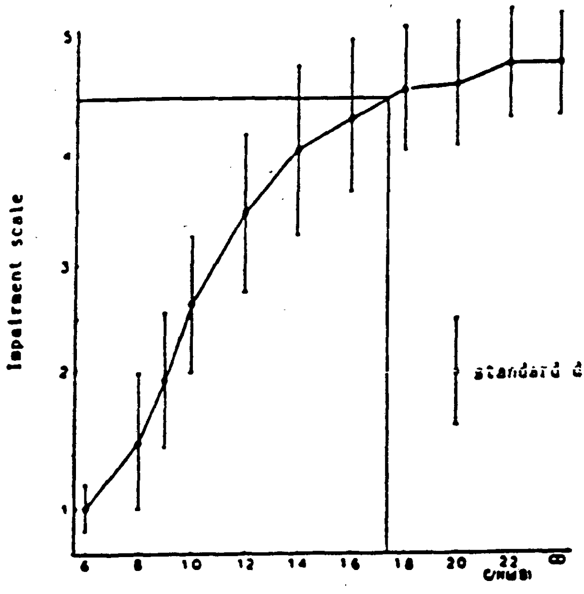


FIGURE 4 - **Results of picture evaluation test**

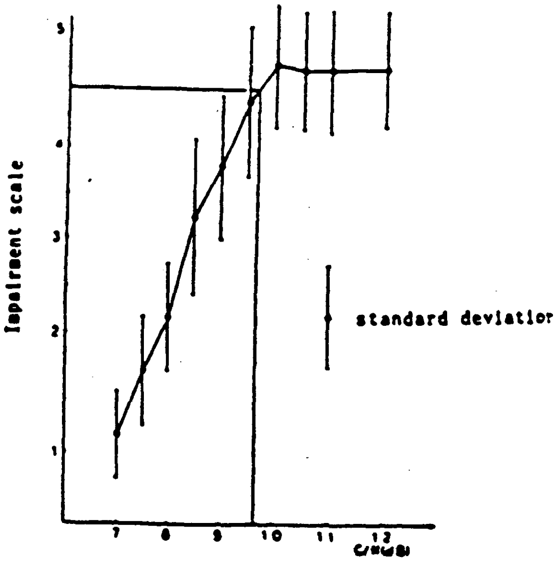


FIGURE 5 - **Results of sound evaluation test**

Subjective assessments have also been made with the first experimental HDTV chain, in the framework of the European HDTV project Eureka 95.

These tests were conducted using a satellite simulation featuring:

- frequency modulation at 70 MHz;
- first up-conversion to 1 GHz;
- filtering;
- second up-conversion to 12 GHz;
- amplification by a TWT of 20 Watts (AM/PM: 4°/dB);
- signal attenuation by a variable attenuator (variation of the C/N ratio, manually or automatically controlled);
- SHF reception and first down-conversion to 1 GHz;
- second down-conversion to 70 MHz and channel filtering;
- frequency demodulation.

The picture impairment has been evaluated for different values of the C/N ratio in a 27 MHz bandwidth. The tests have been done only with still pictures and with the 88 algorithm either in the static mode (80 ms branch) or in the moving mode (20 ms branch). The EBU method was used with non-expert observers as described in Recommendation 500.

The significant viewing conditions were the following:

Viewing distance: 3H
Peak luminance : 80 cd/m^2
Contrast ratio : 90:1
Monitor : 1250/50/2:1
Display tube : shadow mask, 77 cm diagonal

The results obtained are given in Fig. 6. The dashed lines indicate the confidence level (5%) of the mean results (continuous line) obtained from 15 observers.

Taking account of the confidence level, the subjective impairment is 4.5 over a range of carrier-to-noise ratios between 16.2 dB in the best case and 20.5 dB in the worst case.

10.1.2 Effect of channel distortions

A transmission of an HDMAC signal with a total baseband bandwidth of 12 MHz is possible using a 27 MHz channel bandwidth.

The amplitude frequency response after frequency demodulation is related to the shape of the IF filter preceding the demodulator which must have a flat response over a bandwidth of at least 24 MHz. Such a response can be obtained with a SAW filter. With the experimental set-up described above for HDMAC (§ 10.1.1) there was no visible impairment on any of the analysed pictures.

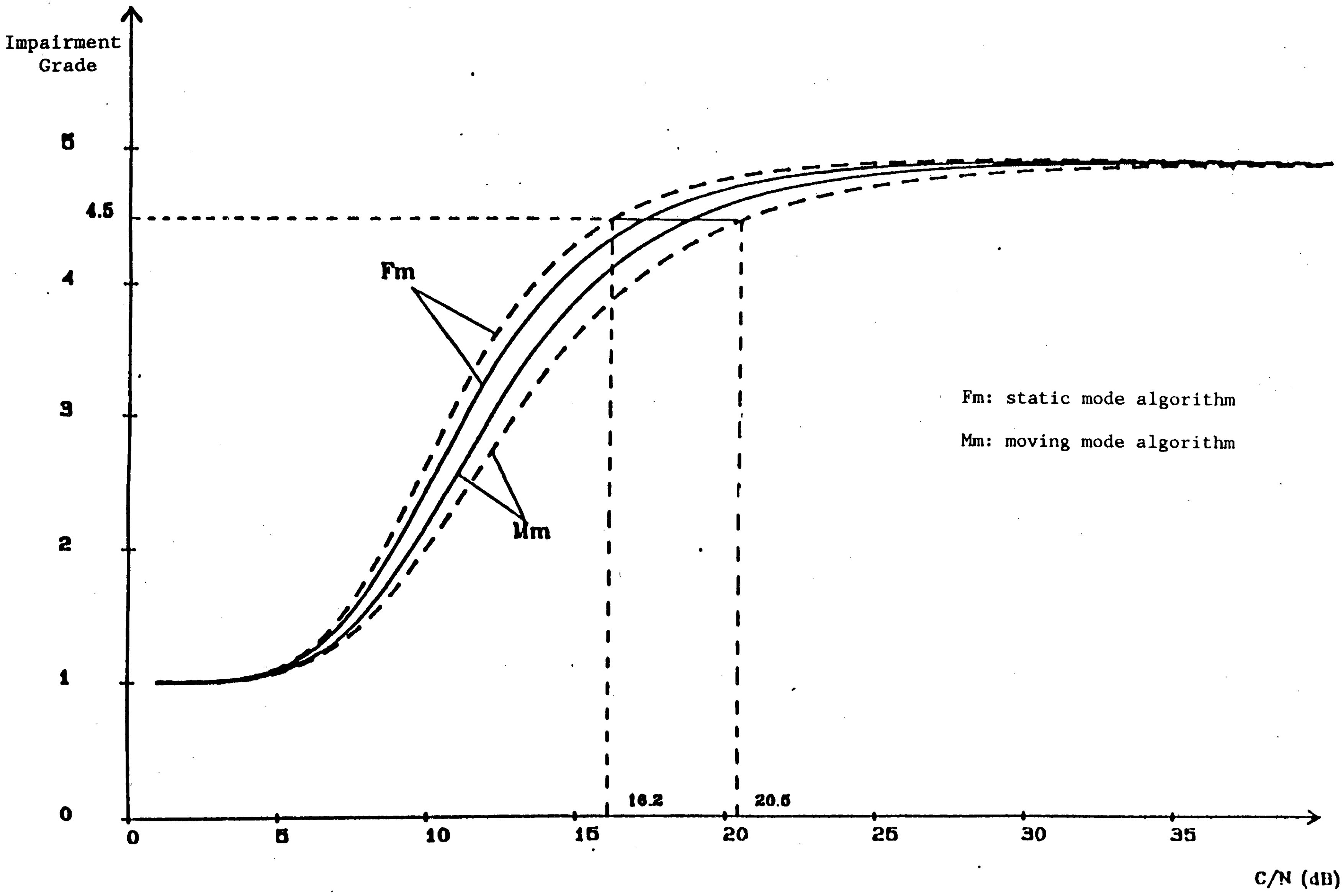


Figure 6 : Impairment grade of the picture signal as a function of the C/N ratio in 27 MHz

The sensitivity of an HD-MAC signal to a static sampling time error in the decoder has also been evaluated. For a 6 ns sampling error, some visible distortions could be observed on some critical pictures, especially on the diagonals where a staircase effect appears. When the error is reduced to 3 ns, then there is no visible impairment on any of the analysed pictures.

It has been noticed that a parabolic group delay error in the transmission chain produced an impairment of the same nature as a static phase error and that this impairment can be strongly reduced by adjusting the sampling time. This justifies the use of an equalizer or at least an automatic phase adjustment in the decoder.

Also, the relationship between picture quality and waveform distortion of the MUSE signal has been investigated. It has been made clear that for the MUSE system the relationship between distortion in the transmission path and the received picture quality can be described with measured values of amplitude errors at the sampling points by using a logistic function.

When a transmission path does not have an ideal frequency response, the line synchronization signals (HD) of the MUSE signal may be distorted. Since the sampling clock in the MUSE decoder is regenerated by using HD, an error in sampling time may occur which also results in multiple echoes in the decoded picture. The amount of impairment due to the error in sampling time can also be calculated by the above-mentioned method. Results of the calculation indicated that the impairment could be neglected when the error in sampling time was less than 2 ns. This was confirmed by subjective assessment tests [CCIR, 1986-90ae].

10.2 Experiments with narrow RF-band systems

Experiments of HDTV transmission and broadcasting through satellites have been made in Japan and France.

10.2.1 MUSE

Based on the MUSE system, extensive experiments have been carried out in Japan since 1986. With an output of 100 W from the BS-2 satellite (giving a boresight e.i.r.p of 57.7 dBW) a received C/N of around 17 dB is obtainable for 99% of the worst month in nearly all of the main islands of Japan using a receiving antenna of 0.7-0.9 m in diameter. With MUSE an HDTV signal is received with a sufficiently good S/N by using a single 12 GHz WARC-BS channel.

The details of the experiments are described in Annex IV. Since June 1989, regular experimental HDTV broadcasting for one hour a day has been started by NHK using BS-2b on a time-sharing basis with the conventional satellite television (NTSC) programming.

Two special instruments for measuring C/N and (audio) bit error ratio have been developed for the purpose of making measurement easier during experimental HDTV satellite broadcasting using MUSE through a broadcasting satellite. Further details are described in Annex IV.

10.2.2 HD-MAC

Some experiments on HD-MAC transmission through the direct broadcasting satellite TDF-1 have been made in France. The satellite has an output power of 230 W delivering an e.i.r.p. of 64 dBW on boresight.

A received C/N of 17 dB is obtainable for 99% of the worst month in all the service area with a 55 cm diameter receiving antenna. Thus an HD-MAC signal of good quality can be received with a small antenna using a 12 GHz WARC channel. **Annex V describes the experiments in detail.**

10.3 Planned experiments with wide RF band systems

In addition to the flight programs described in section 4.5 which have been planned to derive additional propagation and other data, several experimental developmental and demonstration programs are now planned or under way to refine and test new techniques and technology directed primarily toward wide RF band HDTV satellite broadcasting.

Laboratory efforts are focused on modulation methods and channel coding, particularly using digital techniques which offer the prospect of effective bit-rate reduction and efficient image and sound channel coding. Such work is planned in Italy, in Germany (Federal Republic of) and in Japan, amongst other places.

11. Interference within the same service

11.1 Required protection ratios

For HDTV systems intended for use in the 12 GHz band, protection ratios must comply with the requirements of the Radio Regulations Appendix 30 and 30A. Protection ratios for two HDTV systems: MUSE and HDMAC (preliminary results for the "88 algorithm") versions have been measured.

For the MUSE systems subjective assessments were carried out in accordance with Rec.600. Figures obtained with a typical 5th order Butterworth filter are shown in Table XII (Better results will be obtained with a surface acoustic wave filter which is being introduced into satellite broadcasting receivers) [CCIR, 1986-90af].

For HD-MAC, results presented in Table XIII are obtained with the following viewing conditions:

- Viewing distance 3 H
- Peak luminance 80 cd/m^2
- Contrast ratio: 90:1
- Monitor: 1250/50/2
- Display tube: shadow mask, 77 cm diagonal

Six expert observers have been used for all the tests. The frequency demodulator was a conventional discriminator and the IF filter was a 4th order Butterworth with a 3 dB bandwidth of 25.5 MHz [CCIR,1986-90ag].

TABLE XII - *Protection ratios for just perceptible interference (MUSE)*

Wanted signal (test slides)	Unwanted signal (colour bar)	Channel protection ratios (dB)		
		Lower adjacent*	Co-channel	Upper adjacent*
NTSC SMPTE #1 SMPTE #14	MUSE	10.0 11.7	18.0 18.7	10.1 11.2
MUSE Fruits Congress hall	NTSC	7.6 6.2	17.6 19.1	7.8 10.5
MUSE Fruits Congress hall	MUSE	8.3 7.4	23.3 24.0	8.0 8.4

* Adjacent-channel frequency spacing: ±19.18 MHz

TABLE XIII - Protection ratios for just perceptible interference (HD-MAC)

Wanted signal (test slides)		Unwanted signal	Protection ratios (dB)**		
			Lower adjacent channel*	Co-channel	Upper adjacent channel*
HDMAC	Boats	HDMAC (grid)	-	20.5 ± 1	-
	Circus		6 ± 0.8	–	5.2 ± 0.8
SECAM	Boats	HDMAC (Colour bars)	10.5 ± 0.3	23.7 ±1.3	9.8 ± 0.5

* Adjacent-channel frequency spacing: ±19.18 MHz

** Previous experiments on the effect of channel interference strongly suggest that the results for interference of HD-MAC signals into a PAL channel would be very similar.

Measured protection ratios comply with the requirements of WARC-BS 77 for both systems (see Report 634).

For a digital HDTV system a trade-off is required to set the balance between the allowable thermal noise and the interference noise contribution. When the number of mutually interfering signals is large, the interference is similar in effect to Gaussian noise and C/I and C/N can be combined to give an effective C/N + I. When there is only one interferer, or one which is dominant, then the effect of interference is less severe than the equivalent noise power, especially when convolutional coding is used with Viterbi decoding [Newland, 1988; CCIR, 1986-90ah]. If the system is designed so that the threshold bit error ratio is limited primarily by the thermal noise, the satellite transmit power can be minimized. However, this leads to a very high value of C/I and therefore limits the efficient use of orbit/spectrum.

One approach is to keep a fair proportion between C/N and C/I whatever the digital modulation system used.

As an example of trade-off between C/N and C/I, the sets below give typical values with the following conditions:

- required BER:	10^{-5}
- digital modulation system:	2 bits/Hz
- equivalent noise bandwidth:	1/2 bit rate
- margin (including channel impairment effect):	1.5 dB
- contribution of interference from adjacent channels:	1 dB

The following sets are examples which give an overall C/(N+I) of 15 dB:

C/N (dB)	16	17	18	20	22
C/I (dB) (co-channel)	22	19.5	18	16.5	16

Further study is necessary to determine the most suitable digital modulation system.

11.2 Planning aspects

The number of channels that would be necessary to transmit one HDTV program to any receiving location within a continent depends primarily on the protection ratio required for the HDTV system, and on factors such as coverage, transmit and receive antenna radiation patterns, the orbital separation between satellites, etc.

Experience with the preparation of the allotment plan for communications satellites at WARC ORB 88 shows that it is possible to generate a "single frequency" plan. In this Plan, the whole of a band can be used in a given service area. For this type of system, it is necessary to ensure that the satellite and receiver antennas have good directional properties, and that a modulation system is chosen which shows good immunity to interference. Studies by ESA have shown that this approach could be used for HDTV at around 20 GHz if a suitable modulation system is available. If more protection is needed, then the efficiency of spectrum use decreases.

Preliminary studies in Region 2 on planning the 23 GHz band for Region 2 indicate that the 500 MHz bandwidth will accommodate easily about 10 HDTV channels (60 MHz bandwidth) using both polarizations. It is found that if the adjacent orbital positions can be considered independent, as regards polarization, then linear polarization would be more appropriate since each beam could be optimized independently for local vertical or horizontal reception thus minimizing the rain attenuation and depolarization. This could then increase the plan capacity. However, factors like simplicity in receiver alignment and compatibility with 12 GHz systems may lead to the use of circular polarization, precluding the above potential improvements.

In addition, it should be noted that the possibility of re-using frequencies by polarization discrimination may be compromised if the depolarization effects of rain are more severe than estimated from current data.

There may be operational advantages if HDTV satellites are co-located with satellites planned for the 12 GHz band. However, this will not necessarily allow the same receive antenna to be used for both services.

A series of planning exercises was carried out for the European and North African areas within Region 1, using the following assumptions:

- frequency range, 15 to 25 GHz;
- coverage, either "national" providing individual service areas for 33 countries using the beams of the WARC BS-77 Plan, or "regular" coverage using a grid of 27 regularly distributed circular, one-degree beams;
- antenna radiation patterns as in the WARC BS-77 Plan;
- receiving antenna beamwidth of 1.5°;
- orbital separation of satellites, 3°;

For a given number of channels, the planning exercises were repeated with progressive increases in the protection ratio, until there was no longer any "plan" compatible with the interference criterion. The results of the exercises are given in Table XIV in the form of maximum values of the protection ratios that would be achieved.

Although not necessarily correlated at low levels of attenuation, extremely high levels of attenuation are in practice always related to high levels of depolarization. According to Tables III and IV at 23 GHz a digital system should not be degraded by depolarization provided it is planned for a C/I ratio significantly lower than the values given in the tables. For example, at 23 GHz, in Europe, cross polarisation isolation is in excess of 25 dB for 99% of the worst month. The corresponding attenuation value is 4.5 dB (see Table I), a value for which a service can probably still be provided, based on the characteristics of the error-protection scheme. For 99.9% of the worst month XPD is only 15 dB but the attenuation value reaches 13.5 dB, a value at which most probably no service can be provided anyway.

It will therefore be possible to make a "plan" without negative margins and with the indicated number of channels, to provide one program to any service area for any HDTV system requiring protection ratios equal to or lower than the indicated values.

With further assumptions on the actual values of the protection ratios for analogue and digital HDTV systems, it would then be possible to determine the total bandwidth necessary to transmit one HDTV program to any required location. Preliminary results using "national" coverage are of the order of 150 MHz (perhaps as high as 200 MHz), for either an analogue system having an RF bandwidth of 54 MHz, or a digital system of 140 Mbits/s. Spectrum utilization could be improved if the planning were based on the provision of "regular" coverage.

TABLE XIV Maximum values of HDTV protection ratios as a function of the number of channels.

Number of channels necessary to provide one HDTV programme per service area	Maximum attainable protection ratios (dB)			
	"National" coverage (33 countries)		"Regular" coverage (27 areas)	
	Co-chan.	Adj-chan.	Co-chan.	Adj-chan.
2	14	0	24	17
3	22	0	-	-
4	28	14	30	22
6	30	19	34	28
8	31	24	39	28

12. Sharing with other services

Sharing with other services is discussed in Reports 631 (MOD I), 807 and 951, and in the CCIR report to the Second Session of the WARC ORB.

In Resolution 521, the WARC-Orb 88 extended the range of frequencies to be considered as possible candidates for a new HDTV band to include 12.7 to 23 GHz.

Studies of sharing with the services in this range have not been completed. Recent studies by ESA at frequencies of 20 GHz provide new information on the prospects, as well as the problems, of sharing between the BSS and other services.

13. Feeder links

13.1 Suitable frequency bands for the associated feeder links

According to the Radio Regulations, the feeder links to the BSS belong to the FSS and will be operated in FSS frequency bands in the Earth-to-sapce direction. A list of these bands with their allocations in the three ITU Regions is given in Table XV. As can be seen, some of these bands are already allocated for exclusive use by feeder links to the BSS.

TABLE XV - Frequency bands allocated to FSS (Earth-to-space direction) above 10 GHz

Frequency band (GHz)	Region 1	Region 2	Region 3
10.7 - 11.7	B (2)	M	M
12.5 - 12.7	B	-	-
12.7 - 12.75	B	M	-
12.75- 13.25(1)	M	M	M
14.0 - 14.5	M	M	M
14.5 - 14.8	M (2)	M (2)	M (2)
17.3 - 17.7	M (2)	M (2)	M (2)
17.7 - 18.1	B (2)	B (2)	B (2)
27.0 - 27.5	-	M	M
27.5 - 31.0	M	M	M
42.5 - 43.5	M	M	M
47.2 - 50.2	M	M	M
50.4 - 51.4	M	M	M
71.0 - 75.5	M	M	M
92.0 - 95.0	M	M	M

M = Earth-to-space direction only
B = bi-directional

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(1) This band is to be planned in the Earth-to-space direction for the FSS at WARC ORB(2).

(2) Limited to feeder links to the BSS.

It may be possible to accommodate the feeder links for the HDTV in the broadcasting satellite service within the existing frequency bands allocated to feed the BSS satellites.

The bands 14.5 - 14.8 GHz and 17.3 - 18.1 GHz will be used as feeder links to the BSS operating in the 12 GHz band and are likely to be planned for this service. However, the band 10.7 - 11.7 GHz is reserved for the feeder links to the BSS in Region 1 (see footnote 835).

A lower frequency than for the down links should preferably be used to ensure a better availability for the feeder links but this may not be possible due to heavy utilization of lower frequency bands by other services. The other alternative is to operate the feeder links in a frequency band close to the down-link band so that similar propagation conditions can be experienced on both links. A too close proximity of the two bands could however require complex satellite filters to isolate the reception from the transmission.

In those cases where the feeder links would have to use higher frequency bands, the availability of the links can be drastically improved by the use of site diversity, thus enabling a certain flexibility in the choice of the frequency bands.

As was found during the planning of the 12 GHz band, there are many advantages in including considerations about the feeder links to the broadcasting satellites in the definition of the service. The band 27-27.5 GHz is an attractive candidate for the HDTV feeder links, corresponding to the 22.5-23 GHz band or any other down-link band (in Region 1 however, this is currently not allocated to the FSS). In Regions 2 & 3 this frequency band is allocated to the fixed-satellite service in the Earth-to-space direction, and is shared with fixed and mobile services as well as the Earth exploration-satellite service. The spacing between the down-link and feeder-link frequency bands (23/27 GHz) is large enough to allow for straightforward design of the satellite filters. The two bands are close enough to allow the possibility of using the same satellite antenna aperture and feed system. This also results in similar propagation statistics for feeder links and down links.

13.2 Feeder links for wide RF band HDTV

Considerations of feeder-link parameters such as the size of feeder-link antennas and the required tracking accuracy, second adjacent channel interference and the need for satellite filtering, power control and depolarization compensation will need to be addressed very carefully to identify a consistent set of system parameters for the feeder links to HDTV broadcasting satellites.

14. Conclusions

Studies on HDTV satellite broadcasting have led to the general conclusion that such services should provide the potential of a picture quality for reception in homes which comes as close as possible to that of the studio signal. In order to enable the introduction of wide RF band HDTV on a world-wide basis, a world-wide frequency allocation to the BSS is necessary, with a total bandwidth of the order of 500 MHz, preferably not above the 23 GHz band. For countries already planning to fully use their assignments in the 12 GHz plans, this allocation becomes necessary even for narrow RF band HDTV broadcasting, particularly if it were to involve a change of the transmission standard in the currently operating service.

The following specific conclusions can also be drawn:

a) analogue and digital systems are feasible;

b) the quality objectives for HDTV are fundamentally more stringent than those of conventional TV systems;

c) all systems need a certain amount of bandwidth compression;

d) the 12 GHz band is now planned in all regions on the basis of conventional television systems conforming with CCIR Recommendation 650;

e) narrow RF-band systems (operating in a 24 - 27 MHz channel according to the 12 GHz plans) are characterized by high degrees of bandwidth compression and which cannot be supported by all-digital transmission: the narrow RF-band systems described (MUSE, HD-MAC) meet the Plan requirements of the 12 GHz band;

f) use of sophisticated bandwidth reduction techniques can give good picture quality, particularly in a narrow-band system, but with added receiver complexity;

g) in general, system performance may be improved (e.g., picture quality and motion portrayal) if there is a wide RF channel bandwidth available;

h) wide RF-band systems (both analogue and digital) require an RF channel bandwidth typically of the order of 50 - 120 MHz;

i) between about 150 to 200 MHz of RF spectrum could provide one wide RF band HDTV programme per service area, therefore, a total bandwidth of the order of 500 MHz could be used;

j) from a propagation point of view, any band between 12 GHz and 23 GHz would be suitable, but lower frequencies in this range would be preferable;

k) the extension of the allocation of the band 22.5 - 23 GHz to the BSS in Region 1 seems desirable to result in a common world-wide allocation. However, use of this band may prove to be difficult because there are sharing constraints with the radioastronomy service, the inter-satellite service and the fixed service;

l) there is already significant utilization of many of the frequency bands between 12 and 23 GHz which would otherwise be suitable and these have other sharing constraints.

Further study is necessary to determine:

- the subjective performance of HDTV satellite broadcasting systems, particularly the level of degradation introduced by the narrow RF band systems and possible compatibility requirements in comparison with the quality of HDTV in the studio;

- appropriate methods to meet service objectives and efficient frequency utilization by operational HDTV services in the higher frequency bands;

- the extent to which the various possible coding and modulation processes can reduce both satellite power and RF bandwidth requirements at acceptable cost.

Following the conclusions of WARC-Orb 88, which considered the question of a possible frequency allocation for HDTV BSS (see Resolution 521), further study is also required to determine:

system parameters for HDTV transmissions by satellite, with emphasis on the effect of the choice of frequency, e.g.:

- modulation (including baseband coding and channel coding);
- satellite power requirements;
- satellite and earth station technology;
- receiving system characteristics;
- type of polarization (including propagation effects);

propagation characteristics, e.g.:

- attenuation, including precipitation losses;
- atmospheric absorption;
- cross-polar discrimination;

inter- and intra-service sharing and interference, interregional sharing.

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ANNEX I

Availability objectives

There are several criteria which can be proposed for service objectives [CCIR, 1976]. They are to give:

- optimum clear-sky quality
- limited outage time
- defined quality for n% of the worst month
- equal integrated quality.

Fixing the clear-sky quality can lead to a simple but effective technique for system design. Table XVI shows an example of the performance achievable using this method [Stott and Shelswell, 1987]. Some flexibility is needed to reduce the outage times caused by rain attenuation. The example shows how an improvement can be made by a small increase in e.i.r.p.

In general it is not possible to guarantee the target reception quality to 100% of the population in any country. This should be recognized. However, a high percentage (of the order of 98%) is essential for the acceptance of a new service. Such a target would recognize that some areas may, for a variety of reasons, not be served satisfactorily. [CCIR, 1986-90a].

TABLE XVI - Summary of performance for satellite e.i.r.p. of 63.5 dBW at 23 GHz

Country	% time stated C/N ratio is exceeded		
	10 dB C/N	14 dB C/N	20 dB C/N
Norway	99.97	99.9	97
France	99.97	99.9	98.4
Italy	99.88	99.7	96.5
Algeria	99.95	99.9	98.2
Senegal	99.97	99.9	98.9
Zaire	99.6	99.1	94
(Zaire, + 3 dB)	(99.75)	(99.5)	(98)

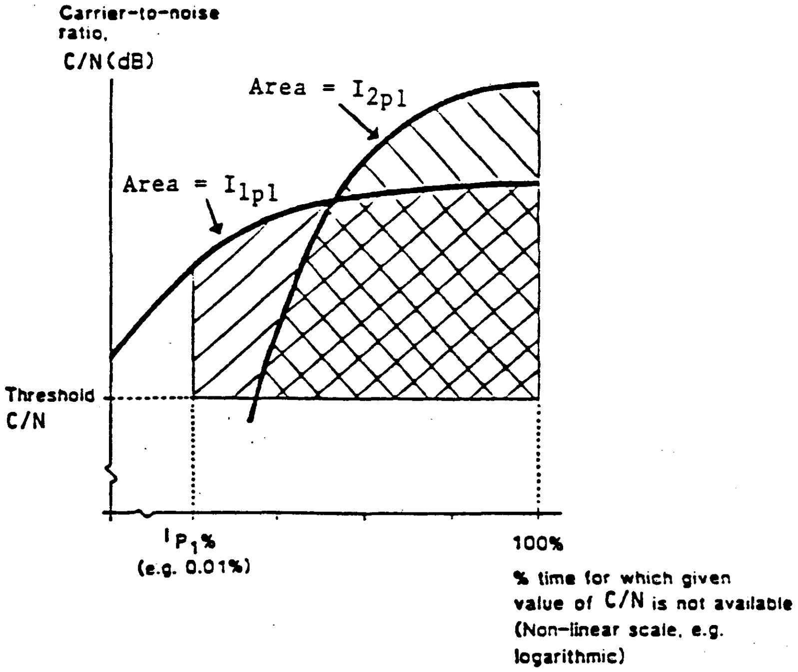
However, equalizing the outage time leads to excessively high transmit powers from the satellite.

The compromise of defined quality for n% of the worst month reduces the outage times of the method of setting the clear sky quality and requires a smaller range of e.i.r.p. than the method based on equalized outage time. Nevertheless, it does not guarantee good clear sky quality on the one hand, whilst now avoiding outage on the others.

The technique of equal integrated quality [CCIR, 1986-90b] an extension of the n% worst month technique which ensures adequate clear sky quality and minimizes the range of e.i.r.p. required for a service, by paying closer attention to the trade-off between reception quality and time availability.

The technique measures the area under the curve of quality versus a function of the percentage of time for which that quality is not achieved; the e.i.r.p.s are adjusted so that the same result is given for all transmissions.

There are many possible measures of quality which could be used in the analysis. It is important to adopt an objective measure which is independent of the modulation system. The carrier-to-noise ratio (C/N) expressed in dB is proposed as the basic measure of quality. The principle is illustrated in Fig. 7. Once this ratio falls below the threshold value the perceived quality remains uniformly unsatisfactory, so in practice what is integrated is the excess C/N, which is defined for this purpose as the difference (C/N_{actual} - $C/N_{threshold}$), unless this difference is negative, in which case the excess C/N is taken to be zero. Periods for which the C/N is below threshold thus, quite appropriately, make no contribution to the integrated measure.



The e.i.r.p.s are adjusted such that $I_{1p1} = I_{2p1}$

FIGURE 7 - Curve showing principle of equal integrated quality (I_{p1})

- The integrated quality measure I_{p1} is defined by

$$I_{p1} = \int_{p=p1}^{p=100\%} X \, d(\log p),$$

where

X is the excess C/N above the desired threshold value, and P is the percentage of time for which X is not exceeded.

An "ideal" country having no rain is used as a reference, having a constant value of excess C/N, equal to X dry. This is set to provide good quality under clear sky conditions and determines the magnitude of the integrated quality to be equalized. This implies that the clear sky value of excess C/N will, in all real countries, exceed the "ideal dry" value.

In an example planning exercise [Shelswell and Stott,1987], it was found that the required satellite power varied by 8.5 dB at 10 GHz between the wettest and dryest countries having equal integrated quality. Using the 1% worst month criterion, the range was 15 dB and using the clear sky criterion, the range was 45 dB.

The equal integrated quality criterion is thus an attractive extension of the 1% worst month method of system design.

Its use permits higher frequency bands to be used by all countries for HDTV and merits further consideration, in particular the choice of the most appropriate quality measure.

The existing procedures for identifying permissible levels of interference and distortion are based on levels of impairment which are just perceptible. These procedures are still valid for analogue HDTV, although of course the precise levels may change because of the new viewing conditions.

In the discussion so far, the use of analogue techniques has been assumed. However, all-digital techniques may be suitable. These have different failure characteristics from analogue and so a revision of the link objectives may be appropriate. In general a digital system will provide good-picture quality over a wide range of carrier-to-noise and carrier-to-interference ratios and then fail abruptly when there is a small increase in noise or distortion.

For digital techniques, the current provisions of the Radio Regulations, Appendix 29^1 if applied, may lead to difficulties of planning. Although it may be desirable to determine link performance and availability objectives in terms of C/(N+I). Some balance of permissible noise and interference power may be the optimum trade-off between link budget constraints on the one hand and planning constraints on the other . This could lead to a significant increase in the efficiency of use of spectrum.

Note 1. - The contribution of interference should not exceed 4% of the total thermal noise, if no coordination is necessary.

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ANNEX II

Technical description of the MUSE system

1. Introduction

An efficient bandwidth compression system, called MUSE (Multiple Sub-Nyquist sampling Encoding), employing phase-alternating sub-Nyquist sampling and motion-compensated interframe coding, has been developed for the primary purpose of achieving single-channel satellite broadcasting of 1125/60/2:1 high-definition television in the 12 GHz band, which has been allocated to the satellite broadcasting service and planned at WARC-BS 1977 for Regions 1 and 3 and at RARC-SAT 1983 for Region 2 [Ninomiya, 1987].

This technique of bandwidth compression can also be applied to various other HDTV equipment. Equipment for consumer use such as VTRs and video-disc players using MUSE, and a converter for reception of MUSE signals with conventional television receivers has already been developed.

2. Sampling and interpolation of the MUSE system

Figure 8 shows the sampling pattern of the MUSE system. This sampling is of a multiple dot-interlaced type, and the cyclic period of the sequence is four fields.

Stationary portions of the picture can be reconstructed by using samples from all four fields of the sequence. The transmissible range in the spatial frequency domain is illustrated in Figure 9 (a) for stationary portions of the picture. It should be noted that this is a basic illustration in reference to Figure 8, and the actual transmissible range of the system will be explained later with Figure 11(f).

For moving portions, the picture has to be reconstructed with spatial interpolation by using samples within a single field only, otherwise a distortion of multi-line blur may appear in the reconstructed picture. The transmissible range in the spatial frequency domain becomes smaller as shown in Figure 9(c) for moving portions of the picture.

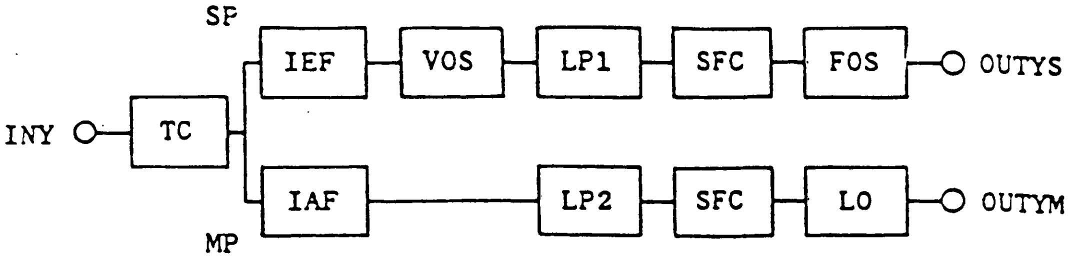

Figure 8
(a)

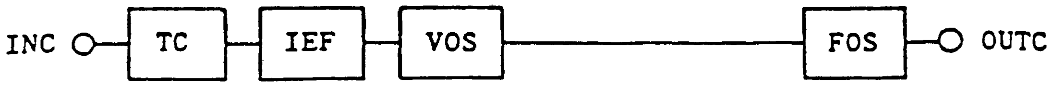

Figure 8
(b)

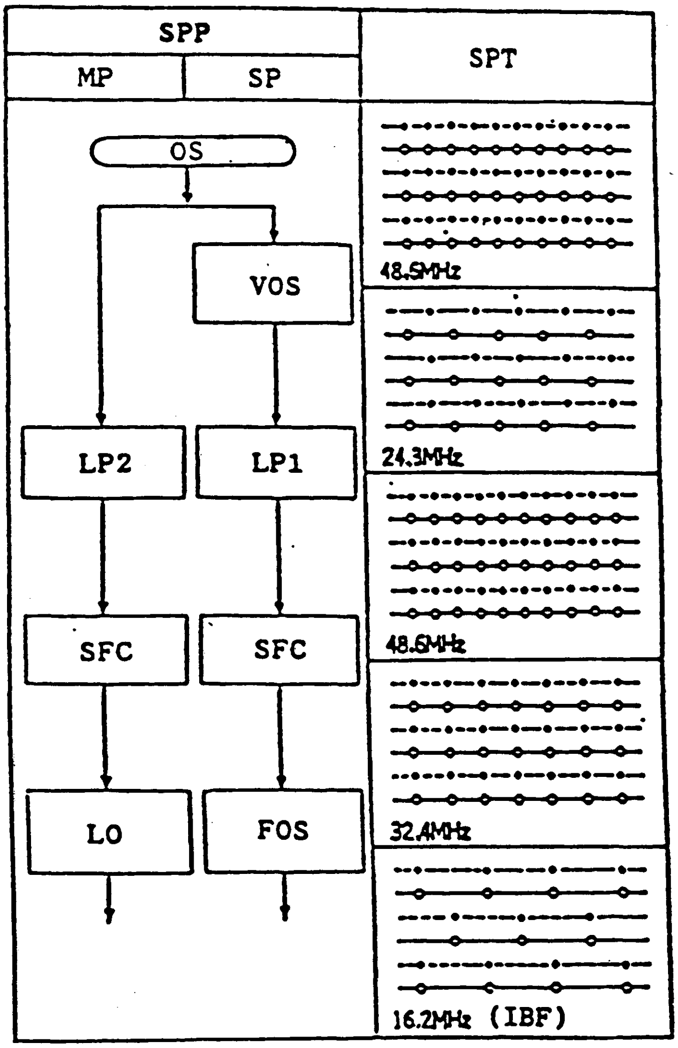

Figure 8
(c)

Figure 8 Principle of MUSE system

(a) Filter arrangement for the luminance signal

(b) Filter arrangement for the colour-difference signals

(c) Sampling pattern

TC : time compression
SP : stationary portion
MP : moving portion
IEF : interfield prefiltering
IAF : intrafield prefiltering
VOS : field-offset subsampling
LP1 : 12 MHz low-pass filtering
LP2 : 16 MHz low-pass filtering
SFC : sampling frequency conversion
FOS : frame-offset subsampling
LO : line-offset subsampling
INY : luminance signal input
INC : colour-difference signal input
OUTYS: luminance signal output for stationary portions
OUTYM: luminance signal output for moving portions
OUTC : colour-difference signal output
SPP : signal processing procedure
SPT : sampling pattern
OS : original sampling
(IBF): invert by frame
—○—: odd field
--●--: even field

It means that the actual resolution of details in the picture is reduced in the moving portions of the reconstructed picture. However, this reduction in terms of actual resolution does not cause any serious degradation in picture quality, because the human perception of the sharpness of picture is not so sensitive to details in moving portions of the picture. This has been confirmed true for almost all pictures observed under typical viewing conditions.

As an exception, however, in the case of uniform movement over the entire picture caused by, for example, panning or tilting the camera, the degradation becomes more noticeable. A technique of motion compensation is successfully employed here, and the degradation is eliminated as follows: A vector signal representing the motion in the picture is calculated for each field at the encoder, and is multiplexed into the field-blanking period for transmission. At the decoder, the position of picture samples of the preceding field is shifted depending on the vector signal so that the same process of temporal interpolation as that for the stationary portions can be applied.

The maximum transmissible spatial frequency in the vertical direction is 1/(2h) for stationary portions of the picture as shown in Figure 9 (a), whereas it is halved to be 1/(4h) for moving portions as shown in Figure 9 (b), because the 2:1 interlace scanning is applied to the original HDTV signal.

3. Encoding and decoding the MUSE signal

In principle, input signals of the luminance and the line-sequential colour-difference signals are first combined into a single time-division multiplexed signal called the TCI (Time Compressed Integration) signal (Figure 12 shows the waveform).

Before the signal is subsampled, as explained above with Figure 8, two different prefilters for suppression of aliasings are applied. The one is designed for use with stationary portions of a picture, and the other for moving portions. Ideal frequency response of these filters must coincide with the transmissible range of the system.

The outputs of the filters are field-offset subsampled for the portions of pictures not moving. After sampling frequency conversion, the signals are mixed, with the ratio determined on a pixel-by-pixel basis depending on the amount of motion detected. Then, a frame-offset subsampling is performed, and the signal is transmittted.

When the motion compensation is applied, some additional data concerning the motion vector is transmitted as a control signal which is inserted in the field blanking period as shown in Figure 14.

In the decoding, motion detection and picture element reconstruction can be performed independently of the encoding. The motion vector is transmitted, and is used in the receiver to give displacement to the picture of the previous field.

4. Sampling frequencies and spectra of the MUSE signal

The sampling-frequency assignment and filtering process for the luminance signal are shown in Figure 10, and the frequency spectra at major points of the process are indicated in Figure 11. These figures are shown in the case of a still picture.

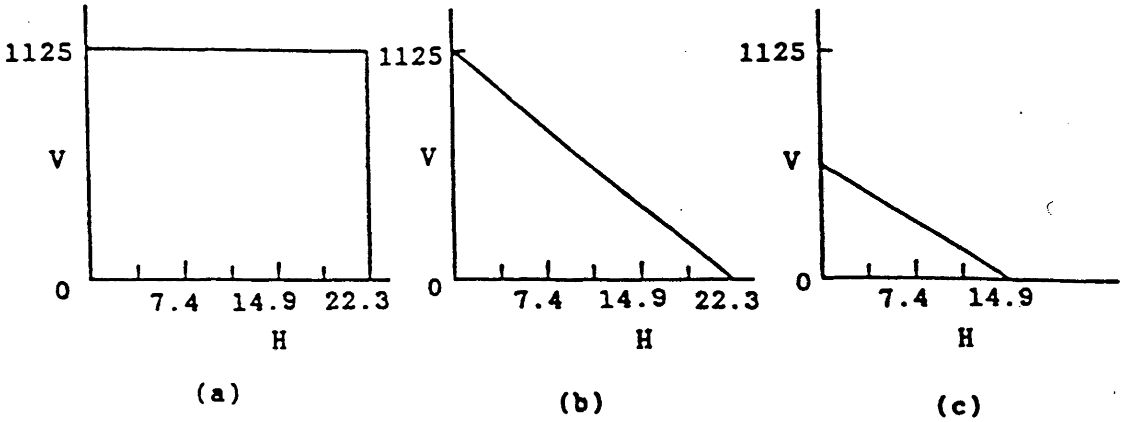

Figure 9 Transmissible range in spatial frequency domain

(a) Original sampling
(b) Interframe and interfield interpolation for stationary portions
(c) Intrafield interpolation for moving portions

H : horizontal frequency (MHz)
V : vertical frequency

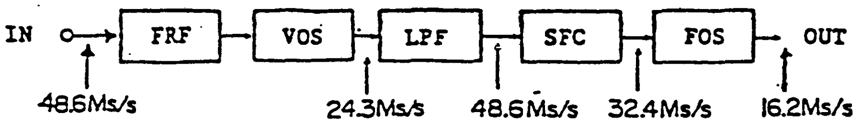

FIGURE 10 - Filtering arrangement of MUSE system (for luminance signal)

IN : luminance signal input
FRF: interfield prefiltering
VOS: field-offset subsampling
LPF: 12 MHz low-pass filtering
SFC: sampling-frequency conversion
FOS: frame-offset subsampling
OUT: output signal

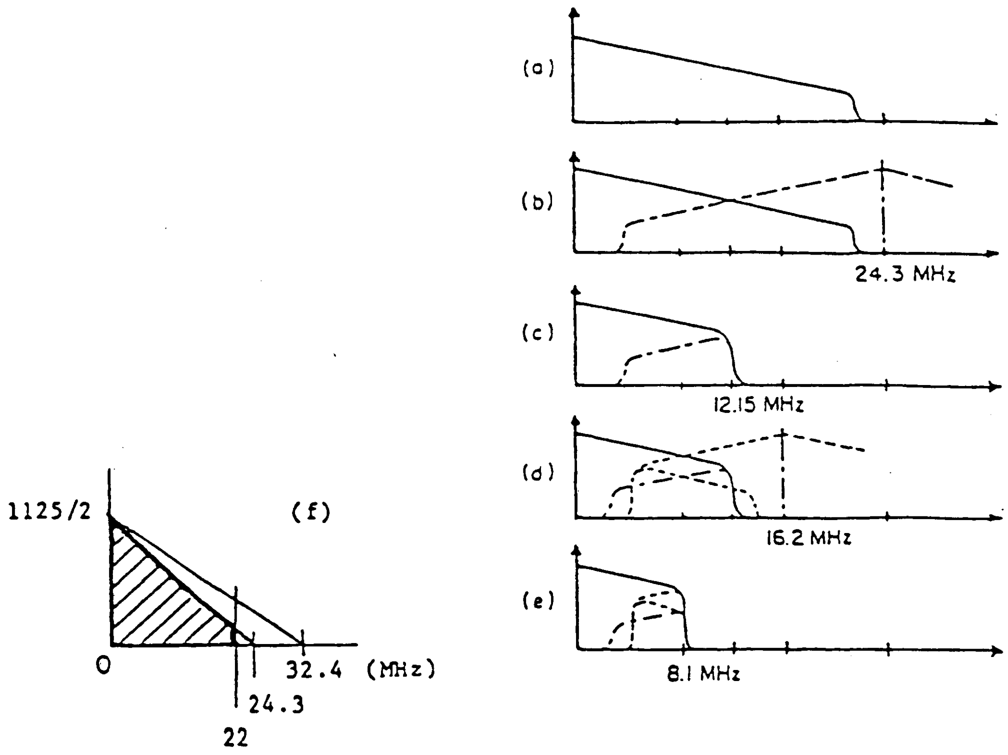

FIGURE 11 - <u>Frequency spectrum of MUSE system (for luminance signal)</u>
(a) Input signal
(b) Field-offset sub-Nyquist sampling at 24.3 MHz
(c) Low-pass filtering at 12 MHz
(d) Frame-offset sub-Nyquist sampling
(e) Output signal
(f) Transmissible frequency range of MUSE system
Abscissa: Horizontal spatial frequency (expressed in MHz)
Ordinate: Vertical spatial frequency

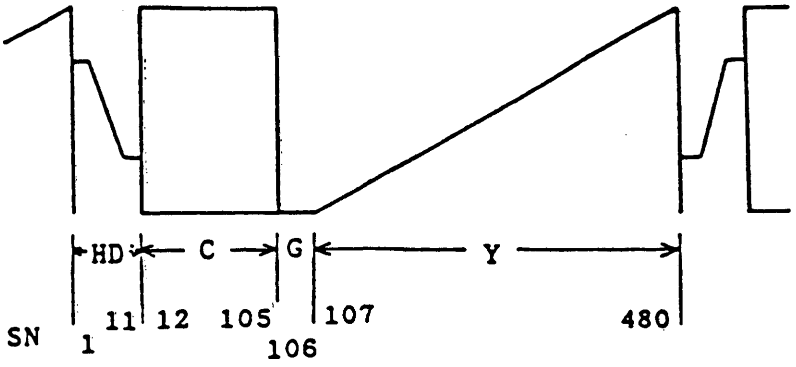

Figure 12 **Video signal in TCI format**
HD : line-synchronizing signal
C : colour-difference signals (line-sequential)
G : guard area
Y : luminance signal
SN : sample number

The luminance signal is supplied with a sample frequency of 48.6 Ms/s (mega-samples per second), and the prefiltering described in the previous section is performed. The sample frequency of the luminace signal is 24.3 Ms/s after the field offset subsampling. A low-pass filter of 12 MHz is applied as shown in Figure 11(c).

At the next stage shown in Figure 10, a sampling-frequency conversion from 48.6 Ms/s to 32.4 Ms/s is introduced in order to get a final sample rate of 16.2 Ms/s after the frame-offset subsampling.

This frequency arrangement achieves an elimination of the interframe alias component from the frequency range of DC to 4 MHz as shown in Figure 11(e), and results in stable operation of the motion detection with a small amount of sacrifice in the trasmissible range as shown in Figure 11(f). The number of required control signals is thus very small ; just information of the subsampling phase and the motion vector signal (in total,10 bits/field).

5. Signal formats of the MUSE system

Figure 12 shows signal composition for the video signal, called TCI (Time Compressed Integration), applied in MUSE processing. The compression ratio for the colour-difference signal is four with respect to that for the luminance signal, and two colour-difference signals are transmitted line-sequentially.

Basic video characteristics of the MUSE system are summarized in Table XVII.

The line-synchronizing signal is shown in Figure 13 (a) and the frame-synchronizing signal in Figure 13 (b). The amplitude of these signals does not extend beyond the dynamic range of the video signal so as to avoid amplitude loss due to the synchronizing signal.

The control signals, including motion vector, and digital sound/data signals are multiplexed into the baseband video signal during the field-blanking period as shown in Figure 14. Details of the sound signal processing in the baseband can be found in [CCIR, 1986-90a], but, for the reader's convenience, these are summarized in Table XVIII with the format of the digital sound/data signals.

Two modes of sound-channel usage, A mode and B mode, are provided with the MUSE system, as for existing conventional satellite broadcasting in some countries as described in Report 1073. In the A mode, four channels of 15 kHz sound signal can be accommodated with HDTV, and in the B mode, two 20 kHz channels. The bit-rate reduction systems are successfully applied to the differential PCM signal with 15-to-8-bit near instantanecus companding in 8 ranges for the A mode, 16-to-11-bit and 6 ranges for the B mode. The required bit rate is 1 350 kbit/s, including some independent data information.

In order to accomodate such an amount of information with baseband multiplexing in the field-blanking period, a ternary code is applied, with a rate of 12.15 Mbaud.

TABLE XVII - Basic video characteristics of MUSE system

System description		motion-compensated multiple subsampling system (multiplexing of Y and C signals is done in TCI format)
Scanning rate		1125 lines/ 60 fields/ 2:1 interlace
Bandwidth of transmitting baseband signal		8.1 MHz
Sampling clock rate		16.2 MHz
Reproduced signal bandwidth	Y signal	22 MHz (for stationary portions of picture) 14 MHz (for moving portions of picture) *
	C signals	7.0 MHz (for stationary portions of picture) 3.5 MHz (for moving portions of picture) *
Synchronizing signal		positive polarity with respect to video signal polarity

* These values should be 16 MHz for Y and 4 MHz for C respectively, if a perfect digital two-dimensional filter could be used.

TABLE XVIII - Basic sound characteristics of the MUSE system

Mode of sound-channel usage	A mode	B mode
Bandwidth of base band signal	15 kHz	20 kHz
Sampling frequency	32 kHz	48 kHz
Number of sound channels	4	2
Encoding signal	differential PCM signal	
Companding law	15-to-8 (8 ranges)	16-to-11 (6 ranges)
Leakage factor	$1 - 2^{-4}$ (0.9375)	
Sound emphasis	not used	
Error correction	BCH SEC DED (82, 74) additional BCH SEC DED (7, 3) for range bits	
Capacity of data channel	128 kbit/second	112 kbit/second
Sound and data rate	1350 kbit/second	
Transmitting code	ternary code	
Transmitting period	field-blanking period	
Symbol rate	12.15 Mbaud	

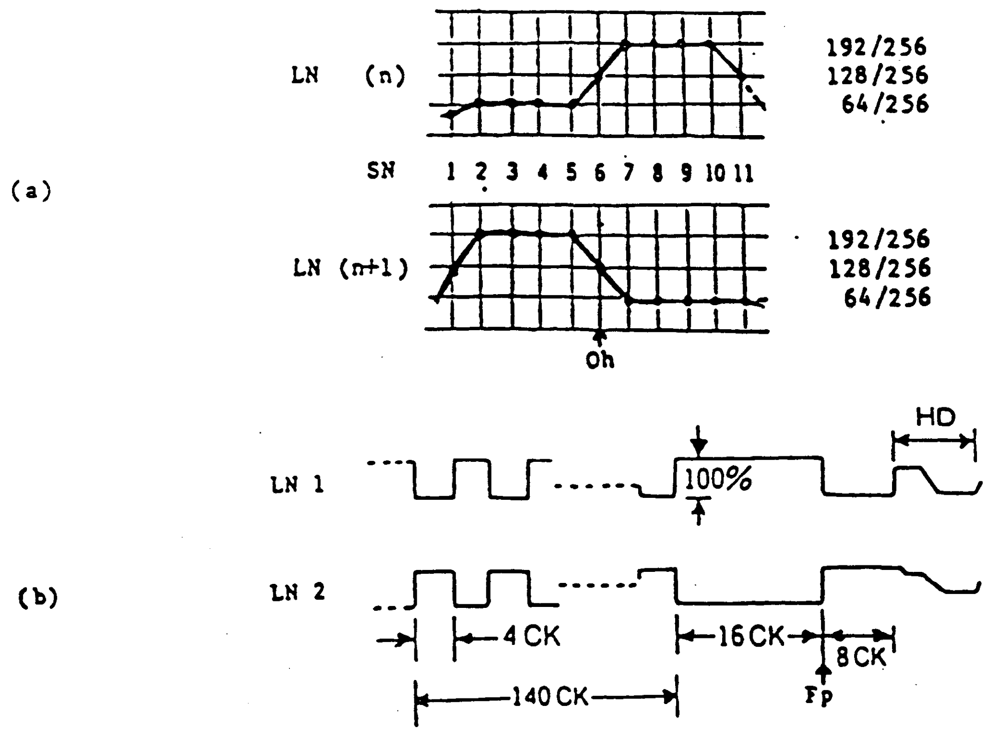

FIGURE 13 - **Synchronizing signals**

(a) line-synchronizing signal
LN (n): n th line
LN (n+1): (n+1) th line
SN : sample number
Oh : timing reference for line synchronization

(b) frame-synchronizing signal
LN : line number
HD : line-synchronizing signal
Fp : frame-pulse point
CK : one clock-time duration at 16.2 MHz

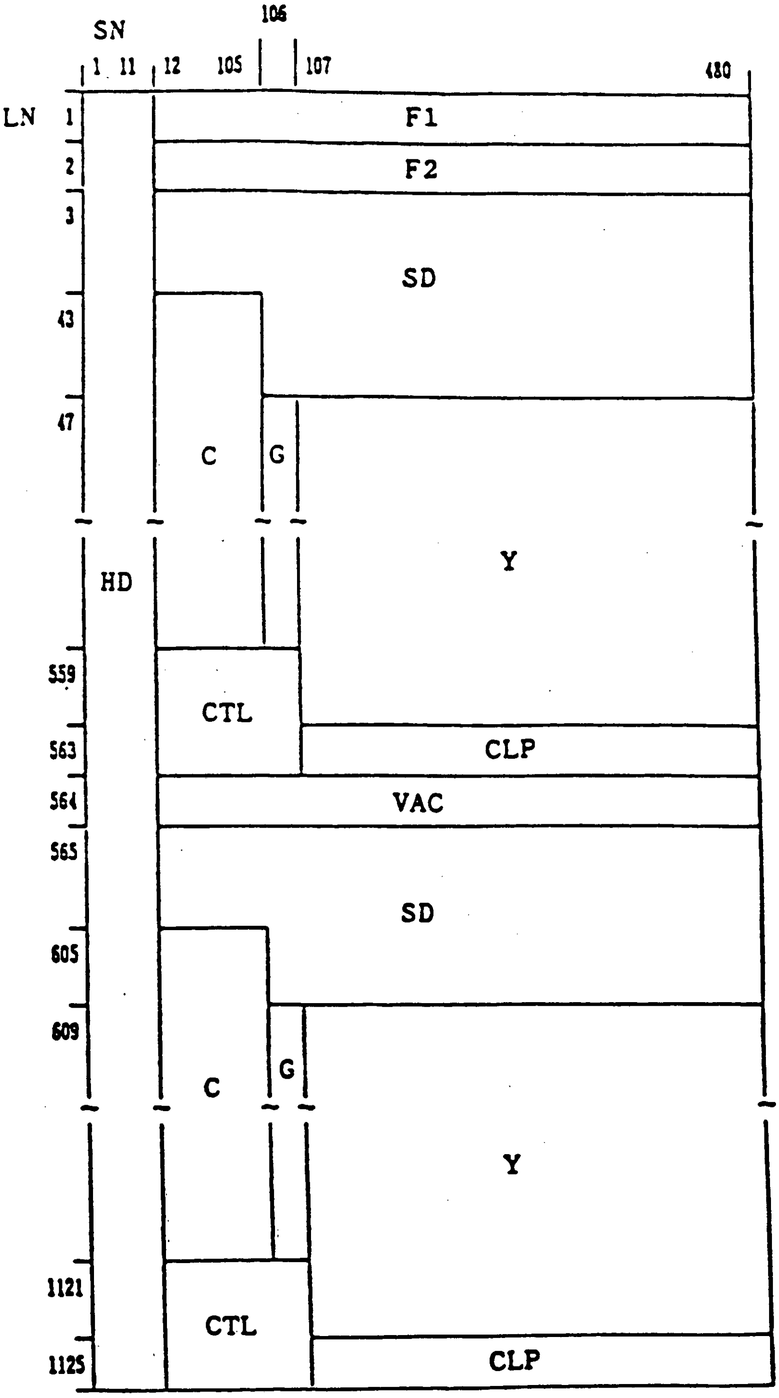

Figure 14 Signal allocation map

SN	: sample number	LN	: line number
HD	: line-synchronizing signal	F1	: VITS No. 1 and Frame Pulse No. 1
SD	: sound and data signals	F2	: VITS No. 2 and Frame Pulse No. 2
C	: colour-difference signals (line-sequential)	G	: guard area
Y	: luminance signal	CTL	: control signals
CLP	: clamp level (128/256)	VAC	: vacant

6. Quasi-constant luminance processing in association with MUSE system

The input signals of R', G' and B' (the ' designates gamma pre-corrected signals) are put into a circuit called Inverse Gamma and converted into the quasi-linear R, G and B signals. But, as is well known, these R, G and B signals are susceptible to transmission noise.

To overcome this susceptibility, non-linear circuits are introduced, one in the luminance channel for improvement of signal-to-noise ratio in dark regions, and the other in the colour-difference channel for improvement in regions having colours of low saturation. Figures 15 and 16 depict the non-linearity specified for the colour-difference channel and the luminance channel of MUSE system, respectively. This non-linearity introduced for the purpose of transmission will completely be compensated at the receiver back to the quasi-linear signals mentioned above.

7. Frequency modulation and non-linear emphasis for MUSE system

When the MUSE signal is transmitted with frequency modulation, a non-linear emphasis is effectively used. The characteristics of it can be defined by the composition of the de-emphasis circuit to be used in receivers. An example is shown in Figure 17.

Figure 18 shows characteristics of the non-linear processing in Figure 17. Figure 19 shows frequency response of the de-emphasis circuit defined in Figure 17.

The basic modulation parameters for the satellite broadcasting of MUSE within a 27 MHz channel are given in Table XIX.

8. MUSE applications

Technical considerations and some results of application to a satellite broadcasting system can be found in [CCIR, 1986-90b and c].

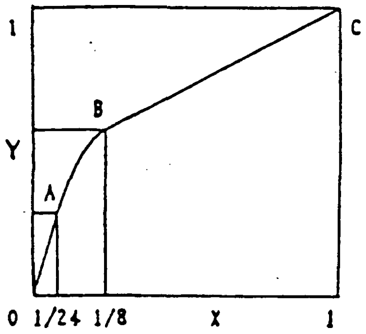

FIGURE 15 - Characteristics of non-linear circuit for transmission of colour-difference signals

Abscissa: Input level X

Ordinate: Output level Y

Only the positive half of the curve is shown in the Figure. The negative half is symmetrical to it with respect to the origin. The curve is defined as follows when the signal level is normalized to unity:

$Y = (5/3)X$ ....for section 0 - A

$Y = -(48/11)X^2 + (67/33)X - (1/132)$ ....for section A - B

$Y = (31/33)X + (2/33)$ ....for section B - C

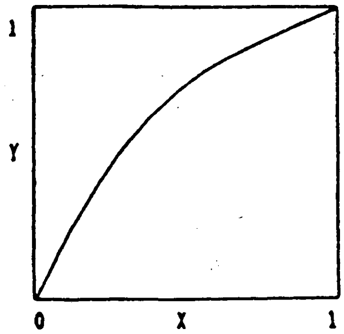

FIGURE 16 - Characteristics of non-linear circuit for transmission of luminance signal

Abscissa: Input level X

Ordinate: Output level Y

The curve is defined as follows when the signal level is normalized to unity:

$X = (3/5)Y^2 + (2/5)Y$

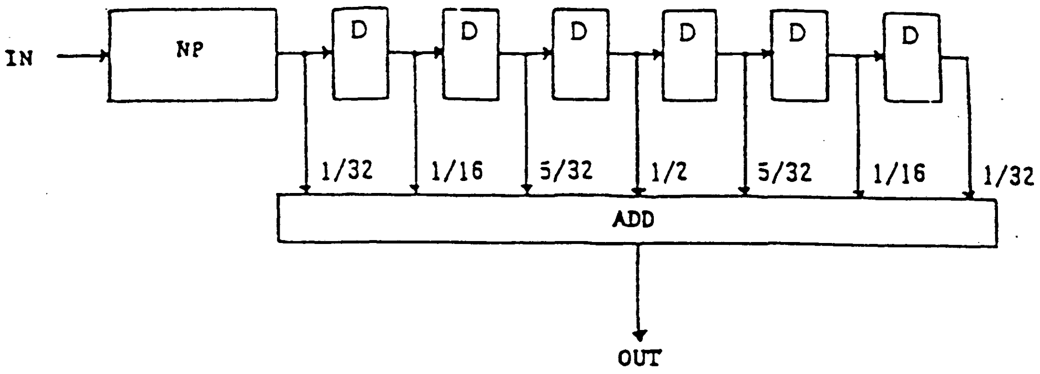

FIGURE 17 - An example of de-emphasis circuit to be used in the receiver

IN : input signal
NP : non-linear process (see Figure 18)
D : one-clock delay element at 16.2 MHz
ADD: adder
OUT: output signal

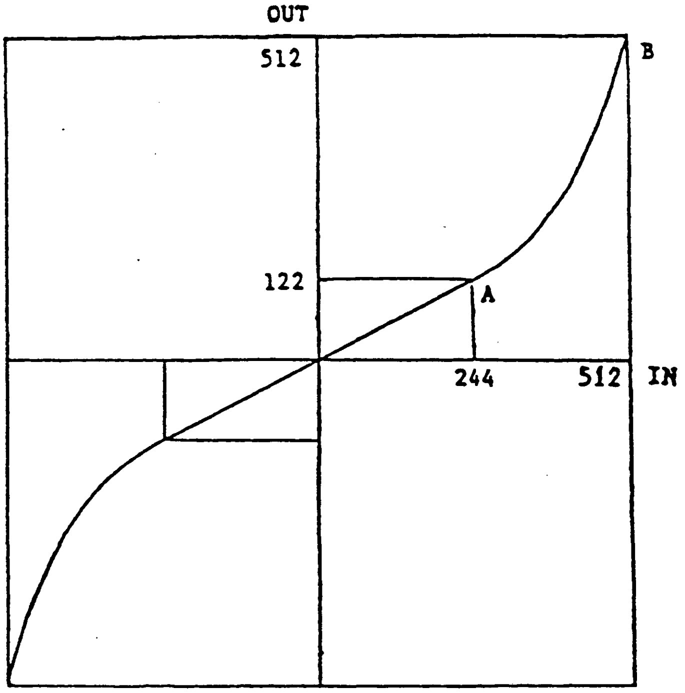

FIGURE 18 - Characteristics of non-linear process placed before de-emphasis shown in Figure 17

IN : input signal level
OUT: output signal level

The curve is defined as follows:

straight line with a gradient of 1/2 .....for section 0 - A
elliptic curve with gradients 1/2 at A, 5/2 at B .....for section A - B

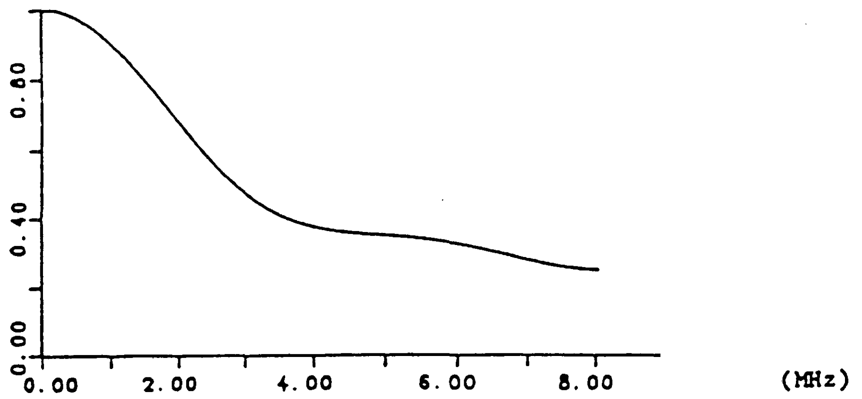

FIGURE 19 - <u>Frequency response of de-emphasis shown in Figure 17</u>
Abscissa: Frequency (MHz)
Ordinate: Response (normalized value)

TABLE XIX - Modulation parameters for MUSE

Nominal video signal bandwidth (MHz)	8.1
Nominal channel bandwidth (MHz)	27
Vision signal modulation	FM
Sound and data ~~signal~~ modulation	Ternary PCM multiplexing in field-blanking period
Symbol rate (Mbaud)	12.15
Sound and data rates (Mbit/s)	1.35
Polarity of frequency modulation	Positive
DC component	Preserved
Frequency deviation (MHz)	10.2
Pre-emphasis characteristics	Non-linear emphasis [Ninomiya, *et al*, 1987]
Energy dispersal (kHz)	600 Triangular frame synchronous waveform

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ANNEX III

THE HDMAC COMPATIBLE HDTV SATELLITE BROADCASTING SYSTEM

1. Design consideration

HDMAC is designed to allow the introduction of HDTV on existing MAC/packet systems, or directly as a new service. [CCIR, 1986-90a, b] describe the design considerations of HDMAC bandwidth reduction.

These include the performance of the system with respect to the received HDTV picture quality, the full utilization of current technological capabilities, the feasibility of system development as technology advances, and the economic viability and suitability of the system with respect to its adoption, and subsequent use, by broadcasters and viewers. As a consequence, receiver manufactures can produce and market HDMAC receivers as an extension to their product range, without making existing products obsolate. Additionally, the HDMAC product range is broadened by the potential for display up-conversion. The use of DATV significantly reduces the complexity of HDMAC decoders, and therefore their cost; and makes their behaviour uniform, regardless of channel distortions.

HDMAC is optimized to allow HDTV services on WARC-BC-77 emission channels, while preserving the compatibility with the MAC/packet system. These constraints involve the EUREKA 95 project in global tradeoffs between the receiver complexity, the quality of the high definition picture generated with the 1250 line/50 field scanning standard, and the quality of the compatible picture viewed on domestic MAC/packet receivers.

This system is designed to employ spectrum folding, subsampling and motion adaptation to preserve the resolution of both static and tracked motion for high-definition reception [Hurault, et al., 1988].

2. System description

The specification in Europe of a high-definition television system (HDTV), studied in the context of the European EUREKA 95 project, is based for its complete description, on the specification of the MAC/packet family which is presented in Report 1073 [CCIR, 1986-90c].

The time division multiplex is used for picture/sound/data multiplexing for HDMAC transmissions which include two members of the MAC/packet family: D-HDMAC/packet and D2-HDMAC/packet systems. These two systems are suited for use in satellite broadcasting and any transmission medium which guarantees a baseband of about 11 MHz. In addition, to improve the noise performance, non-linear pre-emphasis is used (see Section 2.6).

2.1 Structure of the multiplex

The structure of the multiplex is based on a 40 msec digital frame which contains 625 lines of 624 us each. The multiplex is composed of three main components (see Figure 20):

- the HDMAC vision signal;

- the line blanking interval (LBI) data burst, which carries the sound/data multiplex;

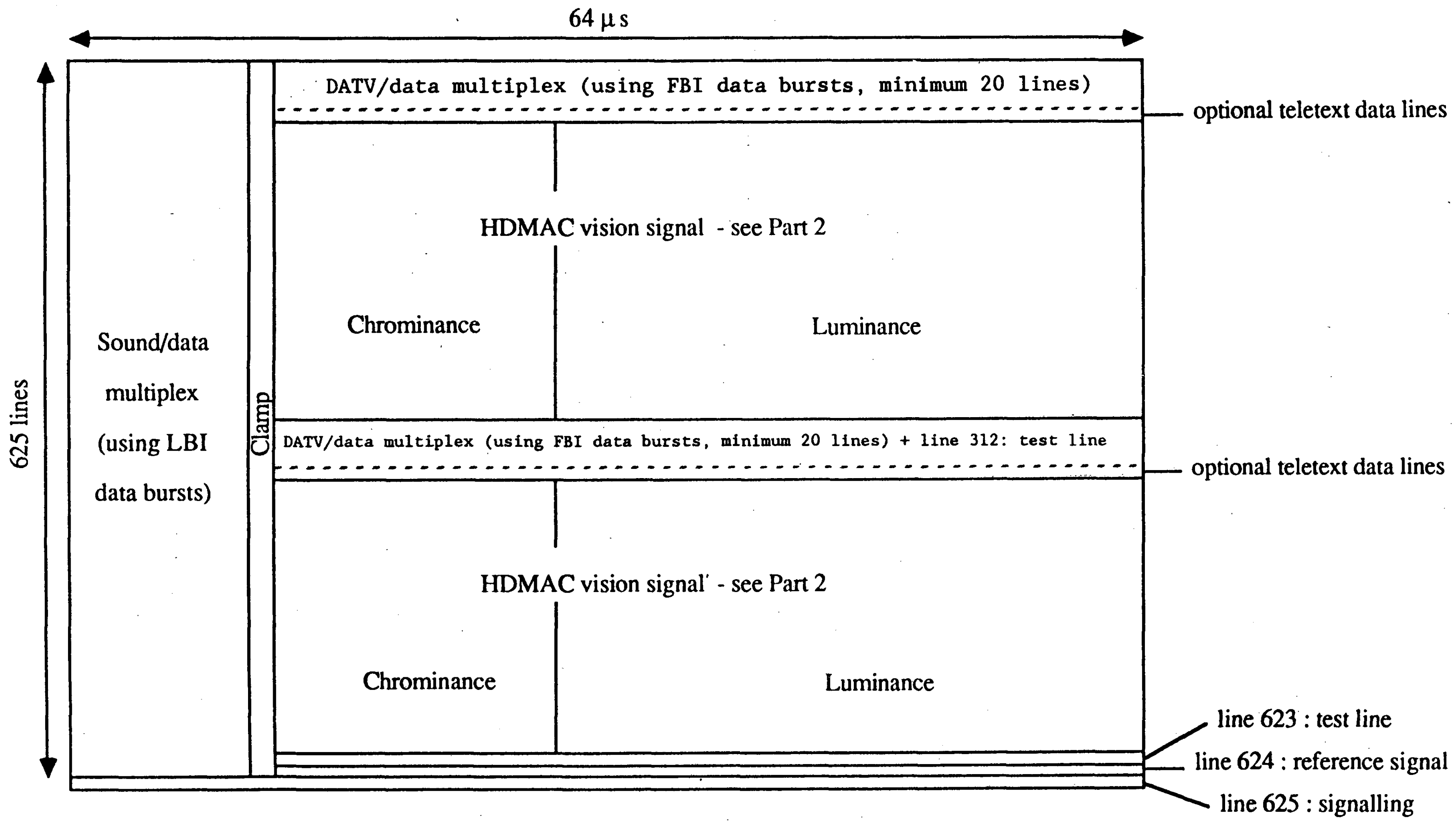


FIGURE 20

General HDMAC/packet TDM structure

- the field blanking interval (FBI) data burst, which carries the DATV/data multiplex.

2.2 Sound

Sound is coded according to the MAC/packet specification. The available capacity in the LBI is equivalent to four high-quality or eight medium-quality sound channels compatible with MAC/packet for the D2 system and eight high-quality or sixteen medium-quality sound channels compatible with MAC/packet for the D system.

2.3 Vision

Document [CCIR, 1986-90d] gives the baseband characteristics (summarised in Table XX). The modulation parameters of the emitted HDMAC signal are given in Table XXI.

2.4 General video characteristics of the HDMAC vision signal

See Table XX.

2.5 Bandwidth reduced signal

Multi-branch coding is used for HDMAC band reduction [Vreeswijk, *et al.*, 1988; Arragon, *et al.*, 1988; Pele and Choquet, 1988].

[CCIR, 1986-90a] reports on the subjective assessments that were performed by five laboratories throughout Europe and that led the Eureka EU 95 project to select the final HDMAC bandwidth reduction system. Seven candidates' algorithms were evaluated. Eight scaled-down moving picture sequences were used covering a range of possible source material (originated in 1250- and 625-line interlaced video cameras, 25 and 50 pictures/sec. film). For the tests a double stimuluse method was used with continuous graphical quality-scaling (in line with CCIR methods). The ranking order for the seven algorithms was generally the same for each of the five laboratories that undertook the tests and there was a high degree of correlation for the quantative differences between the mean grades. The results gave confidence in the method and the validity of the ranking order.

The HDMAC BR codec uses three luminance coding branches, all with quincunx subsampling lattices;

- an 80 msec branch with HD resolution for stationary areas;

- a 40 msec motion compensated branch for velocitites up to 12 samples per 40 msec.

- a 20 msec branch for rapid motion and sudden picture changes except when in 25 picture/sec. film mode.

The transmissible range of spatial frequency is given in Figure 21 for all modes. To carry the information contained in a 120 line HD system through a 625 line MAC/packet channel, a process, termed "shuffling", is used.

TABLE XX

General video characteristics of the HDMAC vision signal

Number of emitted lines per picture :	625
Number of fields per second :	50
Interlace ratio :	2:1
Analog bandwidth approximately :	11 MHz[1]
Aspect ratio :	16:9 (associated with panning information for compatible 4:3 displays).
Compression ratios	
luminance :	3:2
color difference :	3:1
Sampling frequency :	20.25 MHz[2]
High definition reception :	
Luminance resolution	
horizontal	
static and tracked motion :	620 c/apw[3]
untracked motion :	310 c/apw
vertical	
static :	400 c/apw[3]
motion :	200 c/apw
Compatible reception :	
Samples per active lines	
luminance :	697
color difference :	349

Note 1 : Allowing for practicable Nyquist filter

Note 2 : Conventional MAC sampling frequency

Note 3 : Cycles per active picture width/picture height

TABLE XXI

HDMAC modulation parameters for DBS

Nominal vision signal bandwidth :	10.125 MHz at -3 dB
Nominal channel bandwidth :	27 MHz
Modulation :	FM
Polarity of frequency modulation :	positive
DC component :	preserved
Pre-emphasis characteristics:	non linear process applied only to HDMAC samples and linear applied to all the multiplex (same as for MAC)
Frequency deviation :	13.5 MHz at the cross-over frequency of the linear pre-emphasis network (1.37 MHz).
Energy dispersal :	triangular frame synchronous waveform (corresponding carrier deviation : 600 kHz peak-to-peak)

The 40 msec branch is motion compensated. One motion vector is emitted for each block of 16 samples by 16 lines on the HD grid via the DATV data.

The HDMAC BR codec uses three colour-difference coding branches, the first and third using a quincunx, the second an orthogonal subsampling lattice:

- an 80 msec branch with HD resolution for stationary areas;

- a 40 msec branch for rapid motion and sudden picture changes;

- a 20 msec branch for rapid motion and sudden picture changes, except when in 25 picture/sec. film mode.

The transmissible range of spatial frequency is given in Figure 22 for all the modes. Intra-field shuffling is used for the 80 and 20 msec branches and inter-field for the 40 msec branch.

A film mode option is implemented, which only activates the 80 and 40 msec branches. In this way maximum benefit is taken from the knowledge that 25 picutres/sec. film is the source material.

The branch selection information is conveyed, after formatting by the DATV data [Storey, 1986].

DATV information that contains the branch switching signal allows for 1700 possibilities, coded in 11-bit-long codewords. The five route/80 msec period coding results in a bit rate of 891 kbit/s. The colour-difference switching information is derived from the luminance DA data.

Compatibility improvement for edge crawling in stationary areas is done by vertical intra-field filtering, with an attenuation of 6 dB.

2.6 E7 compatible non-linear pre/de-emphasis network example

Here a short description of E7 is given. The full description is given in Report 1074 [CCIR, 1986-90e].

"E7" is a non-linear pre/de-emphasis which has been designed to provide noise and interference improvement without any threshold degradation. E7 is a frequency dependent instantaneous compander system. It is "compatible" in the sense that it has no effect at low video frequencies, so the deviation sensitivity of the FM signal is not affected. E7 may be implemented in either analogue or digital form.

In E7, the high frequency components above 2 MHz of the signal are passed through a non-linear network. The non-linearity is defined in Figure 23. The pre-emphasis network is described by Figures 24 and 25.

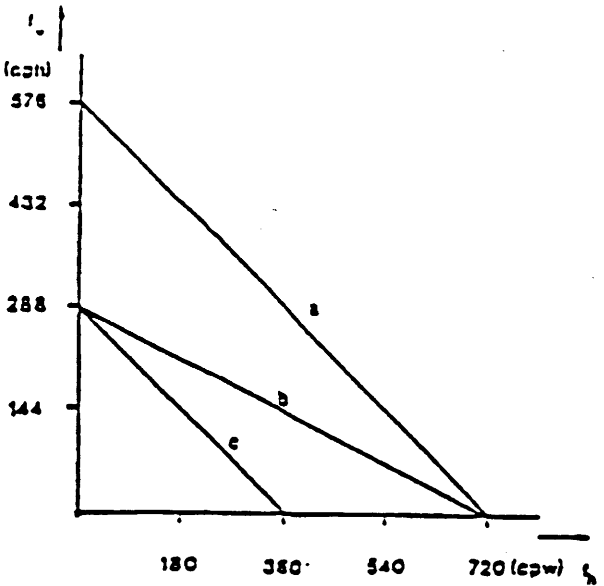


FIGURE 21

Transmissible range in spatial frequency domain for the luminance sampling patterns

(a) 80 ms mode
(b) 40 ms mode
(c) 20 ms mode

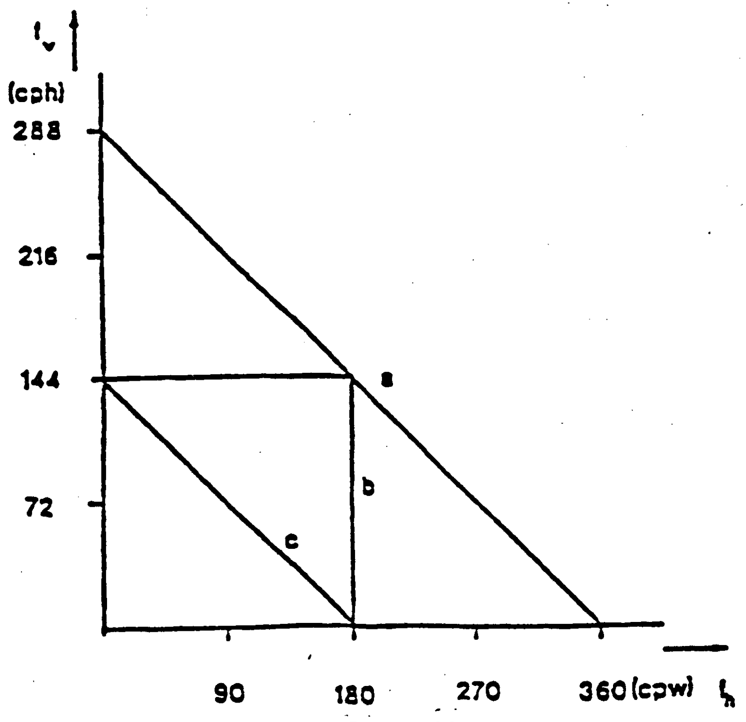


FIGURE 22

The transmissible range of the colour-difference spatial frequency spectrum

(a) 80 ms mode
(b) 40 ms mode
(c) 20 ms mode

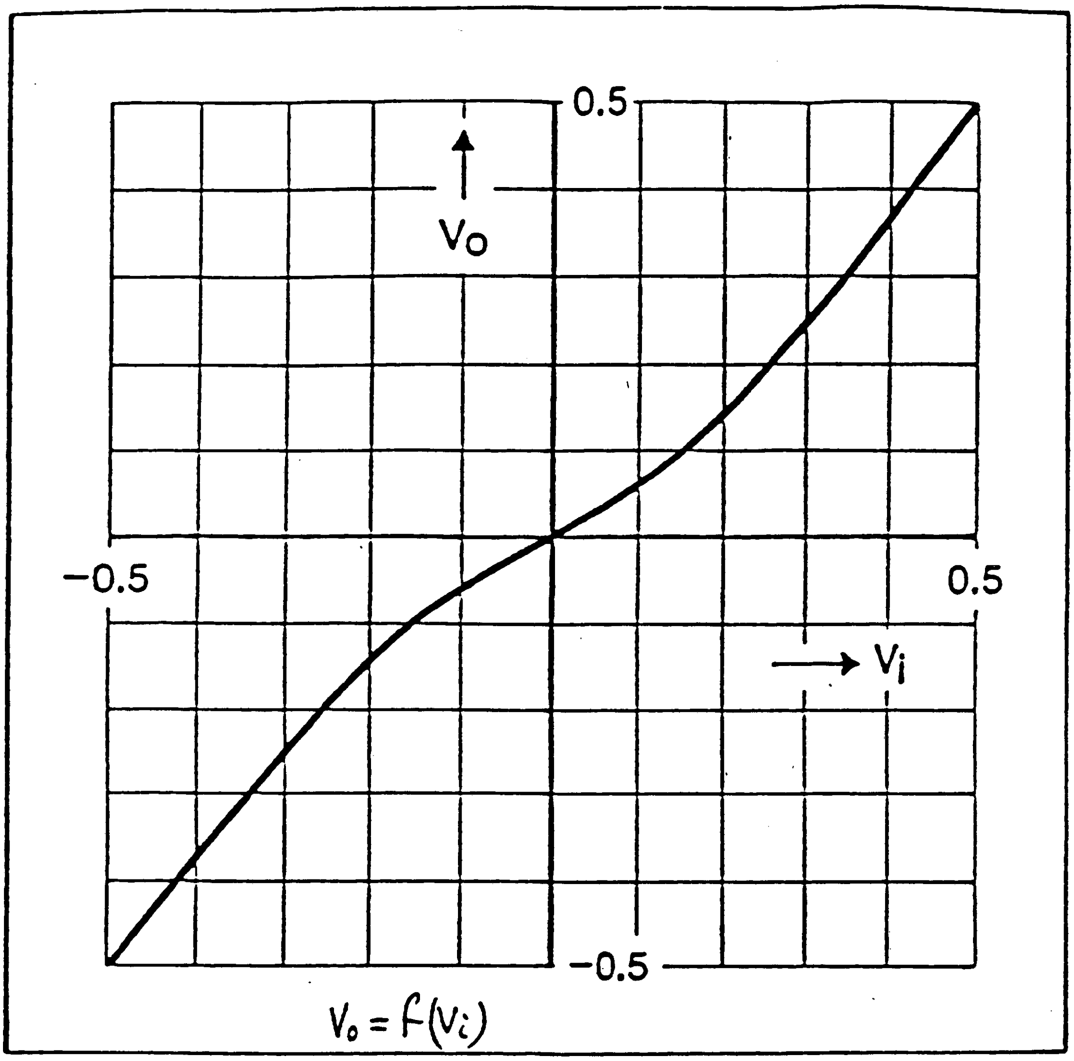
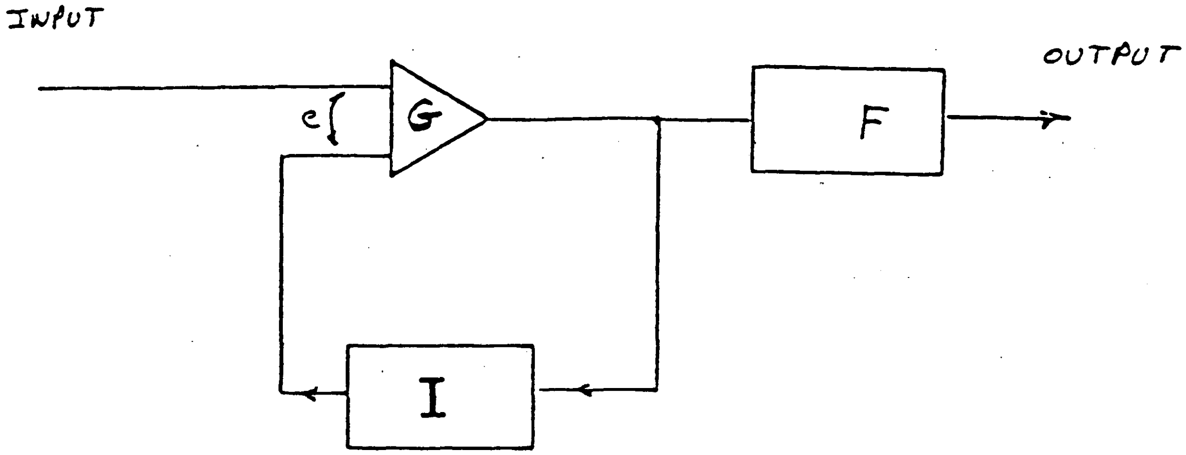


FIGURE 23

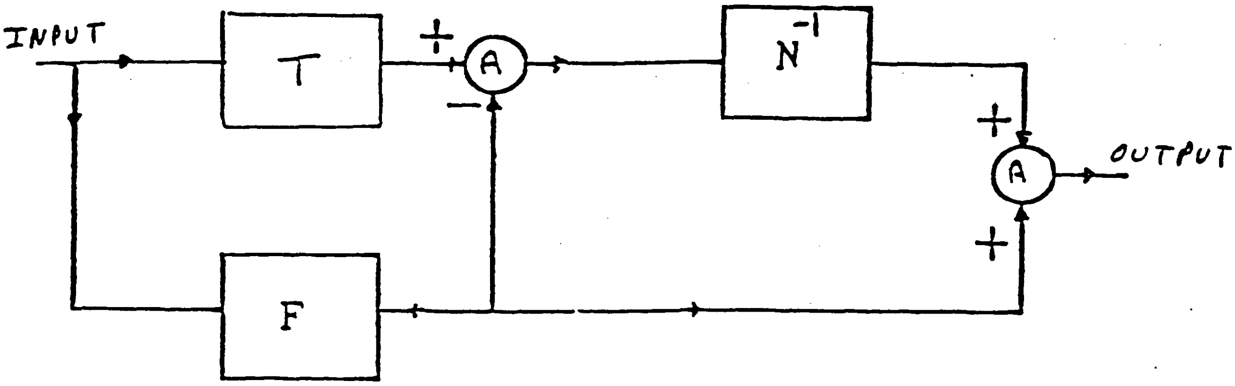
Non-linear function N^{-1}



I: de-emphasis network
F: low pass filter
G: gain of amplifier >> 1
e: error signal

FIGURE 24

Analogue pre-emphasis configuration



A : adder
T : delay element
F : low pass filter
N^{-1} : non-linear function

FIGURE 25

E7 de-emphasis block diagram

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[1986-90] a. 11/6-2013 (Netherlands); b. 11/6-2086 (France, Netherlands, United Kingdom) c. 11/6-2096 (France); d. 11/6-1063 (United Kingdom); e. 10-11/3-108 (JIWP 10-11/3);

ANNEX IV

SYSTEMS UNDER DEVELOPMENT IN NORTH AMERICA

1. HDS-NA satellite signal: AN HDTV MAC format for FM environments

1.1 Introduction

FM environments such as satellite and tape recording present critical links for HDTV television distribution in North America. In addition to existing fixed-satellite service (FSS) transmission of programme material to broadcast stations and cable head-ends, there is also the potential to introduce satellites in the broadcasting-satellite service (BSS). It has been demonstrated that Multiplexed Analogue Component (MAC) signal formats have significant advantages over frequency multiplexed (interleaved) formats (e.g. NTSC) when transmitted over FM satellite links. However, MAC formats are not appropriate for HDTV terrestrial broadcasting, or cable distribution in the United States because of the need to be compatible with the existing NTSC (System M) format. With these constraints in mind, a pair of HDTV signal formats (denoted "a)" and "b)" below) called HDS-NA, has been proposed in the United States for satellite transmission. They are optimum in transmission and emission of HDTV programming, while providing ease of transcoding to each other, and to NTSC, by use of common baseband parameters. This annex discusses the HDS-NA satellite signal for use in an FM emission and transmission environment.

1.2 HDS-NA signal

The required HDTV source signal to the HDS-NA encoder supports a dual format:

a) progressive (1:1):525-lines; 16:9 aspect ratio; 59.94 Hz frame rate; or

b) interlace (2:1):1050-lines; 16:9 aspect ratio; 59.94 Hz frame rate.

The choice between interlaced and progressive scanning may depend on the application: interlaced for stationary imagery, or imagery captured at low temporal rates (e.g. 24 frames per second); and progressive for optimum motion portrayal. The following signal packaging description is based on a 525-line, progressive source. When the source is 1050 lines, interlaced, a spatially correct 525-line scan is generated.

As in all HDTV systems with limited bandwidth, HDS-NA applies a subsampling technique to reduce information content. Linear subsampling, employed in HDS-NA, provides high-quality motion rendition and a high-resolution picture achieved with an inexpensive decoder. It also provides expandability of resolution. If more bandwidth is necessary for high-quality advanced television system (ATV) applications, the horizontal resolution of the HDS-NA satellite signal can be extended gracefully without rendering obsolete the format or existing receiving equipment. If memory is used in the decoder, diagonal resolution can be increased.

When the source signal is 525-lines progressive, alternate lines are replaced by a Line Difference signal containing information for increased vertical resolution. A similar signal, the Line Subtraction signal, is generated when the source is 1050-lines interlaced. This is done in parallel with an initial scan conversion from 1050 interlace to 525 progressive scan. The conversion uses an algorithm optimally designed to provide subsequent conversion capability to 525 interlace scan for NTSC without generating artifacts.

The HDS-NA satellite signal unique packaging format involving time expansion and compression. A 127.11 usec "superline" of twice the duration of one NTSC line is used to assemble a block of eight video and data packets. The "superframe", 525 superlines, has elements from four consecutive 59.94 Hz fields, equivalent in duration to four NTSC fields.

Source:525-line progressive

The Line Difference (LD) signal is derived from contributions from three adjacent lines. Referring to Figure 26, source line S_2 is replaced by LD_2 in the encoded signal. The relationship between LD and the source line is

$$LD_n = S_n - (S_{n-1} + S_{n+1})/2$$

On receipt of the HDS-NA transmission, reconstruction of the source line is accomplished by

$$S_n = LD_n + (S_{n-1} + S_{n+1})/2$$

Source:1050-line interlaced

When the source is 1050-line interlaced, the construction of the superline requires that *first a spatially correct 525-line progressive scan be generated for ease of transcodability to* the NTSC compatible terrestrial/cable emission signal. Two operations are performed. First, a 525 line progressive scan is developed from every field of the 1050-line interlaced signal. Referring to Figure 27, the odd source lines S_1, S_3, S_5,... of Field 1 are transformed to progressive lines P_1, P_3, P_5,... and even source lines S_2, S_4, S_6...,to progressive lines P_2, P_4, P_6...,by the relationship

$$P_{no} = (1/4)S_{2n-1} + (3/4)S_{2n+1} \quad \text{Odd source lines}$$

$$P_{ne} = (3/4)S_{2n} + (1/4)S_{2n+2} \quad \text{Even source lines}$$

In addition, a line-subtraction (LS) signal is derived from the 1050-line interlaced source. The relationship between the source lines and the LS signal is

$$LS_{no} = S_{2n-3} - S_{2n-1} \quad \text{Odd source lines}$$

$$LS_{ne} = S_{2n} - S_{2n-2} \quad \text{Even source lines}$$

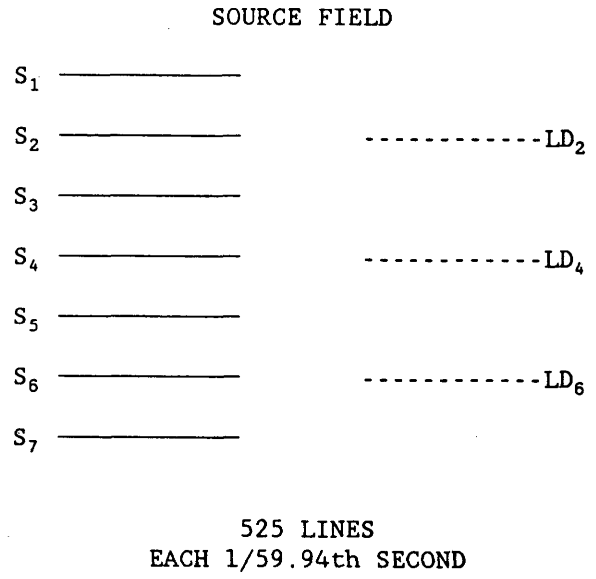


Figure 26. HDS-NA satellite signal - Scanning geometry for 525-line progressive source.

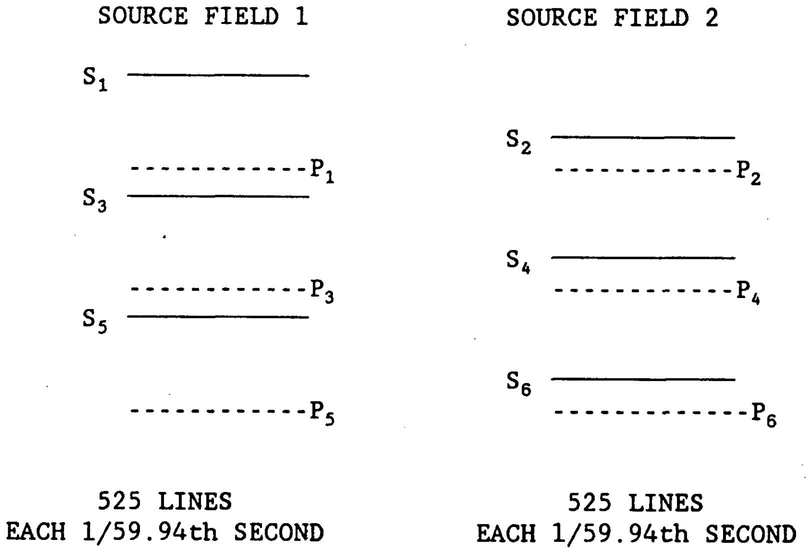


Figure 27. HDS-NA satellite signal - Scanning geometry for 1050-line interlaced source.

In transmission, the luminance signals P_1, LS_2, P_3, LS_4, P_5, LS_6 .... form a progressively scanned frame requiring the same channel capacity as the 525-line progressive signal described previously, followed by a frame P_2, LS_3, P_4, LS_5, P_6, LS_7 .... After reception, the 1050-line interlaced signal is reconstructed by the relationship

$$S_n = (3/4)LS_{n+1} + P_n$$

The exact algorithm for scan conversion when the source is 1050-line interlaced may evolve as further evaluation of the system takes place.

1.2.1 HDS-NA superline

For both 525-line progressive source, and 1050-line interlaced source converted to spatially correct 525-line progressive scan, the packets in the superline are as shown in Figure 28, and are described below:

Y_1	-Luminance signal of Line 1, carrying 280 lines/PH of resolution, horizontally filtered to a bandwidth of 9.54 MHz
Y_3	-Luminance signal of Line 3, carrying 500 lines/PH of horizontal resolution expanded by 16:9 ratio to obtain frequency compression to 9.54 MHz.
LD_2/LS_2	-Luminance Line Difference component, in place of Line 2, carrying 140 lines/PW horizontal information, derived from the horizontally filtered source line minus the average of the two adjacent lines. This packet, vertically high-pass filtered and horizontally low-pass filtered for vertical resolution enhancement, is compressed 2:1
LD_4/LS_4	-Similar to LD_2 or LS_2, in place of Line 4.
I	-Matrixed color component vertically decimated 4:1, with 140 lines/PH horizontal resolution at 59.94 Hz.
Q	-Matrixed color component vertically decimated 4:1, with 70 lines/PH horizontal resolution at 59.94 Hz.
DSS	-Digital Sync and Sound and conditional access information of 8.2 usec duration. Conservatively, the data rate can be 1.375 Mbit/s. As an example, the DSS can support an existing encoding system providing four 243 kbit/s audio channels and 403 kbit/s for conditional access and other services. Digital synchronization, using correlation techniques, requires less than 1 kbit/s.
Clamp	-Grey level clamp period

The subscripts relate to the location of each assembled packet in the four line, four field sequence of the super frame. Table XXII lists the characteristics of each packet. The superline occupies a base bandwidth of 9.54 MHz, which can fit into a 24 MHz or 27 MHz satellite channel.

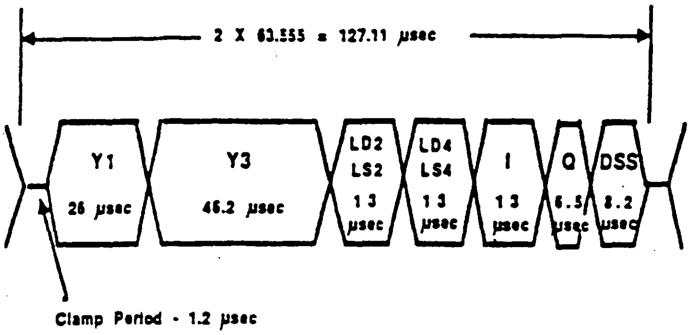


Figure 28. HDS-NA Satellite Signal - Superline, showing the position of the video and data packets

Table XXII- Characteristics of HDS-NA satellite signal components

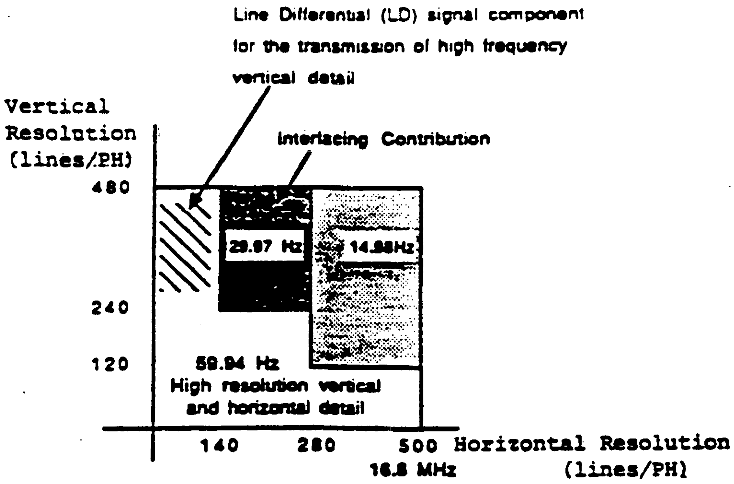
COMPONENT	COMPRESSION RATIO	DURATION (usec)	BASEBAND FREQUENCY	
			Before Compression (MHz)	After Compression (MHz)
Y_1	1:1	26	9.54	9.54
Y_3	9:16	46.2	16.8	9.54
LD_2 LS_2	2:1	13	4.75	9.54
LD_4 LS_4	2:1	13	4.75	9.54
I	2:1	13	4.75	9.54
Q	4:1	6.5	2.375	9.54
DSS		8.2		
Clamp		1.2		

1.3 HDS-NA spectrum

For the case of a 525-line progressive source, the two-dimensional spectral distribution of the encoded signal is shown in Figure 29. The luminance horizontal resolution is 500 lines/PH with 480 active lines delivered at a 59.94 Hz refresh rate. Some of the diagonal details are refreshed at reduced rates, 29.97 Hz and 14.98 Hz. In addition, the system delivers four channels (two stereo pair) of near CD quality sound and, in addition, conditional access control information.

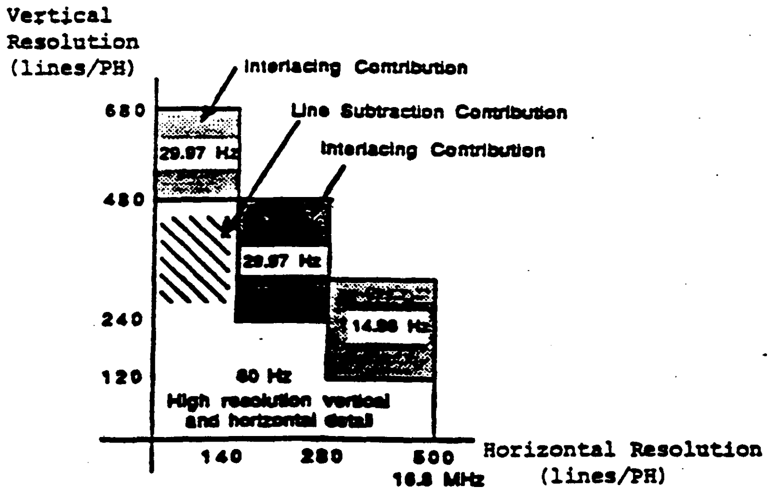
Figure 30 gives the two-dimensional spectral distribution when a 1050-line interlaced source is used. The vertical resolution is nominally 680 lines, and the diagonal resolution is reduced. The amount of data delivered for sound and conditional access information is the same as available when a 525-line progressive source is used.

The HDS-NA satellite signal encoder and decoder hardware have been constructed and the processed signal has been demonstrated at baseband. Satellite testing began in late 1989.



LUMINANCE (Y) SPECTRUM

Figure 29. HDS-NA satellite signal - spatial spectrum distribution
Source signal is progressive (1:1), 525-lines,
15:9 aspect ratio, 59.94 Hz frame rate.



LUMINANCE (Y) SPECTRUM

Figure 30. HDS-NA satellite signal - spatial spectrum distribution
Source signal is interlace (2:1), 1050-lines,
16:9 aspect ratio, 59.94 Hz field rate

2. HDB-MAC: an HDTV format designed for satellite transmission and emission

2.1 Introduction

The HDB-MAC system is primarily intended for conditional-access satellite transmissions, but will also pass through cable systems and other media, if required.

HDB-MAC employs a time-multiplex of luminance and chrominance to avoid cross-color and cross-luminance. The signal requires a converter which generates an NTSC output for display on NTSC receivers.

HDB-MAC employs a 525-line, 2:1 interlaced format for transmission allowing simple conversion to NTSC for non-HDTV receivers. (An equivalent system can also be defined for use in a 625-line environment.) HDTV decoders employ an adaptive field-store scan-converter to achieve a 525-line, sequential-scan display. Since HDTV sets will have to accommodate NTSC inputs, it is reasonable to assume that the interlaced/progressive scan-converter will be incorporated in all HDTV sets. This method achieves a vertical resolution of 480 lines per picture height (lines/ph) for static areas of the picture, and 320 lines/ph in moving areas.

HDB-MAC employs sub-Nyquist spectrum folding to trade diagonal resolution for increased horizontal resolution. The processing requires the use of line-memories (not field memories). This technique achieves a horizontal definition of 535 lines/ph for both static and dynamic areas of the picture. The baseband 6 dB bandwidth of the HDB-MAC signal is 10.7 MHz. Folded energy (on the diagonal) occurs only above 7 MHz, so that a simple (non-HDTV) decoder can remove it using a low-pass filter (see Figure 31).

The system allows for display in either 16:9 or 4:3 aspect ratio.(Non-HDTV decoders select a central 4:3 segment of the picture, under pan-scan control, and convert it to NTSC.

HDB-MAC has a line multiplex as shown in Figure 32. The data segments of the signal carry six digital audio channels, as well as text and data. The data multiplex and the conditional access/scrambling systems are identical to the B-MAC system described in Report 1073 and in the CCIR Special Publication "Specifications of transmission systems for the broadcasting-satellite service".

One of the major advantages of HDB-MAC is the low cost of the decoder. The use of 2-dimensional spectrum folding to increase horizontal definition requires only line-store signal processing. The total gate-count for this part of the receiver, including all other B-MAC functions (audio, text, data and conditional-access) is 450,000 gates.

The use of field-store scan-conversion to extend vertical resolution incurs a requirement for at least a single field-store in the TV set. But such a field-store will invariably be present in HDTV receivers to allow the set to accept non-HDTV, NTSC inputs.

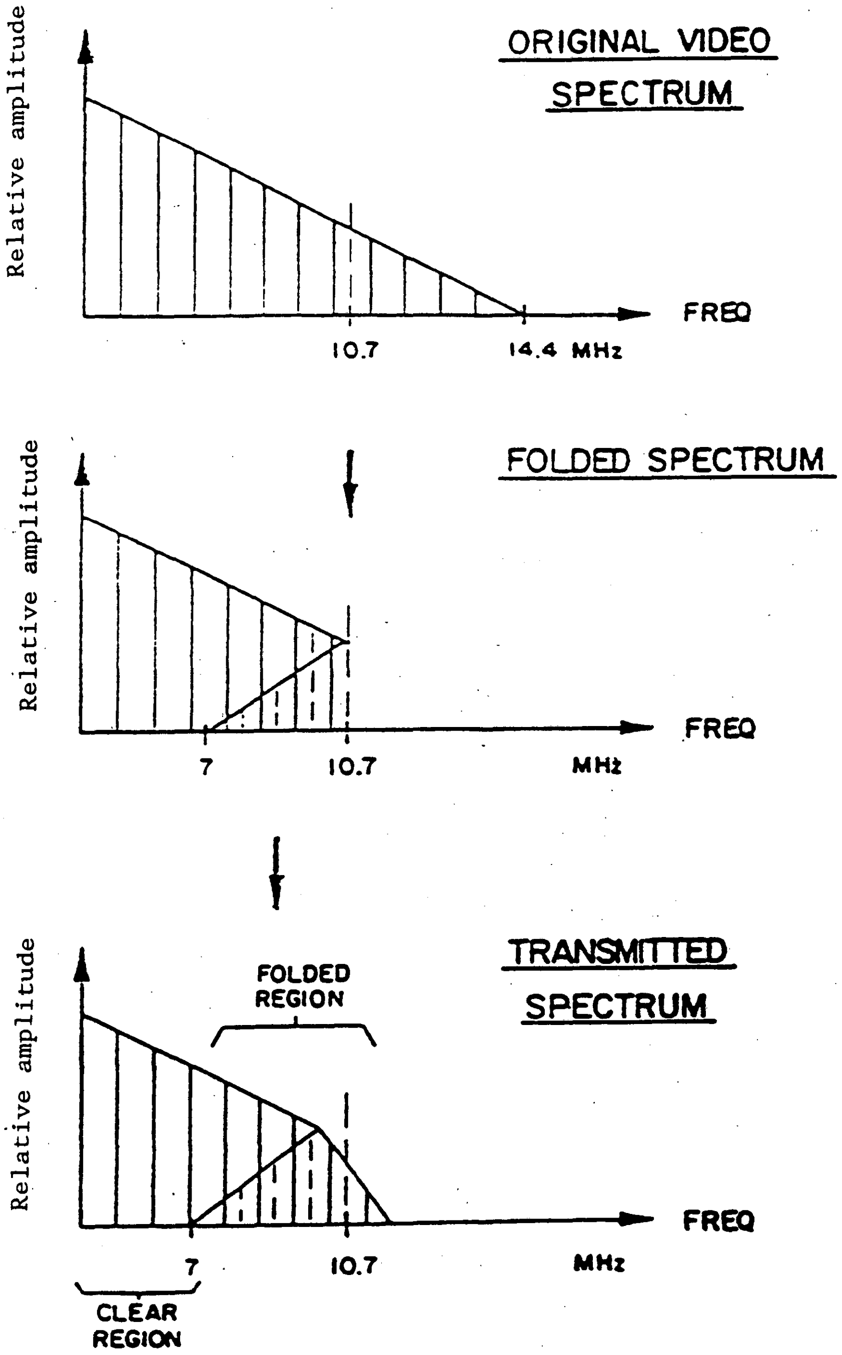
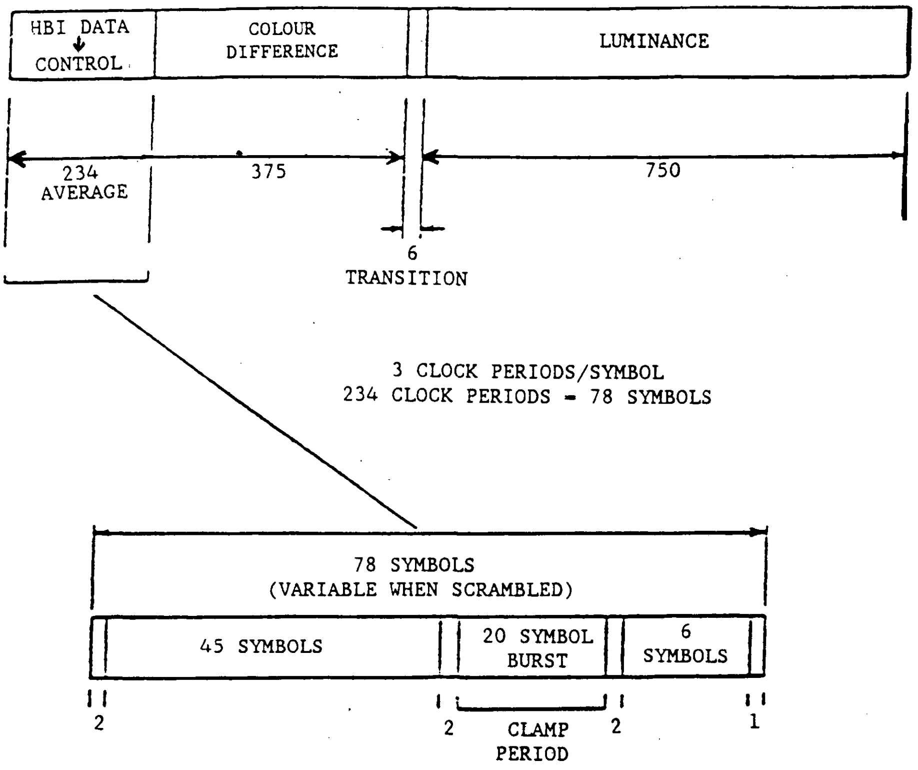


FIGURE 31

Spectrum folding

CLOCK PERIODS AT 13651_H



NOTES:

(a) IN AN UNSCRAMBLED LINE: THE NUMBER OF USEFUL DATA SYMBOLS IS 51.

(b) IN AN UNSCRAMBLED LINE: THE POSITION OF THE BURST IS AS SHOWN ABOVE.

(c) IN A SCRAMBLED LINE: THE NUMBER OF USEFUL DATA SYMBOLS MAY VARY IN THE RANGE 43 - 59.

(d) IN A SCRAMBLED LINE: THE BURST MAY BE POSITIONED PSEUDORANDOMLY AMONG THE USEFUL DATA SYMBOLS.

FIGURE 32

B-MAC line multiplex

The system allows for a wide range in the quality of the decoder and the display standard. CRTs and projection systems may operate with the following display standards:

4:3	**525-line**	**2:1 interlace**
4:3	**525-line**	**1:1 progressive**
16:9	**525-line**	**2:1 interlace**
16:9	**525-line**	**1:1 progressive.**

The HDB-MAC system is based on, and is an expansion of, the fully developed, completely tested, operational B-MAC system. The B-MAC system has been selected for domestic use in Australia, and over 100 satellite channels are now operating world-wide.

The HDB-MAC system has been demonstrated in the United States at both the 1989 Conference of the National Association of Broadcasters and the 1989 Conference of the National Cable Television Association. An experimental HDTV network using HDB-MAC was scheduled to begin operation in North America in the fall of 1989.

2.2 System characteristics

2.2.1 Compatibility

HDB-MAC requires a satellite transponder having a bandwidth of either 24 or 27 MHz.

HDB-MAC generates an output with the following characteristics:

- 525-line sequential scan;
- Separate RGB components;
- 18 MHz luminance bandwidth;
- 16:9 aspect ratio.

A number of advanced television formats for terrestrial and cable systems require an input signal with these characteristics. HDB-MAC may therefore be used as a feeder signal, or for direct reception.

2.2.2 Luminance and chrominance spatial/temporal resolution

The static and dynamic luminance response is shown in Figure 33. Static horizontal resolution is 535 lines/ph. Static vertical resolution is 480 lines.

Dynamic horizontal resolution is unchanged at 535 lines/ph. Dynamic vertical resolution is 320 lines.

The chrominance response is shown in Figure 34. Both the static and dynamic chrominance horizontal resolution is 260 lines. The static chrominance vertical resolution is 120 lines. There is no loss of diagonal chrominance resolution.

2.2.3 Chromaticity/colorimetry characteristics

The color-difference axes are R-Y and B-Y. Primary colors are as defined for NTSC.

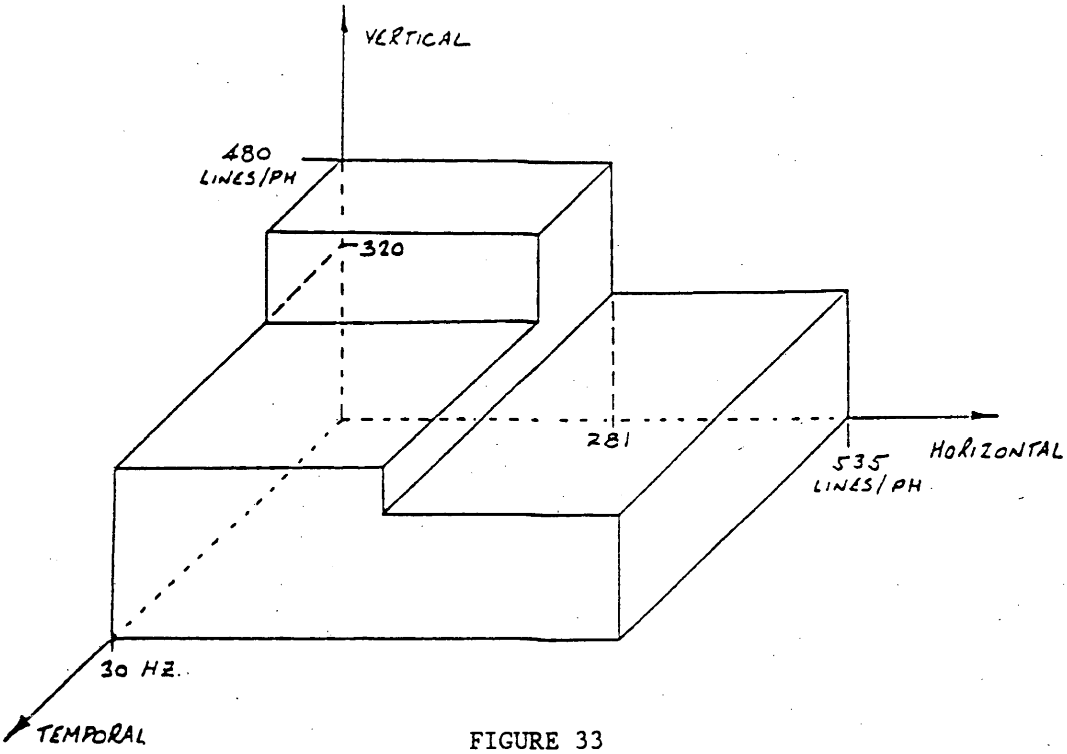


FIGURE 33

HDB-MAC luminance resolution (static and dynamic)

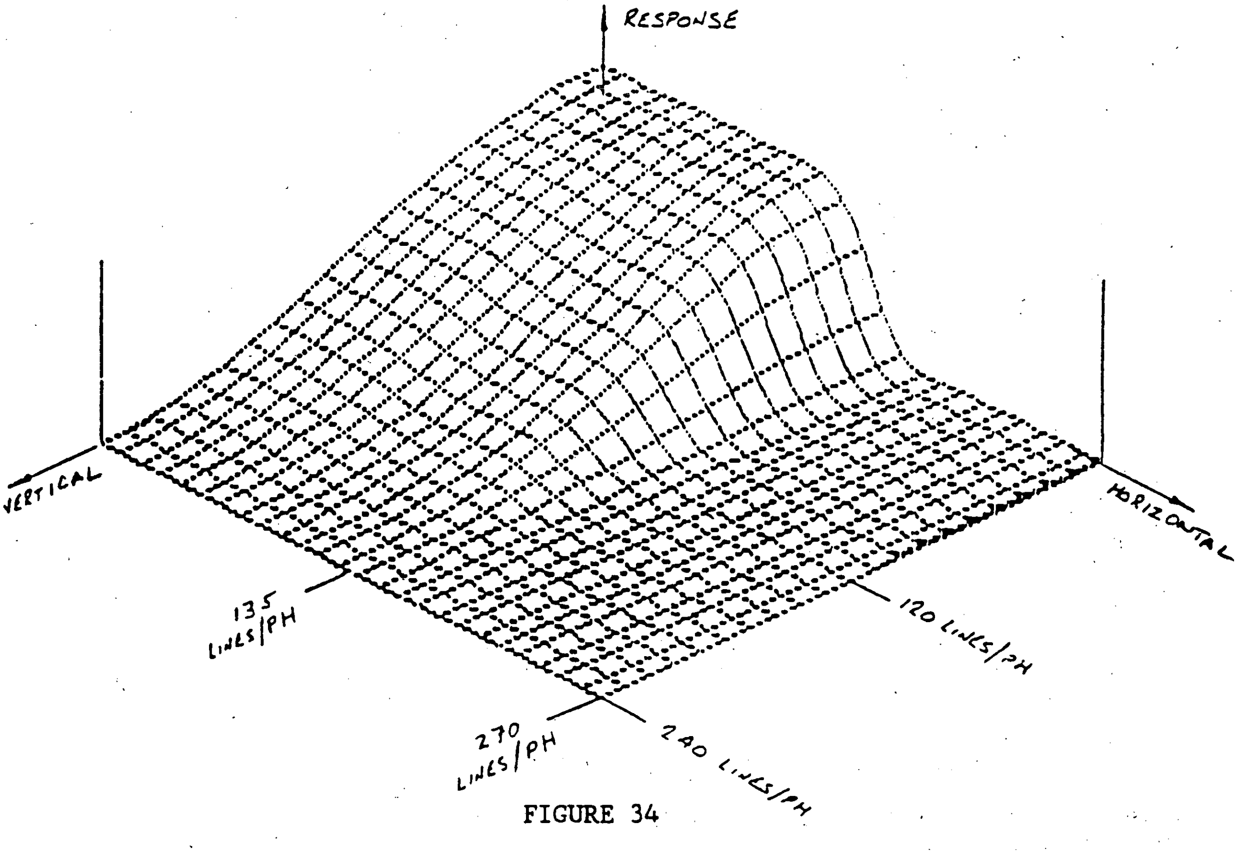


FIGURE 34

HDB-MAC chrominance resolution (static and dynamic)

2.2.4 Artifacts

HDB-MAC has no cross-color, cross-luminance or line-structure artifacts.

Motion detection is required in the luminance scan conversion between 525-line interlace and 525-line progressive. The presence and severity of artifacts will depend on the quality of the adaptive signal processing, which will improve as technology improves in coming years.

2.2.5 Aspect ratio, display size and viewing angle

A choice of the aspect ratios 16:9 or 4:3 can be made on a programme-by-programme basis. (A central 4:3 segment of the picture is converted to NTSC for viewing on non-HDTV receivers.)

HDB-MAC is designed to be viewed at 3 times Picture Height of a 16:9 display (that is, with an included viewing angle of 33 degrees).

2.2.6 Baseband video bandwidth and FM deviation

The transmission bandwidth is 10.7 MHz (-6 db bandwidth), while the display bandwidth for luminance is 18 MHz and 5 MHz for chrominance.

The amount of deviation and the pre-emphasis characteristic are still under investigation. Non-standard circuits will be required for both clamping and de-emphasis.

2.2.7 Audio and ancillary signal capabilities and characteristics

HDB-MAC carries six digital audio channels of 15 kHz bandwidth, using the Dolby Adaptive Delta Modulation (ADM) system described in Report 953. This ADM system provides an instantaneous signal-to-noise ratio (at 1 kHz) greater than 58 dB, and a dynamic range in excess of 90 dB.

Each channel is encrypted with a separate pseudo-random bit sequence derived from a 56-bit key, updated at intervals of 0.25 seconds.

Since there is no connection between the separate digital channels, stereo separation depends only on audio equipment quality.

In addition to the six digital audio channels, the system carries:

63 kbit/s utility data channel
Up to 600 rows per second of text data
Conditional-access data channel

3. SC-HDTV: spectrum compatible HDTV

3.1 Introduction

The basis of the spectrum compatible HDTV system, SC-HDTV, is the choice of scanning parameters having a simple relationship with those of conventional NTSC (system M) for more efficient video encoding and transmission processing of video. Application of the principles of spectrum compatible HDTV to FM satellite emission results in improved received signal-to-noise ratio. The FM spectrum of SC-HDTV is also much more symmetrical about the carrier frequency than conventional satellite video signals due to the removal and digital encoding of DC and low video frequencies. This makes possible a more efficient receiver design with narrower filters and better threshold performance.

3.2 Scanning

The vertical and horizontal scan rates have been chosen to be equal to, or a multiple of, the NTSC rates in order to avoid interference with NTSC when the baseband format of this system is used for terrestrial broadcasting. These rates are 787.5 lines per frame, progressively scanned, 59.94 frames per second (fps). 787.5 corresponds to 47,203 lines per second which is three times the NTSC horizontal line rate. (PAL and SECAM countries could employ this technique by chosing a 937.5 line 50 fps transmission scan rate.)

3.3 Video encoding

High definition video encoding compresses the 28.9 MHz R, G, B source into transmission fields of video components as shown in Figure 35. The encoding process is designed for redundancy reduction to match human vision. Some low frequency components of one-third of the source bandwidth (9.6 MHz) are transmitted at full frame rate of 59.94 fps for good motion rendition. This is component LL in the spatial-temporal resolution diagram of Figure 36. (The following resolution symbols are used in Figure 36: L/PH = lines/picture height and L/PW = lines/picture width.) The remaining luminance components (LD, MH, HH) are transmitted at lower rates (11.988 Hz) but with good detail for static images.

Color difference components R-Y and B-Y (or C1 and C2) are also transmitted at the lower rate of 11.988 Hz. Overall, the incoming video is separated into six components, each of one-third of the source bandwidth. The last step in the video encoding consists of time expansion to limit the final bandwidth of each component to 3 MHz.

The six video components are time-multiplexed into two 3 MHz signals. A full set of the six video components is transmitted every five lines, as illustrated in Figure 37.

3.4 Transmission processing

Transmission encoding steps shown in Figure 38 are performed to minimize peak and average power and minimize mutual interference with NTSC for AM transmission and to minimize peak and average deviation for FM transmission. The first step limits the power of the SC-HDTV signal to the video content of the signal by eliminating conventional sync signals, carrier and subcarriers. The motivation for the first step of Figure 38 is more even distribution of average power over the 6 MHz channel. Most of the power of a conventional signal is

HD ENCODING FOR TRANSMISSION

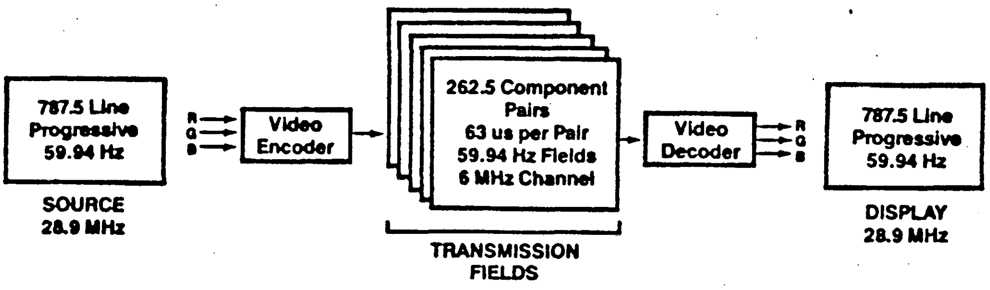


FIGURE 35

SPATIAL - TEMPORAL RESOLUTION

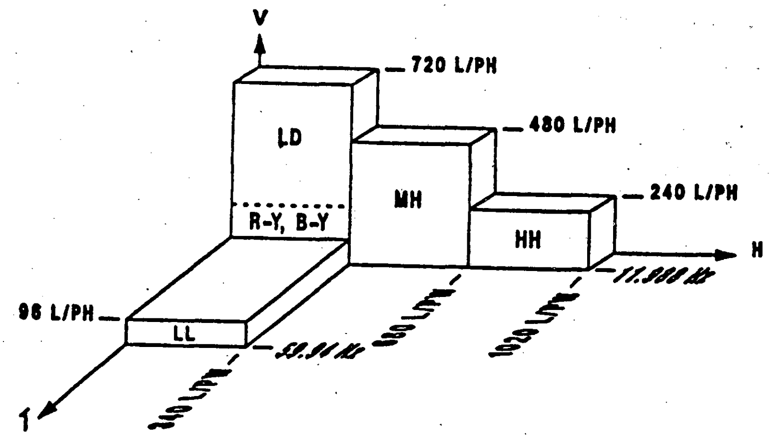


FIGURE 36

MODULATION ON IN-PHASE AND QUADRATURE CHANNELS

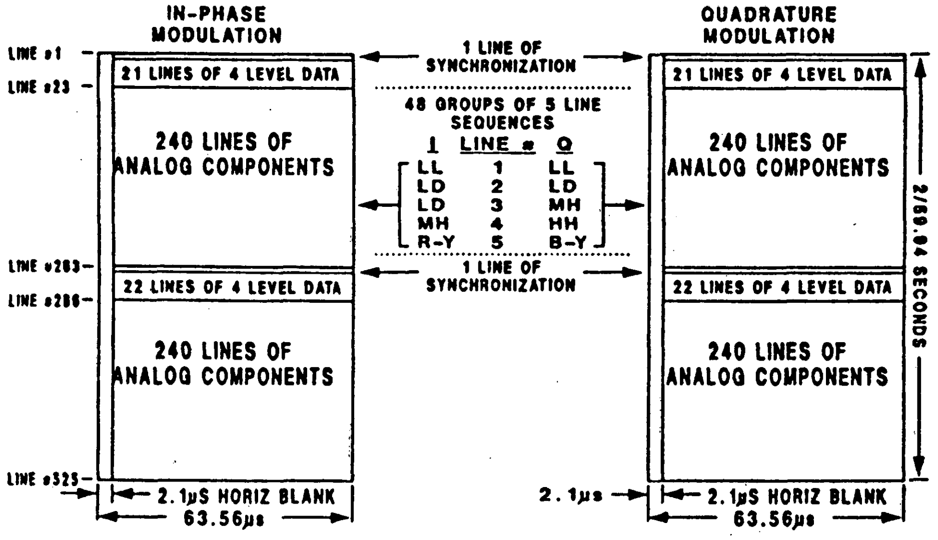
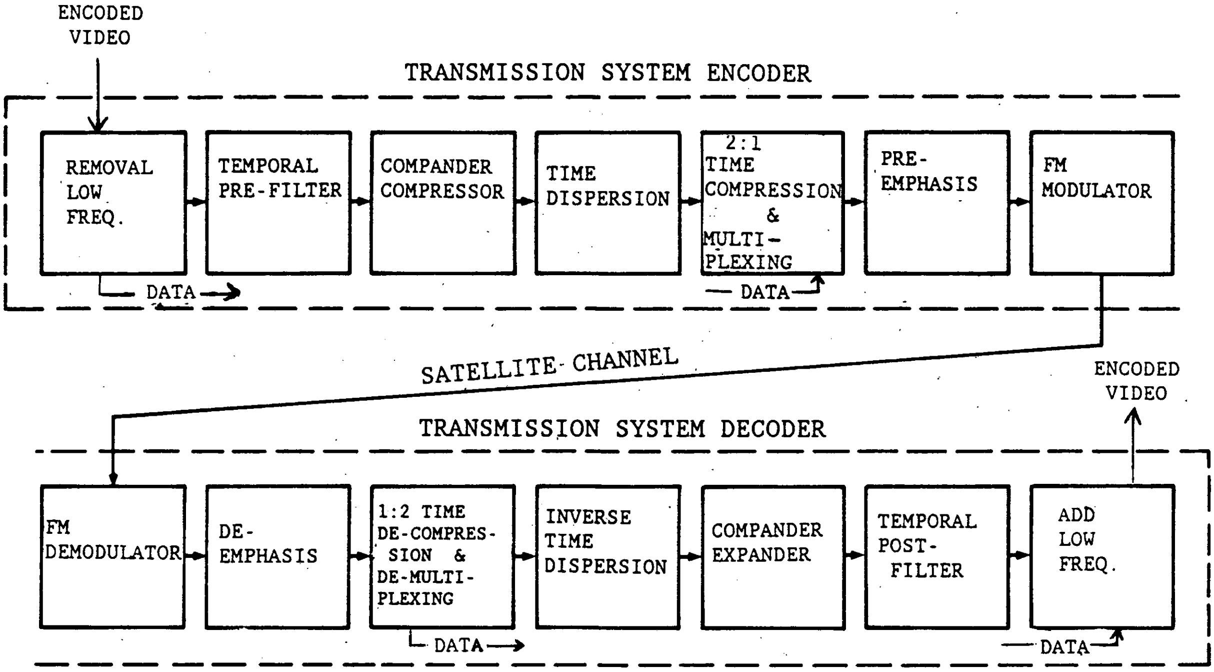


FIGURE 37



SC-HDTV system
FIGURE 38

concentrated at D.C. and low-frequency video. By subtracting D.C. and the lowest 200 kHz of video and transmitting these signals in digital form during the vertical blanking interval, the average power is reduced significantly.

The digital modulation is 16-QAM of 5.35 M symbol/s. The audio channels associated with the SC-HDTV signal are in digital format and are transmitted as part of the same 16-QAM signal.

Another significant step in power/deviation reduction is temporal pre-filtering (frame combing) and post filtering as illustrated in Figures 39 and 40. Rather than transmitting the actual signal value, the difference between the present frame and 75% of the previous frame is transmitted. This produces a 12 dB signal reduction on static images.

The next step in power reduction is instantaneous compression (Figure 41), included to further reduce noise visibility and peak signals. This is not always guaranteed by average power reduction.

Compression is followed by time dispersion (Figure 42) which is dimensioned to contribute to peak power/deviation reduction as well.

3.5 Modulation

For AM transmission the two 3 MHz signals, I and Q, modulate an in-phase and a quadrature carrier in the center of a conventional 6 MHz band by suppressed carrier-double sideband-amplitude modulation.

The transcoding process for FM satellite transmission includes time compression and time multiplexing processes whereby the two 3 MHz signals are multiplexed into one 6 MHz component suitable for FM modulation. Figure 43 shows the timing relationships.

The single 6 MHz SC-HDTV transmission signal has no D.C. and no low-frequency components resulting in an FM spectrum that is narrower and more symmetrical than an NTSC FM spectrum as shown in Figure 44.

Frame synchronization is achieved by a clock signal, transmitted during part of the vertical interval. A small horizontal reference pulse is transmitted between two lines. The data signal also includes bits to help motion rendition interpolation. The data signal occupies alternately 21 and 22 lines per frame during the vertical blanking interval.

3.6 The satellite delivery system

Regardless of whether the satellite link is used for network or cable feed or for home delivery of TV programs, the SC-HDTV signal format has two important advantages over the NTSC format and over NTSC-based HDTV systems.

As a first advantage, DC and low video frequencies are absent which results in a narrower and more symmetrical spectrum. Increased deviation within a given transponder bandwidth is possible which results in less distortion and less noise and extends the threshold. Secondly, FM noise addition is less noticeable for SC-HDTV than for NTSC. The portion of the signal farthest removed for the FM carrier is most noise contaminated. In NTSC it is the color that suffers but in SC-HDTV the signal farthest removed from the carrier consists mainly of moving edges on which interference and noise are less noticeable. This difference becomes particularly significant at FM threshold.

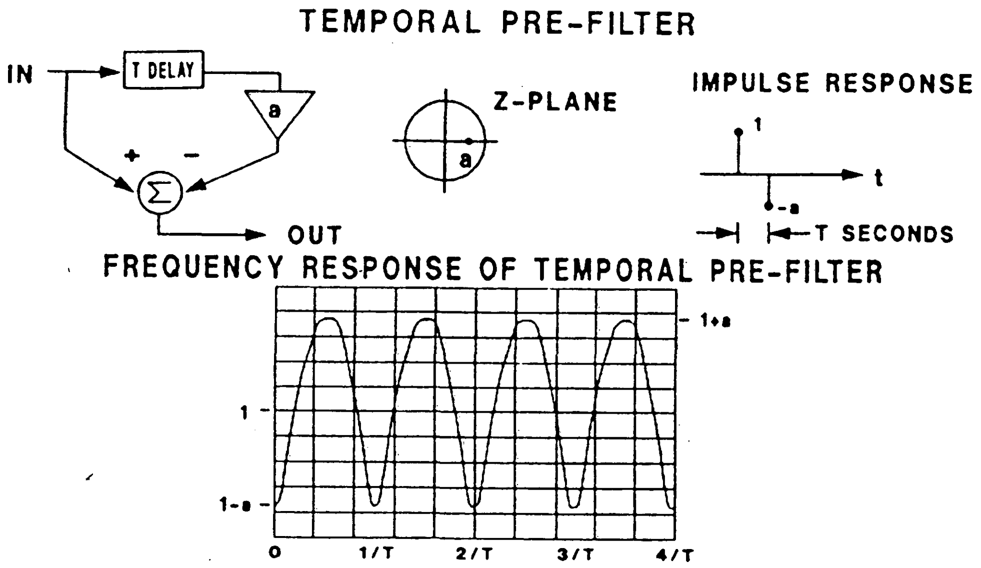


FIGURE 39

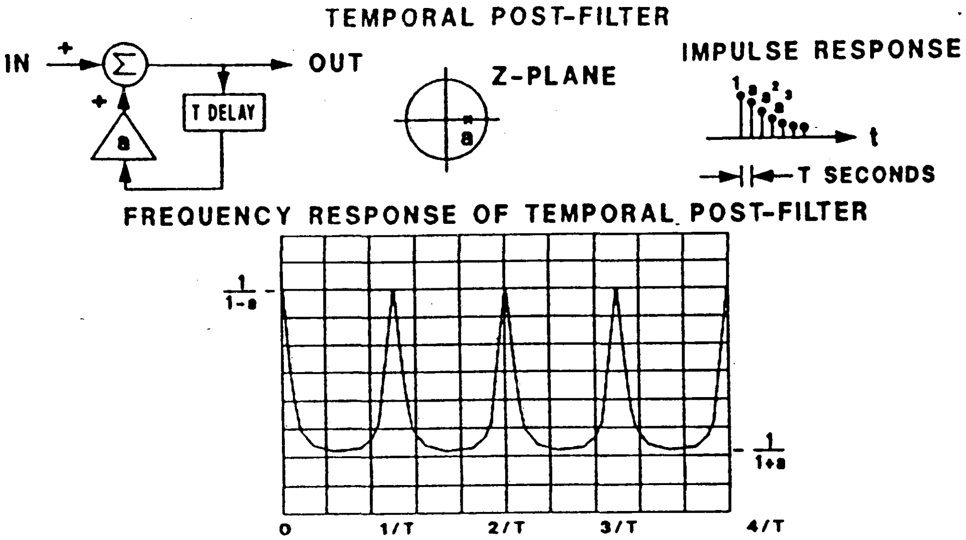


FIGURE 40

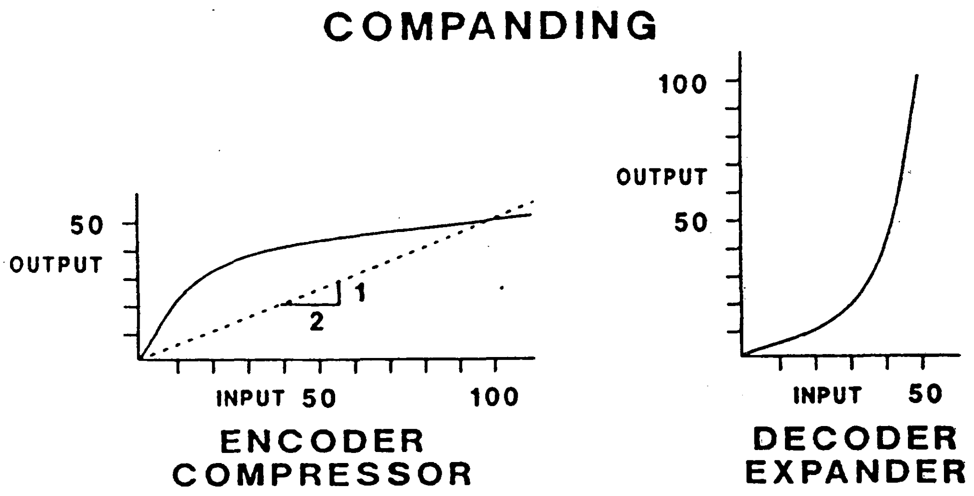


FIGURE 41

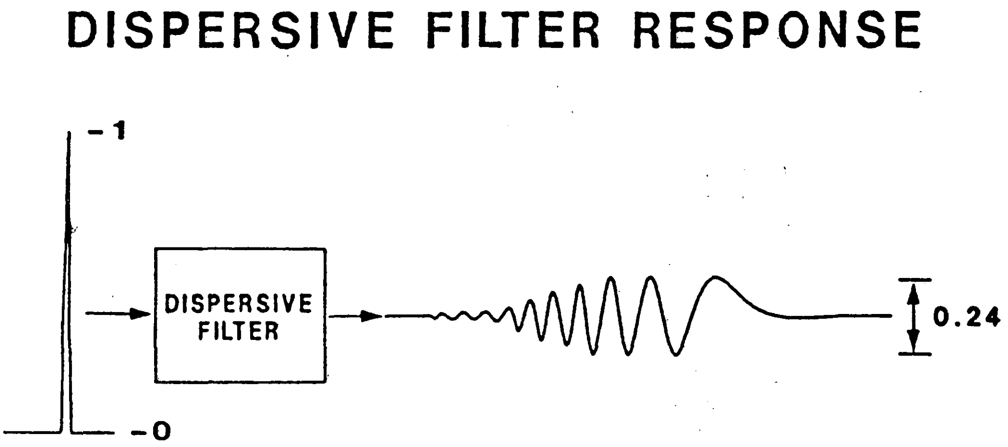


FIGURE 42

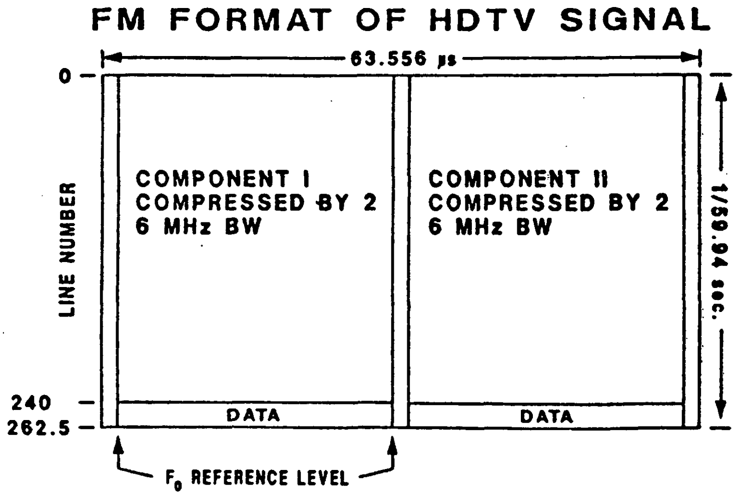


FIGURE 43

The received signal is the 6 MHz time-multiplexed version of the I and Q components. The video baseband input for the SC-HDTV consumer type receiver can be designed for separate I and Q inputs or for combined 6 MHz input. In the latter case the time expander and demultiplexer are made an integral part of the receiver. The same can serve the VCR output signal.

3.7 Encryption

The delivery of services requiring scrambling for satellite and cable delivery can be conveniently accomplished by encryption of the data signal. Since the analog video is also digitally processed, this part of the transmission signal is readily encryptable as well. Digital encryption, when properly decrypted, has the advantage of retaining signal quality. Repeated encryption/decryption cycles are possible without loss of quality. The conditional access box illustrated in Figure 45 performs decryption.

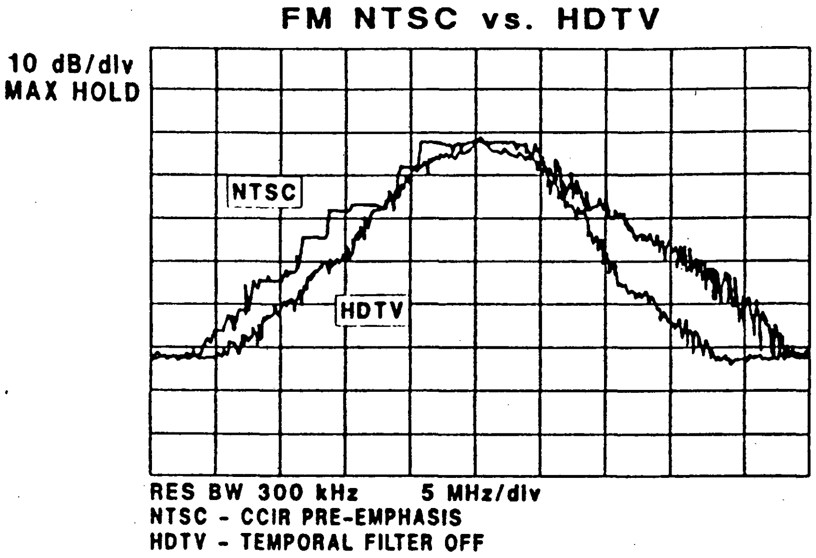


FIGURE 44

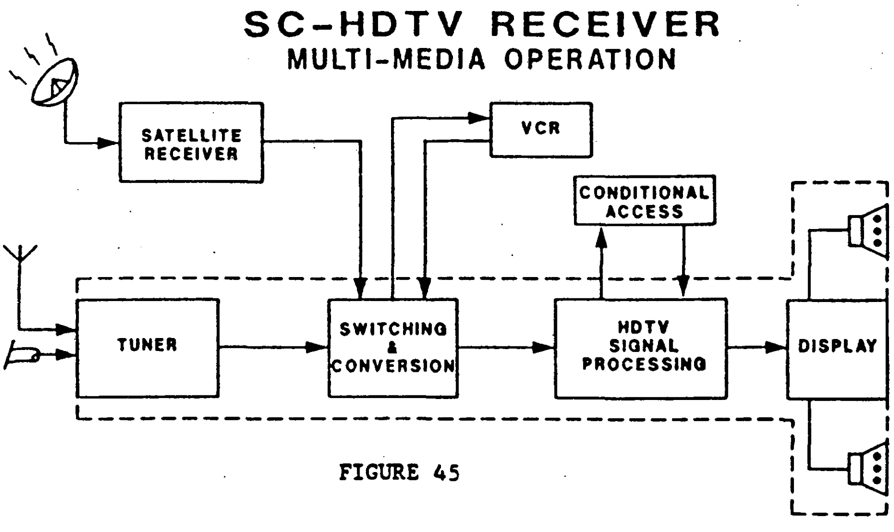


FIGURE 45

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ANNEX V

HIGH-DEFINITION TELEVISION TRANSMISSION EXPERIMENTS USING THE MUSE SYSTEM

1. Introduction

FM transmission experiments of the MUSE signal have been carried out. Results of the experiments are described in this annex.

2. First experiment in 1986 using a 100 W broadcasting satellite in the 12 GHz band

2.1 Experiment system

Figure 46 illustrates the block diagram of the experiment. The broadcasting satellite BS-2 is able to broadcast on the WARC-BS satellite channel in the 12 GHz band. Modulation parameters for MUSE are shown in Table XIX of Annex II. Experimental equipment including both transmitter and receiver were installed at the NHK Broadcasting Center in Tokyo and satellite channel No. 11 was used. A commercially available converter with a noise figure of 2.1 dB was used for the experiment.

The link budget at the edge of coverage area with rain attenuation of 2 dB not exceeded for 99% of the worst month was calculated as shown in Table XXIII. In this case, a G/T of 16 dB would be required for reception at a carrier-to-noise ratio of 17 dB corresponding approximately to the perception limit of noise impairment (see section 10.1.1 of the body of the present Report).

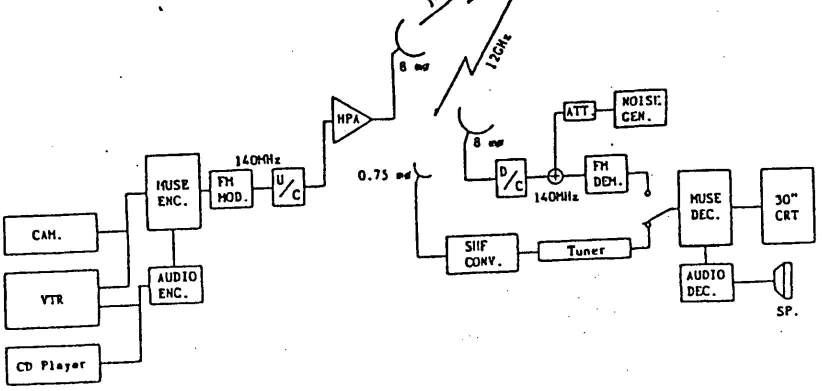

FIGURE 46

Schematic block diagram of experimental transmission of MUSE-encoded HDTV signal via broadcasting satellite BS-2

2.2. Received C/N and picture quality

Using an antenna of 0.75 m diameter the received C/N was 17.8 dB. The S/N of the demodulated FM signal (with a bandwidth of 8.1 MHz) was 39.5 dB including the emphasis improvement of 9.5 dB.

It was found that the noise impairment of the received picture was almost equal to the limit of perception even when an antenna of 0.75 m in diameter and a receiver NF of 3 dB were used under clear weather conditions in Tokyo.

3. Experiments and demonstrations in 1987 and afterwards

The experiments were carried out in seven rounds from 1987 to 1988, using the BS-2b broadcasting satellite.

Eleven Japanese television receiver manufacturers and NHK took part in the experiments. The MUSE signals were received and measured in Tokyo, Osaka, Nagoya, and their vicinities.

All the receivers produced by the manufacturers participating in the experiment showed good reception capability of MUSE signals. The signals were received with little aliasing and little ringing. Tests for sound mode switching controlled with codes also went well.

The tests produced received C/N ratios of 17 to 21 dB under clear weather, which were also corresponding to, or better than, the limit of perception for noise impairment. The S/N ratios of baseband signal demodulated with the tuners were almost coincident with theoretical values (C/N + 11.9 dB).

Bit error ratios of digital sound/data signals were 10^{-3} or better at a C/N of 10 dB. They were measured under a low C/N condition deliberately provided with an attenuator inserted after the receiving antenna. No extreme picture degradation was observed with this C/N condition of 10 dB.

Picture quality was evaluated as better than grade 4 in the 5-grade scale using test materials extracted from HDTV programmes and still pictures. The sound was evaluated as grade 5 for all cases.

The same modulation parameters mentioned above were used in this experiment and were confirmed as adequate for practical use. It was also confirmed that the DBS tuner developed for the reception of conventional television could be used for MUSE with minor modifications.

Further demonstrations took place in Japan in 1987 using the BS-2b on a time-sharing basis with the transmissions of conventional television broadcasting. Another demonstration was conducted in Canada and the United States in October 1987 using Anik-C and RCA-K1 communication satellites delivering the signal to seven cities.

Among other programmes broadcast in HDTV, the most attractive event was the Seoul Olympic Games in 1988. At opening and closing ceremonies, live satellite broadcasting using BS-2b was carried out with HDTV programmes relayed through the Intelsat to Japan from Seoul, Korea. Other sporting events were recorded on video tape and also broadcast in HDTV through the BS-2b satellite the next day. The total amount of broadcasting was 73 hours 20 minutes in 17 days.

The broadcasts were received with parabolic antennas of 75 cm to 160 cm in diameter depending on the location, and pictures were demonstrated at 81 locations throughout Japan in department stores or public facilities by using 205 various display equipments. About 3.7 million people in totalt observed HDTV, and were impressed with the excitement of the games conveyed by HDTV.

Since June 1989 regular experimental HDTV broadcasting has been started. For this purpose an HDTV programme production facility has been implemented which provides production capablilities needed for broadcasting of one hour each day. The 1125/60/2:1 HDTV system is used and standards conversions between HDTV and conventional television systems are incorporated. This equipment has been implemented by NHK over several years based on a long-term schedule [CCIR, 1986-90a].

A new instrument for checking C/N ratios has been developed in which the noise power is measured in a narrow band slightly outside the channel. This instrument can be used with any television system including HDTV.

Another instrument has been developed to measure audio bit error ratio during broadcasting. It has two modes of measurement. One utilizes the frame synchronizing code, the other the error-correction code. The former counts error bits of the frame synchronizing code of a 16-bit fixed pattern which is transmitted during an interval of one millisecond. The latter counts error bits detected with the error-correction code in each audio data block which is transmitter at a rate of 16 blocks/millisecond [CCIR, 1986-90b].

Regular experimental HDTV broadcasting for one hour a day has been done using BS-2b since June 1989.

TABLE XXIII

Link budget for MUSE transmission of 1123/60 system

Frequency	(GHz)	12
Type of modulation		FM
Equivalent RF bandwidth	(MHz)	27
C/N (exceeded for 99% of the worst month)	(dB)	17.0
S/N unweighted	(dB)	39.0
Figure of merit G/T	(dB/K)	16.0
Required power flum-density (edge of beam - exceeded for 99% of the worst month)	(dBW/m²)	-110.5
Free-space attenuation	(dB)	205.6
Rain attenuation	(dB)	2.0
Atmospheric absorption	(dB)	0.1
Feeder-link noise contribution	(dB)	0.3
Edge of coverage of area factor	(dB)	3.0
Required e.f.r.p. from satellite (beam centre)	(dBW)	57.7
Satellite antenna beamwidth (-3 dB)	(degrees)	1.3 x 1.8
Satellite antenna gain (beam centre)	(dBi)	40.0
Losses (feeder, filters, etc.)	(dB)	2.3
Required TWTA power	(dBW)	20.0
	(W)	100

4. Conclusion

Satellite transmission experiments of the MUSE signal were carried out on a single 12 GHz WARC-BS channel by using the operational Japanese broadcasting satellite BS-2 with an output power of 100 W. Based on the results of these experiments, a received C/N of around 17 dB is obtainable for 99% of the worst month in nearly all of the main islands of Japan using a receiving antenna of 0.7-0.9 m in diameter. It has been confirmed that a MUSE signal can be received with a sufficiently good S/N by using a single 12 GHz WARC-BS channel.

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ANNEX VI

HIGH-DEFINITION TELEVISION TRANSMISSION EXPERIMENTS USING THE HD-MAC SYSTEM

1. Introduction

FM transmission experiments of the HD-MAC signal have been carried out using the French broadcasting satellite TDF 1. The configuration of these experiments is described in this annex.

2. Experimental system

These experiments were conducted in December 1988. Fig. 47 illustrates the block diagram of the experiment. The D2-HDMAC/packet signal was sent to the TDF-1 earth station through a FM microwave link with 14 hops. The signal was received by a commercially available outdoor unit with a 55 cm parabolic antenna. The noise figure of the SHF converter was equal to around 2 dB.

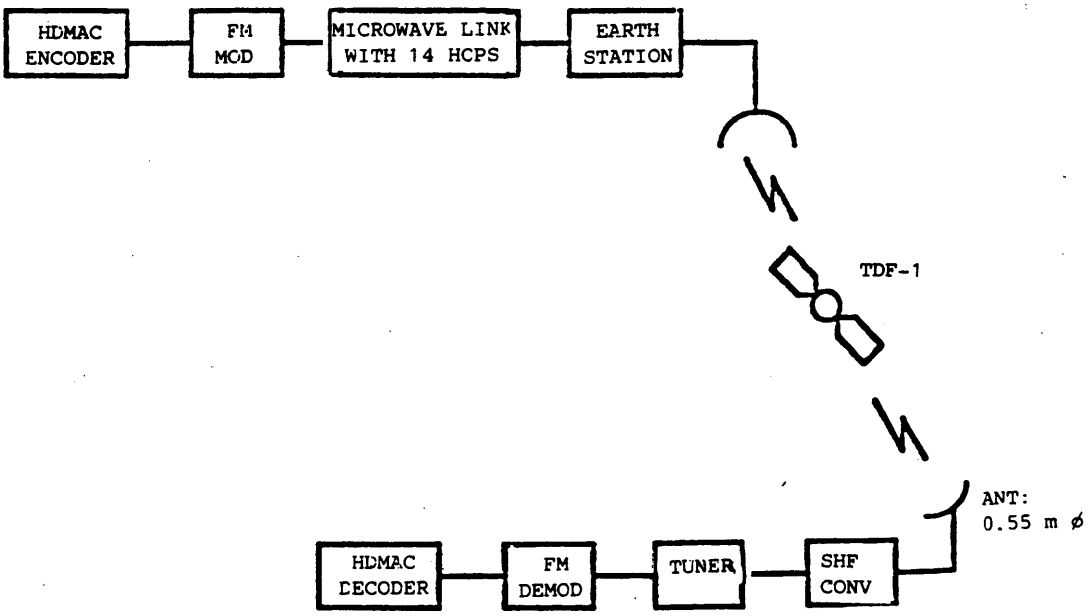

FIGURE 47

Schematic block diagram of experimental transmission of HDMAC signal via the DSB satellite TDF-1

Table XXIV shows the modulation parameters used for HD-MAC transmission through an FM WARC BS-77 channel. The basic parameters are the same as for MAC signals in order to ensure the compatibility with conventional MAC decoders. One extra process is applied to the HD-MAC samples, namely non-linear pre-emphasis.

Table XXIV: Modulation parameters for HD-MAC

Normal vision signal bandwidth:	10.125 MHz at -3 dB
Normal channel bandwidth:	27 MHz
Modulation:	FM
Polarity of frequency modulation:	positive
DC component:	preserved
Pre-emphasis characteristics:	non-linear process applied only to HD-MAC samples and linear applied to all the multiplex (same as for MAC)
Frequency deviation:	13.5 MHz at the cross-over frequency of the linear pre-emphasis network (1.37 MHz)

Table XXV shows the main parameters of this experimental transmission

Table XXV: Parameters of the experimental transmission with TDF-1.

Channel number:	17
Channel frequency:	12034.36 MHz
EIRP towards the receiving station:	62 dBW
Rain attenuation:	0
Free-space attenuation (dB):	205.7
Receiving equipment (dB):	11.0 dB/K
Calculated C/N:	21.6 dB
Measured C/N:	21 dB

3. Results of transmission experiments

The measured C/N was 21 dB in a 27 MHz bandwidth, which corresponds to an impairment grade better than 4.5.

Some distortions were noticed due to the group delay in the microwave link and were compensated for by adjusting the sampling time in the HD-MAC decoder.

4. Conclusion

Satellite transmission experiments of the HD-MAC signals were carried out on a single 12 GHz WARC-BS channel by using the operational french braodcasting satellite TDF 1 with an output power of 230 W.

A received C/N of 17 dB is obtainable for 99% of the worst month through out the service area with a 55 cm receiving antenna. Thus an HD-MAC signal of good quality can be received with a small antenna using a 12 GHz WARC BS-77 channel.

REPORT 955-2*

SATELLITE SOUND BROADCASTING WITH PORTABLE RECEIVERS AND RECEIVERS IN AUTOMOBILES

(Question 2/10 and 11, Study Programmes 2B/10 and 11, 2K/10 and 11)

(1982-1986-1990)

This report contains:

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* This Report should be brought to the attention of Study Groups 5, 6 and 8.

1. Introduction

In Resolution No. 505, the WARC-79 invited the CCIR to continue and expedite its studies on the technical characteristics of a satellite sound-broadcasting system for individual reception by portable and automobile receivers in the frequency range 500 to 2000 MHz. ← WARC-ORB-85 considered this matter and issued Recommendation No. 2 calling for further studies on satellite sound broadcasting.

WARC ORB-88 also considered this matter and issued Resolution 520 which extended the upper end of the frequency range of interest to 3 000 MHz and invited the CCIR to conduct technical studies on:

1) the impact of choice of frequency on system parameters, especially satellite power requirements, the characteristics of transmitting and receiving antennas, and on propagation characteristics;

2) the bandwidth required by the service; and

3) the technical aspects of sharing between services with special consideration to geographical sharing.

Several administrations, the EBU and the European Space Agency, had already undertaken studies on such a system under Study Programme 2K/10 and 11, and a summary of those contributions appeared in the SPM Report (1978). Since then, experiments were made in France and ~~some~~ studies were also undertaken in a number of other countries. During the period 1986-90 new studies were undertaken in the United States of America and within the EBU, mainly in the area of advanced digital techniques for UHF satellite sound-broadcasting.

On the basis of all these studies a technical report was prepared by the CCIR for submission to WARC ORB-88 [CCIR, 1986-90a]. This report presents clear evidence that the provision of a satellite sound-broadcasting service to vehicle and portable receivers is feasible with the current level of technology.

In the present report, different analogue and digital techniques are considered with their relevant link budgets showing some trade-off between service quality, service continuity, transmitted power and receiver complexity.

The AM sound satellite broadcasting systems intended for Band 7 were the subject of preliminary studies in the United States, the United Kingdom and the USSR.

2. Systems for band 9

2.1 *Quality objectives and service availability*

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 [CCIR, 1978-82a and b] a high quality FM sound channel was assumed as a reference. For the cases considered below, the test-tone to noise power ratio at the output of receiver ranged between 40 and 57 dB in a 15 kHz baseband bandwidth. The need for FM sound channels of such quality needs further study taking into account economic factors.

In the case of an FM model, the quality objective at the edge of the coverage area is taken as a subjective quality corresponding to grade 3 on the 5 point CCIR quality scale. This corresponds to a weighted signal-to-noise ratio (S/N) of 40 dB. As a second condition to be met, the carrier-to-noise ratio (C/N) needs to be kept above the FM threshold (10 dB). The interference protection ratios should be high enough to ensure that the system noise is the factor controlling the system availability.

In the case of a digital model, the quality objective at the edge of the coverage area is equivalent to a subjective quality of grade 4 on the 5 point CCIR quality scale. This will translate into an allowed bit error-ratio depending on the type of source coding used and on the level of protection against errors, and will translate into a required carrier-to-noise ratio depending on the channel coding used. In this case, interference is considered as additive noise and the protection ratios can be set such that the noise contribution from the co-channel interference is 1 dB and each adjacent channel contributes 0.5 dB.

For the advanced digital systems the objective is to provide high quality stereophonic service with fixed, portable and mobile receivers.

2.2 *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) to provide national coverage, and designed for reception with low-cost portable domestic receivers, receivers installed in automobiles and permanently installed receivers. In the first two cases, the receiving antenna would be small and would have limited directivity.

Three types of systems have been studied to date. The first uses frequency modulation with parameters compatible with terrestrial FM broadcasting, this first type includes also the companded FM system which would not be compatible with present FM receivers. The second type assumes simple digital modulation. The third type is also digital, but it uses a series of advanced techniques to reduce the bit-rate and, above all, to guarantee reception in the presence of fading caused by multi-path propagation.

2.2.1 FM system

The FM model would enable monophonic reception in the case of portable and mobile receivers using small antennas with limited directivity, and stereophonic reception in the case of permanent installations where obstructions can be minimized and larger antennas can be used. In such a case, the receiver could be identical to those available on the current market, with a simple addition (or exchange) of the freqeuncy converter at the input stage.

The same carrier deviation and the same pre-emphasis are assumed as well as the same stareophonic multiplex. Preliminary analyses tend to show that these modulation parameters are close to optimum in terms of minimizing the required satellite power and optimizing the spectrum usage.

A number of administrations attach great importance to the use of existing FM receivers for the broadcasting-satellite service with the possibility of a quality similar to that offered by terrestrial VHF/FM services.

Some modifications to the parameters could offer advantages. By way of example, a system is shown that has 10 kHz audio bandwidth and uses companding to permit a reduction of the deviation.

2.2.2 Simple digital system

The second modulation technique assumes a digital source coding similar to one of the systems suggested in Report 953 for a near-instantaneous companded 15 kHz high quality monophonic sound channel. Error protection is provided on the range code and error concealment on samples resulting in a total bit rate of 338 kbit/s. A channel coding in the family of 4-PSK with differential demodulation (e.g. DMSK, 2-4 PSK, TFM . . .) was assumed with the following characteristics in mind: spectrum efficient coding, ruggedness against channel non-linearity and demodulator simplicity for low cost implementation with minimum margin with respect to the theoretical performance. The minimum level of signal quality ($Q = 4$) is found to be achievable at a bit error ratio of 10^{-3} with a channel bandwidth equivalent to the bit rate and with a C/N of 9 dB including the implementation margin (see Annex I of Report 632).

An alternative to 4-PSK which has similar spectral characteristics, but which may offer the possibility of more economic receivers, is VSB/2-PSK [Pommier and Veillard, 1979].

In the case of simple digital modulation, the model has been based on monophony. Stereophony would require a second channel or a doubling of the bit rate but stereophonic reception would then be possible in the same reception conditions as the monophonic reception. In addition, any digital system also has a large flexibility to accommodate different types of facilities such as the number and quality of channels and data broadcasting.

Report 953 also describes a source coding method based on adaptive delta modulation which may allow adequate audio quality to be obtained at a somewhat lower bit rate.

Current developments in digital sound and data systems indicate that they are now becoming economically attractive to the mass consumer market and the inherent flexibility of signal options which may be readily built into these systems may make them become more attractive than FM systems.

2.2.3 Advanced digital systems

Advanced digital systems can overcome the problems caused by obstruction effects and the presence of multipath propagation which results from specular or diffuse reflections. This occurs on roads in rural areas where the path passes through foliage and in urban areas where there are numerous obstacles. When the fading has Rayleigh distribution (see Annex II) and is frequency-selective, the error rate of a simple digital system cannot fall below an acceptable limit, so the resulting poor quality cannot be improved by increasing either the link margin or the satellite power [CCIR, 1986-90a, b]. The effects of frequency selectivity can be overcome through the use of symbol durations which are large with respect to the dispersion of the echo delays, which limits the bit-rate per carrier [CCIR, 1986-90b, c]. A powerful channel coding mechanism can then be applied (convolutional code with Viterbi decoding), but it is necessary to ensure the independence between successive symbols with respect to channel fades. This is achieved by interleaving the symbols either in time or in frequency (the total bit rate is thereby distributed between several carriers spaced sufficiently far apart in frequency [Pommier and Yi Wu, 1986]. Temporal interleaving is effective, however, only if the receiver is mounted in a vehicle travelling above a certain speed. If the receiver is stationary, frequency interleaving must be used or, alternatively, space diversity reception [Miller, 1987], [CCIR, 1986-90d]. When frequency interleaving is used, carriers modulated with other sound channels may be placed between those carrying the parts of a given channel, using orthogonal frequency division multiplexing (OFDM) [Alard and Lassalle, 1987]. Finally certain proposals for advanced digital systems involve the use of a source coding offering powerful bit-rate reduction (e.g., sub-band coding); with this technique the bit-rate is barely 220 kbit/s for one high-quality stereophonic programme. Further details on advanced digital systems are given in Annexes III and IV.

2.3 *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 in proportion of the square of the frequency.

All the examples of the present report assume a carrier frequency of 1 GHz. It is considered as non-economic to increase the satellite power by more than 6 dB which, according to the law of the square of frequency, leads to a maximum frequency of 2 GHz. In addition, however, the frequency also affects to some extent the link margin needed for a given service quality. For instance, experiments at 1 500 MHz [Guilbeau, 1982] have suggested that the link margin in an urban area increases from 15 dB to 18 dB for 20° elevation, when considering the case B defined in section 2.6.3.3

In Resolution 520, WARC ORB-88 extended the possible frequency range for the broadcasting-satellite service (sound) to 3 GHz.

Table I shows a comparison of the satellite power required at 0.5, 1, 2 and 3 GHz, taking as a reference the link budget for the advanced digital system II, code A at 1 GHz (see Table VI, §2.6.4.5). The link margins at 2 and 3 GHz are based on a conservative extrapolation of the propagation data currently available for Europe. This data is subject to further experimental studies.

TABLE I - *Comparison of the satellite power required at 0.5, 1, 2 and 3 GHz*

Frequency (GHz)		0.5	1.0	2.0	3.0
Increase of power due to f^2 law (dB)		-6	0	6	9.5
Increase of link margin (dB)		-2	0	3	5
Satellite antenna input power for one stereophonic programme in a 1° beam	(dBW)	4.9	12.9	21.9	27.4
	(W)	3.1	19.5	154.9	549.5
Total satellite antenna input power for 16 programmes	(W)	49.4	311.0	2478.0	8793.0

It is seen from Table I, which neglects some other secondary factors like the coupling loss and the receiver noise temperature, that a system operating at 2 GHz requires a satellite power which is roughly 8 times higher than at 1 GHz; at 3 GHz, the required power is roughly 30 times higher than at 1 GHz; at 0.5 GHz, the required power is however about 6.3 times lower than at 1 GHz.

It should be noted that the same considerations as regards the effect of frequency apply to other modulation schemes, such as conventional or companded FM and simple digital modulation. Also, sharing difficulties may be exacerbated at higher frequencies due to high link margins required.

2.4 Satellite transmitting antenna

Studies summarized in this report have consistently assumed a reflector or similar physical aperture type transmitting antenna (as opposed to wire-type antennas) with a 3 dB beamwidth of 1°. This suggests that technology studies of physical aperture type antennas for 12 GHz satellite transmitting applications may, upon extrapolation of the physical dimensions of the antenna to the new operating frequency, be applicable to the satellite sound broadcasting application in Band 9. In particular, the satellite antenna diagrams used at WARC-77 are considered to be feasible in Band 9 [CCIR, 1986-90e]. Further details are given in Annex I.

2.5 Alternative satellite orbits

The link budget examples below are all derived assuming the use of a geostationary satellite, where it can be seen that the link margin increases substantially as the elevation angle decreases. Some preliminary studies (J.H. Stott, 1985; FTZ, 1986; ESA, 1988) have been made on the possible use of highly-elliptical orbit to alleviate this effect.

Examples of such orbits are those inclined at an angle of 63.43° with periods of either 12 hours ("Molniya") or 24 hours ("Tundra") arranged such that the satellite appears to be almost directly over the target coverage area for a significant part of its orbit period. This has the advantage for medium to high latitude countries of maintaining a high elevation angle at the receiver with the result that both shadow-loss and multipath may be greatly reduced. In addition, it is possible to take advantage of the constantly high elevation value to increase the antenna gain of the mobile.

Consequently, satellite power requirements would be similarly reduced, giving a considerable easement of both inter- and intra-service sharing constraints. This would lead to more efficient spectrum planning with mixed use of geostationary and non-geostationary satellite orbits as appropriate to the coverage areas.

The major differences between geostationary and non-geostationary systems are that the latter comprise either two ("Tundra" orbit) or three ("Molniya" orbit) satellites in differently phased orbits which are required to provide 24 hour service. Additional factors, such as launch and orbiting spares arrangements, Doppler correction and satellite hand-over strategies, variation of coverage and radiation hardening, at least for "Molniya" orbits, to protect the payload from damage on repeatedly passing through the Van Allen radiation belts need to be considered. Further details are given in draft Report AD/8, but further study is required to quantify the balance of advantages and disadvantages and determine the relative economics of geostationary and non-geostationary approaches for the BSS (sound).

2.6 *Link budget*

2.6.1 *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.

The C/N objective for the digital system includes 1 dB equivalent additive noise from co-channel interference and 0.5 dB from each one of the two adjacent channels. The noise performance for the digital system is given in terms of subjective quality (4 = good).

For the advanced digital systems, the objective is defined in terms of the E_b/N_o ratio needed for a specified error-ratio, where E_b denotes the average energy received for useful bits of information and N_o the noise spectral power density.

2.6.2 *Receiving antennas*

Receiving antennas for stationary, portable, and vehicular applications are discussed in this section.

Stationary receiving antennas

In fixed locations such as houses, apartment buildings, and commercial buildings it is feasible to provide a higher service quality by using fixed outdoor antennas exhibiting a higher gain (e.g., about 15 dB) than might be used on portable and vehicular receivers. A helix is an example of a suitable type antenna.

Portable receiving antennas

The use of simple antennas such as a crossed-dipole, cavity-backed dipole, and slotted dipoles exhibiting a gain in the range of 3 dBi to 5 dBi has generally been assumed in the studies.

Vehicular receiving antennas

Vehicular receiving antennas play an important role in determining sharing possibilities and system cost in satellite sound broadcasting systems. Simply stated, the greater the vehicular receiving antenna gain, the lower the satellite per-channel e.i.r.p. Studies to date have generally assumed the vehicular receiving antenna to have a gain on the order of 5 dBi. However, work is currently under way [Ball Aerospace, 1984, 1985; Cubic Corp. 1984, 1985] to develop circularly polarized, steered array antennas with gains of the order of 6-12 dBi suitable for use on automobiles, vans, and trucks. This work may have applicability to satellite sound broadcasting systems for specific applications [CCIR, 1986-90f].

Mechanically and electronically steered rooftop antennas have been studied. They provide reasonable gains at mid to high latitudes, and suppress ground reflections to minimize multipath fading. Medium gain (6-12 dBi) steerable vehicular antennas may be a viable alternative to low gain omnidirectional vehicular antennas. The implied additional expense in using a steerable antenna may be offset by lower e.i.r.p. from the satellite, by the enhanced possibility of sharing with other services, and by improved orbit-spectrum utilization.

2.6.3 Propagation aspects

The design, and as a consequence the cost of a satellite sound broadcasting system, is strongly dependent on the factors affecting the propagation characteristics on the space-to-Earth path to the vehicular receiver in particular, and generally to a lesser extent to the portable receiver. The propagation path is subject to attenuation by shadowing due to buildings, trees, and other foliage; and to multipath fading due to diffuse scattering from the ground and nearby obstacles such as trees and buildings. The degree of impairment to the received signal level depends on the operating frequency, the elevation angle to the satellite, and the type of environment in which the receiver is operating: whether it is an open, rural, wooded or mountainous, suburban or dense urban environment.

2.6.3.1 Propagation models

For moderate satellite elevation angles, it is known (see Annex II) that over large areas (of the order of several hundred wavelengths), the mean value of the field strength follows a log-normal distribution. However, within small areas (of the order of a few wavelengths), two distribution models may be applied:

- Rayleigh distribution where there is no direct line-of-sight to the satellite; or
- Rice distribution where there is direct line-of-sight to the satellite; giving one component of constant amplitude.

Although the presence of waves with constant amplitude applies to a large number of receiving locations, the Rayleigh model, which is the least favourable, cannot be ignored since it is applicable in many urban areas.

Results of recent measurements [Loo, 1985], [Jongejeans, *et al*, 1986] and [Lutz et al, 1986] suggest that for the purpose of analyzing the performance of advanced digital satellite sound broadcasting systems using forward error correction coding, that the satellite-to-vehicular propagation path may be modeled as a Rayleigh fading channel with a mean excess path loss dependent on the type of operating environment.

Four different propagation paths are considered:

- a portable receiver operating inside a house that is not shadowed by trees;
- a vehicle operating in a rural environment devoid of significant multipath and shadowing by foliage;
- a vehicle operating in a rural or suburban environment with some multipath and shadowing by trees and foliage; and
- a vehicle operating in a dense urban environment with significant multipath from nearby buildings, cars and other objects.

In general, the UHF satellite propagation path is characterized by shadowing and by the presence of multiple reflected paths. The channel can be frequency selective or non-selective depending on the relationship between the delay spread of the reflected waves and the channel bandwidth. The values associated with the delay spread will be minimal in rural areas, and will be progressively larger in suburban and urban areas. Measurements made at 910 MHZ in a rural area on a simulated space-to-Earth path indicate that the delay spread is predominantly less than 1 μs and is primarily due to reflection and scattering from the trunks of trees [Bultitude, 1987].

Comparable results with somewhat larger delay spreads may be anticipated for the space-to-Earth paths in an urban environment. The multipath propagation characteristics of the satellite channel are usually described in terms of the multipath delay spread and correlation bandwidth. The delay spread T_o is a measure of the duration of an average power delay profile of the channel. The correlation bandwidth B_c is the bandwidth at which the correlation coefficient between two spectral components of the transmitted signal takes a certain value, say 90%. The empirical relationship between the correlation bandwidth at 90% correlation and the delay spread is given in section 4 of Annex II.

Considering a simple digital modulation system operating in a frequency selective channel, the error performance is dependent upon the spread of delays introduced by the different paths, as well as by the amplitude of the component signals. Assuming that each wave is affected by a multiplicative Rayleigh process [Pommier and Wu, 1986], with an exponential distribution of delays of standard deviation, T_o, a level of intersymbol interference will be introduced which depends upon the delay-spread to the symbol-period ratio, T_r (i.e., the ratio, T_o/T, where T is the duration of the modulation symbol).

2.6.3.2 Mitigation techniques

The use of diversity techniques on the vehicular receiver can significantly improve the performance of the receiver when operating in a heavily shadowed, Rayleigh fading environment. There are three primary diversity techniques: 1) frequency diversity, 2) time diversity and 3) spatial diversity [Proakis, 1983]. Each of these techniques may be used with systems employing digital modulation methods. However, for systems employing frequency modulation, spatial diversity is the most practical fading mitigation technique [Miller, 1988]. These diversity methods are briefly described below.

2.6.3.2.1 Frequency diversity

Frequency diversity uses a number of carriers spaced in frequency by an amount that equals or exceeds the correlation bandwidth of the channel. Spectrum efficiency is retained by frequency interleaving a number of separate programme channels to completely fill the frequency band. Spectrum occupancy can be maximized by the use of overlapping orthogonal carriers. Independent fading of the carriers requires that the delay spread of the channel exceed some minimum value. For a channel characterized by an exponential distribution of the delay (typical of a terrestrial path), the mean value of the delay spread must typically be greater than the reciprocal of the programme carrier spacing. In the case of the system described in Annex IV, however, the condition that applied is simply that the total channel bandwidth has to be at least twice the reciprocal of the mean value of the channel delay spread. When this condition is met (independent, frequency selective, Rayleigh fading), a reduction in the link margin of up to 36 dB is possible for a digital system under ideal conditions.

Because of this dependence on delay spread, frequency diversity is most suitable for use in heavily shadowed urban areas where the mean delay spread will be the greatest and independent fading (selective fading) of adjacent carriers may be assured. In rural environments, the delay spread is sometimes too small to provide a narrow enough correlation bandwidth, then the fading on the channel will tend towards flat fading and the actual coding gain will be less than expected. If such a situation occurs, an efficient mitigation technique is either the combination of frequency and time diversity or the use of space diversity. A system based on the use of frequency and time diversity is described in Annex IV.

2.6.3.2.2 *Time diversity*

Time diversity is a technique that is most suitable for use with digital transmission methods. It requires an orderly scrambling of the data symbols prior to transmission and the restoration of the order at the output of the receiver. The introduction of the orderly scrambling and descrambling transforms a burst of errors that occurs during a deep fade into random errors. The use of time diversity combined with forward error correction coding will restore the performance of forward error correction codes by transforming the burst error channel caused by shadowing and Rayleigh fading into a random error channel. Ideally, a reduction in the link margin of up to 36 dB is possible.

The principal disadvantages of time diversity are: the need for all receivers to incorporate the descrambling circuitry (primarily memory chips); poor performance at vehicle speeds lower than the system design, and practical signal processing considerations which limit application to digital modulation methods. Annex III describes the design and performance of a system based on the use of time diversity.

2.6.3.2.3 *Spatial diversity*

Spatial diversity is based on the use of multiple receiving antennas which are spaced sufficiently far apart so that the received signals fade independently. The independently fading signals at the output of each antenna are then combined to form an output signal whose fading depth is significantly less than the fading depth of the individual signals. One combining method is maximum-ratio combining. One implementation of this method uses M phase-locked loops to bring the signals at the output of M antennas into phase coherence. The signals are then amplitude weighted and summed to form a composite signal. Quad-diversity with maximal-ratio combining in a Rayleigh fading environment will permit a 36 dB reduction in the link margin for a digital system under ideal conditions.

For an analogue FM system, a 26 dB reduction in the depth of a fade at the 0.001 probability value may be achieved with quad-diversity and maximal-ratio combining [Miller, 1988]. The advantages of spatial diversity are: applicable to both analogue FM and digital systems, and, it does not impose complexity on all receivers, only on those (vehicular receivers) which need the added performance afforded by the use of spatial diversity. The disadvantage of spatial diversity is the need for multiple antennas on the vehicle associated with a set of several interdependent phase locked loops. Additional studies are needed to fully evaluate the effectiveness of spatial diversity when applied to FM and digital systems particularly in urban environments.

2.6.3.3 Link margins

Several values of link margin have been assumed in the following table. These are estimates of the allowances required in the various cases listed below. Further discussion of this problem is given in Annex II.

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, 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 [Guilbeau, 1979].

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.)

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

Case E: This case applies to the advanced digital system for vehicular receivers operating in a slightly shadowed rural area. The channel is conservatively modelled as a Rayleigh fading channel with a mean excess path loss of 0 dB.

Case F: This case also applies to the advanced digital systems for vehicular receivers operating in a heavily shadowed rural area or even in a dense urban area where channel frequency selectivity must be taken into account. The channel is modelled as a Rayleigh fading channel with mean excess path loss of 10 dB.

For advanced digital systems, case F is directly comparable with Case B for analogue systems; the link margin is reduced by 5 dB because the advanced digital systems eliminate the effect of Rayleigh fading and thus only the factor (10 dB) representing the log-normal distribution of the field-strength over large aeras needs to be included (see Annex II).

Case G: This case applies to the operation of a portable receiver inside a single storey house. The channel is modelled as an additive white Gaussian noise (AWGN) channel with a mean excess path loss of 12 dB.

2.6.4 Link budgets for various systems

The link budgets for the various types of systems studied are given below.

2.6.4.1 FM systems

Table II shows the link budgets for the two FM system examples with the various link margin cases A, B, C and D as defined in section 2.6.3.3. The C/N values indicated are those required for an audio S/N of 40 dB (weighted, monophonic reception) and assume the use of a phase-locked-loop demodulator. (For a conventional demodulator a C/N value of about 10 dB would be necessary because of threshold effects). For a given standard of service the p.f.d required is less for companded FM with 10 kHz audio bandwidth than for conventional FM with 15 kHz bandwidth. For example, for link margin case "A", the p.f.d. values are -123.4 dB(W/m^2) and -114.1 dB(W/m^2), respectively.

TABLE II - Link budget at 1 GHz for FM systems

Polarization		Circular	
Type of modulation		FM companded	FM conventional
Reception mode		Monophonic	Monophonic(1)
Audio bandwidth	kHz	10	15
Carrier deviation	kHz	26.5	75
Noise bandwidth	kHz	73 (= 48.6 dBHz)	180 (= 52.6 dBHz)
Required (C/N) total(2)	dB	4.0	9.3
Subjective sound impairment grade	(3)	3	3
Degradation due to up-link C/N	dB	0.4	0.4
Required down-link C/N	dB	4.4	9.7
Implementation margin	dB	1	1
Receive antenna gain	dBi	5	5
Coupling loss	dB	1	1
Receiver noise temperature	K	600 (= 27.8 dBK)	600 (= 27.8 dBK)
Area of isotropic antenna at 1 GHz	dBm^2	-21.4	-21.4

Link margin case		A	B	C	D	A	B	C	D
Link margin	dB	6	15	25	33	6	15	25	33
Line-of-sight PFD at edge of beam (-3 dB)	$dB(W/m^2)$	-123.4	-114.4	-104.4	-96.4	-114.1	-105.1	-95.1	-87.1
Equivalent field strength at edge of beam (dB(μV/m))		22.4	31.4	41.4	49.4	31.7	40.7	50.7	58.7
Spreading loss	dBm^2	162.4	162.9	162.9	162.9	162.4	162.9	162.9	162.9
E.i.r.p. on axis	dBW	42	51.5	61.5	69.5	51.3	60.8	70.8	78.8
Transmitter power for 1° beamwidth	dBW	-1.9	7.6	17.6	25.6	7.4	16.9	26.9	34.9

(1) - Stereophonic reception is possible for fixed receiver with higher gain antenna.

(2) - The use of a phase-locked loop demodulator is assumed. This C/N is required for 40 dB audio S/N. It exceeds the PLL threshold.

(3) - See Recommendation 562.

2.6.4.2 FM system using space diversity on the vehicle

Table IV shows a link budget for a vehicular receiver using quad-spatial diversity and maximal ratio combining to receive an analogue FM channel [Miller, 1988]. The receiving environments correspond to those described as Case E (slightly shadowed rural area with Rayleigh fading and a mean excess path loss of 0 dB) and Case F (heavily shadowed rural area with Rayleigh fading and a mean excess path loss of 10 dB). It is noted that fixed and portable receivers do not require multiple antennas and signal combining circuitry in order to receive the analogue FM sound programme channel.

2.6.4.3 Simple digital systems

The example described in this section (see Table IV) is based on a source bit rate of 338 kbit/s per monophonic channel which can be obtained by near-instananeous companding [CCIR, 1982-86a] or by adaptive delta modulation.

A great number of modulation schemes exist. Most of those which can be detected with reasonably simple receiver circuitry have generally similar power requirements; they differ slightly in such areas as spectral characteristics, sensitivity to channel distortions (such as arise in the satellite high-power amplifier), and ease of demodulation. The example uses VSB 2-PSK.

The performance of these simple digital systems will be affected by the channel frequency selectivity. However, the link budget of this example refers to the best propagation case where no frequency selectivity occurs in the transmission channel.

2.6.4.4 *Advanced digital system I* (see also Annex III)

The advanced digital system example described in this section is based on a combination of technologies in various stages of development that should reach a suitable stage of development for satellite sound broadcasting for individual reception by portable and automobile receivers in or before 1990 [CCIR, 1986-90d]. The key features of this system are:

- the use of a low-cost adaptive delta modulation (ADM) sound encoding technique which has already been reduced to practice for high quality consumer audio applications [Dolby, 1985; Signetics, 1985];
- the use of convolutional coding (R = 1/2; K = 7) and Viterbi maximum likelihood decoding for forward error correction (FEC); and
- interleaving/de-interleaving as an effective means to mitigate the serious effects of rapid fading on the satellite-to-vehicular receiver propagation path;
- the use of spatial diversity reception on a vehicle to provide service continuity when the vehicle is stationary.

TABLE III

Link budget for an analogue FM satellite sound broadcasting system/s serving a vehicular receiver using quad-spatial diversity and maximal ratio combining

Polarization		Circular			
Type of modulation		FM companded		FM conventional	
Reception mode		Monophonic		Monophonic$^{(1)}$	
Audio bandwidth	kHz	10		15	
Carrier deviation	kHz	26.5		75	
Noise bandwidth	kHz	73 (= 48.6 dBHz)		250 (= 54 dBHz)	
Required (C/N) total$^{(2)}$	dB	4.0		10.0	
Subjective sound impairment grade	(3)	3		3	
Degradation due to up-link C/N	dB	0.4		0.4	
Required down-link C/N	dB	4.4		10.4	
Implementation margin	dB	1		1	
Receive antenna gain	dBi	5		5	
Coupling loss	dB	1		1	
Receiver noise temperature	K	600 (= 27.8 dBK)		600 (= 27.8 dBK)	
Area of isotropic antenna at 1 GHz	dBm^2	-21.4		-21.4	
Link margin case		E	F	E	F
Link margin	dB	3.5	13.5	3.5	13.5
Line-of-sight PFD at edge of beam (-3 dB)	$dB(W/m^2)$	-125.9	-115.9	-114.5	-104.5
Equivalent field strength at edge of beam (dB(μV/m))		19.9	29.9	31.3	41.3
Spreading loss	dBm^2	163.0	163.0	163.0	163.0
E.i.r.p. on axis	dBW	40.1	50.1	51.5	61.5
Transmitter power for 1° beamwidth	dBW	0.4	4.2	5.8	57.5

(1) - Stereophonic reception is possible for fixed receiver with higher gain antenna.

(2) - The use of a phase-locked loop demodulator is assumed. This C/N is required for 40 dB audio S/N. It exceeds the PLL threshold.

(3) - See Recommendation 562.

TABLE IV - Link budget at 1 GHz for a simple digital system

Polarization	Circular			
Type of modulation	VSB 2-PSK			
Reception mode	Monophonic(1)			
Error protection	Concealment			
Total bit rate (kbit/s)	364			
Required E_b/N_o (for 10^{-4} bit-error ratio) (dB)	8.4			
Subjective sound impairment grade(2)	4			
Required C/N_o total (dBHz)	64			
Degradation due to up-link (dB)	0.4			
Required down-link C/N_o (dBHz)	64.4			
Implementation margin (dB)	1			
Interference allowance (dB)	2			
Receive antenna gain (dBi)	5			
Coupling loss (dB)	1			
Receiver noise temperature (K)	600 (= 27.8 dBK)			
Area of isotropic antenna at 1 GHz (dB(m^2))	-21.4			
Link margin case	A	B	C	D
Link margin (dB)	6	15	25	33
Line-of-sight PFD at edge of beam (-3 dB) (dB(W/m^2))	-110	-101	-91	-83
Equivalent field strength (dB(μ V/m))	35.8	44.8	54.8	62.8
Spreading loss (dB(m^2))	162.4	162.9	162.9	162.9
E.i.r.p. on axis (dBW)	55.4	64.9	74.9	82.9
Transmitter power for 1^o beam (dBW)	11.5	21	31	39

(1) - Stereophonic mode requires doubling the total bit-rate. Consequently, the transmitter power would also be doubled.

(2) - See Recommendation 562

Link budgets for three link margin cases are given:

- a vehicular receiver operating in a heavily foliaged rural environment (10 dB excess path loss) (case F);
- a vehicular receiver operating in a lightly foliaged rural environment (0 dB excess path loss) (case E); and
- a portable receiver operating inside a house (12 dB excess path loss) (case G).

As discussed in section 2.6.3.3 and provided that the correlation bandwidth is small in comparison to the bandwidth of the transmitted signal, the first case is also comparable to a vehicular receiver operating in an urban environment with an excess path loss of 10 dB.

Values given in Table V for power flux-density and spectral power flux-density are some 10 to 20 dB less than for conventional FM or simple digital systems operating in a similar environment. **Note that comparable performance is available to the vehicular receiver solely by the use of quad-spatial diversity and maximal ratio combining. Relying on the use of space diversity in the vehicular receiver instead of time diversity permits the design and manufacture of fixed and portable receivers that are simpler and that should cost less.**

2.6.4.5 *Advanced digital system II (see also Annex IV)*

Advanced digital system II is specifically designed to overcome the frequency selectivity of the channel, so it is well suited for vehicular reception in urban environments [CCIR, 1986-90b, c]. It is based on:

- efficient source sound encoding with substantial bit-rate reduction;
- convolutional channel coding with Viterbi decoding;
- frequency and time interleaving in order to overcome selective fading effects;
- coded orthogonal frequency division multiplexing (COFDM);
- the use of a guard interval between two successive symbols.

Basic assumptions

- source bit rate per stereophonic sound programme: 168 kbit/s (system example A), 224 kbit/s (system example B);
- modulation: 4-PSK with differential detection;
- channel coding: frequency interleaving and convolutional code of rate 1/2 constraint length 7 and free distance 10;
- typical delay spread: 2 μs which is representative of dense urban environments in Europe.

Depending on the source rate (A or B) and with a total of 256 carriers, there are respectively 16 and 12 stereophonic programmes available in a 4 MHz band.

The link budget for Case F with a link margin of 10 dB is given in Table V.

TABLE V - *Link budget examples for an advanced digital satellite sound broadcasting system I operating in Band 9*

System parameter	Value
Type of modulation	QPSK
Reception mode	monophonic (1)
Bit rate (kbit/s)	204
Symbol rate (ksp/s)	408
Required RF bandwidth (kHz)	400
Received S/N (dB)	58
Subjective sound impairment grade (2)	4.5
Received bit-error ratio	10^{-5}
Audio bandwidth (kHz)	15
Carrier frequency (MHz)	1000

Link margin case	F	E	G
	Automobile		House
	Heavy foliage	Light foliage	
Receiver antenna gain (dBi)	5.0		5.0
Coupling loss (dB)	1.0		1.0
Receiver system noise temp. (K)	600		600
Required E_b/N_0 (dB)	7.4		3.8
Implementation margin (dB)	1.0		1.0
Mean excess path loss (dB)	10	0	12.0
Line-of-sight PFD at beam edge (dB(W/m^2))	-111.8	-121.8	-113.4
Equivalent field strength at beam edge (dB(μV/m)	34.0	24.0	32.4
Maximum beam-centre PFD per 4 kHz (dB(W/(m^2·4 kHz)))	-125.9	-135.9	-127.5
Maximum spreading loss ($\varphi_o = 17°$) (dB/m^2)	163.0		163.0
E.i.r.p. on-axis (dB(W))	54.2	44.2	52.6
Satellite antenna gain (D=20 m) for 1° beamwidth (dBi)	43.9		43.9
Antenna input power (dB(W))	10.3	0.3	8.7
Antenna input power (W)	10.7	1.1	7.4

(1) - Stereophonic mode requires doubling the bit rate. Consequently the symbol rate, required RF bandwidth and antenna input power would also be doubled.

(2) - See Recommendation 562

TABLE VI

Link budget for the advanced digital system II (1 GHz)

	System example A (16 progr./4 MHz)	System example B (12 progr./4 MHz)
Polarization	Circular	Circular
Error protection	FEC (1/2)	FEC (1/2)
Total bit rate per stereophonic sound programme (kbit/s)	336	448
Required E_b/N_o for 10^{-3} BER (dB)	8.5	8.5
Subjective sound impairment (1)	4.5	4.5
Required C/N_o total per stereophonic channel (dBHz)*	60.8	62
Degradation due to up-link C/N_o (dBHz)*	0.4	0.4
Required down link C/N_o (dBHz)*	61.2	62.4
Implementation margin (dB)**	2	2
Interference allowance (dB)	1	1
Receive antenna gain (dBi)	5	5
Coupling loss (dB)	1	1
Receiver noise temperature (K)	600 (=27.8 dB/K)	600 (=27.8 dB/K)
Satellite antenna gain for 1° beamwidth (dBi)	43.9	43.9
Standard of service (see § 6.4.2)	F	F
Link margin (dB)	10	10
Line-of-sight PFD at beam edge (-3 dB) (dB<W/m^2>)*	-109.2	-108
Equivalent field strength at beam edge (dBμV/m)*	36.6	37.8
Line-of-sight PFD at beam centre per 4 kHz for the full sound multiplex (dBW/<m^2 4 kHz>)	-123.6	-123.6
Spreading loss (dB/m^2) (δ = 17°)	163	163
E.i.r.p. on axis (dBW)*	56.8	58
Antenna input power for a 1° beam (dBW)* (2)	12.9	14.1
Antenna input power for a 1° beam (W)*	19.5	25.7

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* These figures describe the power, etc. requirements per stereophonic programme.

** This value includes a 1 dB allowance for the use of a 20% guard interval (see Annex IV).

(1) See Recommendation 562

(2) These link budgets have been calculated on the basis of input power to the antenna to satisfy given link quality criteria. Given the distortion that will arise for the complex modulation system used, it is probable that the final output amplifier will have to operate under backoff. Whilst future studies continue, it is currently expected that the necessary output backoff value will be between 4 and 5 dB.

2.7 *Sharing* considerations

The frequency band selected for the sound broadcasting satellite service will affect inter-service sharing. The sharing possibilities are dependent upon the permissible level of interference into existing services and susceptibility of the newly proposed service to interference from the existing services. Assuming a fixed receiving antenna gain for near omni-directional reception, the required level of p.f.d. for acceptable reception quality will increase with an increase in frequency and conversely will decrease with a decrease in frequency.

The Table of Frequency allocations for bands within, and also outside but near the range 500 MHz - 2 000 MHz provides for numerous radiocommunication services, including broadcasting, fixed and mobile services, as well as aeronautical, radionavigation and radiolocation services. Sharing criteria were, however, found to be only available at this time for the broadcasting, fixed and mobile services in certain bands.

2.7.1 *Application of system models to sharing*

Section 2.6 describes several systems which represent a wide range of possible cases which can be applied to different receiving situations in rural and urban areas and at high or low latitudes. From these, four system models have been selected which are believed to represent the most likely applications. Table VII contains the parameters of these four system models which are relevant to sharing considerations. Table VII is based on operation at 1 GHz for all systems.

TABLE VII - *System model parameters relevant to sharing*

System	Conventional FM	Companded FM	Digital	Advanced Digital(1)
Class of service	A(2)	A(2)	A(2)	F(3)
Link margin	6 dB	6 dB	6 dB	10 dB(4)
PFD at the centre of the coverage area(5) (dBW/m^2)	-111.1	-120.4	-107	-109
PFD/4 kHz at the centre of the coverage area(5) (dB(W/(m^2·4kHz)))	-111.1(6)	-120.4(6)	-123.6	-126

(1) Two different advanced digital systems with almost equal sharing parameters are represented in this column

(2) Intended for reception in rural areas at low latitude

(3) Intended for reception in dense urban areas at high latitude

(4) Equivalent to 15 dB for the other systems

(5) The PFD increases with the square of the operating frequency. (3.5 dB higher value required at 1.5 GHz; 6 dB lower value at 500 MHz)

(6) No energy dispersal was assumed in these cases.

2.7.2 *Energy dispersal*

Energy dispersal may be desirable to facilitate sharing between the broadcasting-satellite service (sound) and the terrestrial services. There are two forms of energy dispersal. The first is natural energy dispersal associated with the characteristics of the information (sound programme) and the modulation method; and the second is artificial energy dispersal applied to the transmitted signal to spread the power flux density over a larger bandwidth and thus decrease the spectral power flux density.

Natural energy dispersal associated with the analogue FM transmission method for satellite sound broadcasting is virtually nil because of the pauses in speech and programme transition times. During these pauses, the carrier is radiated at full power at its rest frequency. Natural energy dispersal associated with transmitter oscillator instability is expected to be negligible for satellite sound broadcasting systems operating in Band 9. Artificial energy dispersal may however be used with analogue FM transmission systems for improved sharing with narrow-band services. The method described in Report 384-4 for use in multi-channel FDM/FM telephony transmission systems can be applied to satellite sound broadcasting systems.

Natural energy dispersal associated with digital satellite sound broadcasting systems can be substantial. The advanced systems specified in this chapter can provide energy dispersal gain in the range from 17 to 19 dB in a reference bandwidth of 4 kHz compared to an unmodulated carrier. The realization of this degree of energy dispersal requires that the modulating digital sequence approaches a truly random sequence of 1's and 0's. Details about the corresponding procedure can be found in Annex III to Report 384-4.

In order to achieve a similar energy dispersal gain with the FM system (17 dB), a peak-to-peak deviation of 200 kHz would be required. However, the use of such artificial energy dispersal could require modifications of conventional receivers.

2.7.3 Overview of sharing situations

To provide a comprehensive picture of sharing situations, the services which have an allocation in the UHF bands are considered in Table VI. The table lists the services, by frequency band, and indicates the corresponding constraints which are either laid down in the Radio Regulations or studied in CCIR texts, with cross references to the more specific sharing criteria contained in Table VII. These tables are provided as a means to understand the overall sharing situation in the frequency range 0.5 - 3 GHz as it may relate to BSS (sound) and they may not contain all the sharing aspects indicated in Article 8 of the Radio Regulations.

2.7.4 *Analysis of specific sharing situations*

2.7.4.1 *Sharing with the terrestrial television broadcasting service*

To protect the terrestrial broadcasting service operating in the UHF band from interference caused by a sound broadcasting satellite service, it is essential to determine the permissible power flux-density generated by the satellite in the service area of the terrestrial television broadcasting station. Sharing will be facilitated with systems producing the lowest power flux-density, whether energy dispersal is used or not.

TABLE VIII
(Source: Table 6-X in the CCIR Report to WARC ORB-88)

pfd limits by frequency bands

(For full information on sharing conditions see Article 8 of Radio Regulations)

Band (MHz)	Interfered services with specified limits*	Notes	Strictest limit (for elevation angle = 0)	Cases referred to Table VII
470 - 890	Broadcasting Radioastronomy (608-614)	(4)	-129 dB(W/m^2) -136 dB(W/m^2) -185 dB(W/m^2) in 6 MHz	A RR: Rec. 705 G CCIR Rep. 631 I CCIR Rep. 224
890 - 960	Fixed Mobile		-146 dB(W/(m^2·16 kHz))	H CCIR Rep. 631
960 - 1 215		(3)		
1 215 - 1 240		(3)		
1 240 - 1 300		(3)		
1 300 - 1 350		(3)		
1 350 - 1 400		(3)		
1 400 - 1 427	Radioastronomy	(4) (1)	-180 dB(W/m^2) in 27 MHz - 80 dB(W/m^2) typically	I CCIR Rep. 224 J CCIR Rep. 697
1 427 - 1 525		(3) (7)		
1 525 - 1 530	Fixed Mobile	(5)	-154 dB(W/m^2) in 4 kHz	C RR: Article 28 Section IV
1 530 - 1 535		(8) (5)		
1 535 - 1 626.5		(3)		
1 626.5 - 1 660.5	Radioastronomy (1 660.5 - 1 660.5)	(4)	-194 dB(W/m^2) in 20 kHz	I CCIR Rep. 224

* According to current Radio Regulations and CCIR Reports or Recommendations

TABLE VIII(continued)
(Source: Table 6-X (continued) in the CCIR Report to WARC ORB-88, except the last two rows)

Band (MHz)	Interfered services with specified limits*	Notes	Strictest limit (for elevation angle = 0)	Cases referred to Table VII
1 660.5 - 1 670	Radioastronomy	(4) (1)	-194 db(W/m^2) in 20 kHz - 80 dB(W/m^2) typically	I CCIR Rep. 224 J CCIR Rep. 697
1 670 - 1 700	Meteorological aids	(5)	-133 dB(W/m^2) in 1.5 MHz	B RR: Article 28 Section IV
1 700 - 1 710	Fixed Mobile	(5)	-154 dB(W/m^2) in 4 kHz	C RR: Article 28 Section IV
1 710 - 2 290		(3)		
2 290 - 2 300	Fixed Mobile	(5)	-154 dB(W/m^2) in 4 kHz	C RR: Article 28 Section IV
2 300 - 2 483.5		(3)		
2 483.5 - 2 500	Fixed Mobile	(6)	-154 dB(W/m^2) in 4 kHz	C RR. Article 28 MOD 2558. 2559
2 500 - 2 655	Fixed Mobile	(2)	-152 dB(W/m^2) in 4 kHz	E RR: Article 28 Section IV
2 655 - 2 690	Fixed Mobile	(2)	-152 dB(W/m^2) in 4 kHz	E RR: Article 28 Section IV
2 690 - 2 700	Radioastronomy	(4) (1)	-177 dB(W/m^2) in 10 MHz -76 dB(W/m^2) typical value	I CCIR Rep. 224 J CCIR Rep. 697
2 700 - 3 100		(3)		

* According to current Radio Regulations and CCIR Reports or Recommendations.

Notes to Table VIII
(Source: Table 6-X in the CCIR Report to WARC ORB-88)

(1) This limit applies to services whose intermodulation products can arise in a band where the radioastronomy service has an allocation.

(2) The BSS in the band 2 500 - 2 690 MHz is limited to national and regional systems for community reception (see No. 761 of the Radio Regulations). Furthermore, in some countries this is an alternative allocation and the BSS consequently has no allocation in this band. Services in the band 2 655 - 2 690 MHz are obliged to take all practicable steps to protect the radioastronomy service in the band 2 690 - 2 700 MHz.

(3) No limit specified.

(4) Table I or Table II of CCIR Report 224. To enable radioastronomy observations to be carried out at 5° from the geostationary orbit, levels 15 dB lower are required (see § 4.3 of CCIR Report 224 and CCIR Recommendation 611); e.g. for the band 470 - 890 MHz the level would be -200 dB(W/m^2).

(5) In the case of tropospheric scatter systems, refer to Article 28, in particular No. 2560, of the Radio Regulations.

(6) This limit was adopted by WARC MOB-87 in the band 2 483.5 - 2 500 MHz (see Radio Regulations, Article 28, MOD 2558, 2559).

(7) CCIR Report 941 considers sharing between the broadcasting-satellite service (sound) and the fixed service in this band. CCIR Report 955-1 considers sharing between these two services in the band 0.5 - 2 GHz.

(8) The limits of RR Article 28, Section IV, apply up to 1 January 1990.

In Report 631-3, the EBU has suggested a minimum field strength of 65 dB (μV/m), and the USA suggested 56 dB (μV/m). Furthermore, the EBU considered that a corresponding protection ratio of 54 dB be employed and the USA suggested 35 dB to protect terrestrial TV broadcasting from the BSS (TV-FM). (Indications are however that the 54 dB protection ratio could be pessimistic in the case of digitally modulated carriers.)

This results in a range of permissible power flux-density for the satellite sound broadcasting service ranging from -132 dB(W/m^2) to -122 dB(W/m^2) (aggregate per television channel) based on the range of minimum field-strength values to be protected as seen above and assuming a 3 dB reduction in interference from the use of circular polarization.

65 dB (μV/m) - 146 dB(W/uVm) - 54 dB + 3 dB = -132 dB(W/m^2)
56 dB (μV/m) - 146 dB(W/uVm) - 35 dB + 3 dB = -122 dB(W/m^2)

Furthermore, No. 693 of the Radio Regulations provide a PFD of -129 dB(W/m^2) for use by the BSS (TV-FM) in the band 620-790 MHz.

TABLE IX
(Source: Table 6-XI in the CCIR Report to WARC ORB-88)

Specific sharing criteria

	References	Interfering services	Services subject to interference	Bands (MHz)	PFD limits (δ = elevation angle)
A	RR: Rec. 705	Broadcasting satellite	Terrestrial broadcasting	620-790	-129 for $0^\circ \leq \delta < 20^\circ$ -129+0.4 (δ - 20) for $20^\circ \leq \delta < 60^\circ$ -113 for $60^\circ \leq \delta < 90^\circ$ dB(W/m^2) on a provisional basis
B	RR: Article 28 Section IV	Earth exploration satellite Meteorological satellite	Meteorological aids	1 670-1 700	-133 dB(W/m^2) in any 1.5 MHz band
C	RR: Article 28 Section IV	Meteorological satellite Space research Space operation Radiodetermination-satellite	Fixed Mobile	1 525-1 530 for Regions 1 and 3 1 530-1 535 for Regions 1 and 3 1 670-1 690 1 690-1 700 1 700-1 710 2 290-2 300 2 483.5-2 500	-154 for $0^\circ \leq \delta < 5^\circ$ -154+0.5 (δ -5) for $5^\circ \leq \delta < 25^\circ$ -144 for $25^\circ \leq \delta < 90^\circ$ dB(W/m^2) in any 4 kHz band -154 dB(W/m^2) in 4 kHz
D	RR: Article 28 Section IV 2560	The same as in case C	Fixed using tropospheric scatter	The same as in case C	-168 dB(W/m^2) in any 4 kHz band at the receiver input of the station of the fixed service
E	RR: Article 28 Section IV	Broadcasting satellite Fixed satellite	Fixed Mobile	2 500-2 690	-152 for $0^\circ \leq \delta < 5^\circ$ -152+0.75 (δ - 5) for $5^\circ \leq \delta < 25^\circ$ -137 for $25^\circ \leq \delta < 90^\circ$ dB(W/m^2) in any 4 kHz band
F	CCIR: Rec. 358-3	Fixed satellite	Fixed (line-of-sight) Mobile (line-of-sight)	2 500-2 690	-152 for $0^\circ \leq \delta < 5^\circ$ -152+0.75 (δ - 5) for $5^\circ \leq \delta < 25^\circ$ -137 for $25^\circ \leq \delta < 90^\circ$ dB(W/m^2) in any 4 kHz band
G	CCIR Report 631-3	Broadcasting-satellite	Terrestrial broadcasting	620-790	Proposals for the provisional limits given in RR Rec.705 (case A) -129 becomes -136 (EBU) -125 (USA) -124 (USSR)
H	CCIR Report 631-3	Broadcasting-satellite	Mobile service (under some hypotheses)	around 800	High quality: -133 dB(W/(m^2 · 16 kHz)); mobile station -146 dB(W/(m^2 · 16 kHz)); base station Medium quality: -127 dB(W/(m^2 · 40 kHz)); mobile station -134 dB(W/(m^2 · 40 kHz)); base station
I	CCIR Report 224-5		Radioastronomy	408 610 1 420 1 420 1 665	For continuum: -189 dB(W/m^2) in 3.9 MHz -185 dB(W/m^2) in 6.0 MHz -180 dB(W/m^2) in 27 MHz For spectrum lines: -196 dB(W/m^2) in 20 kHz -194 dB(W/m^2) in 20 kHz
J	CCIR Report 697-2	Intermodulation of out-of-band signals	Radioastronomy	1 400-1 427 1 660-1 670	-80 dB(W/m^2) (1)

(1) This limit applies to services whose intermodulation products can arise in a band where radioastronomy service has an allocation."

Assuming an operational condition whereby each service area would be covered by 4 sound channels, all within the same television channel, and a receiving location at the edge of two adjacent service areas (where the signal is reduced by 3 dB), where reception from two satellite systems would be possible, the aggregate effect would correspond to a 6 dB increase in received unwanted PFD.

Considering the required p.f.d. for the system models mentioned in § 2.7.1 and comparing it to the permissible p.f.d. limits set above for single entry and aggregate cases, values for the required additional isolation for the non-constrained operation of the two services can be found. These values are given in Table X for the four system models. Such additional isolation can only be provided through both the discrimination from the satellite transmitting antenna on the basis of geographical sharing, as will be covered in § 2.7.5, and through the discrimination of the television receiving antenna towards the satellite.

In the case of the discrimination from the television receiving antenna towards the satellite, the elevation angle dependency, as implied in RR Rec. 705, will be assumed in this Report. We note, however, that in RR 693, no restriction is given above 20°.

$$\begin{array}{lll} \text{PFD (dB(W/m}^2\text{))} & & \text{for } \delta \leq 20^\circ \\ \text{PFD} + 0.4\ (\delta - 20) & (\text{dB(W/m}^2\text{))} & \text{for } 20^\circ < \delta \leq 60^\circ \\ \text{PFD} + 16\ (\text{dB(W/m}^2\text{))} & & \text{for } 60^\circ < \delta \leq 90^\circ \end{array}$$

TABLE X - *Additional isolation required to allow sharing between the sound BSS and the* terrestrial broadcasting service

System	PFD at centre of coverage area (dB(W/m^2))	Required isolation (minimum/maximum) (dB)
Conventional FM	-111.1	16.9/26.9
Companded FM	-120.4	7.6/17.6
Digital	-107	21/31
Advanced digital	-109	19/29

Receiving installations located at low latitudes can be able to take fullest advantage of this discrimination from the receiving antenna. Some advantage can be available at higher latitudes.

Upon more detailed consideration of the protection ratios for narrow-band carriers interfering into the television broadcasting service, it can be found that Recommendation 418 and Report 306 indicate some relaxations in protection ratios for certain relationships between the wanted and interfering television channel signal spectra. A 10 dB relaxation in protection ratio is feasible if the nominal frequency difference between the wanted television carrier and the unwanted sound carrier is an odd multiple of half the line frequency and the interfering carrier is not in the region of the colour sub-carrier. Furthermore, in the region between the low frequency luminance spectrum and the chrominance spectrum located around the colour sub-carrier, the television signal is less susceptible to interference from narrow-band carriers. A maximum relaxation of 10 dB to 20 dB, depending on the television system, is feasible in this region with 15 dB as a common value which would be applicable throughout. It should be noted, however, that only a limited number of carriers can be fitted in this less critical region of the television signal. Finally, in the region adjacent to the sound carrier, indications are that a relaxation of 25 dB in the protection ratio would be feasible over a relatively narrow band.

In those cases where the width of the frequency slot only allows for a limited number of sound carriers, the 6 dB aggregate value used in Table X can be decreased accordingly.

In the specific case where a single sound BSS carrier is located close to the television sound carrier, a total relaxation of 31 dB from the protection values used in Table X can be assumed.

It should be realized, however, that the relaxations as described above based on specific interfering sound carrier locations within the television channel, will only be feasible on a common basis if the television channels have been assigned according to a regular channel plan, i.e., as is the case in Region 2 (universal 6 MHz channel separation).

For all the cases mentioned below where geographical separation is required to avoid interference into the television broadcasting service, there is no need to consider the interference aspects in the reverse direction, namely from the television signal into the satellite sound broadcasting receiver since the geographical separation to insure a proper discrimination from the satellite transmitting antenna would bring the service area of the satellite sound broadcasting clearly beyond the coverage of the television transmitter.

However, in those cases where co-located operation is possible without undue interference to television broadcasting, further consideration should be given to the possibility that the television signal will create an unacceptable level of interference to the reception of the sound BSS.

Table X shows the required isolation to permit sharing with the terrestrial broadcasting service.

Sharing with conventional FM will be more difficult than in the case of companded FM. It should be noted that for both FM cases, the sharing situation would have been more difficult if it had been applied to the urban case. With respect to the digital systems, the greatly improved performance of the advanced system is accompanied by slightly improved sharing possibilities. Consideration of the discrimination available from the television receiving antenna improves the situation. Geographical sharing will be greatly facilitated for those areas between the sub-satellite point and the coverage area. For sharing with areas at an elevation angle of 60° to the satellite, 16 dB additional isolation would be afforded.

2.7.4.2 *Sharing with fixed services*

Since most systems in the fixed services are of the narrow band type, the sharing criteria are based on the spectral power flux-density (per 4 kHz). Consequently, energy dispersal will greatly improve the sharing situations. In the case where no energy dispersal can be applied to preserve compatibility with present FM receivers, the sharing will be quite difficult. This is supported by a study on sharing with fixed services in the 1429 MHz to 1525 MHz band as given in Report 941. This Report, based on the assumption of conventional FM transmission, is rather pessimistic on the acceptability of sound BSS in the 1500 MHz band.

The following permissible power flux-density limits for sharing with the fixed services at 1.7 GHz are taken from RR 2557. Assumption will be made that these limits can be used in order to provide a p.f.d. limit for this discussion, for all frequency bands where sharing between FS and sound BSS is considered. Furthermore, these limits are used in the present context as threshold p.f.d. values above which the interference to the fixed services would be considered unacceptable:

-154 dB(W/(m^2 · 4 kHz)) for $\delta \leq 5°$
$-154 + (\delta - 5)/2$ dB(W/(m^2 · 4 kHz)) for $5° < \delta \leq 25°$
-144 dB(W/(m^2 · 4 kHz)) for $25° < \delta \leq 90°$

It can be noticed that, in the 2.6 GHz band, the permissible p.f.d. for community reception, as per Radio Regulations 2562 to 2564, gives values very close to those stated above. Table XI shows the required isolation to permit sharing with the fixed service.

TABLE XI - *Required additional isolation to allow sharing between the sound BSS and the fixed service*

Systems	PFD at centre of coverage area (dB(W/(m^2 · 4kHz))	Required isolation (dB)	
		Low elevation angle	High elevation angle
Conventional FM	111.1	42.9	32.9
Companded FM	-120.4	33.6	23.6
Digital	-123.6	30.4	20.4
Advanced digital	-126	28	18

It can be seen from this Table that additional discrimination is required in all cases to allow sharing.

2.7.4.3 *Sharing with the mobile service*

The permissible power flux-density values are given in CCIR Reports 770, 631 and 358 for land mobile systems operating at frequencies between 470 MHz and 960 MHz and more specifically between 806 MHz and 942 MHz in Region 2. Report 770 provides directly applicable typical data whereas other sources, in particular Report 358, give the background considerations. These values are summarized in Table XII below for low elevation angles (below 20°) to provide protection to high grade services.

As seen in Table XII , the worst case of p.f.d. not to be exceeded is given in Report 770.

These limits have been used in the preparation of Table XIII . The required isolation referred to in Table XIII refers to p.f.d. limits for a base station. This will be the worst case unless the receiving antenna discrimination for a signal arriving from sound BSS exceeds 16 dB. Beyond this value, the mobile station will become the constraining case.

TABLE XII - *Typical system parameters and permissible p.f.d. for mobile services*

CCIR Reports	Base station			Mobile station		
	PFD (dB(W/m^2))	Band-width (kHz)	Receiving antenna gain (dB)	PFD (dB(W/m^2))	Band-width (kHz)	Receiving antenna gain (dB)
631	-146	16	15	-133	16	
358	-142.1	16		-132.1	16	
770	-147.9	30	17	-132	30	4.1

TABLE XIII - *Additional isolation required to allow sharing between the sound BSS and mobile services*

Systems	PFD at centre of coverage area (dB(W/(m^2 · 4 kHz)))	Required isolation (Report 770) (dB)
Conventional FM	-111.1	36.8
Companded FM	-120.4	27.5
Digital	-123.6	33
Advanced digital	-126	30.6

As can be seen from this Table, additional isolation will be required in all cases to permit sharing with the mobile service.

2.7.5 *Geographical sharing*

Geographical sharing can be used to resolve some difficult sharing situations. In such cases, co-located sharing of a given frequency band between the two concerned services is *not* possible: in contrast, for sharing to take place between networks of the two services in question, a *geographical separation* of the service areas of the two networks is required. When both of the services in question are terrestrial in nature, the geographical separations required may be in the tens to hundreds of kilometres in the UHF portion of the radio spectrum. In contrast, when one of the services is a space service, in this case the sound broadcasting satellite service, the separation required may be in hundreds to thousands of kilometres.

The concept of geographical sharing between the sound broadcasting satellite service and a terrestrial service is dependent on the permissible flux level from the sound broadcasting satellite space station into the terrestrial network. The actual level is determined by the power flux-density needed in the service area of the sound broadcasting satellite service and the required level of protection to the terrestrial service. The difference between these two levels will determine the amount of isolation between the two services to operate without undue interference to the terrestrial service. This isolation can be provided by the discrimination of the satellite transmitting antenna if the service area of the terrestrial service is located far enough from the satellite beam coverage. In situations where required separation distances are small, interference from the terrestrial network into sound BSS receivers should also be considered.

Section 2.4 of this Report deals with satellite transmitting antenna technologies and indicates that good sidelobe rejection will be possible in the future and that the reference pattern used at the WARC-77 to plan the BSS at 12 GHz could be realistically assumed.

Table XIV gives the separation distances needed for different required antenna discriminations for the minimum case where the satellite beam covers an area close to the satellite sub-point; and for the maximum cases where the beam is directed away from the satellite sub-point and the location where the interference occurs is just at the edge of the Earth where the interfering signal from the satellite arrives at 0° elevation angle. These separation distances indicate the radius around the centre of the beam beyond which there is enough discrimination from the satellite antenna alone to allow frequency re-use by other services.

TABLE XIV - *Range of required separation distances on the Earth from the sound BSS beam centre to ensure a given satellite antenna discrimination for 1° and 2° antenna beamwidths*

Required antenna dicrimination (dB)	Separation distance (km)				
	Off-axis angle (x φ_o)	φ_o - 1°		φ_o - 2°	
		Minimum	Maximum	Minimum	Maximum
3	0.5	312	2108	624	2965
10	0.91	570	2835	1142	3990
20	1.29	807	3362	1620	4742
30	1.58	989	3716	1988	5251
30.1	3.19	2007	5275	4098	7578
35	5.01	3183	6655	6740	9876
40	7.94	5183	8573	12938	14464

From the distances found above, geographical sharing can be applied to all cases of sharing where additional isolation beyond what is available from the receiving antenna is found to be necessary in order to allow operation of the sound BSS without affecting terrestrial services. This results in given separation distances for each specific case of sharing. These sharing situations along with their separation distances are summarized in Table XV.

TABLE XV - *Summary table of the situations and required separation distances*

Sound BSS system model	Interfered with service	Permissible PFD for sound BSS	Required isolation (dB)	Minimum separation distance for 1° beam (km)		
				Elevation Angle (degrees)		
				5	30	60
Conventional FM	Broadcasting					
(Case A)	- maximum protection	-138 dB(W/m^2)	10.9-26.9	3104	1510	676
	- minimum protection	-128 dB(W/m^2)	0.9-16.9	2717	1181	199
(-111.1 dB (W/m^2)) (-111.1 dB(W/(m^2·4 kHz)))	Fixed	-154 dB(W/(m^2·4 kHz))	32.9-42.9	9570	3652	2728
	Mobile - low elevation angle	-147.9 dB(W/(m^2·30 kHz))	36.8	6741	4827	--
Companded FM	Broadcasting					
(Case A)	- maximum protection	-138 dB(W/m^2)	1.6-17.6	2749	1208	264
	- minimum protection	-128 dB(W/m^2)	0 - 7.6	2151	668	0
(-120.4 dB(W/(m^2)) (-120.4 dB(W/(m^2·4 kHz)))	Fixed	-154 dB(W/(m^2·4 kHz))	23.6-33.6	5693	1529	981
	Mobile - low elevation angle	-147.9 dB(W/(m^2·30 kHz))	27.5	3124	1631	--
Digital	Broadcasting					
(Case A)	- maximum protection	-138 dB(W/m^2)	15-31.0	4976	1618	789
	- minimum protection	-128 dB(W/m^2)	5-21.0	2892	1330	463
(-107 dB(W/m^2)) (-123.6 dB(W/(m^2·4 kHz)))	Fixed	-154 dB(W/(m^2·4 kHz))	20.4-30.4	4824	1437	915
	Mobile - low elevation angle	-156.7 dB(W/(m^2·4 kHz))	33.1	5547	3704	--
Advanced	Broadcasting					
digital	- maximum protection	-138 dB(W/m^2)	13-29.0	3171	1567	736
(Case F)	- minimum protection	-128 dB(W/m^2)	3-19.0	2810	1260	361
(-109 dB(W/m^2) (-126 dB(W/(m^2·4 kHz)))	Fixed	-154 dB(W/(m^2·4 kHz))	18.0-28.0	3140	1363	861
	Mobile - low elevation angle	-156.7 dB(W/(m^2·4 kHz))	30.7	4899	3118	--

Case "A": Sound BSS intended for reception in rural areas at elevation angles exceeding 70°, corresponding to a service in low-latitude areas.

Case "F": For vehicular reception in heavily shadowed rural areas or in dense urban areas.

2.7.6 *Sharing with other services*

Besides the primary users of the 500 MHz to 2000 MHz band and its neighbourhood (broadcasting, mobile and fixed services), substantial allocations are provided for aeronautical, radionavigation and radiolocation services. Special sharing constraints on the use of adjacent bands may also arise from passive services such as radioastronomy services. Data for sharing with these other services are not yet available.

2.7.7 *Susceptibility of the sound BSS to interference from other services*

The susceptibility of the different analogue and digital modulation schemes to the interference from the other services with which the same frequency band is to be shared should be considered so that a complete picture of the sharing situation, in both directions, can be established for those cases where geographical separation is not required. It is expected that the digital systems, and even more so the advanced digital systems, will be more robust against interference than their analogue counterparts.

2.7.8 *Discussion of sharing situations*

It should be noted from the outset that the four system models used in the sharing analysis are typical system examples with specific system parameters and operating under given receiving conditions. In this way, the findings as to their sharing feasibility are not absolute since variations in the system parameters and operating conditions will ease or worsen the sharing conditions. For instance, the first three system models selected are assumed to be for reception in rural areas at low latitude. If reception in urban environments was to be covered, the necessary PFD level would need to be increased by 9 dB, therefore making the sharing more difficult. On the other hand, in the case of the fourth system (advanced digital), the grade of service was selected to cover reception in urban areas at high latitude with such systems. Operation in rural areas and low latitudes would make sharing conditions easier. In this study, the p.f.d.s have not been adjusted for operating frequencies different from the 1 GHz assumed. Operation at lower frequency would result in reduction of system PFD, for instance 6 dB at 500 MHz. In the case of sharing with the broadcasting service, some p.f.d. reduction would always be applied since the allocation is below 890 MHz. Also the chart shows a range of distances required for sharing with broadcasting services for various elevation angles. The three elevation angles shown, 5, 30 and 60 degrees, cover the range of discrimination in the vertical plane of the UHF TV receiving antenna assumed in this report, that is, from zero to 16 dB as the elevation angle of the sound BSS signal is increased above the horizontal plane.

It should be noted that the satellite transmitting reference pattern has a plateau at 30 dB isolation which represents a transition of about 1000 km. For those required isolation values slightly exceeding 30 dB, all means should be taken to reduce the isolation to less than 30 dB to obtain a substantial improvement in the sharing situation.

For the conventional FM system, the required separation distances found in Table XV indicate that sharing with fixed and mobile services would not be feasible. For the sound BSS to share with terrestrial broadcasting, a 199 to 3,104 km distance is required (which could further be reduced in the case of operation at lower frequencies) making near co-location possible in some situations at lower latitudes. Near co-location corresponds to the case where the TV station is outside but near the satellite coverage area, a situation which bears similarity to the existing inter-service sharing environment for terrestrial television.

In the case of the companded FM system, the sharing with the terrestrial broadcasting service requires even smaller separation distances (0 to 2,749 km) than for the case of conventional FM discussed above. Therefore, in some cases, operation in the same geographic area would be possible at the lower latitudes, considering only interference from BSS sound broadcasting space station transmitters to terrestrial UHF receivers. However, interference in the reverse direction, that is from terrestrial UHF TV transmitters, which have powers up to 5 megawatts, could cause interference to BSS earth station receivers in large areas around TV stations.

Sharing with the fixed service for low elevation angles requires large distances which can be diminished if energy dispersal is employed. In the case of areas with high elevation angles, sharing with the fixed service would permit near co-located operation with energy dispersal (an energy dispersal removal circuit can be assumed since new receivers with expanders would need to be manufactured in any case). Sharing with the mobile service will require relatively large separation distances which could be diminished to approximately 500 km with energy dispersal.

Considering the simple digital system, a range of 463 to 4976 km is required for sharing with the broadcasting service. Since the p.f.d. for all the operating frequencies must be adjusted, the threshold of 30 dB could easily be avoided and much smaller distances would be needed. Sharing with the fixed service will only be possible in the case of low elevation angles below 1 GHz at very large distances. At high elevation angles, sharing at a lesser distance will be possible. Sharing with mobile services will only be possible below 700 MHz and even so requiring large separations.

.The advanced digital system, in order to share with the broadcasting service, requires distances ranging from 361 to 3171 km. This means that co-location would be possible at high elevation angles. Furthermore, at a frequency of 500 MHz, near co-location would be possible, for elevation angles above 45°. **Sharing is feasible with the fixed service at medium to large distances depending on operating frequencies. Regarding sharing with the mobile service, it is only feasible below 1 GHz and then only for large separation distances.**

2.8 *Bandwidth considerations* [CCIR, 1978-82a] [CCIR, 1986-90a, b]

The total bandwidth required for a band 9 sound BSS depends on the modulation method and the extent of coverage overlap.

For conventional FM and based on the parameters with appropriate modification used for the planning of the broadcasting-satellite service in the 12 GHz band in Region 1, one can conclude from a study carried out by the EBU and ESA 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 national sound broadcasting programme per country. This study is valid for monophonic as well as sterephonic reception. The latter will, however, only be achievable with permanently-installed receivers. The higher protection ratio needed for the higher quality stereophonic FM reception is obtained through:

- the line-of-sight reception of permanently-installed receivers requiring no fade margin; and
- the radiation characteristics of the high-gain receiver antenna which makes it possible to discriminate between the wanted and interfering satellites if the latter are in different orbit positions.

A study conducted in Canada for Region 2 based on the RARC SAT-83 service areas concludes that frequency re-use will not be possible and consequently 10.8 MHz are needed for one national programme per service area. A different coverage approach with a higher degree of overlap results in a bandwidth increase.

Simple digital modulation methods tend to require larger transmission bandwidths per channel which, however, is partly balanced by the lower sensitivity to interference. A study made for Region 2 countries indicates a bandwidth requirement of some 13 MHz for one monophonic programme per Region 2 country. Stereophonic transmissions would consequently require 26 MHz.

The frequency of the carrier within the 500-2000 MHz band affects the level of frequency re-use and hence affects the amount of spectrum required to provide one programme per service area. A lowering of the operating frequency will increase the size of the minimum beam for a given minimum antenna size. The angular distance before the frequency can be re-used will consequently increase thus increasing the spectrum requirement until a point where frequency re-use becomes impossible. From that point onward, the spectrum requirement stays constant. In a study for Region 2, it was found that the spectrum requirement decreased by 25% going from 1 GHz to 2 GHz whereas a smaller increase, between 0% and 12%, was found going from 1000 MHz to 500 MHz.

Advanced digital system II uses, as a matter of principle, channels which are 4 MHz wide in which 12 to 16 stereophonic programmes are transmitted. A planning exercise has shown that with this system a total band of 84 MHz (i.e. 21 channels) can provide one 4 MHz channel with national coverage for each European country. This total bandwith may be reduced if the service areas are identical and regularly distributed.

2.9 *Feeder-link considerations* [CCIR, 1978-82a]

Feeder links for satellite sound broadcasting systems will likely be accommodated in bands allocated to the fixed satellite service. The required bandwidth will likely be small in terms of present FSS usage and will be commensurate with the bandwidth allocated to the broadcasting-satellite service (sound) down links.

2.10 Cost considerations

The economics of introducing a new broadcasting service depend on many factors, including the context in which it is to be introduced [Stott, 1985].

It is relevant to compare the costs of providing a satellite sound broadcasting service with those of providing a similar service by terrestrial means. It should be noted that the digital system may provide a higher quality service than conventional FM broadcasting. Thus, any additional value of such enhanced satellite service would need to be taken into account in any cost comparison with terrestrial means.

The magnitude of these costs, and their significance will vary from country to country and with time. Relevant cost factors include:

For a network of terrestrial transmitters:

- many transmitting sites, with transmitters, antennas, and accommodation;
- roads to provide access to them;
- power distribution or local generation to provide power to the transmitters;
- communication links from the studio centre to transmitting sites;
- staff to operate and maintain them;
- the cost of electricity is significant.

For satellite broadcasting:

- the provision and launch of a satellite together with provisions for back-up in the event of failure;
- one earth station, comprising the feeder-link transmitter and facility for TTC (telemetry, tracking and command - the functions needed to establish and maintain correct operation of the satellite)), which could possibly be situated at the studio centre, obviating the need for extra roads, power distribution and communication links;
- less staff;
- the feeder-link transmitter requires very little power compared with a network of broadcast transmitters.

In either case, the listening public must have suitable receivers and suitable programme material must be available.

System characteristics also affect the cost of receivers. This is one of the reasons why the first studies considered FM with characteristics identical to those in common use for terrestrial VHF broadcasting. Nevertheless, the development of digital systems which are readily amenable to mass production will help to contain receiver costs.

One way to reduce costs is to share the satellite, and thus the space-segment costs, with other services. Possibilities include:

- providing sound broadcasting to more than one country, each having individual national or sub-national coverage;
- providing additional revenue-earning services (e.g., data) which are unrelated to sound broadcasting;
- sharing the same spacecraft with other services such as FSS, MSS, etc.
- any combinations of the above.

Such possibilities would be facilitated by the development of suitable transmitting antennas which can provide more than one beam without significant increase in size and weight. An example is an array antenna with multiple beam ports.

2.11 Receiver complexity

The frequency modulation systems and those using simple digital techniques require only conventional receivers using well-known technologies. For conventional FM using the same modulation parameters as terrestrial VHF broadcasting one would only require to add to the existing receiver a simple frequency translator from the satellite operating frequency for the VHF broadcasting band. The advanced digital systems necessitate more complex signal processing techniques in the receivers (coherent demodulation, programme selection, Viterbi decoding, sound decoding). All these operations can nonetheless be done in future with integrated circuits manufactured in large quantities and hence of low cost.

Indeed, the experimental system described in Annex IV already utilizes large-scale C-MOS integrated circuits to perform complex coding and decoding functions.

2.12 Conclusions

The results of this study suggest that satellite sound broadcasting systems in band 9 could be realized with current technology for all areas ranging from the easiest case of rural equatorial areas to the most difficult case of urban areas at high latitude.

Three types of systems have been studied. The first model uses FM with parameters compatible with terrestrial FM broadcasting and provides monophonic reception in the case of portable and mobile receivers or stereophonic reception in the case of permanent installations where obstructions can be minimized and larger antennas can be used. Alternatively, one can use companded FM with reduced audio-bandwidth and deviation, although this signal is not receivable on conventional FM receivers. The second model uses digital modulation and can provide a wider range of facilities independent of the type of reception. The third model corresponds to advanced digital systems in which special coding, interleaving techniques and/or spatial diversity reception serve to reduce the effects of fading caused by multi-path propagation.

The most stringent service requirements are best satisfied using systems especially tailored for the purpose. Examples include the two advanced digital systems which offer a higher standard of service with reduced power and p.f.d. requirements compared to a simple digital system operating under the same conditions. In other circumstances however, a simple digital or analogue FM system would be adequate and appropriate.

All the digital systems offer the choice of providing a stereophonic service to all types of receiver (mobile, portable and fixed), with the flexibility to re-apportion the capacity, if desired, to provide two or more monophonic or data channels. The complexity of digital systems should not be regarded as a barrier to implementation or penetration of the service since such systems are readily amenable to integrated-circuit realization with attendant cost savings in mass production.

The bandwidth required for a satellite sound broadcasting service in band 9 depends on the modulation method and on the extent of coverage overlap. Studies performed by the EBU and ESA for almost the whole of Africa and Europe, and by Canada in Region 2, arrive at a required bandwidth of 9 to 11 MHz for providing one national sound broadcasting programme per country when this is transmitted by frequency modulation. Simple digital modulation tends to require a somewhat larger bandwidth.

With an advanced digital system, it is nonetheless possible to broadcast up to 16 stereophonic programmes with national coverage to each country, in a total band of 84 MHz as found in a study made for Europe.

Before a satellite-sound broadcasting service could be introduced, a revision to the Table of Frequency Allocations of the Radio Regulations would be necessary in order to make either an exclusive or a shared allocation to the service.

In general it is not easy for a satellite-sound broadcasting service to share a frequency band with other services, and for this reason an exclusive band allocation would be preferred. It can be argued that this arrangement would ultimately lead to the most efficient use of the spectrum when many satellite sound broadcasting systems have been introduced. Nevertheless, sharing on the basis of geographical separation is possible in certain circumstances, especially for low-p.f.d. systems. The discrimination provided by the receiving antennas of the terrestrial services to be protected was found to greatly improve the geographical sharing situation when those services are in areas with high elevation angles to the satellite. The designation of a relatively wide shared band within which adequate segments could be used, subject to varying constraints, might provide a flexible alternative means to implement satellite sound broadcasting systems.

3. Systems for band 7*

It should be noted that the Radio Regulations do not provide for the use of satellite transmissions in this band.

3.1 *Introduction*

Transmissions in this band depend on the reflection and refraction properties of the ionosphere to extend the service area beyond that which is served by the ground wave. There are many variables associated with the use of the ionosphere which are a function of operating frequency, time of day, season, solar activity and geographical latitude and longitude. To provide the desired grade of service in the presence of these variables, it is common practice to simultaneously transmit a single programme in different bands and on multiple channels within the same band, often resulting in congestion and poor service quality.

The application of satellite techniques might lead to better utilization of the allocated bands. The ionospheric conditions which permit penetration of the ionosphere by satellite emissions can, in certain conditions, preclude long distance terrestrial transmissions, particularly above about 15 MHz.

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* Section 3 with Table XVI was not accepted by all administrations at the Interim Meetings of Study Groups 10 and 11 (1983).

The concept of using satellite techniques for sound broadcasting in band 7 is not new. This concept was actively studied within the CCIR until the early 1970s and the results may be found in Report 215-2 (New Delhi, 1970). These studies showed the need for high RF power (of the order of 200 kW) which was due, in part, to the unavailability of spacecraft transmitting antennas with appreciable gain. In the context of the then existing state-of-the-art in satellite technology and launch vehicle capability, the technical and operating characteristics of satellite sound broadcasting systems operating in band 7 were formidable requirements which challenged the technological feasibility of the application. However, recent work within the United States of America on the development and the reduction of weight of large space antennas [Freeland, 1982] and associated technology shows promise. Nevertheless, considerable further study is required before the feasibility at an acceptable cost can be demonstrated.

3.2 *Quality objectives and suitable modulation methods*

It is common practice in HF broadcasting to specify a median field strength within the service area as opposed to specifying a test tone-to-unweighted noise at the output of a fully specified or standard receiver. In keeping with this practice it is deemed sufficient to specify a field strength objective to be equalled or exceeded over the service area.

It is assumed that amplitude modulation will be used because of the large numbers of AM receivers presently in use and for the foreseeable future. To provide an acceptable quality of service to low-cost portable HF receivers in a noisy radio-frequency environment requires that the median field strength be of the order of 50 dB(μV/m) to 60 dB(μV/m). The system example given in § 3.5 assumes 60 dB(μV/m) for the required median field strength.

3.3 *Technically suitable frequencies*

Ionospheric propagation effects are the key technical elements in identifying suitable frequency bands for satellite sound broadcasting. Pending further propagation and interference studies, it is believed that 15 MHz may be the lowest suitable frequency during night-time hours and during periods of low sunspot activity. The suitability would increase with frequency, and frequencies up to 26 MHz could be received by HF broadcast receivers.

3.4 *Propagation factors*

Trans-ionospheric propagation of satellite emissions in band 7 is a function of the complex dielectric properties of the ionosphere and their temporal and spatial distribution. These properties cause Faraday rotation, scintillation, absorption, reflection and refraction of electromagnetic waves traversing the ionosphere. The ionosphere is influenced primarily by solar radiation. As a result, the characteristics of the ionosphere exhibit diurnal, seasonal and solar cycle variations.

Report 725 describes the properties of the ionosphere, and Report 263 describes the ionospheric effects on Earth-space propagation.

Shielding of the Earth by the F layer and to a lesser extent by the sporadic-E layer is the most detrimental effect the ionosphere can have on satellite transmissions. The conditions for which the ionospheric penetration occurs and for what periods of time are factors determining the feasibility of satellite sound broadcasting in band 7. These conditions have been studied and are reported in detail in [Phillips and Knight, 1978].

3.4.1 *Shielding by the F layer*

Penetration of the F layer by geostationary-satellite emissions in the 26 MHz band is such that a sound broadcasting service could be provided to latitudes as great as 55° on 90% of the days around local noon. This service availability would be realized during periods when the smoothed sunspot number (R_{12}) is as high as 100.

3.4.2 *Shielding by the sporadic-E layer*

Shielding by sporadic E is expected to occur for less than 1 to 5% of the time during the summer season, and for small percentages of time for the other seasons.

3.4.3 *Absorption*

Extrapolating data to the 26 MHz band as given in Report 263, absorption under normal conditions will be between 0.9 and 2.2 dB and as much as 20 dB during a solar flare.

3.4.4 *Faraday rotations*

Faraday rotation of a linearly-polarized wave can be of the order of 400 revolutions at 26 MHz. Consequently, circularly polarized satellite emissions are required to avoid deep fading of signals when received using simple dipole antennas.

3.4.5 *Coverage area produced by scatter from the earth and by antenna sidelobe radiation*

In addition to a primary coverage area produced by direct illumination from the satellite, there will be, under certain conditions as illustrated in Fig. 1, a secondary area formed by scatter from the Earth's surface and consequent reflections from the ionosphere, as on ordinary Earth-Earth links [CCIR, 1982-86b].

Factors affecting this scatter propagation mode include: diurnal, seasonal and solar cycle effects on the electron density profile of the ionosphere; the geographic and geomagnetic location of the coverage area; the angle of incidence on the coverage area of the wave emitted by the satellite; and the relative roughness of the surface of the coverage area (must be sufficiently rough to generate diffuse reflections).

Preliminary calculations of the field strength were carried out using the methods described in [Chernov, 1971] for the following conditions: an illumination frequency of 26 MHz; a field strength of 60 dB(μV/m) in the coverage area; a diameter of 1000 km of the primary coverage area located at the equator; and the area is hilly, the ratio of r.m.s. height to the terrestrial irregularity correlation radius is equal to 0.05. The ionospheric conditions were taken for January, sunspot number R_{12} = 100 and 1800 h local time in the coverage area (see Report 340). The results are presented as field strength contours.

The results of the calculations for an illuminated area centred at 0° N, 20° E are shown in Fig. 2. The illustration shows that with an initial field strength of 60 dB(μV/m), the area illuminated by a scatter field strength higher than 30 dB(μV/m) is many times greater than the original area. However, to use the additional area as wanted area is difficult owing to variability of the ionosphere and fluctuating dimensions and borders of the area. This scatter effect is fairly large and may cause interference at the given frequency in adjacent areas. According to the test results [CCIR, 1986-90g] the antenna sidelobe radiation of the satellite may, in some circumstances, be quite substantial and must not be neglected.

Additional study is required to characterize statistically these effects (percentage of time and geographical extent) taking into account the factors enumerated above which affect this propagation mode.

3.5 *Example system*

The technical performance characteristics for an example system operating from the geostationary orbit are shown in Table XVI. This example is intended to highlight technical characteristics associated with a satellite system providing a good grade of service to an area with a high level of man-made noise.

3.6 *Conclusion*

Satellite and launch vehicle technology that may be used for transmission in band 7 is currently under development in the United States of America and the possibility requires examination to see whether it could lead to more effective use of the frequency spectrum. A preliminary analysis of the propagation factors indicate that systems operating in the 26 MHz band are capable of providing better than a 90% service availability during daylight hours independent of the operating period within the 11-year solar cycle. During the period of low solar activity, systems operating as low as 15 MHz may perhaps be capable of providing high availability service at night and to a lesser extent during the day.

However, further study is required before both the technical and economic feasibility of the system and its potential for achieving better frequency usage can be demonstrated.

TABLE XVI – *Link budget for geostationary sound broadcasting-satellite systems in band 7*

Operating frequency (MHz)	26
Modulation method	AM
Transmitting power (kW)	16
(dBW)	42
Satellite transmitting antenna gain (dBi)	40.2
Half-power beamwidth (degrees)	1.6
Satellite antenna diameter (m)	500
E.i.r.p (dBW)	82.2
Spreading loss (¹) (dB)	–163
Absorption (dB)	–2
pfd at edge of beam (–3 dB) (dBW/m²)	–85.8
Field strength (dB(μV/m))	60
(μV/m)	1000
Polarization loss (dB)	–3
Receiving antenna gain (²) (dBi)	0
Received signal power (dBW)	–78.5
System noise figure (³) (dB)	40
Noise bandwidth (kHz)	10
Noise power (dBW)	–122.2
Carrier-to-noise ratio (dB)	43.7
Test tone-to-noise ratio in 5 kHz (⁴) (dB)	43.7

(¹) Corresponds approximately to 20° elevation angle.

(²) Simple dipole or whip assumed.

(³) Median business area man-made noise (see Report 670).

(⁴) 100% modulation assumed.

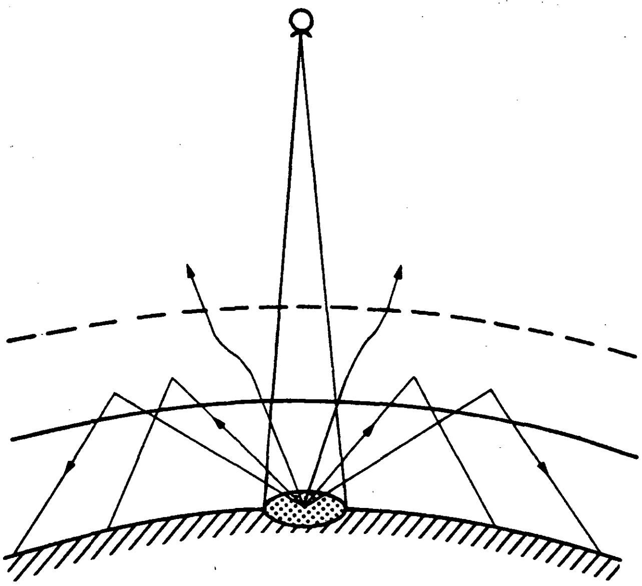

FIGURE 1 – *Area illuminated and scattering of energy*

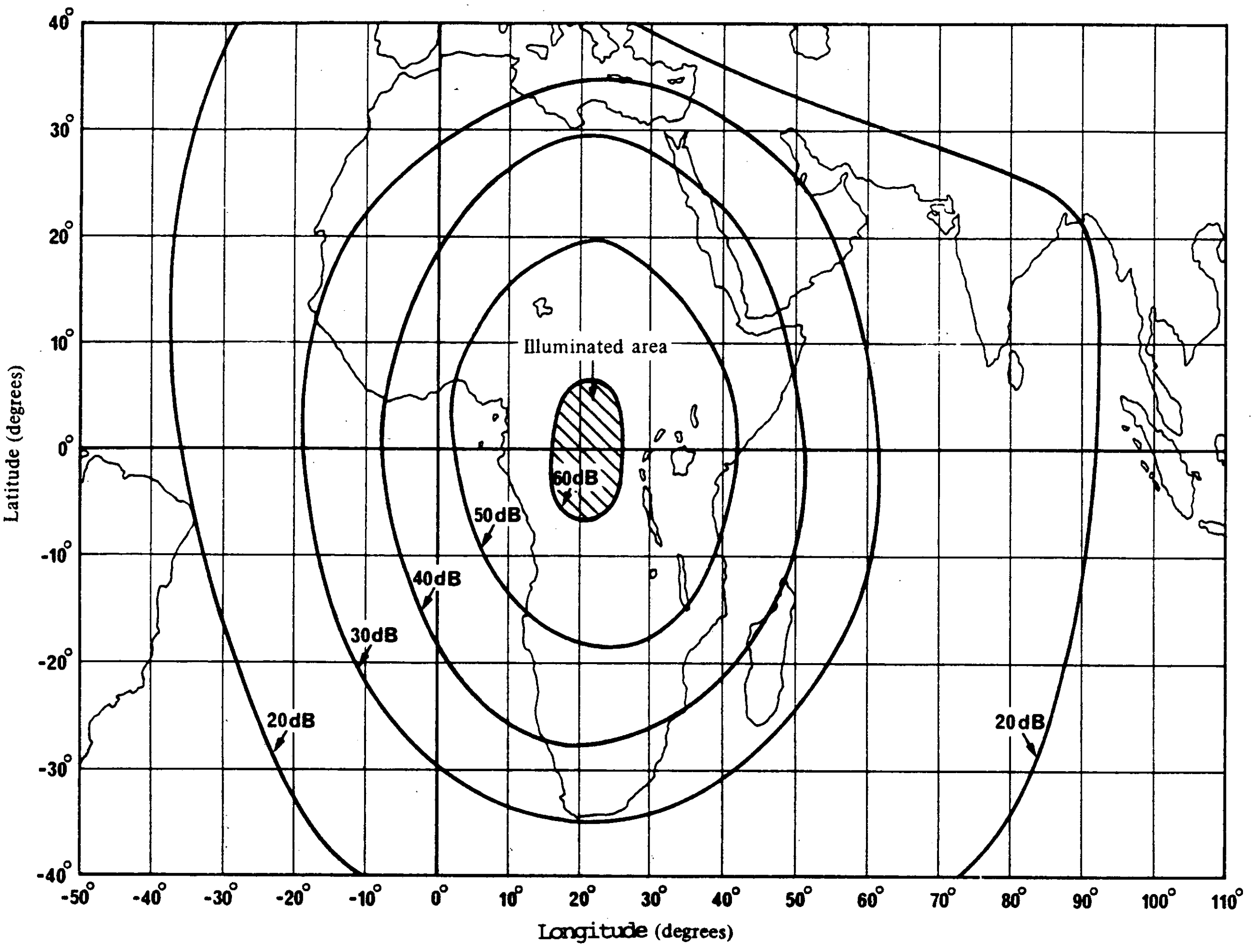

FIGURE 2 – *Calculated results for a 26 MHz transmission frequency and centre of illuminated area at 0° N, 20° E*

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ANNEX I

Satellite transmitting antenna technology

[CCIR, 1986-90a]

1. Introduction

With the relatively lower EIRP now required (see §2.6.4) which will result in a lowering of the required primary power and thus the total satellite size, it seems that the satellite antenna remains the only critical element in the realization of the space segment to provide UHF sound BSS. This annex covers the details of a number of techniques to realize the antennas and their expected performance.

Satellite-borne antennas with diameters in the range of 5 meters to 55 meters are currently in various stages of development for advanced applications such as mobile communications satellites, orbiting very-long-baseline-interferometry (VLBI) astrophysics missions, and Earth remote sensing missions [Freeland et al., 1986]. The technology being developed for these other types of applications is directly applicable to satellite sound broadcasting systems operating in band 9.

Satellite-borne antennas with diameters greater than about 3 to 4 meters must be designed so that they may be launched in a stowed configuration, and deployed once the satellite has achieved its proper orbit and has been stabilized. This constraint has led to large-aperture, reflector antenna designs based on the use of a collapsible or foldable support structure and of a light-weight, pliable, metallized mesh reflector surface.

The types of supporting structures used on the different satellite-borne antennas currently under development include the hoop/column, the tetrahedral truss, and the wrap-rib. Figure 3 shows the wrap-rib and hoop/column antennas both in the partially deployed and fully deployed stages. These deployable antennas are all of relatively light-weight and use a mesh material as the reflecting surface. In the deployed configuration, the mesh antenna surface is formed into a paraboloid either by a series of tie-points between the members of the supporting structure and the mesh (the hoop/column and tetrahedral truss antenna) or by attaching the mesh to a shaped rib (the wrap-rib antenna). The surface accuracies achieved using these shaping techniques are such that the measured radiation patterns of these developmental antennas generally conform to the co-polar reference pattern for satellite transmitting antennas given in Figure 3 of Recommendation 652.

2. SUPPORTING STRUCTURE

2.1 Hoop/Column

A 15 meter diameter hoop/column antenna has been built and tested in a ground environment [Belvin and Edighoffer, 1986]. The antenna deploys from a volume of about 1 meter in diameter by 3 meters high to a structure that is 15 meters in diameter by 9.5 meters in height. A motor driven cable system is used to deploy the antenna.

2.2 Tetrahedral Truss

A technology-demonstration 5 meter diameter tetrahedral truss antenna has been built and tested [Dyer and Dudeck, 1986]. When packaged, the overall antenna height is 1.8 meters, the truss height is 1.1 meters, the mesh diameter is 1.4 meters, and the truss diameter is 0.9 meter. The antenna is a freely deploying system that does not require motors to deploy. Deployment makes use of energy stored in the folded spring hinges (carpenter tape hinges) of the structure.

2.3 Wrap-Rib

Large-aperture, deployable reflector antennas based on the wrap-rib design use the most mature deployable antenna technology available [Naderi, 1982]. A 9.1 meter diameter version of this antenna was flown on the Applications Technology Satellite-6 (ATS-6) in 1974 [Marsten, 1975]. A preliminary design study was conducted in 1979 to characterize offset fed and axi-symmetric reflector antennas for missions requiring antennas in the 100 meter to 150 meter diameter range. The study identified critical technologies, estimated the cost and schedule required to develop the antenna, and developed a technology plan for a low-cost, low-risk "proof-of-concept" demonstration [Freeland et al., 1984].

The proof-of-concept was demonstrated in 1984, when a partial reflector was deployed in a simulated zero-gravity environment. The proof-of-concept model was a segment of a 55 meter diameter reflector consisting of a central hub (around which the ribs are wound when in the stowed configuration) and four ribs (contoured to the shape of a parabola) to which the mesh reflector material was attached. The tests demonstrated the efficacy of the deployment method and of the mesh-deployment management system.

3. REFLECTOR SURFACE

The performance of these large aperture space-borne antennas may be affected by the characteristics of the reflector material and by the accuracy of the reflector contour.

3.1 Effects of the Wire Mesh

A knitted wire mesh is the reflector material of choice for each of the antenna types cited. A typical mesh is a tricot knit of 0.003 cm diameter gold-plated molybdenum wire with about 3 openings per centimeter. An analysis to determine the effects of the knitted wire mesh on the gain, side lobe, and cross-polarization performance of large-aperture antennas has been performed [Rahmat-Samii and Lee, 1985]. It was shown that the performance of the mesh reflector antenna should be comparable to that of a solid reflector antenna when the geometry of the mesh material was properly selected (i.e., by properly selecting the opening size relative to a wavelength, rectangular vs. square openings, and the orientation of the rectangular opening relative to the incident polarization vector). Specifically, side lobes in excess of 30 to 35 dB below the level of the main beam were achievable using a pliable, light-weight, wire mesh reflector material.

3.2 Surface Accuracy

The hoop/column and the tetrahedral truss antennas use tie-points to connect the mesh surface to the support structure and to form the surface into a parabolic shape. It was found that grating lobes were generated in the far-field pattern by periodic "pillowing" of the surface, which was in turn, caused by errors in "tensioning" the uniformly spaced tie-points. When the placement of the tie-points was randomized, the grating lobes were no longer evident [Bailey, 1986]. Figure 4 illustrates the measured performance of an offset-fed, 5 meter tetrahedral truss antenna operating at a scale frequency of 4.26 GHz [Dyer and Dudeck, 1986]. It is noted, that this performance should scale to a 20 meter diameter antenna operating at a frequency around 1 GHz.

The achievable surface accuracy of the wrap-rib antenna has also been studied. This antenna design relies on both the accuracy and on the thermal characteristics of the rib cross-section to define the reflector surface formed by the mesh. Studies of the performance of a 20 meter diameter wrap-rib antenna in a space environment indicate that an rms surface accuracy of 3 mm can be achieved [Freeland, 1987]. This corresponds, for example, to an rms surface accuracy of $\lambda/100$ at an operating frequency of 1 GHz; a value that will ensure low side lobes.

4. IN-ORBIT TESTS

In order to verify that these large aperture deployable antennas will perform as required in a space environment, it is necessary to test them in an environment that simulates, as closely as possible, the zero-gravity and thermal vacuum conditions found in outer space. Ground testing of these antennas, even when suitable facilities exist, is extremely difficult and expensive, and frequently yields results of questionable value. A flight test of a high-performance, low-side lobe, 20 meter diameter wrap-rib prototype antenna system on the Shuttle or on another suitable vehicle is being studied as a means to significantly reduce the risk and uncertainty associated with the operational use of an antenna and to provide the added benefit of helping to validate ground test procedures for future antenna systems [Freeland et al., 1986; Freeland, 1987].

5. SUMMARY AND CONCLUSIONS

There is significant work underway to develop high-performance, deployable, light-weight, space-qualified reflector antennas with diameters ranging from 5 meters to over 55 meters and which exhibit sidelobe levels on the order of 30 dB or more below the peak gain of the antenna. Axi-symmetric and offset-fed antennas are being developed. A tricot knit, gold-plated molybdenum wire mesh is used for the reflecting surface. Analyses, confirmed by experiment, show that a properly chosen wire mesh reflector surface will not degrade the antenna performance in the sidelobe region. When this condition is met, the antenna performance in the sidelobe region is primarily determined by the mechanical deviations of the reflector surface from a paraboloid. During the course of developing the tetrahedral truss antenna, it was found that random positioning of the tie-point locations was an effective means by which to eliminate the grating lobes exhibited by antennas that use regularly spaced tie-points.

The difficulties associated with space-qualifying these large-aperture deployable antenna structures using ground testing has led to the study of using flights of the Shuttle or other suitable vehicles to perform the requisite qualification tests. In-orbit testing of a high-performance, 20 meter diameter wrap-rib antenna is being studied.

It may be concluded on the basis of the on-going work cited in this contribution that the satellite transmitting antenna radiation pattern given in Figure 9 of Annex 5 to Appendix 30 (ORB-85) is a viable reference radiation pattern to use for sharing studies and for system studies involving satellite sound broadcasting systems operating in band 9.

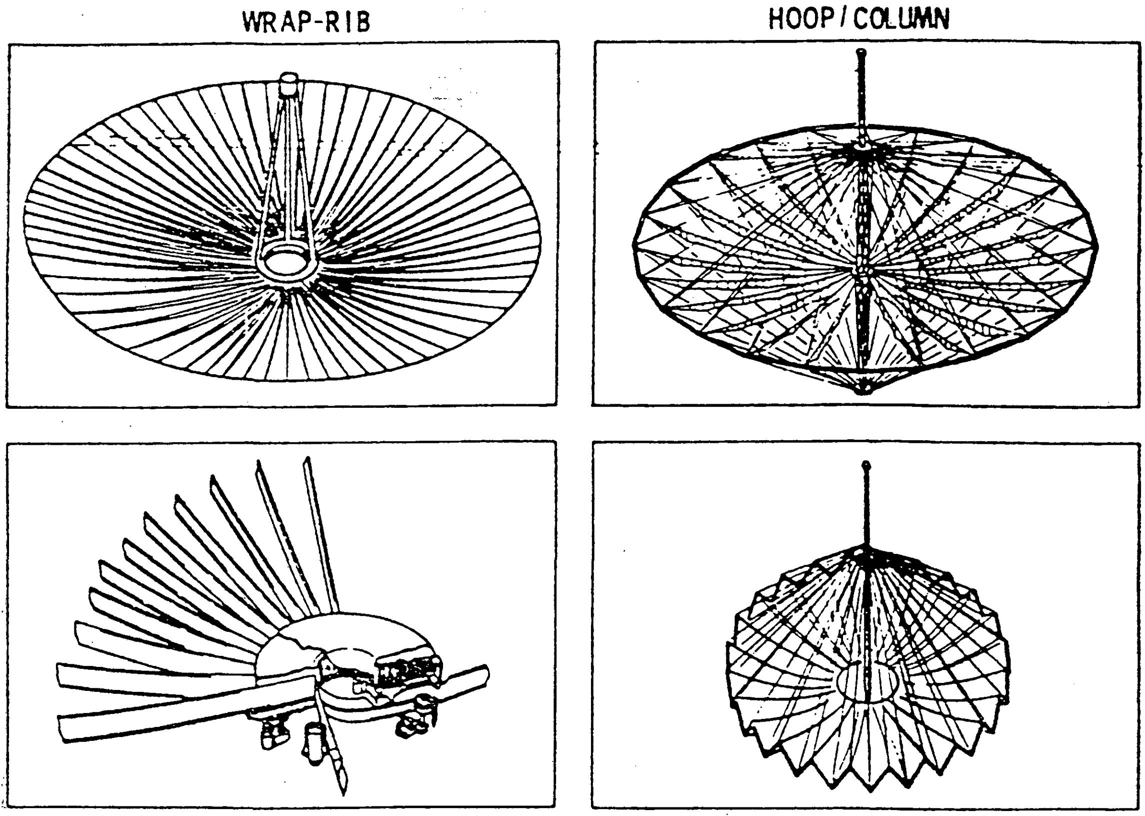

Figure 3 - Partially and fully deployed wrap-rib and hoop/column antennas [Jordon et al, 1984].

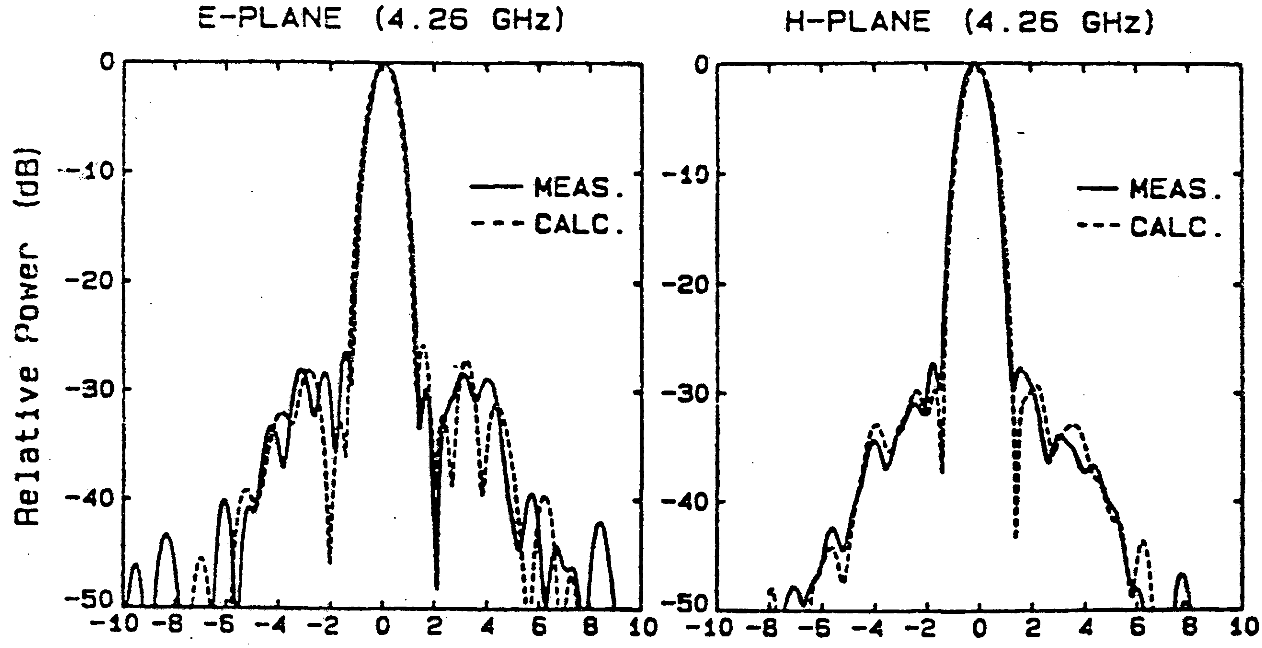

Figure 4 - Comparison of the calculated and measured antenna pattern of a 5 meter tetrahedral truss antenna operating at 4.26 GHz [Bailey, 1986].

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ANNEX II

Propagation characteristics and link margins of the UHF satellite channel

[CCIR, 1978-82a, b, c] [CCIR, 1986-90a]

1. Introduction

Satellite sound broadcasting to portable and mobile receivers is different in several respects from its terrestrial counterpart. On the other hand, there are some similarities with satellite land-mobile communications.

Previous studies by the EBU [CCIR, 1978-82d] and the United States [CCIR, 1978-82e] considered specific examples of link budgets and link margins for certain angles of elevation, conditions of reception and other parameters. Two specific methods have been suggested and various aspects are analyzed and compared in section 3 of this annex.

The recent experiments have shown substantial agreement with the signal power distribution functions for large and small area (see section 2). In the light of the European experimental programme [Jongejans , 1986] , a new composite propagation model is proposed. This model combines both the small area Rice/Rayleigh probability function and the large area log-normal probability distribution.

The design of suitable modulation systems for the type of broadcasting service will rely on propagation statistics relating to time-delay spread and correlation bandwidth of the transmission channel. These concepts, together with other related topics, have not been previously discussed in Report 955; they are now presented in section 4 of this annex, together with the recent experimental data.

2. Propagation models

The probability distribution functions relevant to the reception of satellite signals were found to correspond to a number of statistical distribution models related to the specific environment. These distribution models are generally different in so-called "small areas" and "large areas". The former are usually defined as locations extending over a number of wavelengths (for example over 40 wavelengths resulting in a distance of about 10 m). The latter extend over several small areas.

2.1 Large area distribution function

On large areas, it has been found experimentally [Guilbeau, 1979; Hess, 1980; Lutz, 1986, Jongejans 1986], that the probability distribution function of the mean received signal power takes the log-normal form:

$$P_{LN}\ (S_o;\mu,\sigma) = (K/(S_o\ \sigma))\ \exp\left[\left(-1/2\right)\left((L_{So}-\mu)/\sigma\right)^2\right], \qquad (1)$$
$$K = 10/(\sqrt{2\pi}\ln 10)$$

where:

So(W): mean received signal power over a small area;

$\bar{S}_f$(W): mean received signal power over a large area under free space propagation conditions;

L_{So}(dB) = 10 log(So/$\bar{S}_f$, level of So relative to free space level;

μ(dB) = mean of L_{So} over a large area;

σ(dB) = standard deviation of L_{So} over a large area.

In equation (1), the mean value and the standard deviation are both expressed in terms of dB, relative to the free-field power level, in order to facilitate comparison between the theoretical model and measured data.

The large area model given above was experimentally verified and confirmed by [Lutz *et al*, 1986] and [Jongejans *et al*, 1986]. Using the same notation as in equation (1), the following parameter values were measured (see Table XVII).

TABLE XVII - *Measured large area parameters for various* environments

Environment	Antenna	μ_{sh}(dB)	σ_{sh}(dB)	CF	μ_{los}(dB)	$(C/M)_{los}$(dB)
Urban	C3	-10.7	3.0	0.60	-1.8	3.0
	D5	-12.2	4.4	0.78	-4.9	9.3
	S6	-12.9	5.0	0.79	-5.2	11.9
Woods	C3	-9.3	2.8	0.59	-2.7	9.9
	D5	-5.3	1.3	0.54	-1.8	10.7
	S6	-5.8	1.1	0.56	-2.1	12.9
Highway	C3	-7.7	6.0	0.25	-0.4	11.9
	S6	-7.0	4.8	0.23	-0.6	18.3

where:

μ_{sh}(dB) : μ in shadowed areas,

μ_{los}(dB) : μ in non-shadowed (line-of-sight) areas,

σ_{sh}(dB) : standard deviation of S_o in shadowed areas

CF : clutter factor, defined as the proportion of the time for the direct path being obstructed assuming a constant vehicle speed

$(C/M)_{los}$(dB) : ratio of direct (carrier) signal to the diffuse multipath power in non-shadowed (line-of-sight) areas

C3 : hemispherical pattern, 3 dBi gain

D5 : toroidal pattern, 5 dBi gain

S6 : toroidal pattern, 6 dBi gain

Several points may be deduced from Table XVII:

- The measured average power levels in shadowed areas are very much less than those in non-shadowed areas in the same environments; for example, in urban zones the additional attenuation due to shadowing may be as high as 9 dB, in the woods 6.5 dB and on highways 7 dB. It follows that the main problem in providing a service is to overcome shadowing effects.

- The influence of the type of the receiving antenna seems to be quite significant especially on the ratio between the direct component and the multipath power in the non-shadowed areas.

- In urban areas, the shadowing loss is proportional to the antenna gain. Standard deviation, σ, and C/M ratio are proportional to the antenna gain. This last fact may be significant in the design of digital modulation systems for reception in urban areas.

In the European experiment simulation of the satellite transmission conditions were created by positioning the transmitting antenna on the Eiffel tower in Paris and measurements were made at a frequency of 839 MHz and for an average elevation angle of 25° [Guilbeau, 1979]. From this reference one can extract the parameters for equation (1). Table XVIII lists these parameters together with the values predicted from US data for the frequency of 839 MHz and an elevation angle of 25°. The values of the PROSAT expriment are derived from Table II.

TABLE XVIII

Urban zone			
Parameters of log-normal distribution for urban areas	Average	Obstructed visibility	Direct visibility
μ (dB) Guilbeau	-7.5	-11.5	-0.7
(USA)	-6.3	-10.1	-2.6
PROSAT	-6.3	-10.7	-1.8
σ (dB) Guilbeau	3.2	2.9	2.0
(USA)	3.7	4.3	3.1
PROSAT	-	3.0	-

From this table it can be seen that reasonable agreement exists between the three experiments.

Measurements made with the ATS-6 satellite in the United States [Hess, 1980] provide values for μ and σ for different areas under different receiving conditions. From the above reference a simple method for the assessment of μ and σ can be derived as follows:

$$\mu = -[A + 1.93 f - 0.052 \delta] \quad (2)$$

$$\sigma = 1/2 [B + 0.053 f + 0.040 \delta] \quad (3)$$

where the parameters μ, σ, $\overline{S}_o$ and $\overline{S}_f$ are defined in Equation (1), and

f: frequency (GHz)

δ: elevation angle (degrees)

Values for A and B are given in Table XIX for different receiving conditions. In the Table direct visibility indicates instances where the streets in the urban area are running parallel to the satellite azimuth and obstructed visibility is on streets running perpendicular to the satellite azimuth combined with the unfavourable side of the street.

TABLE XIX

	Urban zone			Suburban/rural zone		
	Average	Obstructed visibility	Direct visibility	Average	Obstructed visibility	Direct visibility
A(dB)	6.0	9.8	2.3	1.1	5.1	0.5
B(dB)	6.4	7.6	5.2	1.1	2.4	-

These values were partially derived from [Hess, 1980] by extrapolating with the assumption that sensitivities were 0.1 dB/percent for rural and 0.2 dB/percent for urban areas, below the specified 90% coverage level. They were confirmed by the European experiments [Lutz and Jongejans ,1986] for urban areas and woods. However, this modelling does not seem to be appropriate for the non-shadowed highways.

2.2 Small area distribution functions

The recent European [Jongeans, 1986] and United States' data indicate that the small area behaviour of the received signal can be modelled by a Rician distribution (constant vector plus Rayleigh distributed vectors).

If the ratio of direct signal power C to the diffuse multipath signal power M is denoted as C/M, the envelope probability distribution in an isolated small area is given by equation (4):

$$p(r) = (r/M)(\exp(-r^2/2M - C/M) \cdot I_0 [r \sqrt{2C}/M] \quad (4)$$

The parameter C/M is important as a measure of fading characteristics* of the channel. If C/M is high, the envelope probability distribution p(r) approaches a Gaussian distribution with mean $\sqrt{2C}$ and standard deviation $\sqrt{M}$. If C/M is low, p(r) approaches a Rayleigh distribution since: the modified Bessel function of first kind zero order

$$I_0(z) = \sum_{n=0} z^{2n}/2^{2n} (n!)^2 = 1 + z^2/4 + \dots$$

approaches 1 as z approaches 0.

The corresponding probability density of $y = \frac{r^2}{\overline{r^2}}$ is given by:

$$p_R(y) = (C/M + 1) \exp [-y(C/M + 1) - C/M] \cdot I_0 [2\sqrt{y(1 + C/M)C/M}] \quad (5)$$

where:

$$y = r^2/\overline{r^2} = r^2/s_0$$

---

* The time intervals with received power level below a certain threshold are called fades.

The level crossing rate (LCR) at the level V is given by equation (6):

$$LCR = \frac{b}{\sqrt{2\pi}} p_R(V) \qquad (6)$$

where $p_R(V)$ is the envelope of the Rice probability density function at the value V, and b is the function of magnitude and the frequency content of the multipath reflections:

$b = 2 \pi^2 B_d^2 \cdot M$, where B_d is a Doppler spread.

Equation (6) shows that the level crossing rate and probability density function are closely linked. Therefore, the parameter C/M of $p_R(y)$ can be determined through the measurement of LCR.

The average fade duration (AFD) at the level V is given by:

$$AFD = (1/LCR) \int_0^V p_R(r)\, dr \qquad (7)$$

AFD is an important factor in designing a digital transmission system which should be designed in such a way that it overcomes long fades using a complex interleaving system.

The validity of the Rice model has been demonstrated by the PROSAT experiment on the basis of a composite log-normal - Rice mode (see § 2.3).

Some typical average values of C/M for non-obstructed visibility are given in Table XVII (see § 2.1). Since C/M is the only parameter $p_R(y)$ given by equation (5), the Rice probability function $p_R(y)$ is fully characterized if C/M is known.

In /Jongejans, 1986/ some typical values of LCR and AFD at mean envelope level are given for vehicle speed 30 km/h. They are reproduced in Table XX below:

TABLE XX - The LCR and AFD values in different environments

	LCR (Hz)	AFD (ms)
Open area	30	20
Suburban	14	40
Rural	16	33

2.3 *The combined propagation model*

European researches [Jongejans, et al, 1986] and [Lutz, 1986] concluded that the probability density function of the received power should combine log-normal and Rice (Rayleigh) distribution in order to take account of both large-area variations and small-area variations. The distribution of instantaneous values in a small area is obtained by considering a Rice or Rayleigh variable whose mean value is itself a random variable having a log-normal distribution. The combined distribution of the received power S may be described as shown in equation (8):

$$P(S) = CF \int_{0}^{s_m} P_r(S,So)\, P_{LN}(So)\, dSo + (1-CF) \int_{s_m}^{s_M} P_R(S,So)\, P_{LN}(So) dSo \qquad (8)$$

where:

S_o : average received signal power over small area ($S_o = C + M$)

p(S) : combined distribution density function of the instantaneous received power in a small area

P_r (S,So) : Rayleigh distribution over obstructed (shadowed) small areas

P_{LN} (So) : distribution of mean power of small areas distributed over a large area

Sm : maximum obstructed power over a large area concerned

P_R (S,So) : Rice distribution over nobstructed (renshadowed) small areas

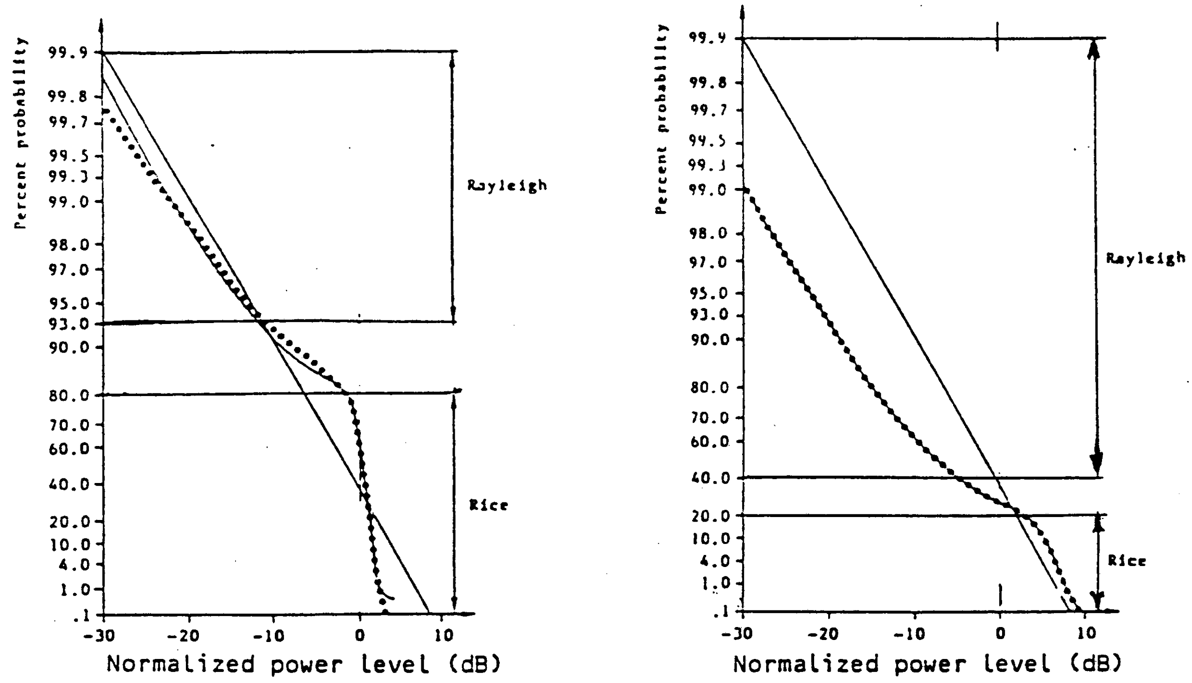
S_M : Maximum line of slight power over a large area concerned

CF : clutter factor, defined as the proportion of the time for the direct path being obstructed assuming a constant vehicle speed.

Figures 5a) and 5b) show complementary cumulative probability distribution functions of the normalized received power on highway and in city environments [Lutz *et al*, 1986]. The two figures are plotted on a Rayleigh scale. The full lines represent the theoretical channel model. Statistics of the recorded channel obtained by the measurements are designated as dots.

Three parts of the curves can be distinguished. At low values of the received power, the curve slope approximates the slope of the straight diagonal line which corresponds to a Rayleigh distribution; thus this part of the curve has clearly Rayleigh characteristics. At high values of received power, the slope of the curve indicates a Rice distribution; on highways, the Rice law is followed in 80% of small areas whereas in city environments it applies in 20% of small areas. The central part of the curves follows a log-normal law.

Similar results have been obtained [Jongejans *et al*, 1986]. They all demonstrate very good compliance between the theoretical models and the measuring results.



a)

b)

FIGURE 5 - *Complementary cumulative probability distribution function of received power*

[Lutz, 1986]

a: Highway, antenna S6
b: City, antenna S6

3. Link margins

For a satellite sound-broadcasting system, the link margins must be carefully specified – they should be neither optimistic nor pessimistic. An optimistic estimate will result in the service quality objective not being met, whereas a pessimistic estimate will needlessly result in the over-design of the satellite. Both of these extremes have substantial cost implications.

Two specific methods for the calculation of the required margins needed to provide a given quality of service are indicated below:

3.1 *Method 1*

Method 1 requires that in a small area the received signal envelope must be above the receiver threshold with probability 0.9:

$$P(r \geq R_0) = 0.9 = \int_{R_0}^{\infty} p(r)\,dr \qquad (9)$$

where

R_0 is the receiver threshold and $p(r)$ is given by equation (4).

It is also required that this condition be met over a larger area with probability 0.9. Invoking the large area probability distribution given in equation (1):

$$P(S_0 \geq \hat{S}_0) = 0.9 = \int_{\hat{S}_0}^{\infty} p(S_0) dS_0 \qquad (10)$$

Where $\hat{S}_0 = \dfrac{E_0^2}{2} + \sigma_r^2$, which satisfies equation (9).

Equation (9), conditioned by equation (10) can be solved numerically using Marcum's Q fuctions [Brennan and Reed, 1965] or by using the tables supplied by [Nortion et al., 1955]. Bothe methods were used in calculation as a cross check on each other. Equations (9) and (10) were solved to satisfy the given probabilities in terms of $G = \mu + 10 \log (2 \bar{S}_f/R_o^2)$ which is the difference between the large area mean received power and the receiver threshold. Total link margin is given by $L = G - \mu$ (in dB).

Table XXI shows the results of the above calculation for the frequency of 1 GHz and an elevation of 30°.

TABLE XXI

	Urban zone	Rural zone
σ (dB)	3.8	1.2
μ (dB)	-6.4	-1.5
G (dB)	15.4	6.1
L (dB)	21.8	7.6

It should be noted that the values used for σ and μ are average values and are not those applicable to the obstructed visibility case.

The calculated margin of 21.8 dB for the urban area compares with the observed margin of 24.2 dB (translated to 1 GHz) in urban Denver of the United States [Hess, 1980].

It is pointed out that the computed margin depends on the required service quality and coverage. In this example it was assumed that the required service quality was achieved when the signal was above threshold with probability 0.90, and that this condition was to be met with probability 0.90 over the coverage area. Other requirements will lead to different margins.

3.2 *Method 2*

Method 2 requires that the received signal envelope in a given area must be above the receiver threshold (R_0) with probability 0.9. This leads to:

$$P(r \geq R_0) = 0.9 = \int_0^{\infty} \int_{R_0}^{\infty} p(r) p(S_0) dr\, dS_0 \qquad (11)$$

This integral is evaluated numerically using Marcum's Q functions in steps of $G = 10 \log_{10} (2\bar{S}_0/R_0^2)$.

Results are shown in Table XXII, again for the frequency of 1 GHz and elevation angle of 30°.

TABLE XXII

	Urban zone	Rural zone
σ (dB)	3.8	1.2
μ (dB)	-6.4	-1.5
G (dB)	12.0	4.4
L (dB)	18.4	5.9

These calculated values may be compared with measured values. Measurements were made so as to determine the margin as a function of the percentage of locations [Guilbeau, 1979].

4. Frequency selectivity effects

Another important characteristic of UHF radio propagation channel in urban and suburban mobile radio environment is the existence of multiple propagation paths with different and varying time delays. In the case of sound satellite broadcasting, the shortest (direct) path between the satellite and the portable receiver is often blocked by intervening buildings, so that propagation by way of scatter or reflection from buildings around the receiver is significant. Two cases should be considered:

- a stationary receiver; in this case, the radio channel, and thus the propagation statistics of the link, is relatively stable. The multipath propagation characteristics can be described in terms of the multipath spread and correlation bandwidth.
- a moving receiver, the propagation statistics of the radio link is a time-varying function. Different Doppler shifts are associated with scatter paths arriving at the vehicle receiver from different angles. In this context, the key terms are the Doppler spread and correlation time.

The statistical functions which describe the frequency and time selective radio link can be readily obtained by measuring the complex bandpass impulse response of the link. These statistical descriptors and parameter values set bounds on digital communication system performance parameters.

4.1 Delay spread and correlation bandwidth

Consider a statistically stationary channel first. Two spectral components of a modulated signal which are close in frequency will fade in a correlated way, i.e. the two sets of phasors resulting from a given multipath environment will be similar in amplitude and phase. As the frequency separation between the two spectral components increases, the correlation between the two sets of phasors reduces, resulting in amplitude variations (decorrelation) as a function of frequency. This is known as frequency selective fading. The bandwidth at which decorrelation occurs is termed the correlation bandwidth.

The delay power spectrum (also termed as the multipath intensity profile) and spaced-frequency correlation function constitute a Fourier transform pair (Figure 6).

As a result of the Fourier transform, there is a relationship between correlation bandwidth of the statistically stationary channel and of the "delay spread" of the channel:

$$B_c \approx 1/T_o \qquad (12)$$

where B_c is a correlation bandwidth (Hz), and

T_o is a delay spread (s)

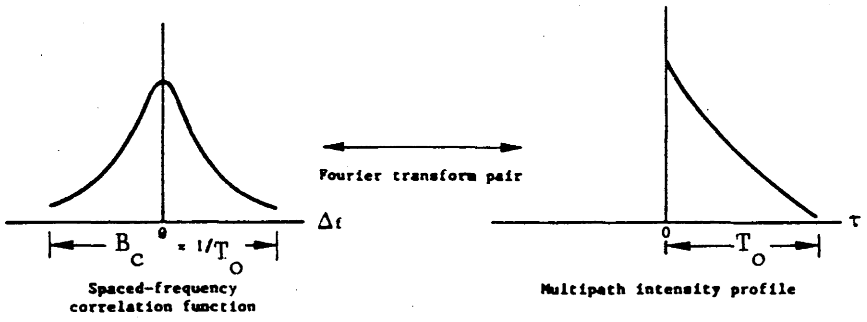


FIGURE 6 - Relationship between T_o and B_c

The delay spread T_o of the channel is a measure of the width of an average power delay profile. It is defined as the square root of the second central moment of a profile m [Cox, D.C., 1972].

$$T_o = \left[\frac{\sum_{k=1}^{M} (\tau_k - D)^2 \, P(\tau_k)}{\sum_{k=1}^{M} P(\tau_k)} \right]^{1/2} \qquad (13)$$

where

$k = 1,\ldots, M$ k ranges over the delay axis and M is the index of the last sample along the delay axis

$P(\tau_k)$ an average power delay profile for a set of N consecutive individual profiles

D average excess delay. It is defined as the first moment of the profile with respect to the first arrival delay τ_A:

$$D = \frac{\sum_{k=1}^{M} \tau_k P(\tau_k)}{\sum_{k=1}^{M} P(\tau_k)} - \tau_A \qquad (14)$$

If the correlation bandwidth is small in comparison to the bandwidth of the transmitted signal, the channel is frequency-selective. In this case, the signal is severely distorted by the channel. On the other hand, if the correlation bandwidth is large in comparison to the bandwidth of the transmitted signal, the channel is frequency non-selective.

In order to overcome the selectivity of the channel which may cause intersymbol interference, the delay spread T_o must be much less than the symbol period T_S or, in other words, the delay-spread to symbol-period ratio, i.e. $T_r = T_o/T_S$, should be much less than 1.

The empirical relationship between the correlation bandwidth at 90% correlation and the delay spread (see Figure 7) was obtained from [Cox, Leck, 1975]:

B_c (90%) = 90/To,

where

B_c (90%) is the correlation bandwidth at 90% correlation between two spectral components (in kHz) and

T_o is the delay spread (in µs).

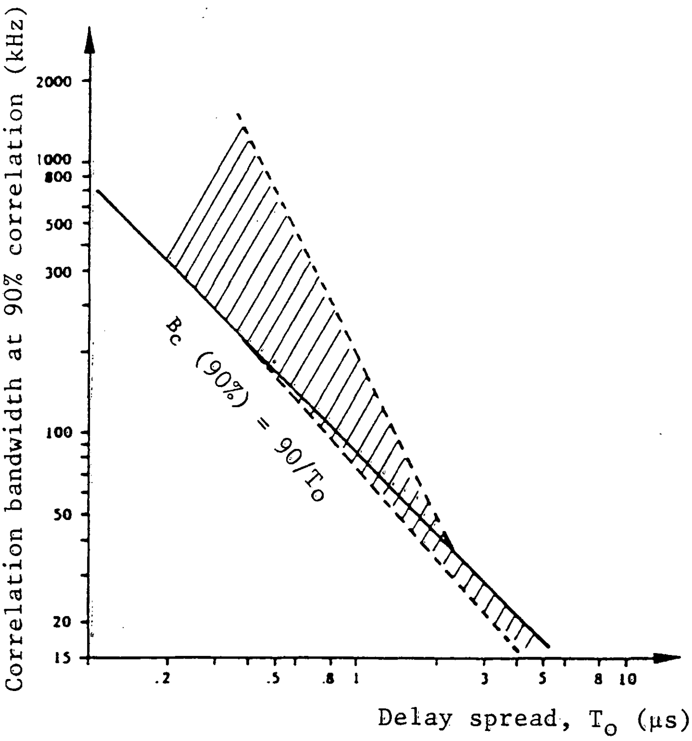


FIGURE 7 - Correlation bandwidth at 90% correlation versus delay spread [Cox and Leck, 1975]

The corresponding cumulative distribution of delay spreads is shown in Figure 8 below:

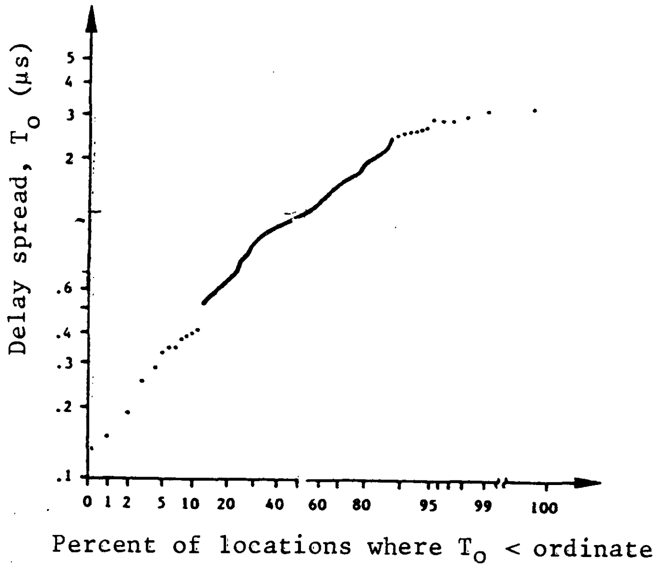


FIGURE 8 - Cumulative distribution of delay spread [Cox and Leck, 1975]

It can be deduced from the above figure that about 10 percent of small areas have $T_o > 2.5$ μs and about 50% have $T_o > 1.2$ μs.

The corresponding cumulative distribution for B(90%) is depicted on Figure 9 below:

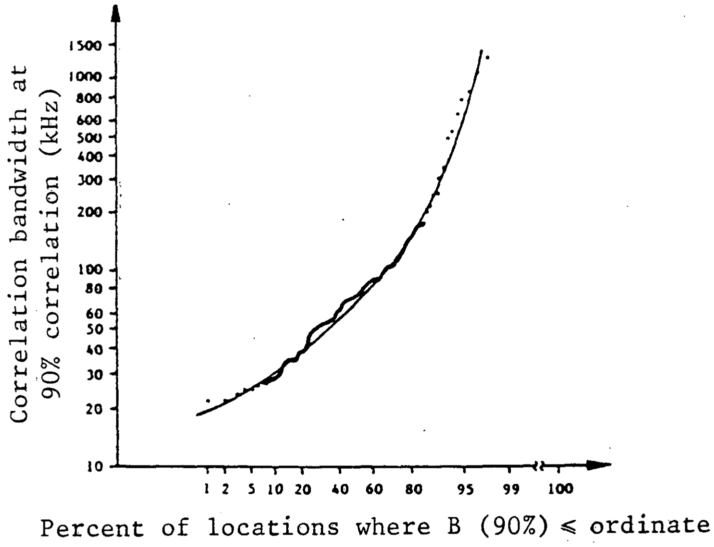


FIGURE 9 - Cumulative distribution of correlation bandwidth at 90% correlation [Cox and Leck, 1975]

Delay spreads have been measured in residential locations and in a medium sized office building [Devasirvatham, 1986]. The worse case delay spreads of less than 325 ns were obtained when the propagation path followed line-of-sight. When there was no line-of-sight between transmitter and receiver, the delay spread increased up to 422 ns.

Doppler spread and correlation time

In the case of a moving receiver, the time variations of the propagation link result in a Doppler broadening of the received spectrum. If a pure frequency tone is transmitted, a Doppler spread B_d of the channel can be measured.

Analagous to our consideration in the previous section, a measure of the correlation time T_c of the channel could be defined:

$$T_c \approx 1/B_d \qquad (16)$$

where T_c denotes the correlation time (s), and

B_d denotes the Doppler spread (Hz).

A slowly changing channel has a large correlation time and a small Doppler spread. Figure 10 shows that the Doppler power spectrum and the spaced-time correlation function constitute a Fourier transform pair.

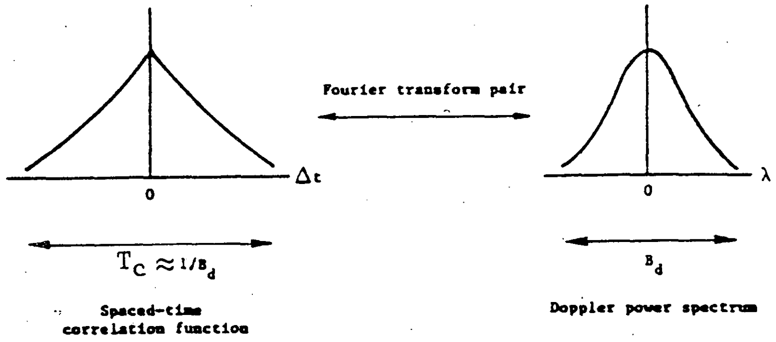


FIGURE 10 - Relationship between B_d and T_c

Fig. 11 **shows the averaged signal envelope spectrum obtained during a time period of approximately 1 minute in a suburban area (residential with trees).** A **distinct frequency cut-off at around** 110 Hz **is visible in this figure and this value is twice the Doppler frequency** f_d **given by** [Jongejans, 1986]:

$f_d = v/\lambda = 55$ Hz for $v = 40$ km/h and
$f = 1.5$ GHz
$\varepsilon = 27°$

This is an indication that in urban environments frequency-spreading of up to twice the Doppler frequency can be expected due to scattering from surrounding obstacles. **Thus the Doppler spread B_d equals to 110 Hz.**

FIGURE 11 - Spectrum of signal envelope (suburban area); vehicle speed: 40 km/h frequency: 1.5 GHz
[Jongejans, 1986]

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d. 10-11S/10 (EBU); e. 10-11S/29 (USA).
[1986-90]: a. 10-11S/1 (EBU).

ANNEX III

Summary description of advanced digital system I

[CCIR, 1986-90a]

1. Introduction

This annex presents a flexible concept for the implementation of a satellite sound broadcasting system to serve portable and vehicular receivers. The concept is based on the selective use of advanced digital techniques such as convolutional coding, spatial diversity, and Viterbi maximum likelihood decoding. The unique characteristic of this design concept is that varying levels of complexity of the advanced digital technologies are incorporated into different types of receivers only as they may be required by the intended operating environment of the receiver [Miller, 1987]. Thus, to achieve approximately the same overall level of performance, the simplest type of portable receiver operating in high signal-level areas requires only a simple decoder while a vehicular receiver operating in heavily shadowed, rural areas with Rayleigh fading requires quad-spatial diversity, with maximal ratio combining and Viterbi decoding added to provide a very high-quality (Q=4.5), monophonic, sound program channel.

2. Sound coding and modulation

The significant characteristics of the advanced digital satellite sound broadcasting system are given in Table XXII. It is a monophonic or stereophonic sound broadcasting system using adaptive delta modulation with a dynamic range of 85 dB and a sampling rate of 204 ksp/s or 48 ksp/s (kilo samples per second) respectively to provide a measured instantaneous signal-to-noise ratio of at least 58 dB in a 15 kHz baseband bandwidth. Subjectively, at a bit error ratio (BER) of less than 10^{-5} this corresponds to an impairment rating greater than 4.5 (see Report 632-3).

An R=1/2, K=7 convolutional code is used for forward error correction in conjunction with QPSK (4-PSK) and coherent detection with 3 bit quantization at the receiver. Symmetrical phase shift keying is assumed.

TABLE XXIII- Significant characteristics of example advanced digital system I

S/N objective (dB)	58
Baseband bandwidth (kHz)	15
Sound encoding method (ksp/s)	ADM, 204
Forward error correction	Convolutional code, R = 1/2, K = 7
Modulation method	QPSK
RF bandwidth (kHz)	400
Demodulation method	Coherent
Demodulator quantization (bits)	3
Interleaver/de-interleaver	
N	31
M (symbols)	16 384
Decoder	Maximum likelihood, Viterbi decoder with soft decisions
Nominal BER objective	10^{-5}

The combination of QPSK with coherent detection, and the use of interleaved/de-interleaved convolutional forward error correction coding and Viterbi maximum likelihood decoding requires an E_b/N_o of 3.8 dB for an additive white Gaussian noise channel (AWGN) (applicable to portable reception) and an E_b/N_o of 7.4 dB for a memoryless Rayleigh fading channel (applicable to vehicular reception). The use of these techniques provides a coding gain in excess of 37 dB at a BER of 10^{-5} when compared to uncoded transmissions over the Rayleigh fading channel.

The performance given above for forward error correction techniques on the Rayleigh fading channel is based on the assumption that the received symbols undergo independent fading. That is, there is no correlation of the received signal energy from one symbol to the next. One way to ensure that adjacent symbols are uncorrelated is to use an interleaver/de-interleaver pair. This technique is effective for a vehicle velocity greater than a designed minimum value (10 m/s for the example system). Another possible way to mitigate the effects of deep fades on adjacent symbols is to use spatial diversity on the vehicle (two or more antennas) to provide service continuity when the vehicle is stopped [Miller, 1987], see also section 3.

A convolutional interleaver shown in Figure 12 has been chosen for the satellite sound broadcasting application. Synchronization of the de-interleaver is accomplished using a technique proposed by [Viterbi, et al, 1979] and described in [Clark and Cain, 1981]. Referring to Fig.12, a synchronization sequence is added modulo 2 to the coded symbols at the interleaver input and removed modulo 2 by a local estimate of the sequence at the output of the de-interleaver. When the de-interleaver is not synchronized with the interleaver, the synchronization sequence is not removed from the input to the decoder. This results in a BER of 0.5 at the input to the decoder. This condition is easily detected by the decoder and the local estimate of the sync sequence is incremented by one symbol duration. This new estimate is tested and if the BER is significantly less than 0.5, synchronization of the de-interleaver occurs.

The use of the synchronizing sequence has two other advantages:

- it ensures a minimum density of transitions in the transmitted sequence which improves carrier tracking and symbol synchronization at the receiver, and
- it spreads the transmitted power spectral density and will thus facilitate sharing between the broadcasting-satellite service (sound) and terrestrial services.

3. Spatial diversity

Spatial diversity is based on the use of multiple antennas. The antennas must be spaced sufficiently far apart so that the received signals at each antenna fade independently. For a terrestrial mobile system, the required spacing is on the order of one-half wavelength or greater [Lee, 1982]. Comparable spacings are required for space-to-earth paths [Hess, 1980].

The probability of error on a Rayleigh fading, convolutionally coded link that is received with an Mth-order spatial diversity, maximal-ratio combiner receiver and a Viterbi decoder has been evaluated [Miller, 1987]. Table XXIV gives the results of BER calculations for 3rd and 4th order diversity with maximal ratio combining. It is seen that 4th order diversity with a mean bit-energy-to-noise density per branch of about 7.4 dB achieves a BER=10^{-5}.

TABLE XXIV - Probability of error for R=1/2, K=7 convolutional code with Mth spatial diversity and maximal ratio combining
(Eb/No corresponds to the mean bit-energy-to-noise density per antenna)

Eb/No	Pe	
(dB)	(M=3)	(M=4)
2.0	7.821E-03	1.234E-03
3.0	4.295E-03	5.382E-04
4.0	2.318E-03	2.307E-04
5.0	1.232E-03	9.744E-05
6.0	6.478E-04	4.068E-05
7.0	3.373E-04	1.682E-05
8.0	1.743E-04	6.904E-06
9.0	8.948E-05	2.816E-06
10.0	4.572E-05	1.143E-06
11.0	2.327E-05	4.621E-07
12.0	1.181E-05	1.863E-07
13.0	5.976E-06	7.488E-08
14.0	3.018E-06	3.004E-08
15.0	1.522E-06	1.203E-08
16.0	7.667E-07	4.814E-09
17.0	3.857E-07	1.924E-09
18.0	1.939E-07	7.684E-10
19.0	9.744E-08	3.067E-10
20.0	4.893E-08	1.223E-10

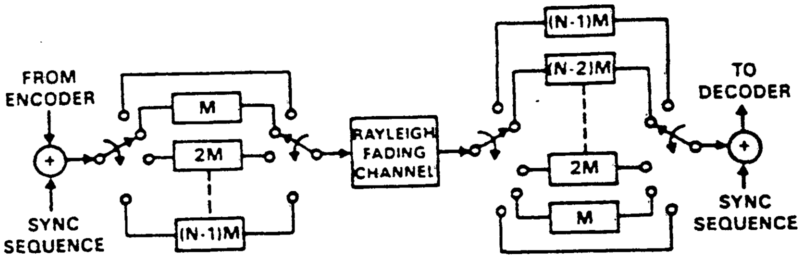

FIGURE 12 - Shift register implementation of the convolutional interleaver/de-interleaver

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ANNEX IV

SUMMARY DESCRIPTION OF ADVANCED DIGITAL SYSTEM II

[CCIR, 1986-90a, b, c]

1. Introduction

The purpose of this annex is to describe a new sound radio broadcasting system specifically adapted to channels impaired by multipath distortion. The general philosophy consists in breaking down the information to be transmitted into a large number of low bit rate elementary sub-channels, which turns a highly selective wideband channel into a large number of unselective FDM narrow-band channels. This solves the intersymbol problem by increasing the symbol time in the ratio of the number of sub-channels.

Combined with this FDM narrow-band transmission technique, the use of a convolutional coding system suited to the fading character of the channel substantially enhances the performance obtained. In a Rayleigh selective channel the performance in terms of E_b/N_0 for a given bit error ratio approaches that for a Gaussian channel to within about 2 dB using the same channel coding scheme.

2. Signal description

The transmitted signal is a Coded Orthogonal Frequency Division Multiplex (COFDM) using equally spaced and mutually overlapped carriers. [Pommier and Wu, 1986; Alard and Lassalle, 1987.] With this arrangement each carrier is an element of a Discrete Fourier Transform of the overall transmitted signal (Figure 13). The receiver as well as the transmitter structure is then based on the use of a Fast Fourier Transform (FFT) algorithm. The multiplexing of the sound channels should be chosen to permit reduced receiver complexity when each given service occupies only a part of the total capacity. Indeed, as the receiver has then to deal only with a part of the transmitted data multiplex, the basic idea is to arrange the coding and modulation such that one given part of the data multiplex can be processed separately from the others. This can be done by either a frequency or a time division multiplex. When the frequency division multiplex is used, programme selection and demodulation can then be effected by decimation of the FFT algorithm so as to restore the wanted programme. In both cases, receiver tuning and demodulation are therefore entirely digital.

3. Use of a guard interval

With the COFDM technique the selectivity effect of the channel is largely reduced in proportion to the number of carriers. An additional provision against intersymbol interference is taken by transmitting symbols of a period greater than the nominal value. This additional guard interval absorbs all the intersymbol interference generated by any delay spread ranging from 0 to the guard interval duration.

4. Channel coding

A convolutional code processed with soft decision is used in conjunction with a two dimensional interleaving:

- time interleaving, which is useful with mobile reception;
- frequency interleaving, which is essential for this system in urban environments, for fixed reception and stationary vehicles.

Figure 14 shows the error rate as a function of the mean E_b/N_o ratio in a frequency selective channel of which the correlation bandwidth (see also Annex II) is small in comparison to the bandwidth of the transmitted signal and where the COFDM technique is used. Curves show the performance with convolutional coding ($R = 1/2$, $k = 7$, $D_{free} = 10$) for 2PSK and 4PSK with differential and coherent demodulation compared to that of the uncoded system. The COFDM modulation technique using convolutional codes effectively solves the frequency selective fading problem.

5. Source coding

Digital sound broadcasting requires significant bit-rate reduction of audio signals while preserving excellent quality of the sound. Recent progress in source coding techniques has made available coding and decoding procedures that allow bit-rate reductions from 16 bit/sample as currently used in digital audio equipment to about 2 bit/sample; using a sampling frequency of 48 kHz, the total bit rate of a monophonic signal is around 100 kbit/s.

In order to match the quantizing noise to the human ear characteristics, two different source coding techniques are under investigation. They both use spectrum analysis techniques and frequency-dependent bit-allocation. The goal of these advanced coding schemes is to give compact disc quality and the preliminary results have shown that this goal is likely to be achieved.

5.1 Transform coding

This coding method involves the conversion of a block of consecutive samples into the frequency domain <Krahé, 1986, Brandeburg, 1988, Johnston, 1988> (e.g. Fourier transform or cosine transform). This strategy enables a reduction in the redundancy of the audio signal and also a matching of the quantization to the thresholds of perception of quantizing errors. Only those values of amplitude and phase that are relevant with respect to the masking effects of the human ear are quantized.

5.2 Sub-band coding

This coding method divides the broadband signal into a number of sub-band signals with a suitable filter bank and into digital frames of about 4 to 10 ms long <Theile et al., Dehery, Vörös, 1988)>. In each frame, the maximum level attained by each sub-band signal (i.e. the scale-factor) is quantized and transmitted. Each sub-band is quantized with the bit-allocation based on the masking thresholds. This method avoids problems with time domain windowing and whatever the dynamic range of the input signal, it optimizes the distribution of the quantizing noise across the spectrum with regard to the perceptibility. Sub-band coding is characterized by an inherent low sensitivity to transmission errors because the spectrum of the noise energy is confined to a single sub-band and is limited by the scale-factor if this one is satisfactorily protected.

In the sub-band coding, the basis for dynamic bit-allocation to the sub-bands is an exact calculation of the instantaneous masking threshold in the coder. The bit-allocation control data are transmitted together with the scale-factors as side-information. Thus the complexity of the decoder is reduced to inverse filtering operation. This technique gives a constant bit rate by providing optionally a dynamically varying bit-rate margin, which can be used, for instance, to transmit arbitrary data.

6. System considerations

The very first realization has been developed in France to validate the system principles. It offers a capacity of 16 stereophonic sound programmes, each with an individual capacity of 336 kbit/s, in an overall bandwidth of 7 MHz.

Nevertheless, the results already achieved in audio data bit-rate reduction and the assurance, based on the knowledge of the channel behaviour, that a 4 MHz band is sufficient to provide an excellent quality, led to two sets of representative system parameters for the link budget:

- system A, which transmits 16 stereophonic programmes each with an individual source bit rate of 168 kbit/s, in a 4 MHz band;
- system B, which transmits 12 stereophonic programmes each with an individual source bit rate of 224 kbit/s, in a 4 MHz band.

The existing realization described below has a capacity of 33 channels (C0 to C32). The channel C0 can be used for data broadcasting. Channels C1 to C32 are nominally allocated to sound broadcasting. Each one can transmit a high-quality monophonic sound compressed at 168 kbit/s, a rate that includes program-related data. The general architecture of the system is shown in Figure 15.

6.1 COFDM/4PSK modulation system

The basic parameters for the first version of the COFDM system are as follows:

Symbol duration	$T_s = 80\ \mu s$
Useful period	$t_s = 64\ \mu s$
Guard interval	$\Delta = 16\ \mu s$

The 16 μs duration of the guard interval absorbs multiple paths in almost all practical situations. Loss due to the guard interval amounts to approximately 1 dB. In addition, symbol T_s is of sufficiently short duration to ensure temporal coherence in the received signal, even at mobile receiver speeds of approximately 200 km/h and an operating frequency of 2 GHz. This condition is vital if the demodulator is to function correctly, whether it is of the differential or, a fortiori, of the coherent type.

The multiplex consists of 448 carriers spaced by $1/t_s$, i.e. 15625 Hz. The resulting bandwidth is approximately 7 MHz. Each of the carriers is modulated in 4-PSK with differential coding. This allows for simplified receivers based on differential demodulation.

6.2 Frame organization

Time Division Multiplex is based on a frame of 300 symbols, or time slots, i.e. 24 ms, as shown in Figure 16. The first slot in the frame is always set to zero and is used for receiver synchronization. The second slot is a frequency sweep used as a phase reference for differential demodulation. The third slot transmit static data. The remaining 297 slots are divided out between the 33 channels, each channel having nine consecutive slots.

6.3 Channel coding system

The channel coding retained is of the convolutional type. For each channel, a block is formed corresponding to the data transmitted in one frame, i.e. 24 x 168 = 4032 bits. The convolutional code has a rate 1/2 and a constraint length k = 7, forming an 8064 bits block at the output. The data from the convolutional coder are then interleaved in time over 16 frames, i.e. 384 ms. Frequency interleaving spreads the data over the 448 carriers of the multiplex.

6.4 Diversity techniques

The diversity techniques play a vital rôle in the system. The convolutional code cannot function correctly in a Rayleigh channel unless independent Rayleigh laws have been allocated to the successive samples presented to the Viterbi decoder. As shown in Section 6.3, the temporal interleaving extends over 384 ms, which, in the case of frequencies of the order of 500 MHz to 2 GHz, provides the necessary independence even when the vehicule is travelling at very low speeds. When the vehicle stops, then the frequency diversity alone ensures that the system functions correctly. From this point of view, the existence of multipath propagation is a form of diversity and should be seen as an advantage for this system.

6.5 Source coding system

The prototype implementation of an advanced source coding system called MASCAM (Masking Adapted Sub-band Coding And Multiplexing) was developed in Germany (Federal Republic of). It used a sampling frequency of 32 kHz and a static bit-allocation. Further work has been carried out in European research centres [Theile et al., Dehery, 1988] in order to optimize a 48 kHz sub-band coding scheme with a view to establish the best trade-off as regards subjective quality, bit-rate, delay, bit-error ruggedness, decoder complexity and post-processing capability. The studies have been oriented in two directions:

- redesigning the characteristics of the sub-band analysis and synthesis filter bank in order to improve the corresponding spectral analysis and quantizing noise confinement property and in addition try to reduce the overall coding-decoding delay;
- applying a dynamic bit-allocation, based upon an exact calculation of the masking threshold. The resulting bit-rate for transmitting an audio signal providing a subjective quality of 16 bit linear could in such a case be reduced to less than 100 kbit/s per monophonic channel.

The block diagram of the new coder using a sub-band coding scheme is shown in Figure 17. Further information on advanced source coding schemes is given in Report [Study Group 10].

7. Receiver design

The general architecture of the receiver is shown in Figure 18.

7.1 RF, IF and baseband

The receiver input stages are totally conventional in the RF stages. In IF, channel filtering is performed by a SAW filter with a bandwidth of 7.5 MHz. The IF signal is then demodulated and the signals I and Q are converted into digital form. Note that the local oscillator corresponds to the center of the channel. In order to avoid any mixer isolation problems, the carrier corresponding to this frequency is not emitted.

7.2 Demodulation of the COFDM multiplex

The incoming signal is demodulated by a processor which performs a 512 complex point FFT in about 1 ms. This allows for the processing of two elementary channels in a real time, i.e. one stereophonic sound. The 448 useful carriers are then demodulated differentially using complex multiplication.

7.3 Viterbi decoding

The Viterbi decoding function is performed by a custom designed integrated circuit which provides for a large range of codes among which is the $R = 1/2$, $k = 7$, $D_{free} = 10$ code, and can process a maximum useful rate of the order of 500 kbit/s.

7.4 Synchronization

Synchronization is performed digitally by measuring the energy received and detecting slot 0. This first estimate provides a mean of prepositioning the FFT window. This positioning is then refined by a channel impulse response estimation.

7.5 Sound decoder

The sub-band decoder (Figure 19) is characterized by inverse transcoding and by inverse filtering of the sub-band samples. For inverse transcoding the allocation control and the scale factors are used.

The computation power required by the decoder is significantly less compared to the coding process and is mainly determined by inverse filtering, characterized by simple structures which can be easily implemented in a special VLSI.

8. Experimental results

The remarkable performance of the system has been particularly confirmed by the first demonstration of COFDM/MASCAM, which was organized under EBU's auspices during the WARC ORB-88 in Geneva [Ch. Dosch et al., 1988].

The COFDM/MASCAM signal transmitted at 834 MHz from the top of the Mont Salève was received in a demonstration car travelling in the streets of Geneva. The quality of the transmission monitored both on loudspeakers and headphones was excellent, even when the car was shadowed by the buildings and in strong multipath conditions.

The modulation and source coding parameters of the experimental system are given in Tables XXV and XXVI, respectively.

The subjective quality of the sound received in the car was evaluated after the demonstrations on the basis of the replies to the questionnaires given to the delegates.* 70% of all participants could not detect any interruptions at all during the 20 minute ride. Only 30% of the participants noticed one to four disturbances, such as clicks, short beeps or brief mutings. All participants judged the sound quality as more then adequate. 80% of the participants evaluated the overall performance as "excellent" (i.e. grade 5), and no passenger assessed it worse than "good" (i.e. grade 4).

TABLE XXV

System parameters of the first implemented version of COFDM

Total number of carriers processed by FTT		512
Total number of useful transmitted carriers		448
Spacing between two successive carriers		15625 Hz
Useful symbol period		64 μs
Total bandwidth		7 MHz
Modulation		4 PSK
Interleaving:	- time domain	(not implemented in Geneva demonstrations)
	- frequency domain	7 MHz
Demodulation		differential
Channel coding		convolutional code
	- rate	1/2
	- constraint length	7
	- free distance	10
Channel decoding		maximum likelihood Viterbi decoder
Total useful bit-rate		5.5 Mbit/s
Number of stereophonic sound programmes		16

---

* More than 200 delegates attending WARC ORB-88, from 40 countries, participated in a test drive in the car.

TABLE XXVI

System parameters of the first implemented version of MASCAM

Bit-rate per mono channel	- Total bit-stream	168 kbit/s
	- Samples	112 kbit/s
	- Scale-factors	24 kbit/s
	- Error protection	32 kbit/s
Number of sub-bands		24
Width of sub-bands		500 Hz (up to 8 kHz) 1 kHz (above 8 kHz)
Sampling rate		32 kHz
Block length		8 ms (below 8 kHz) 4 ms (above 8 kHz)
Code-words per block		8 samples
Length of samples		1.56 to 12 bit/sample depending on the sub-band location
Scale-factor length		6 bits
Error protection	- Block code	Golay (24,12) covering scale-factors of all sub-bands - 2 MSB of sub-bands Nos. 1 and 2 - 1 MSB of sub-bands Nos. 3, 4 and 5

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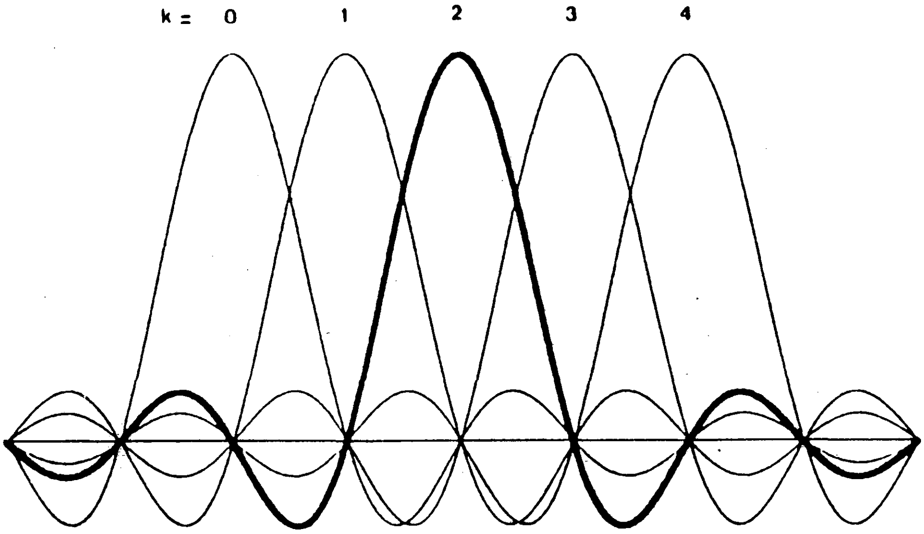
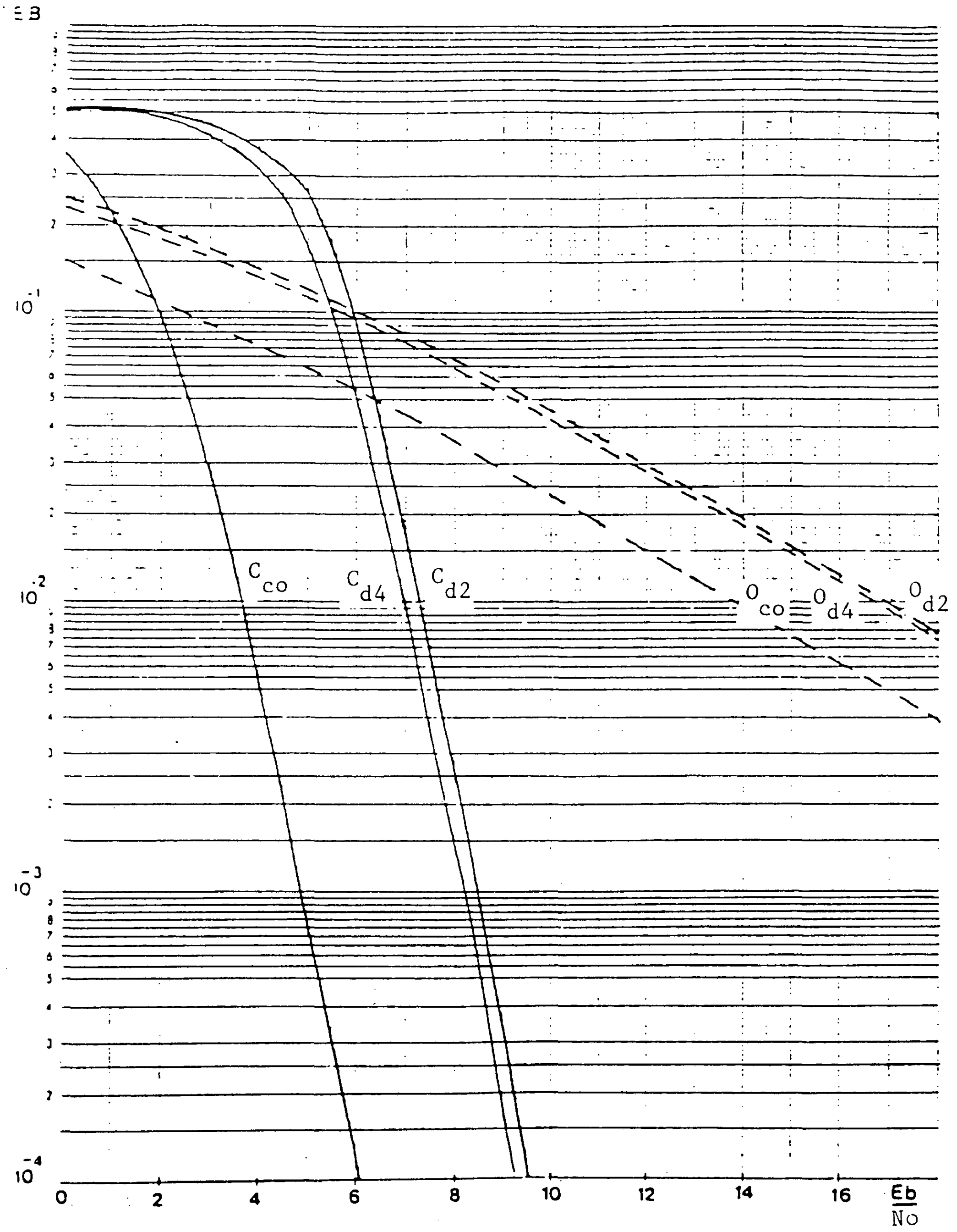


FIGURE 13

Spectrum of the COFDM elementary carriers



C	convolutional code
O	no coding
co	coherent demodulation
d2	differential demodulation (2PSK)
d4	differential demodulation (4PSK)

FIGURE 14

Comparison of binary error rate performance of convolutional code with COFDM in a Rayleigh channel using coherent and differential demodulation (2PSK, 4PSK)

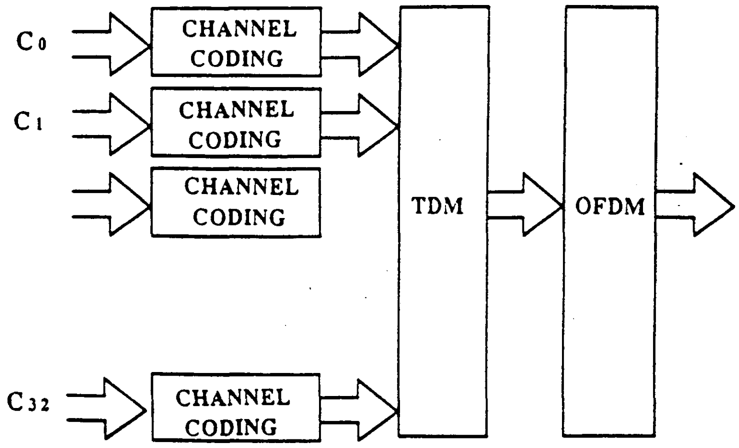


FIGURE 15

Schematic diagram of coding system

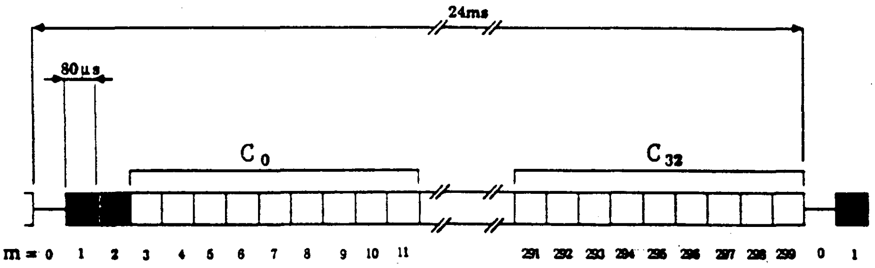


FIGURE 16

Frame structure

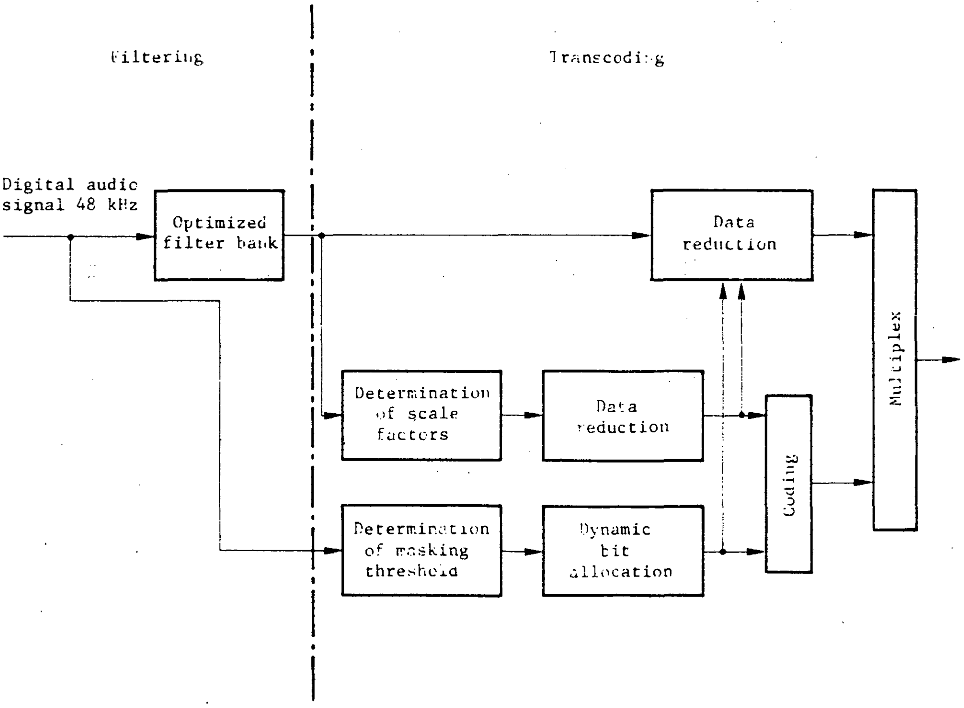


FIGURE 17

Block diagram of an optimized sub-band coder

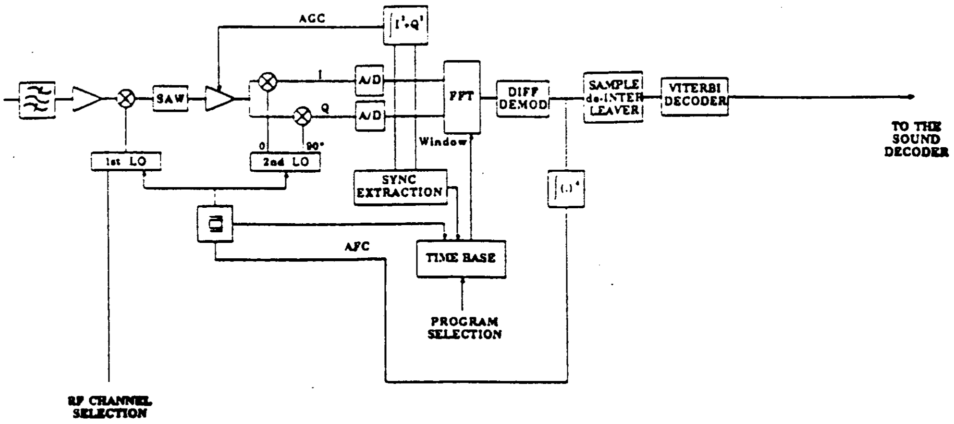


FIGURE 18

Block diagram of the receiver

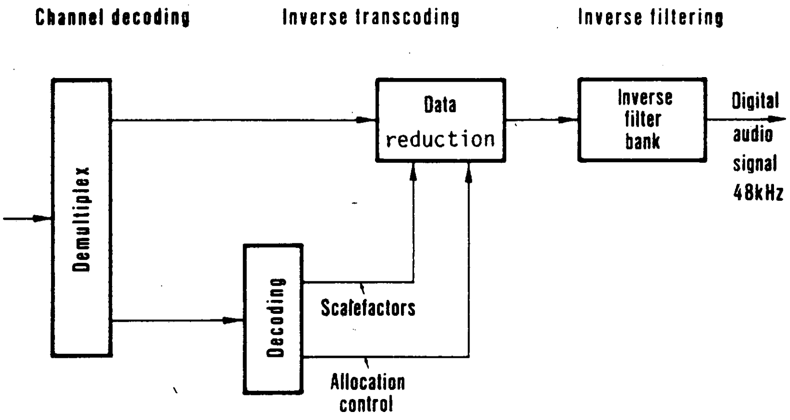


FIGURE 19

Block diagram of the sub-band decoder

REPORT 632-4

BROADCASTING-SATELLITE SERVICE (SOUND AND TELEVISION)

Technically suitable methods of modulation

(Question 2/10 and 11,
Study Programmes 2B/10 and 11, 2C/10 and 11, 2F/10 and 11)

(1974-1978-1982-1986-1990)

1. Introduction

There are a large number of possible methods of modulation for the broadcasting-satellite service, the choice depending on several factors. This Report 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.

2. Sound broadcasting

This section concerns the methods of modulation suitable for sound broadcasting when this is the main service on the carrier(s) considered.

2.1 *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, 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 (see 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.

2.2 *Digital methods of modulation*

For the broadcasting of a large number of sound channels, it may be advantageous to use TDM digital techniques. In this case, the choice of the modulation does not depend upon the nature of the signals to be broadcast, but only on the characteristics of the radio-frequency channel. In § 6 of this Report the choice of these digital modulation techniques for any kind of signal (e.g. sound, data, picture, etc.) is discussed.

Concerning the organization of the digital multiplex, several procedures may be used; they are described in Report 954. Details of digital coding methods are contained in Report 953.

Digital sound coding is described in Report 953 and subjective results related to C/N or bit error ratio are reported in the Annexes to this Report. It should be noted that sound quality is dependent upon the overall transmission process (multiplexing procedure, modulation type, bit interleaving, error protection strategy, demodulator characteristics, etc.) and upon the nature of the errors arising therein. Account must be taken of this when comparing results.

3. 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 on 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 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 III of Report 215, 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 [CCIR, 1978-82a] 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.

4. 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.

4.1 *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-83) 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 (see Study Programme 47A/10).

The sound quality should be at least as good as that attained under the single FM sub-carrier system mentioned in § 3 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.

4.2 *Frequency multiplexing*

4.2.1 *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 an insignificant or no increase in the width of the radio-frequency channel. However, intermodulation between the picture and sound signals, and between the various sound signals, may occur if the sub-carrier levels are not set properly within the common channel.

Regarding the technical basis of the 12 GHz plan for Regions 1 and 3, studies carried out in France and the Federal Republic of Germany [CCIR, 1978-82b and c] 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. Tests carried out in the Federal Republic of Germany showed that the sub-carrier deviation may be increased to ± 63 kHz, thus improving the signal-to-noise ratio while retaining compatibility with existing receivers. In those countries where there is no compatibility problem with existing systems, the deviation may even be increased to ± 100 kHz. In this last case, measurements made in France demonstrated that the audio signal-to-noise ratio was 50 dB (CCIR quasi-peak weighting) in the presence of video and transmission noise. For these systems, the results of the measurements carried out with the OTS satellite are given in Annex I.

In Japan a two sub-carrier sound system for the 525-line M/NTSC system, has been studied by use of home receivers, with the sub-carrier frequencies at 5 and 5.5 MHz [CCIR, 1978-82d]. When the carrier frequency deviations by video signal and by each sound sub-carrier signal were set to be 17 MHz peak-to-peak and ± 1.3 MHz, respectively, and the sub-carrier deviation by sound signal was set to be ± 75 kHz, the signal-to-noise ratios achieved were 38 dB for video (unweighted), 59 dB for the first sub-carrier sound and 58 dB for the second sub-carrier sound (r.m.s., unweighted), without producing visible beat pattern and truncation noise at the carrier-to-noise of 14 dB.

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 [CCIR, 1974-78a].

4.2.2 *Use of a digitally modulated sub-carrier*

This section deals with the use of only one digitally modulated sub-carrier. The organization of the digital multiplex applicable to this case is described in Report 954. From the many possibilities, one that is of special interest is that of a single sub-carrier modulated by a digital multiplex with a bit rate of either 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). The feasibility of this type of system has been studied and experiments have been conducted by the BBC [Gilchrist, 1976; Kalloway, 1976], with a sub-carrier at 6.5 or 7 MHz, a bit rate of 700 kbit/s and four-phase PSK modulation. An analogous experiment was conducted in Italy, with four-phase PSK modulation of a sub-carrier at 7.5 MHz; the bit rate was 2.048 Mbit/s and continuous stream multiplexing was used [CCIR, 1978-82e]. Similar studies and tests were carried out in France and Sweden [CCIR, 1978-82f and g] with a sub-carrier at 6.656 MHz, a bit rate of 2 Mbit/s and continuous phase half-index frequency-shift keying modulation, obtained by residual sideband filtering of a two-phase modulation named "simplified MSK" [Amoroso and Kivett, 1977; Pommier and Veillard, 1979]. Theoretical and experimental studies have been undertaken by the EBU with a view to optimizing the modulation parameters and to provide complete specifications for this type of system. On the occasion of the tests carried out in France, a packet multiplexing procedure was tested.

In the United States a system is used in the FSS with a sub-carrier at 5.5 MHz and a 1.79 Mbit/s capacity, i.e., four 15 kHz high quality audio channels, or two stereophonic pairs, or one quadraphonic transmission. Somewhat similar approaches are used in video/audio encryption equipment for applications of satellites utilizing frequency modulation with an RF bandwidth of 36 MHz.

It should be noted, however, that the bandwidth of the baseband signal (video plus digitally modulated sub-carrier) may be, in certain countries, larger than the channel width provided in the television distribution network. This may lead to some difficulties when the signal is to be distributed in such networks.

Whatever may be the modulation process adopted, the sending-end and receiving-end digital sub-carrier filters are essential elements of the system. In the case of a single digital sub-carrier, the function of the sending-end filter is to limit the spectrum of the digital sub-carrier, in order to obviate any disturbance of the television signal. At the receiving end, the digital-demodulator filter must limit the noise band without introducing inter-symbol interference. In order to obtain the optimum performance, the sending-end and receiving-end filters cannot be designed separately. The introduction of a system having the optimum characteristics will therefore necessitate relatively precise characteristics for those filters, while seeking a simple and economical solution for the demodulator filter.

The search for a compromise between efficiency and simplicity of the digital demodulator has led to a preliminary conclusion that the simplified MSK modulation seems attractive for broadcasting with digital sub-carriers. The characteristics of the system judged to be optimum following the EBU studies are given in Annex I, for a service objective corresponding to a bit-error ratio of 10^{-3} at a carrier-to-noise ratio of 8 dB, allowing a 2 dB margin for implementation of the receiver [CCIR, 1982-86a].

A digital sound transmission system by means of four-phase DPSK modulation of a sub-carrier at 5.727272 MHz was adopted in Japan for its planned operational television broadcasting by the satellite BS-2. A bit rate of 2.048 Mbit/s and a frequency deviation of ± 3.25 MHz of the main carrier by the sub-carrier was selected. The specifications of this system are given in Report 1073. Experimental results obtained are given in Annex II of the present Report [CCIR, 1982-86b].

The United States commercial equipment referred to above uses QPSK modulation on the sub-carrier with 14-bit PCM with instantaneous companding, thus resulting in 11 bits plus sign. After adding parity bits at word lengths of 13 bits, the sub-carrier is injected -19 dB relative to video level and produces a bit error ratio less than 1×10^{-6} at $C/N = 13.5$ dB. Transmission quality is excellent for both terrestrial microwave (RF bandwidth = 20 MHz) and satellite (RF bandwidth = 36 MHz and main carrier peak deviation = 12 MHz) channels. Additional information is given in Report 488 and Report 215.

4.2.3 *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.

Studies in this field carried out in France and the United Kingdom with a bandwidth of 27 MHz and 625-line systems, have shown that all the foregoing conditions can be met, provided that the design of the receiver is such as to obviate any risk of disturbance of the picture by intermodulation products due to the presence of the two sub-carriers. It is, however, to be noted that spreading the spectrum of the digital sub-carrier renders such beats, when they occur, less visible than those generated by two analogue sub-carriers.

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.

4.3 *Time-division multiplexing*

The procedures for setting up a digital multiplex may be similar to those foreseen for a digitally modulated carrier of sub-carrier systems (see Report 954).

4.3.1 *Baseband insertion of digital audio signals in the line-blanking interval using full-response coding*

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.

The use of this technique in terrestrial television is the subject of Report 958. Certain systems are also described in Report 488 and in [CCIR, 1970-74a]. Report 958 states in particular in the case of B/PAL and M/NTSC (Japan) television systems, that there is little hope that any system employing digital signals in the line-blanking interval will be compatible with existing receivers, even if only half the total capacity of the line-blanking interval is used. Moreover, new studies are necessary in the case of other television systems. On account of this compatibility problem, Report 958 concludes that it will be necessary to introduce new types of terrestrial television receivers if it is desired to use the line-blanking interval to transmit up to four high-quality sound channels.

This technique is more appropriate for satellite broadcasting where compatibility with existing receivers is not as critical as in the case of terrestrial 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, multipath propagation, which might cause impairment to the received picture when this system is used with terrestrial television, will not occur in the case of satellite broadcasting.

The insertion at baseband of a digital audio and data multiplex signal during the line blanking interval has been fully developed in the B-MAC system described in Report 1073. The instantaneous bit rate for the 525-line B-MAC signal is either 14.3 Mbit/s using a 4-state coding technique or 7.15 Mbit/s using a 2-state coding technique. Such 4-state and 2-state FSK modulation allows signal detection through a simple FM demodulator. The corresponding data transmission capacity is 1.57 Mbit/s or 0.785 Mbit/s providing for up to 3 or 6 high quality audio channels respectively and a utility data channel of 9600 bit/s or 4800 bit/s protected with 5:1 majority logic. This sound and data multiplex does not require more bandwidth than the accompanying vision MAC signal. Australia has adopted the 625-line B-MAC system providing for a capacity of either 1.594 Mbit/s or 0.797 Mbit/s using the 4-state or 2-state coding respectively. This provides for up to 6 or 3 high quality audio channels respectively.

In both versions of the B-MAC format, adaptive delta modulation (ADM) with a sampling rate of 204 kHz (13 times line frequency) is used for high quality sound coding to be able to fit the required number of channels. Report 953 gives a detalied description of this adaptive delta modulation coding, and gives results of subjective measurements conducted in Australia, Canada and the United States. Results show that with appropriate error concealment as described in Report 1073, the service failure ($Q = 1.5$) occurs at a bit error ratio of 15×10^{-2}. Results also show that in a non-impaired transmission channel, ADM will give similar performance to the 14-10 semi-instantaneous companding scheme described in Report 953 except in the case of critical programme material. It is also found that an increase of the sampling rate for ADM will bring it closer to the performance of the semi-instantaneous companding scheme for all types of programme material.

This time multiplexing at baseband avoids intermodulation with the vision signal and degradation in threshold performance caused by the usual sound sub-carriers. It also allows for wider carrier deviation within the RF channel and permits the use of a simple vision FM demodulator to recover vision, sound and data channels.

Tests have been carried out within the framework of the EBU on a system of this type in association with a PAL television signal, using an instantaneous bit rate equal to twice the colour sub-carrier frequency and with digital synchronization inserted in the field-blanking interval. The available capacity is then 1.625 Mbit/s, which is equivalent to four high-quality sound channels. Taken alone, this system satisfies the service continuity criterion requiring a bit error ratio of 10^{-3} at a carrier-to-noise ratio of 8 dB. However, this criterion is not satisfied if a digital sub-carrier system of the type described in Annex I is added in the hope of increasing the capacity to a value close to 3.5 Mbit/s.

4.3.2 *Baseband insertion of digital audio signals in the line-blanking interval using partial response coding (duobinary)*

Two systems combining MAC image coding with TDM baseband multiplexing of the digital signals have been studied in Europe. These systems, Known as "D-MAC/packet and D2-MAC/packet", employ baseband multiplexing (type B) with duobinary coding. For the D-MAC/packet system a gross bit rate of 3.28 Mbit/s is obtained from 10 μs bursts, and an instantaneous bit rate of 20.25 Mbit/s. For the D2-MAC/packet system a gross bit rate of 1.64 Mbit/s is obtained from 10 μs digital bursts, and an instantaneous bit rate of 10.125 Mbit/s. For both systems the other coding and multiplexing characteristics are common to the systems of the MAC/packet family.

The D-MAC/packet and the D2-MAC/packet system possesses the original feature of being able to adapt to the physical characteristics of the transmission media. This type of flexibility results from the TDM baseband multiplex concept associated with the use of a duobinary code for the transmission of the digital signal. The D-MAC/packet system combines optimum use of the broadcasting-satellite channel and compatibility with channels used in cable networks of at least 12 MHz bandwidth. The D2-MAC/packet system appears as one of the best compromises between the optimum use of a broadcasting-satellite channel and direct compatibility with the 7 or 8 MHz bandwidth channels used in cable networks.

For the D2-MAC/packet system in satellite broadcasting, the baseband signal is transmitted with a bandwidth of at least 8.4 MHz. Thus a picture signal complying with Report 601 does not undergo any passband reduction and the digital signal can meet the continuity of service criterion, corresponding to a bit error ratio of 10^{-3} for a carrier-to-noise ratio of 8 dB.

For the D-MAC/packet system in satellite broadcasting, the baseband signal is transmitted with a nominal bandwidth of 10 MHz. Thus a picture signal complying with Report 601 does not undergo any passband reduction and the digital signal can meet a continuity of service criterion, corresponding to a bit-error-ratio of 10^{-3} for a carrier-to-noise ratio of 8 dB when the appropriate passband filtering and error-reduction techniques are used in the receiver.

Both systems have the following other main advantages:

- possibility of increasing the video bandwidth in the case of an adaptive filter demodulator for C/N ratios greater than the frequency demodulation threshold (about 11 dB);
- no intermodulation between baseband signal components;
- demodulation of the entire signal by the same demodulator;
- the possibility of reducing the bit error ratio and picture impulsive noise by optimized filter bandwidths;
- the possibility of using digital processing of the duobinary coded signal to reduce the effect of bit errors;
- flexible hence evolutive organization of the multiplex as a whole.

Further advantages of the D-MAC/packet system are as follows:

- direct compatibility with all transmission channels with a baseband equal to or greater than 9 MHz;
- highest practical data transmission rate of 20.25 Mbit/s;
- continuous broadcasting of data at a rate of 20.25 Mbit/s by elementary D-MAC/packet multiplex.

Further advantages of the D2-MAC/packet system are as follows:

- direct compatibility with all transmission channels with a baseband equal to or greater than 4.5 MHz;
- continuous broadcasting of data at a rate of 10.125 Mbit/s by elementary D2-MAC/packet multiplex.
- with the use of a demodulator with adaptive filtering, a bit error ratio of 10^{-3} can be reached for a carrier-to-noise ratio of 6.5 dB.

In view of these advantages, the full specifications of the D-MAC/packet and D2-MAC/packet systems have been established for satellite broadcasting at 12 GHz with a 625-line standard (see Report 1073). Report 634 gives the noise sensitivity measurement data [CCIR, 1982-86c and CCIR, 1986-90a].

U.K. industry and broadcasting laboratories have carried out comprehensive joint experiments on the D-MAC/packet system. These experiments used the full range of media; satellite, cable and terrestrial radio-relay links and have confirmed the practicability and economics of receiver implementation. The results for satellite broadcasting are summarized in Annex IV to the present Report.

European industry and the CCETT Laboratories have carried out numerous joint experiments on the D2-MAC/packet system. These experiments were performed using numerous media: satellite, cable and land radio-relay networks. The results for satellite broadcasting are summarized in Annex III to the present Report.

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

The modulation is analogue (frequency modulation) during the active line period and digital during the line-blanking interval. This type of system offers a capacity close to 3 Mbit/s (equivalent to eight high-quality sound channels) and it is naturally compatible with the coding of time-compressed and time-multiplexed image components (MAC) [Lucas and Windram, 1981]. Additional equipment is needed at the receiver if transcoding to existing receivers is required, but taken as a whole the receiver is not more complex than those needed for other systems using digital sound modulation. It is not possible to use this system in terrestrial television, but simple transcoding can be effected to a type B system (see § 4.3.1) of lower capacity for which most of the circuitry of a type C receiver is re-used.

The main properties of the radio-frequency time-multiplex system are the following:

- high capacity for digital sound and data signals with good error performance; in particular, it is possible to satisfy the service continuity criterion corresponding to a bit error ratio of 10^{-3} for a carrier-to-noise ratio of 8 dB;
- potential for increased video bandwidth;
- simple video filtering;
- no degradation of the frequency demodulation threshold;
- no intermodulation problems;
- one-step demodulation of the digital signal;
- in principle, easy conversion to suit cable distribution*; and
- can be made fully compatible with continuous data transmission.

In view of these advantages, system C has been fully specified in association with a MAC picture and a packet multiplexing system for satellite broadcasting at 12 GHz with 625-line standards (see Report 1073). Measurements of sensitivity of interference are given in Report 634.

The EBU has conducted numerous tests with a type C system associated with a MAC television picture signal (see Annex V).

For this system, preference is accorded to 2-4 PSK modulation [Duponteil, 1981] in which the phase shift is instantaneous and equal to 90° for each bit (before filtering), as this offers the following advantages:

- suitable spectrum shape and low spectrum spreading after passage through a non-linear device such as a satellite repeater;

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* It should be noted, however, that if the full capacity is required, the bandwidth may be, in certain countries, larger than the channel width provided by the channelling arrangement in the cable network. This may lead to some difficulties when the signal is to be distributed in such networks.

- simple receiving equipment with good performance for differential demodulation* ; and
- possibility of using the same FM demodulator for vision and sound in areas of high signal strength.

5. Digitally modulated radio-frequency carrier

This section relates to a modulation system in which the radio-frequency carrier is directly modulated by a digital bit stream. It concerns the broadcasting of all signal types: sound, pictures, data, etc.

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

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 [CCIR, 1974-78b]. 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.

5.1 Modulation techniques

The type of 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 [CCIR, 1978-82h and i]. Among the modulation processes of this type are included, notably, the half-index duobinary FSK and tamed FM processes [de Jager and Dekker, 1978], which may be considered as derivatives of MSK modulation, wherein the phase transitions are rendered interdependent by the nature of the code employed. These processes also have many features in common with the four state phase-shift keying with offset-streams modulation processes, such as the offset QPSK [Gronemeyer and McBride, 1976]. In fact, the half-index duobinary FSK and offset QPSK processes are both four-state phase-shift and offset-stream processes; the so-called tamed FM process, on the other hand, may be considered as half-index duobinary FSK modulation in which there is a higher level of correlation between the phase-transitions of the emitted signal. All these similarities are important, because they suggest that, at the demodulation level, there is considerable compatibility among these forms of modulation. This is particularly interesting in the case of broadcasting, wherein the effect of the existence of large numbers of terminals, when new systems involving different radio-electric constraints are being defined, is well known.

5.2 Interference

A constructive study using digital technique [CCIR 1978-82j; Pommier and Siohan, 1981] gives some results based on QPSK and MSK modulation, when digital modulation is used on a carrier of the frequency plan of the 12 GHz band (Regions 1 and 3). One of the points studied concerns the protection of adjacent channels, which has to be effective even in the presence of spread spectrum phenomena due to the non-linearities of the satellite power tube used in near-saturation conditions. Indeed for MSK and QPSK, the adjacent channel interference seems to be the main reason for the limitation of the usable bit rate.

Two distinct phenomena affecting the analogue FM channel suffering interference must be considered separately:

- the first phenomenon is the impairment of the signal received above the demodulator threshold;
- the second phenomenon is the apparent shift of the demodulator threshold, at a given thermal noise power N, to higher carrier-to-noise (C/N) values.

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* The theoretical degradation of differential demodulation as compared to coherent demodulation corresponds to an increase in carrier-to-noise ratio of 1.1 dB for a given bit error ratio of 10^{-3}.

This study has shown that interference into the FM adjacent channels may lead to an impairment manifested mainly by a shift of the threshold to higher values of the carrier-to-thermal-noise ratio. The limitation of the bit rate due to this phenomenon depends on the tolerated increase in threshold. For a threshold increase kept down to about 0.15 dB, usable bit rates with QPSK and MSK are 26 Mbit/s and 20 Mbit/s respectively. If a greater threshold increase is accepted, for example of the order of 0.3 dB, bit rates of 34 and 27 Mbit/s may be used with QPSK and MSK modulation respectively, these values were obtained with a receiving filter of width 27 MHz and conventional frequency demodulator, for the demodulation of the FM carriers suffering interference. Other conditions such as for example the use of demodulators with threshold extension would no doubt give very different results.

For both MSK and QPSK, with coherent demodulators and an equipment margin of 2 dB, a bit error ratio of 10^{-4} may be obtained for a power flux-density of -107 dB(W/m^2) with a bit rate around 21 Mbit/s, at a receiving station figure of merit (G/T) of 6 dB(K^{-1}).

A recent study [Newland, 1988] has established that when digitally modulated signals mutually interfere, the degree of mutual interference which may be tolerated is substantially greater than is the case for analogue signals carrying broadcast-quality pictures or sound. The permissible carrier-to-interference ratio (C/I) depends on the method of modulation and error-correction coding (if any). There is also scope for trade-off between C/N and C/I in the overall link budget. Further information is given in Report 634.

5.3 Advanced modulation and coding methods

Modern trends in digital communication by satellite use forward error-correction (FEC) by concatenation of block codes and convolutional codes or trellis modulation. Soft decision Viterbi decoding is used in the receiver. High coding gains are achievable, allowing a reduction of satellite power and the service outage times. The hardware implementation of these techniques at high bit-rates (e.g. 140 Mbit/s) has provided recently an adequate solutions for professional applications. A comparison of the performance of some digital systems for satellite transmission is given in Table [I]. The Eb/No values have been obtained by computer simulations and laboratory tests [Cominetti and Morello, 1989] and from the existing literature [Seo and Feher, 1988]. Convolutional and trellis coding schemes offer high coding gains. However, to overcome the effect of error bursts at the output of the Viterbi decoder, interleaved BCH code or Reed Solomon code may be used.

TABLE I - Performance of some modulation and coding systems via satellite

System	Modulation	FEC 1	FEC 2	Eb/No AT B.E.R. of 10^{-8}	RELATIVE SPECTRAL EFFICIENCY (%)
1	QPSK	-	-	15.7	100
2	QPSK	BCH(255,239,2)	-	11.2	94
3	QPSK	CONVOL. 3/4	BCH(255,239,2)	7.4	70
4	QPSK	CONVOL. 1/2	BCH(255,239,2)	6.2	47
5	8PSK	BCH(255,239,2)	-	16.4	141
6	8PSK	TRELLIS 2/3	BCH(255,239,2)	8.2	94
7	16SQAM	BCH(255,239,2)	-	16.0	187
8	16SQAM	TRELLIS 3/4	BCH(255,239,2)	12.1	141

6. Other consideration

6.1 Formulae governing modulation performance for analogue TV and audio signals

6.1.1 Video modulation only

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 II).

6.1.2 Audio modulation only (low level audio FM sub-carriers)

The unweighted signal-to-noise ratio of accompanying audio channels, which consist of FM sub-carriers located above the video baseband, is determined by the following equation:

$$S/N_a = 10 \log \left[\frac{3}{4} \left(\frac{b}{f_a}\right) \left(\frac{D_s}{f_s}\right)^2 \left(\frac{D_a}{f_a}\right)^2\right] + \left(\frac{C}{N}\right) + k_a$$

where:

S/N_a: audio channel r.m.s. signal to r.m.s. noise ratio (dB);

D_s: peak deviation of the main carrier by the sub-carrier (MHz);

D_a: peak deviation of the sub-carrier by the audio (MHz);

f_s: frequency of the sub-carrier (MHz);

f_a: highest audio frequency (MHz);

C/N: pre-detection carrier-to-noise ratio (dB);

k_a: combined improvement factor due to pre- and de-emphasis for the audio channel (dB). (See CMTT Report 496, Table II, for improvement factors corresponding to various audio channel baseband bandwidths);

b: pre-detection RF bandwidth (MHz) defined by equation (1) of § 6.1.3.

6.1.3 Combined video and audio (low level FM sub-carrier) modulation

Combined video and audio FM sub-carrier signals form a composite baseband signal as illustrated in Fig. 5. The required RF bandwidth is approximated by the following equation:

$$b = D_{b_{p-p}} + 2f_b \qquad (1)$$

where $D_{b_{p-p}}$ is the peak-to-peak deviation of the carrier by the composite baseband signal.

It is not certain how the deviation of a high level video signal should be combined with the individual deviations of a multiplicity of low-level audio signals. Further study and measurements are required on this subject especially on the effect of additional deviation caused by the multiple sound sub-carriers on the video performance.

However it can be assumed for practical purposes that the overall peak-to-peak deviation can be approximated by the peak-to-peak deviation due to the video signal only, provided the individual deviations of the few audio channels are small in comparison, thus:

$$D_{b_{p-p}} \approx D_{p-p} \qquad (2)$$

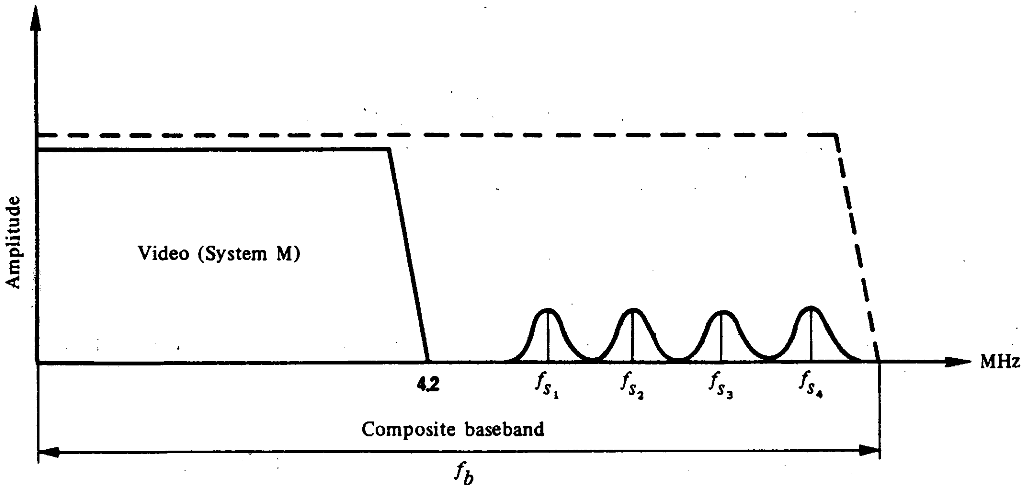

FIGURE 5 – *Composite video and multiple FM sub-carrier baseband*

Substitution of equation (1) and approximation (2) into the equation in § 6.1.1, and combining constants, results in the following equation for the weighted video signal-to-noise ratio:

$$\frac{S}{N_v} = 10 \log \left[\left(\frac{D_{p\text{-}p}}{f_v} \right)^2 \left(\frac{D_{p\text{-}p} + 2f_b}{f_v} \right) \right] + \frac{C}{N} + k_e + 1.8$$

where:

k_e: combined noise weighting and pre-emphasis advantage (e.g. 12.8 dB for System M/Canada, United States).

This equation can be used to estimate the effect of multiple audio FM sub-carriers on the signal-to-noise ratio of the video signal in FM transmission systems operating above threshold.

TABLE II – *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.

6.2 Analogue component TV signals

Future television receivers are expected to have an input socket for component signals (*Y, U, V* or *R, G, B*) 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.

Analogue component TV signals are the subject of Report 1073.

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[1978-82]: **a.** 11/81 (Japan); **b.** 10-11S/17 (France); **c.** 10-11S/7 (EBU); **d.** 10-11S/112 + Corr.1 (Japan); **e.** 10-11S/161 (Italy); **f.** 10-11S/124 (EBU); **g.** 10-11S/126 (Sweden); **h.** 10-11S/18 (France); **i.** 10-11S/30 (USA); **j.** 10-11S/137 (France).

[1982-86]: **a.** 10-11S/42 (EBU); **b.** 10-11S/6 (Japan); **c.** 10-11S/165 + Corr.1 (EBU).

/‾1986-90_7 : a. 10-11S/14 (UK).

ANNEX I

STUDIES AND TESTS CARRIED OUT BY THE EBU ON BROADCASTING OF SEVERAL SOUND CHANNELS WITH A 625-LINE ANALOGUE TELEVISION SIGNAL USING ONE OR TWO SUB-CARRIERS

1. Television with two analogue sub-carriers

Tests carried out in France and Germany using the video characteristics of L/SECAM and G/PAL television systems (625 lines) with the following parameters:

– Sub-carrier frequencies:	5.5 MHz and 5.75 MHz
– Frequency deviation of sub-carrier:	± 63 kHz,
– Carrier deviation by the picture signal:	14 MHz/V,
– Deviation of the carrier by each of the sub-carriers:	± 2.8 MHz.

TABLE III – *Typical measurement results*

C/N (dB)	Weighted *S/N* picture channel (dB)	Weighted quasi-peak *S/N* 1st sound channel (5.5 MHz) (dB)	Weighted quasi-peak *S/N* 2nd sound channel (5.75 MHz) (dB)
14	44	45.8	47.8

Similar measurements have shown that, with a ± 100 kHz peak-to-peak deviation of each of the sub-carriers, the weighted quasi-peak signal-to-noise ratio may attain 50 dB in each of the sound channels, with a carrier-to-noise ratio of 14 dB.

The conclusion of the tests carried out in France is that the satellite broadcasting of a TV signal accompanied by two high quality analogue sound signals in a 27 MHz channel is possible provided that the receivers' IF filters are within certain group-delay range and have a peak-to-peak tolerance of the order of 16 ns. Under these conditions, the picture is very slightly disturbed by the presence of two sound-sub-carriers and the CCIR-weighted quasi-peak sound signal-to-noise ratio may attain the value of 50 dB.

2. Television with a digitally-modulated sub-carrier (Type A System)

The EBU studies on this type of system have led to consideration of the following characteristics as being optimum in the case of 625-line television standards:

2.1 *Basic assumptions*

2.1.1 *Modulation characteristics applicable to 625-line television systems in a 27 MHz satellite channel*

– transmitted video bandwidth	6 MHz*
– carrier deviation produced by 1 V of video signal**:	13.5 MHz
– pre-emphasis for PAL and SECAM	according to Recommendation 405
– energy dispersal	600 kHz (related to field rate)

2.1.2 *Bit error ratio corresponding to the continuity limit of the sound services:* 10^{-3}

2.1.3 *C/N ratio corresponding to the continuity limit of the sound services:* 8 dB (27 MHz)

2.1.4 *Bit-rate:* a multiple of the sampling frequency of 32 kHz (in accordance with the recommendation proposed by the EBU and given in Report 953)

2.2 *Characteristics of the digitally-modulated sub-carrier*

2.2.1 *Type of modulation:* vestigial sideband two-state phase-shift keying (VSB-2-PSK) with transmission of the upper sideband and coherent demodulation

2.2.2 *Bit rate:* 2.048 Mbit/s***

The stability of the broadcast binary signal should ensure:

- long-term clock-frequency stability of 10^{-6},
- maximum clock jitter of 5 ns r.m.s.

2.2.3 *Sub-carrier frequency*****

The frequency of the original carrier of the 2-PSK modulation (f_1) is 6.5 MHz (6.5 MHz = 416 times the television line frequency).

The long-term stability of this carrier frequency f_1 should be at least 10^{-6}.

The centre frequency of the transmitted spectrum of the sub-carrier signal (f_0) is 7.012 MHz, i.e.:

$$7.012 \text{ MHz} = 6.5 \text{ MHz} + \frac{2.048}{4} \text{ MHz}$$

---

* This value permits the use of a version of the image component coding system using time-compression and time-multiplexing.

** The deviation quoted is for a 1 V peak-to-peak sinusoidal signal at a frequency of 1.52 MHz.

*** This value corresponds to five or six high-quality sound channels, depending on the type of multiplexing used.

**** The description of the modulated sub-carrier requires that two parameters be defined: the frequency of the original carrier of the 2-PSK modulation f_1, and the centre frequency f_0 of the spectrum obtained after vestigial sideband filtering.

2.2.4 *Deviation of the main carrier by the digitally-modulated sub-carrier:* 2.5 MHz r.m.s.

2.2.5 *Coding between the binary signal and the digitally-modulated sub-carrier*

An absolute code is used between the binary signal and the two-state phase modulation (this code requires the use of an ambiguity resolution device in the demodulator).

2.3 *Experimental results*

The following is a summary of the results of numerous tests that have been done with the type A system described above, used in conjunction with a SECAM vision signal and a packet multiplex of 5 high-quality audio channels (coded with near-instantaneous companding and with error-protection using one parity bit covering the 5 most significant bits of each sample).

2.3.1 *Bit error ratio:* see Fig. 2 below.

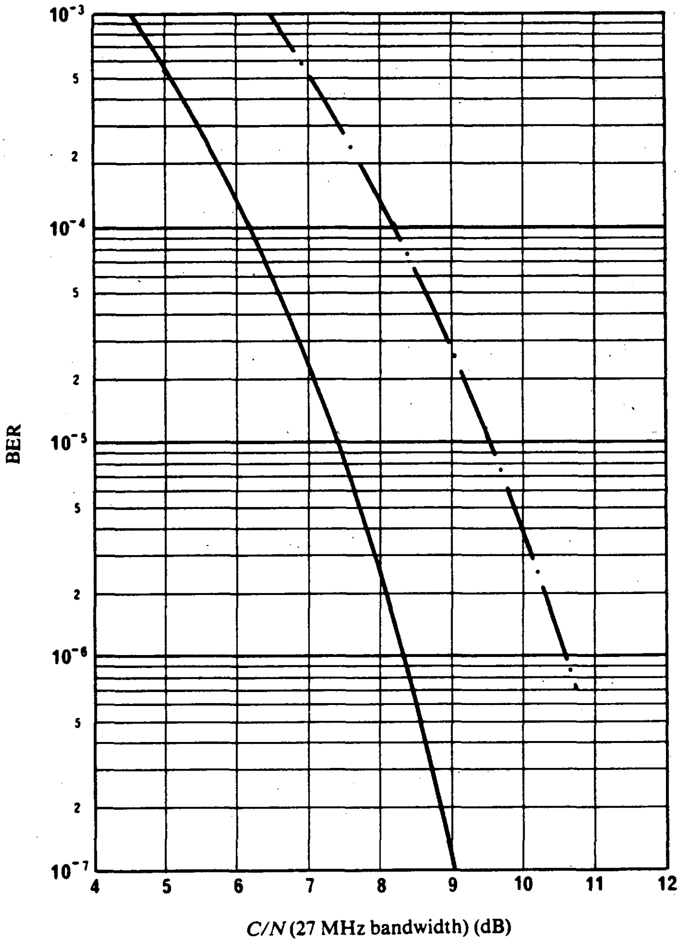


FIGURE 2 – *Typical values of bit error ratio (BER) with a video signal carrying 75% colour bars*

——— theoretical characteristic (Gaussian white noise)

.——.——. typical measured characteristic
(from laboratory experiments and experiments with OTS)

2.3.2 *Vision and sound quality*

Subjective tests have been conducted with a group of 37 observers; they used the single stimulus method for the vision and conformed to the provisions of Recommendation 562 for the sound. The laboratory measuring apparatus included a satellite simulator with a non-linear element. The pictures were derived from EBU test slides. The sound was evaluated independently of the vision, using two musical extracts considered to be sensitive to faults and errors in digital systems (a Haydn trumpet solo and Japanese theatre music). The results are shown in Fig. 3 on the 5-grade quality scale. It will be seen that the best vision quality was 0.65 grade below the quality provided by the 4:2:2 digital television standard of Recommendation 601.

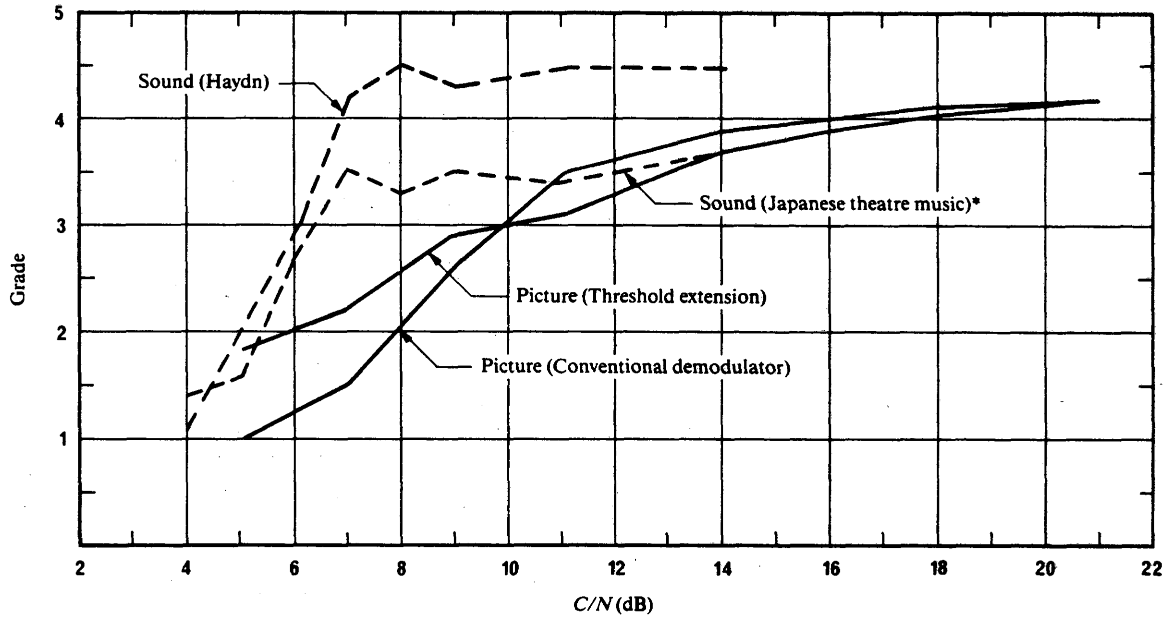


FIGURE 3 – *Quality as a function of C/N ratio for the A/SECAM system (37 observers)*

* The EBU experts involved in the relevant subjective tests are of the opinion that the degradation of Japanese music at carrier-to-noise ratios above 8 dB with reference to Haydn music was due to an overload of the A/D converter at the modulation input.

2.3.3 *Vision and sound failure points*

Taking the failure point to correspond to quality grade 1.5, subjective tests in which the vision and sound programmes were presented simultaneously, and were obtained using guitarists in the studio gave the following results in terms of carrier-to-noise ratio.

Vision

Normal demodulator: 5 dB

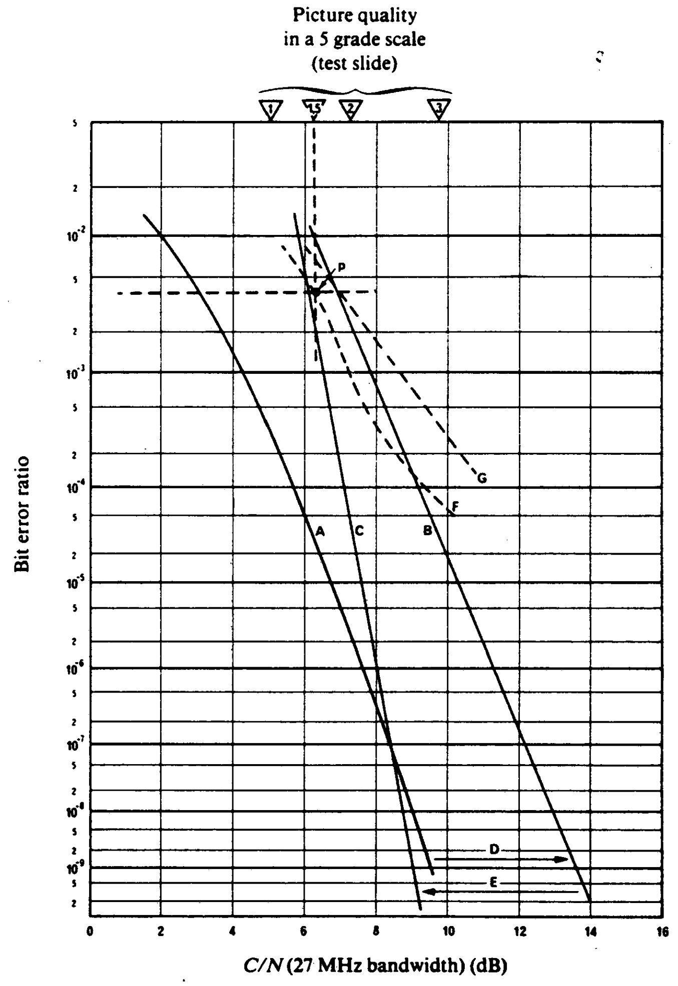
Threshold-extension demodulator: 4 dB

Sound: 4 dB

It should be noted that differences from results given in Fig. 3 are due to the test methodology and evaluation criteria.

ANNEX II

EXPERIMENTAL RESULTS FOR THE DIGITAL SUB-CARRIER SYSTEM INTENDED FOR USE WITH TELEVISION SYSTEM M (JAPAN)



Relation between bit error ratio and C/N for the digitally-modulated sound sub-carrier system

Maximum video signal frequency: 4.5 MHz
Frequency deviation of main carrier by video signal: 17 MHz peak-to-peak
Sub-carrier frequency: 5.727272 MHz
Frequency deviation of main carrier by sub-carrier: ±3.25 MHz
Transmission bit rate : 2.048 Mbit/s

——————— *C/N* versus bit error ratio
A theoretical value (Nyquist)
B experimental value, without error correction and interpolation
C experimental value, with error correction and interpolation

— — — — bit error ratio when the subjective quality of sound is equal to that of picture (with 14/10 bits near-instantaneous companding)
F test slide (woman/sea-side)
G colour bar

D degradation from theoretical value to experimental value
E improvement of bit error ratio by error correction and interpolation technique
p bit error ratio of 4×10^{-3} corresponding to grade 1.5 on a 5 grade scale without error correction and interpolation

ANNEX III

EXPERIMENTAL RESULTS FOR THE TDM BASEBAND MULTIPLEXING SYSTEM

"D2-MAC/packet" (type B system using duobinary coding)

This Annex summarizes the results of numerous laboratory tests carried out in France with broadcasting-satellite simulation equipment having the following characteristics:

- input filter (including the earth-station transmitting filter, assuming linear mode operation):
  - -3 dB bandwidth 34 MHz
  - parabolic distortion of group-delay time in 27 MHz bandwidth 20 ns
- TWT amplitude-phase conversion 5°/dB

The output filter, with a width of 50 MHz, introduces no measurable distortion in the signal.

- the frequency demodulator is of a conventional or threshold-extension type.

1. Bit error ratio

In view of the precoding effected on transmission (modulo 2 division of the binary signal by the duobinary code $(1 + 2)$ generating polynomial), the bit errors are independent.

The curves of Fig. 4 show the error rate measured by means of the simulation model, where:

Curve A: conventional frequency modulator,

Curve B: adaptive filter threshold-extension frequency demodulator.

The principle of the threshold-extension frequency demodulator used for these tests is shown in Fig. 5. With the device as described, the IF filter retains a bandwidth of 27 MHz for carrier-to-noise ratios higher than 11 dB, a value which corresponds to the frequency demodulation threshold. Below 11 dB, the IF filter bandwidth is gradually reduced to about 14 MHz.

Tests performed in similar conditions in the United Kingdom, i.e., with two IF bandwidths, provide results which corroborate those of Fig. 4.

Further improvements of about 0.5 dB may be obtained by the use of the Viterbi decoder [Alard, 1986 a and b: Jankowiak, Lamnabhi and Arragon, 1985].

2. Sound and picture quality with the D2-MAC/packet system

Subjective tests have been carried out in France by observer groups consisting mostly of experts. These tests, together with the common features of the C-MAC/packet and D2-MAC/packet systems described below, were used to plot the sound and picture quality curves. To avoid a proliferation of data, the results given are confined, for the D2 system, to the quality curves corresponding to those of Annex V for the C-MAC system.

2.1 *Description of features common to the C-MAC/packet and D2-MAC/packet systems*

- *Picture:* The two systems are identical with regard to picture transmission:
  - same coding,
  - same pre-emphasis,
  - same frequency deviation,
  - same energy dispersion.

Hence any quality differences in the picture signal can derive only from differences in the behaviour of the frequency demodulator.

- *Sound:* The two systems differ only with regard to bit rate, digital signal coding and modulation characteristics. However, in view of the interlacing of bits and error distribution, the test results established that the same error rate for the two systems provides the same sound quality for a given coding law and a given level of protection.

2.2 *Conventional demodulator*

The curves of picture and sound quality, quasi-instantaneous coding and parity bit protection with a conventional frequency demodulator are given in Fig. 6.

2.3 *Threshold-extension demodulator*

The picture and sound quality is given in Fig. 7 for an adaptive filter threshold-extension frequency demodulator. The sound is quasi-instantaneously coded with a parity bit for error protection.

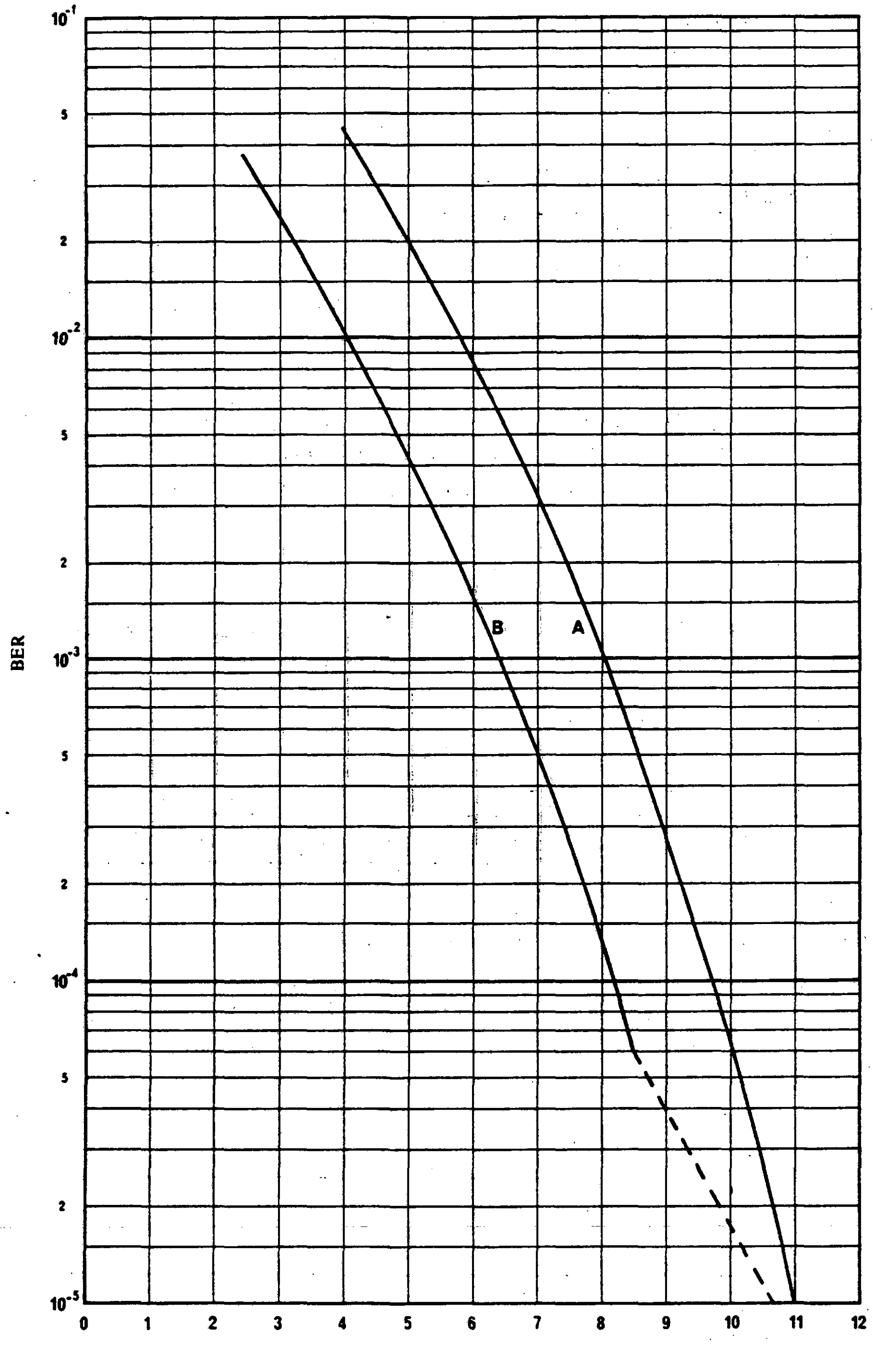


FIGURE 4 – *Bit error ratio measured using the satellite simulator*
– bit rate: 10.125 Mbit/s
– modulation: duobinary FM

Curves A: conventional demodulation
B: adaptive filter threshold-extension demodulator

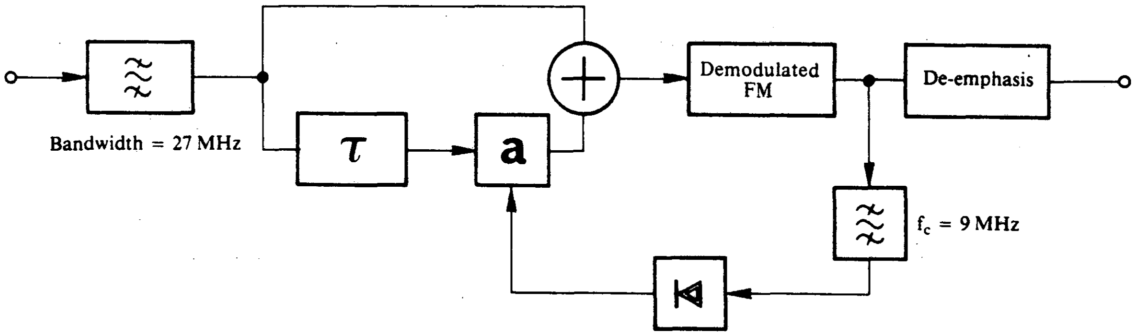


FIGURE 5 – *Principle of a threshold-extension demodulator based on progressive bandwidth reduction of the IF filter when the carrier-to-noise ratio reaches the frequency demodulation threshold (11 dB)*

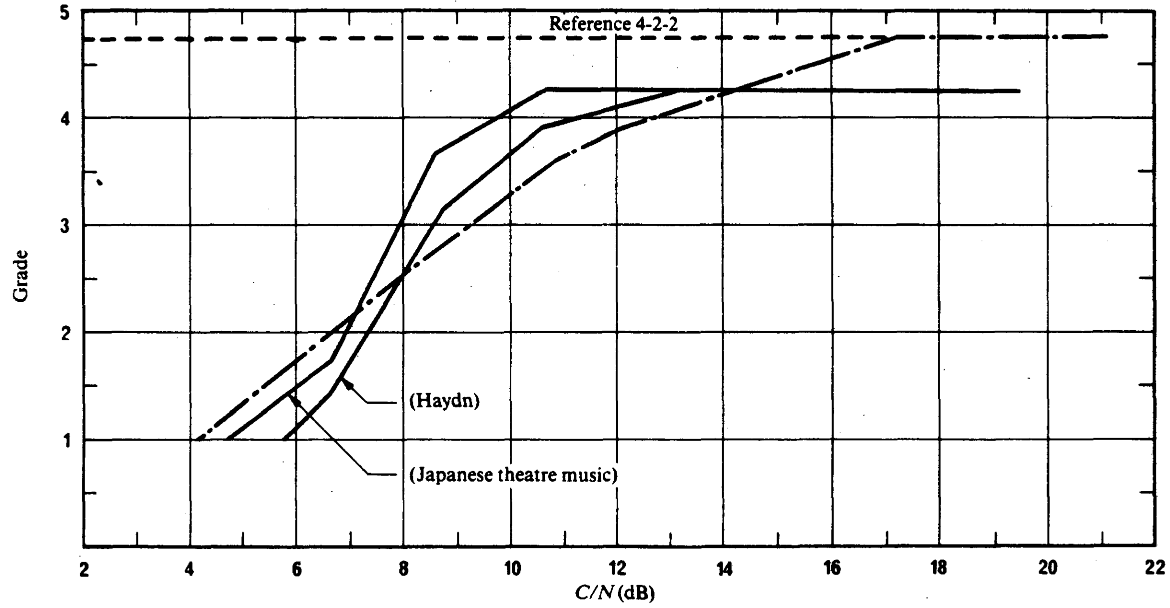


FIGURE 6 – *Picture and sound quality as a function of the carrier-to-noise ratio for a conventional demodulator*

——— sound (quasi-instantaneous coding and protection by parity bit)

—·— picture

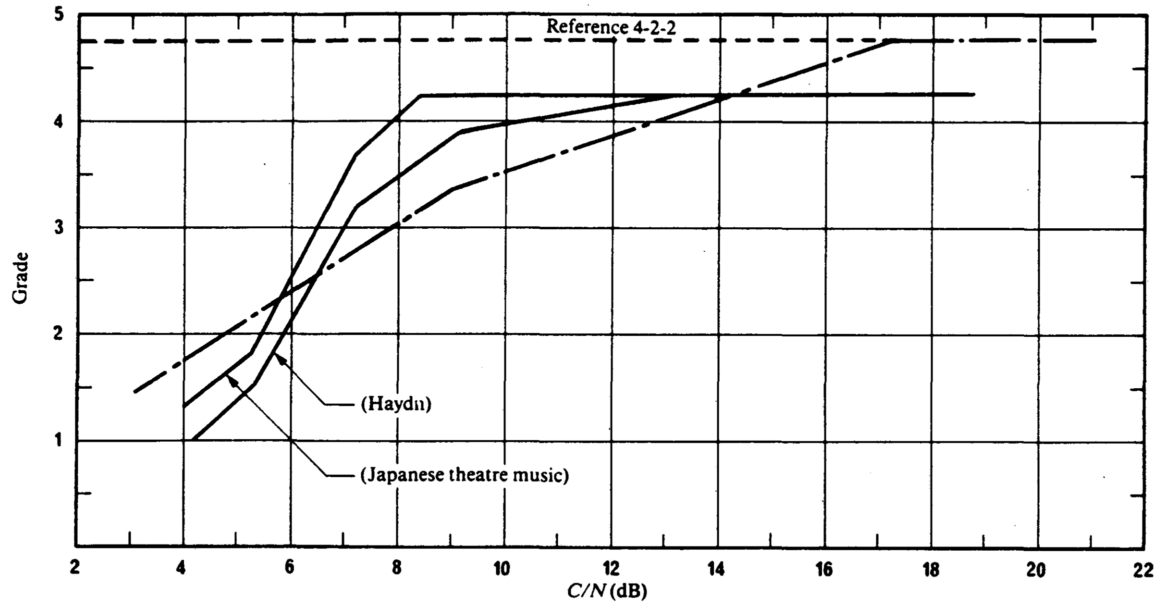


FIGURE 7 – *Picture and sound quality as a function of the carrier-to-noise ratio for an adaptive filter improved threshold demodulator (see Fig. 5)*

——— sound (quasi-instantaneous coding and protection by parity bit)

—·— picture

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ANNEX IV

EXPERIMENTAL RESULTS FOR THE TDM BASEBAND MULTIPLEXING SYSTEM

"D-MAC/packet" (type B system using duobinary modulation)

1. Introduction

This Annex summarizes the results of laboratory tests carried out in the U.K. with satellite channel simulation equipment (Priestman and O'Neill, 1987 and Beech 1987) and in a linear channel (Clark, 1987).

The characteristics of the satellite channel simulation equipment were as follows (see Stickland and Barber 1984):

Satellite Input Filter
3 dB bandwidth : 36 MHz
20 dB bandwidth : 44 MHz
Group delay : 5 ns at centre frequency ± 13.5 MHz

Satellite Output Filter
3 dB bandwidth : 38 MHz
20 dB bandwidth : 52 MHz
Group delay : 8 ns at centre frequency ± 13.5 MHz

Satellite TWT Amplifier

AM to PM factor: 5.5 degrees/dB. This is the measured figure and is typical of TWTs used in high power satellite broadcasting applications. The TWT was operated at saturation. (The specified figure is 5 degrees/dB).

The AM to PM factor is not significant for the data component of the D-MAC/packet system. The transmitted frequency modulated data component has an essentially constant envelope and there is only a very small amount of energy outside the passband of the typical direct broadcasting satellite input multiplexing filter. Hence the signal at the input of the travelling wave tube has essentially constant amplitude.

The feeder link transmitter was a nominally 1.5kW klystron operated at about 1kW output power.

No thermal noise was added on the feeder link.

2. Bit error ratio

The curves of Figure 8 show the bit error ratios obtained for various transmission conditions.

Curves C and B apply for a linear channel and with 27 MHz and 21 MHz bandwidth IF filters, respectively. It can be seen that the 21 MHz bandwidth IF filter provides about 1 dB performance improvement at 10^{-3} bit error ratio. Such a filter bandwidth is compatible with low distortion MAC vision transmission and also provides about 1 dB frequency modulation threshold extension improvement for the vision signal compared to a 27 MHz bandwidth IF filter. Curve A applies to the simulated satellite channel and a 27 MHz bandwidth IF filter.

Further improvements in performance can be obtained using maximum likelihood decoding technques (the Viterbi algorithm). Figure 8, curves D and E, relate to a receiver employing such techniques with a 21 MHz IF filter in a linear channel and via the satellite simulator respectively. The carrier to noise ratio for 10^{-3} bit error ratio is 8 dB. Therefore, using such techniques, the continuity of service criterion of 10^{-3} bit error ratio for 8 dB carrier to noise ratio is satisfied. The degradation due to the satellite channel is negligible.

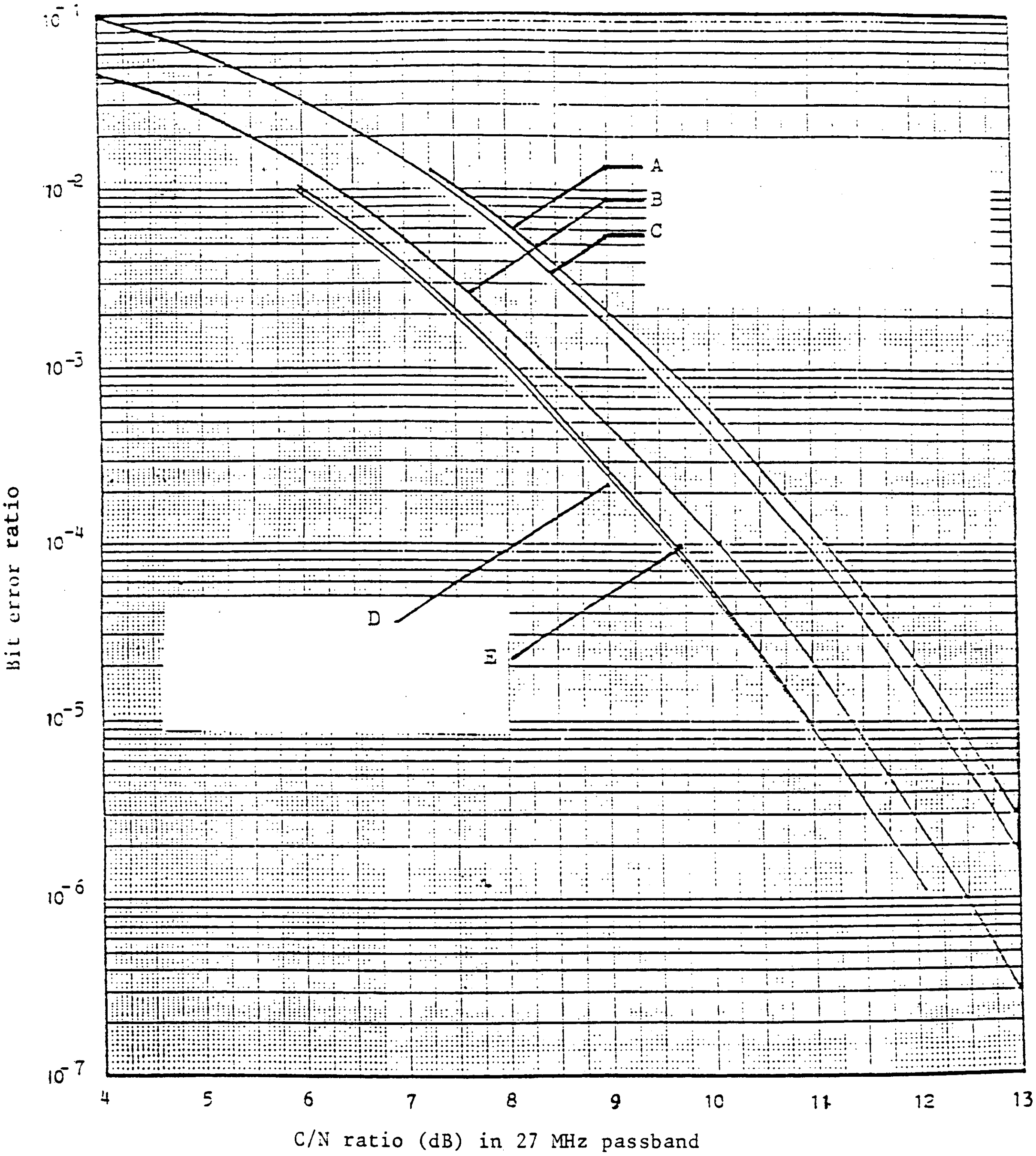

FIGURE 8

Bit error ratio performance of the D-MAC/packet system using frequency modulation

A: Simulated satellite channel 27 MHz)
B: Linear channel 21 MHz) normal decoding
C: Linear channel 27 MHz)

D: Linear channel 21 MHz) Viterbi coding
E: Simulated satellite channel 21 MHz)

Table IV indicates the results of measurements of multiple bit errors for the D-MAC/packet system using normal decoding in a linear channel (Clark, 1987). The double-, triple- and higher-order bit error ratios are small compared to the total bit error ratio. The result of de-interleaving these errors in the D-MAC/packet receiver is to distribute the individual bit errors through the data multiplex such that the output data contains predominately isolated single bit errors.

TABLE IV - Multiple bit error parameters for the D-MAC/packet system using frequency modulation

Receiver IF filter bandwidth	R(1)=BER	R(2)	R(3)	R(4)
27 MHz	3.2×10^{-3}	2.9×10^{-4}	1.2×10^{-5}	4.8×10^{-7}
20 MHz	1.3×10^{-3}	5.3×10^{-5}	1.8×10^{-6}	4.9×10^{-8}

Carrier-to-noise power ratio : 8.5 dB in 27 MHz bandwidth.
(Measurement performed in a linear channel.)

$$R(n) = \frac{\text{rate of occurrence of a group of n consecutive bit errors (events/s)}}{\text{data rate (bits/s)}}$$

3. Sound and picture quality of the D-MAC/packet system

3.1 Sound

Resulting from the de-interleaving process used in the MAC/packet systems,the sound channel performance is dependent only on the channel bit error ratio. Therefore it is possible to use the results applying to the C-MAC/packet system for the sound quality of the different MAC/packet sound coding options, scaled appropriately for the carrier-to-noise ratio differences between the C-MAC/packet system and the D-MAC/packet system.

Using the Viterbi decoding algorithm, the sound quality of the D-MAC/packet system is equal to that of the C-MAC/packet system at carrier-to-noise ratios equal to or greater than 6 dB.

Thus,receivers for the D-MAC/packet system using the Viterbi decoding algorithm can satisfy the service criterion for the MAC/packet family of systems.

3.2 Picture

The picture coding and modulation for the D-MAC/packet system are identical to those of the other members of the MAC/packet family. Hence the picture quality is identical to that of the C-MAC/packet and D2-MAC/packet systems described in the Annexes to this report. The baseband frequency response of the D-MAC/packet system is shown in

Figure 9 for the case of a receiver baseband filter of 8.4 MHz. It will be noted that, in the case of a 21 MHz filter, there is a small degradation of the high frequency response. However, this is limited to less than 0.5 dB reduction in the worst case encountered with typical vision signals corresponding to -3 dB relative to 1 V p.-p. The use of a 27 MHz filter will permit an increased system bandwidth.

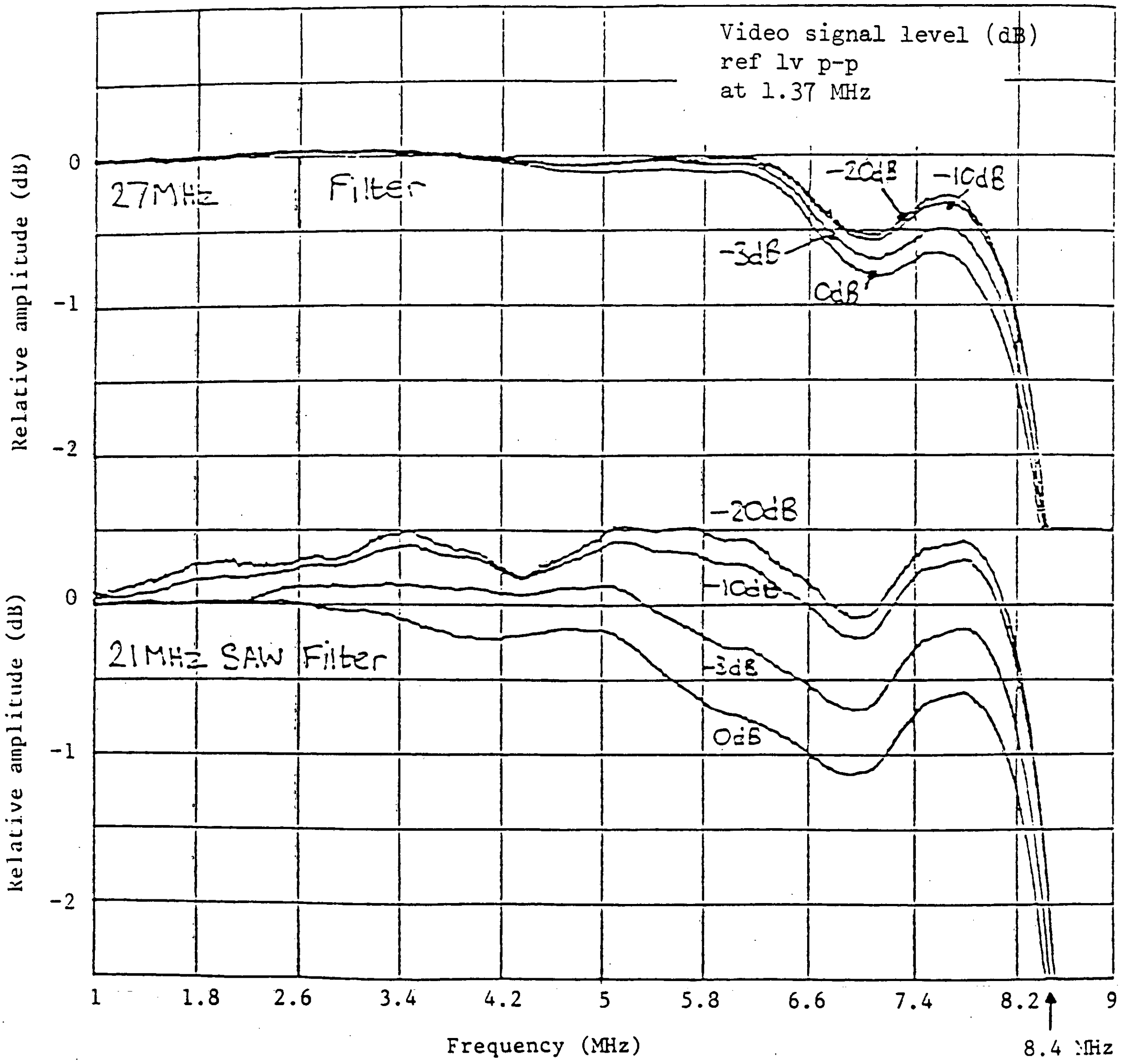

FIGURE 9

Baseband frequency response of the D-MAC/packet equipment using two different channel filters and an 8.4 MHz baseband filter in the receiver

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ANNEX V

EXPERIMENTAL RESULTS CONCERNING THE RF TIME-MULTIPLEX SYSTEM (TYPE C SYSTEM)

The following summarizes the results of numerous tests conducted by the EBU, both in the laboratory and with the use of the OTS satellite, on the type C system, operated in conjunction with a MAC vision signal and in the case of either a continuous structure-map multiplex or a packet multiplex.

1. Bit error ratio

See Figs. 10 and 11 below and Table V.

TABLE V – *Typical measured BER versus C/N for different demodulation methods of 2-4-PSK*

	C/N in 27 MHz for BER of 10^{-3} (dB)
T demodulation i.e. conventional differential demodulator	7.9
T + 2*T* demodulation i.e. "Masamura" demodulator (¹)	7.3
Coherent demodulation (continuous data only)	7.1

(¹) The "Masamura" demodulator [Masamura *et al.*, 1979] gives a result which approaches that of a coherent demodulator and can achieve this performance in burst mode.

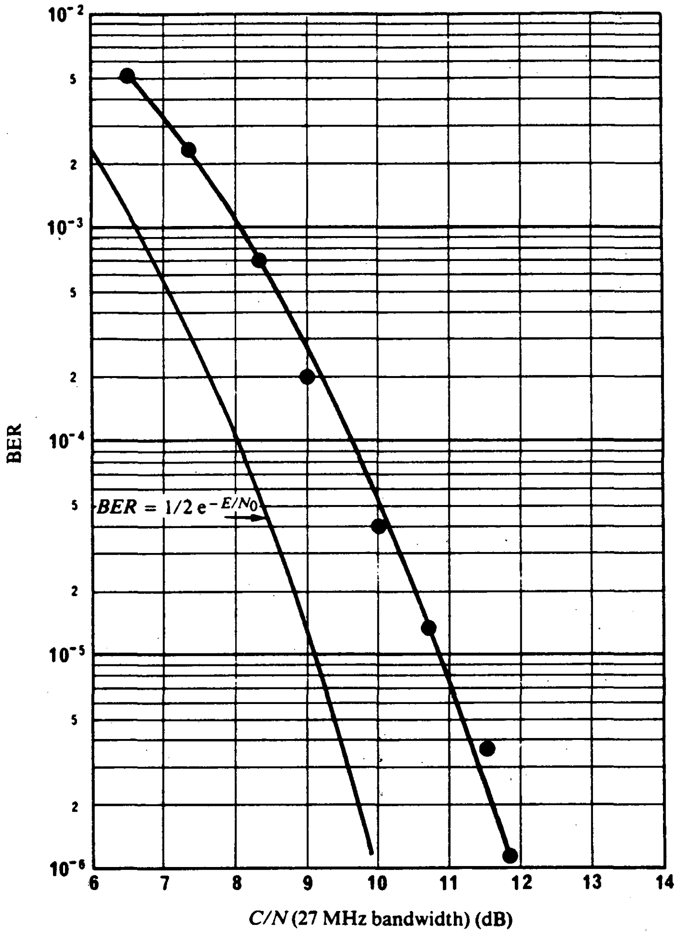

FIGURE 10 – *Typical BER as measured in the case of transmission via the OTS satellite and various satellite simulators*

Bit rate : 20.25 Mbit/s
2-4 PSK differential demodulation

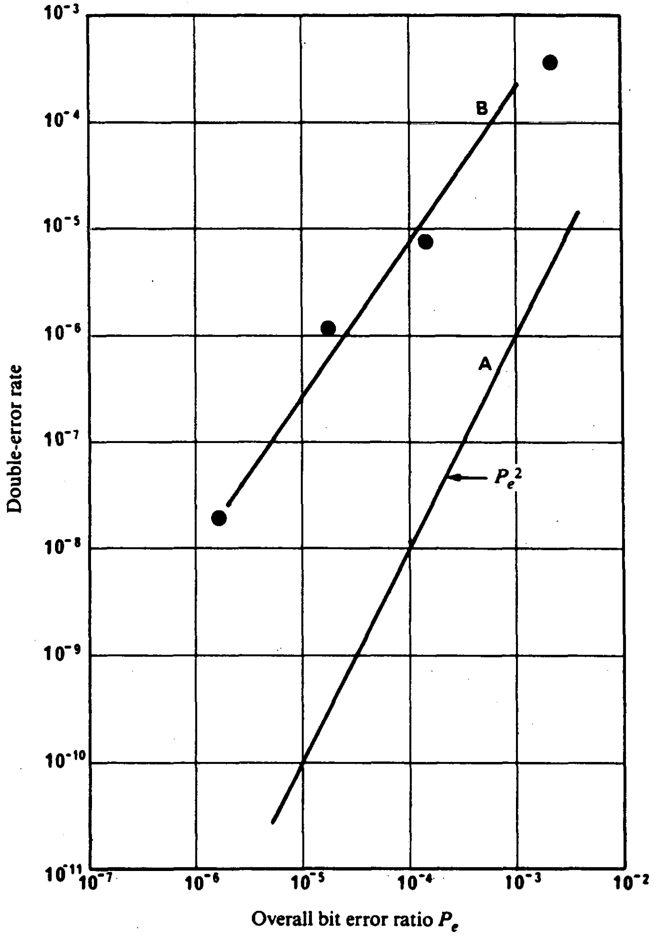

FIGURE 11 – *Double-error rate versus overall bit error ratio*

A: independent errors (theoretical: P_e^2)

B: measured for 2-4-PSK with differential demodulation using analogue delay line and multiplier

2. Vision and sound quality for the C-MAC system

Subjective tests have been conducted with a group of observers (see § 2.3.2 of Annex I).

The sound tests have been carried out with conventional differential demodulation of the 2-4-PSK signal, but with different coding laws, multiplexing systems and protection levels. Two combinations of these different aspects have been the subject of subjective assessments in accordance with Recommendation 562. These results were obtained on different occasions, 37 observers being present for combination 1 and 15 observers for combination 2. To aid comparison between Fig. 12 and Figs. 13a and 13b below, the same bit error ratio was used.

Combination 1: Structure map multiplex used in conjunction with a near-instantaneous companding law, Hamming code protection and transmission of the scale factor within the parity bits. Because of the error protection technique used, the capacity of this combination was reduced from eight to six 15 kHz sound channels.

Combination 2: Packet multiplex as defined in Report 1073 using near-instantaneous companding law with parity protection (first level) and with Hamming code protection (second level). Linear coding using parity protection (first level) and with Hamming code protection (second level). The capacity for 15 kHz sound channels ranges from eight channels in the case of near-instantaneous companding law first level protection to four channels in the case of linear coding with second level protection. In the case of near-instantaneous companded second level protection and in the case of linear coding first level protection, the capacity is six channels.

The corresponding results expressed using the 5 grade quality scale are shown in Fig. 12 for combination 1 and in Figs. 13a and 13b for combination 2.

It can be seen from Fig. 12 that the best vision quality is such that the C-MAC system may be considered as "transparent" to the 4:2:2 standard of Recommendation 601. From Figs. 13a and 13b it can be seen that all four high quality sound coding options of the C-MAC/packet system approach the reference grade (>4.8) above 9.5 dB *C/N*.

3. Vision and sound failure points

For combination 1 and for the near-instantaneous companding law of combination 2 described in § 2, subjective tests in which the vision and the sound elements of the programme were presented simultaneously have been conducted in order to define the relative failure points of sound and vision.

The programme consisted of a transmission of a musical composition played by a guitar.

The following values for the *C/N* ratio at the failure points (quality grade 1.5) were obtained:

Combination 1: *Vision*
- Normal demodulator: 4 dB
- Threshold-extension demodulator: 4 dB

Sound: 4 dB

Combination 2: *Vision*
- Normal demodulator: 3 dB
- Threshold-extension demodulator: 2 dB

Sound: 4.5 dB

The differences from the results presented in § 2 (Figs. 12 and 13) are due to the differences in the assessment methods and evaluation criteria used.

4. Limit of speech intelligibility

For combination 2 the limit of intelligibility of speech was assessed with simultaneous presentation of vision and sound. A figure of 3 dB was obtained for that limit.

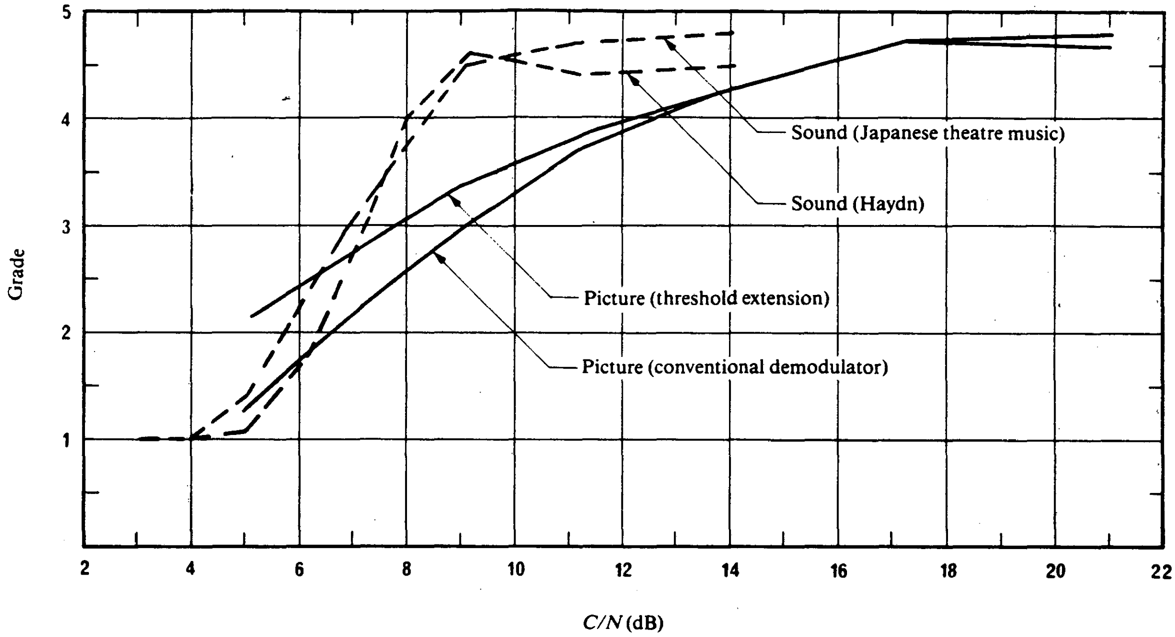

FIGURE 12 – *Quality as a function of the C/N ratio for combination 1 (37 observers)*

REFERENCE

MASAMURA, T., SAMEJIMA, S., MORIHIRO, Y. and FUKETA, H. [June, 1979] Differential detection of MSK with nonredundant error correction. *IEEE Trans. Comm.*, Vol. COM-27, **6**, 912-918.

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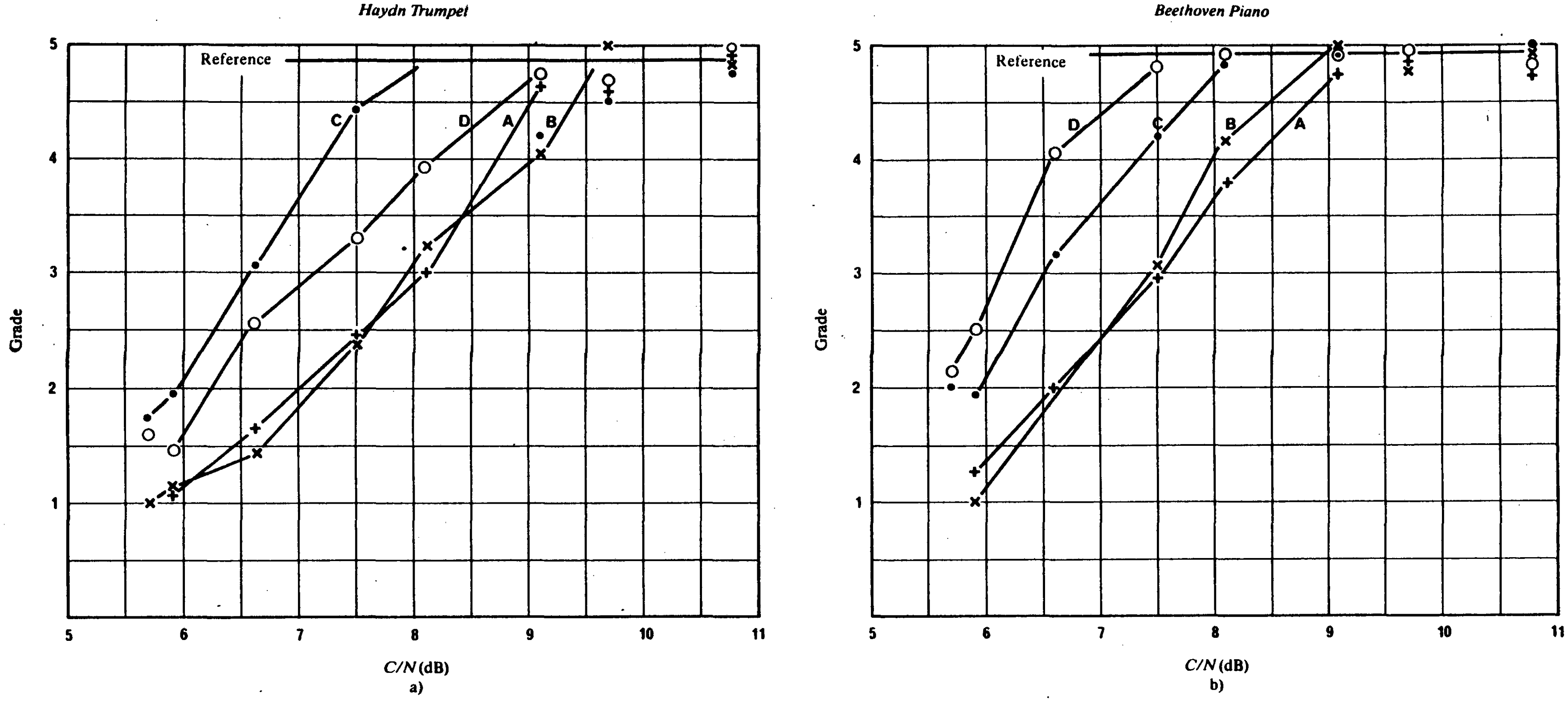

a) b)

FIGURE 13 – *Subjective quality of C-MAC/packet sound coding options**

Key – A companded first level – protected
B linear first level – protected
C companded second level – protected
D linear second level – protected

* For the same bit error ratio, these results could also be valid for the D2-MAC/packet system which uses the same coding law and the same error protection as the C-MAC/packet system. The relation between bit error ratio and *C/N* is shown in Fig. 8 of Annex IV for the C-MAC/packet system and in Fig. 4 of Annex III for the D2-MAC/packet system.

REPORT 953-2*

DIGITAL CODING FOR THE EMISSION OF HIGH-QUALITY SOUND SIGNALS IN SATELLITE BROADCASTING
(15 kHz NOMINAL BANDWIDTH)

(Question 2/10 and 11, Study Programmes 51C/10, 2F/10 and 11)

(1982-1986-1990)

1. Introduction

Technological developments presently allow the emission of digitally encoded audio signals to the public to be envisaged. It would be possible in particular to introduce this technique in the broadcasting-satellite service. This will require the prior definition of characteristics concerning coding, multiplexing and modulation of audio signals. This Report is concerned only with digital sound coding. Multiplexing, bit-error protection strategy and modulation aspects are discussed in Reports 954 and 632 respectively. Information dealing with methods of error correction or concealment can be found in Report 1073.

Study Programme 51C/10 considers that the introduction of digital techniques for emission should allow an improvement in the quality of the signals transmitted. Recommendation 651 deals with digital PCM coding. Results of objective and subjective tests are given in Annex II of the present Report.

Other coding methods leading to a substantial bit rate reduction and at the same time maintaining very high quality are described in Report 1199.

In addition to the improvement of quality, the following should be considered:

- the compromises between quality objectives and bit rate may be different for sound services which may have various quality requirements and planning constraints; they may also vary according to the requirements of individual countries;
- there are clear advantages for broadcasters, receiver manufacturers and the public in using a single standard for each application.

2. Digital PCM coding

2.1 *Linear coding*

The audio signal is encoded into digital form by a high precision analogue-to-digital converter after being passed through an appropriate anti-aliasing filter and possibly through a pre-emphasis network. The uniform coding resulting from this process leads to a linear representation with a minimum of 14 bits per sample. In that case, a 2's complement coding is used for each sample. A possible scale factor can possibly be associated with blocks of successive samples.

2.2 *Floating point or near-instantaneous coding*

A 16 bit linearly encoded sound signal can be transmitted on 14 bits per sample using a floating point coding system where the scale factor is based on 64 consecutive samples. Pre-emphasis may or may not be used.

When a lower bit rate per audio channel is required, the near-instantaneous companding allows for a reduction in the number of bits per sample from 14 bits to 10 bits. This companding is applied on blocks of 32 successive samples with a complementary scale factor on five ranges. A 2's complement representation is still used for each sample. In that case, the use of pre-emphasis is recommended to reduce the programme modulated noise.

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* This Report should be brought to the attention of the CMTT.

2.3 *Differential coding*

Differential coding is another technique to achieve a lower bit rate per audio channel by making use of the fact that, in most programme material, correlation between two consecutive samples is high. In this case, the difference between successive samples will generally be smaller than the actual sample values. By coding the differential signal, rather than the original samples, a reduction of bit rate can be achieved for a given requirement of signal-to-noise ratio.

Difference samples can be coded instantaneously, one at a time, as in a linear coder, or by blocks of successive samples (with complementary scale factors) as in near-instantaneous companding. Such a marriage of differential coding with near-instantaneous companding has been proposed [CCIR, 1986-90] to achieve a reduction in the number of bits per sample from 15 bits to 8 bits. The use of pre-emphasis is recommended to reduce the programme modulated noise.

2.4 *PCM emphasis*

The quality of the transmission system, in particular the noise and distortion characteristics, depends largely on the signal statistics and the coding law used. Also, the audible noise detection response of the receiving system, including the human ear, can be considered to be non-uniform. Taking these factors into account, the characteristic could be improved by adopting appropriate pre-emphasis prior to the coding process and the corresponding de-emphasis at the receiver following the decoding process. For PCM systems two such emphasis methods have been exhaustively studied and evaluated. Annex I contains more detailed information on the two systems, i.e., one based on CCITT Recommendation J.17, the other based on 50/15 µs.

3. **Adaptive delta modulation (ADM)**

3.1 *Background*

The adaptive delta modulation (ADM) system is based on delta modulation (the decoder is mathemetically defined in § 3.2). The audio is encoded into digital form by a simple delta modulator after being modified by two processes:

- the audio is passed through a variable pre-emphasis network which alters the audio spectrum; and
- the audio is compressed in level, based on its slope. The compression is "infinite" over a 48 dB input signal level; that is, the audio is compressed to the same level for conversion to digital form. Optimum loading of the digital channel is achieved for most audio signals.

The digital bit stream representing the encoded audio signal is transmitted to the receiver, along with two very low data rate bit streams containing control signal information so that the decoder can precisely reverse the processing performed by the encoder. The decoder recovers audio by integrating the audio bit stream; performing a dynamic range expansion based on the compression (slope) control signal; and performs spectral de-emphasis based on information in the emphasis control signal.

The following points may be noted concerning the use of delta modulation:

(a) the bit rate of delta modulation may be reduced with a minor effect on audio signal quality (S/N degrades by 9 dB for a halving of bit rate);

(b) reproduced errors are tolerable;

(c) a digital-to-analogue converter for delta modulation is very simple, requiring no precision components;

(d) the de-emphasis provides adequate output filtering and sharp cut-off low pass filters are not required.

Items (c) and (d) affect the required decoding circuitry.

3.2 *ADM decoder definition (Fig. 1)*

3.2.1 *Audio decoder*

The audio decoder consists of a leaky integrator fed with pulses derived from the audio data bit-stream so that data 1's and 0's at a rate in the order of 250 kbit/s cause the output to move positively or negatively by equal steps. The size of the pulses is linearly proportional to an applied control signal over a range of about 50 dB, and the leaky integrator has a frequency response defined by:

$$(1 + sT_0)^{-1}$$

where $T_0 = 0.5$ ms.

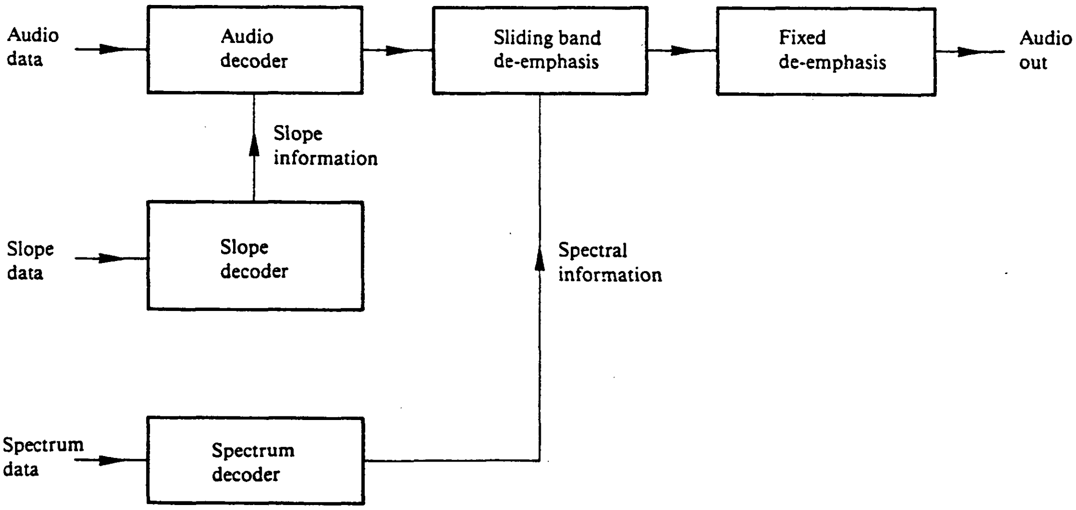

FIGURE 1 – *Adaptive delta modulation decoder*

3.2.2 *Sliding band de-emphasis (Fig. 2)*

The de-emphasis has the variable frequency response:

$$\left[\frac{10sT_1}{1+sT_1} + \frac{1+sT_2}{1+sT_3} \right]^{-1}$$

where $T_2 = 5$ µs, $T_3 = 50$ µs, and T_1 is variable under the control of the spectrum data.

Note that the first term in the bracket is a high-pass characteristic at frequency f_1 where:

$$f_1 = \frac{1}{2\pi T_1}$$

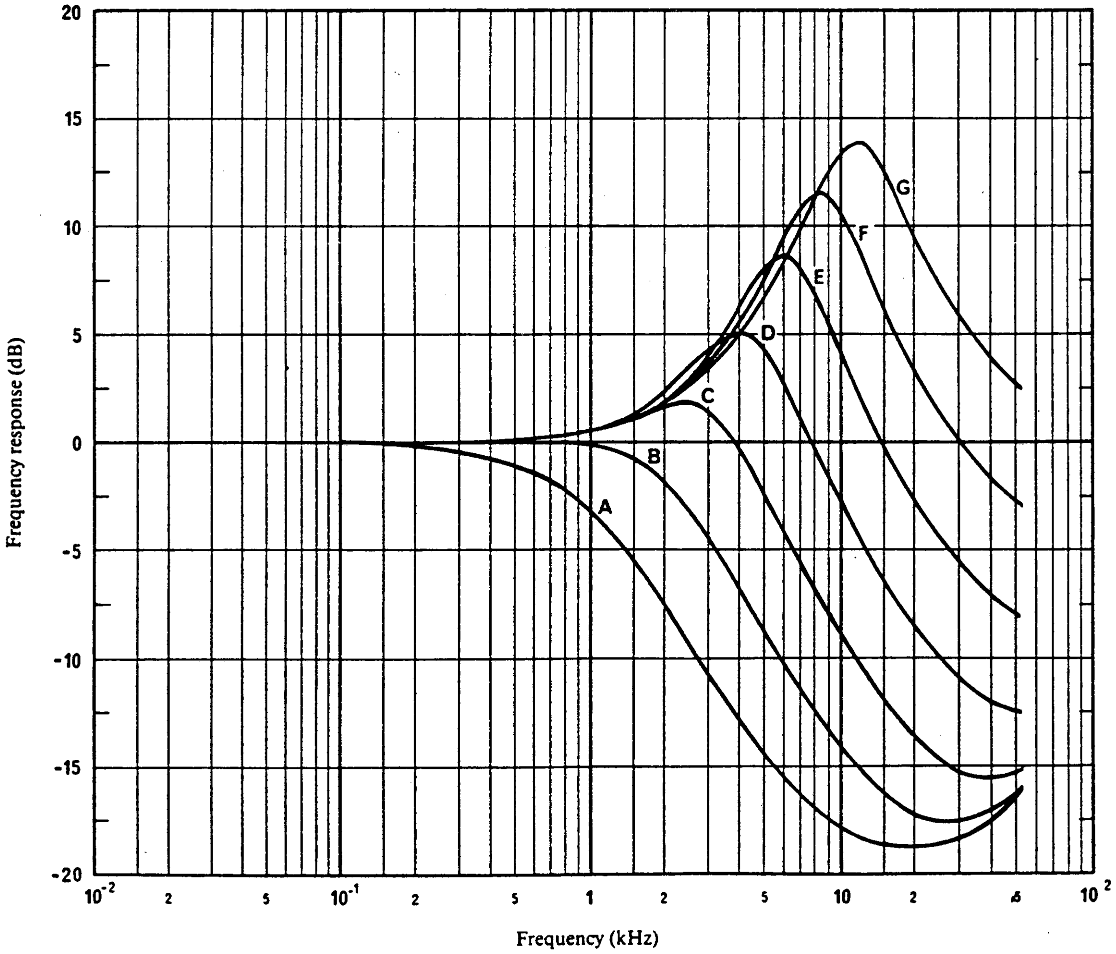

FIGURE 2 – *Adaptive delta modulation (ADM) de-emphasis filter*

3.2.3 *Spectrum decoder*

The de-emphasis control information is contained in a data bit stream at about 8 kbit/s, typically but not necessarily an integral sub-multiple of the audio data bit-rate. The mean level V_m of the bit-stream is derived by feeding the data via a three-pole low-pass filter with the characteristic:

$$(1 + sT_4)^{-3}$$

where $T_4 = 2$ ms.

If the data pulses have height V_p, a controlling parameter x is given by:

$$x = \frac{V_m}{V_p}$$

The output of the filter is fed into an exponentiator to produce a control signal to operate on the variable emphasis. The circuit constants are such as to provide the relationship:

$$f_1 = \frac{1}{2\pi T_1} = 4000\,(2^{10x}) \qquad \text{Hz}$$

With this definition, a change in x of 0.1 moves f_1 by one octave.

3.2.4 *Slope decoder*

The signal slope information is contained in another data bit stream at about 8 kbit/s. This bit stream is converted to a control signal by means of a low-pass filter and exponentiation exactly as in the spectrum decoder. The height of the pulses integrated in the audio decoder is linearly proportional to this control signal.

As in the spectrum decoder, the mean level V_m of the bit stream is derived using a three-pole low-pass filter with the following characteristic:

$$(1 + sT_4)^{-3}$$

where $T_4 = 2$ ms,

and is then fed into an exponentiator to provide the step or pulse size control signal V_{ss} for use in the audio decoder. This exponentiator has the characteristic:

$$V_{ss} = V_0(2^{10y})$$

where y is the normalized mean level of the pulses (as x above) and V_0 is a constant scaling factor to suit the audio decoder. With this definition, the pulse height changes 6 dB for each change in y of 0.1.

3.2.5 *Fixed de-emphasis*

The fixed de-emphasis is a single pole low-pass filter with the characteristic:

$$(1 + sT_5)^{-1}$$

where $T_5 = 25$ µs.

In consumer decoders no further output filtering is necessary.

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ANNEX I

EMPHASIS TECHNIQUES FOR HIGH-QUALITY PCM SOUND SIGNALS

In the technique of digital PCM sound coding, pre- and de-emphasis methods are to be used for several purposes:

- in the case of digital audio signal processing, the emphasis reduces the subjective perceptibility of the quantizing noise, especially for the so-called programme-modulated noise with companded coding;
- in the case of both companded and linearly coded audio signal proçessing, emphasis may reduce the impairment due to bit errors at low *C/N* values.

Two different characteristics have been proposed for both companded and linearly coded systems. The first pre-emphasis system is based on CCITT Recommendation J.17 (with an insertion loss of 6.5 dB at 0.8 kHz) and the second on the characteristic of 50/15 µs time constant. Characteristics of these are depicted in Fig. 1 of Recommendation 651.

Results of investigations into linear coding [CCIR, 1982-86a] and linear and companded coding [CCIR, 1982-86b and c] clearly show the advantages of using pre-emphasis in most cases. It has been observed that both systems have the quality of reducing the quantizing noise, with a slight advantage for 50/15 µs pre-emphasis in the case of non-companded operation. Concerning the risk of overloading, the documents [CCIR, 1982-86a, b and c] reflect different points of view. No clear difference between these two systems has been noted on impairments due to bit error at low *C/N* levels.

Results of theoretical assessments [CCIR, 1982-86b] and subjective tests [CCIR, 1982-86d and e] carried out for companded systems, based on the pre-emphasis characteristics shown in Fig. 1 of Recommendation 651, show that a significant reduction of the subjective audibility of the programme modulated noise could be achieved by applying CCITT Recommendation J.17 pre-emphasis. However, results of other subjective tests [CCIR, 1982-86f and g] showed no significant difference. In [CCIR, 1982-86f], insertion loss adjustment in each system was performed in order to avoid overloading.

As far as digital coding of sound programme signals is concerned, CCITT Recommendation J.17 (with an insertion loss of 6.5 dB at 0.8 kHz) is widely used for transmission purposes, as specified by CCITT Recommendation J.41, and the 50/15 µs pre-emphasis system is widely used for consumer applications.

REFERENCES

CCIR Documents

[1982-86]: **a.** 10/21 (EBU); **b.** 10-11S/201 (EBU); **c.** 10-11S/139 (Japan); **d.** 10/269 (Germany (Federal Republic of)); **e.** 10-11S/206 (France); **f.** 10-11S/205 (Japan); **g.** 10-11S/207 (Canada).

ANNEX II

SUBJECTIVE TEST RESULTS ON ADAPTIVE DELTA MODULATION AND OTHER CODING METHODS FOR HIGH-QUALITY SOUND

1. Subjective measurements conducted in Australia

The Australian Broadcasting Corporation (AuBC) has conducted subjective tests on the adaptive delta modulation (ADM) system [AuBC, 1985] in accordance with Recommendation 562 to relate subjective audio quality to bit error ratio, with the eventual objective of relating this to *C/N* ratio.

The supplied ADM equipment had a random error generator card to introduce errors into the data stream in a known switch-selectable ratio. The accuracy of the switch settings was checked and found to be accurate within normal statistical variations.

A carefully controlled and measured environment was used to replay the material in sequences according to Recommendation 562.

For evaluation of the audio part of the system, seven different segments of material were chosen from compact disc or original 16 bit PCM recordings and recorded in sequence in 16 bit PCM on a videotape machine for subsequent replay. The seven programme segments are listed in Table I.

TABLE I – *Reference programme segments*

Item (and curve) No.	Description
1	Male solo
2	Male spoken word
3	Piano
4	Flute, then boys' choir
5	Female spoken word
6	Orchestral
7	Mixed modern group

Figure 1 indicates that for a given BER, the impairments vary widely but consistently with the programme material, but that a mean impairment rating of 3.5 is achieved for a BER around 10^{-3}.

The overall impairment rating of 3.5 for a BER of 10^{-3} was thought to be equivalent to a *C/N* less than 9 dB. However, this would be degraded when using four levels of data as proposed for Australia. It was not possible to make measurements on this mode of operation, but results suggest a degradation of approximately 1 dB for the outer levels of data and approximately 1.8 dB for the inner levels. This may have implications as to which programmes should be carried on which data channels. However, facilities have not been available to the AuBC to corroborate these figures.

Independent correlation is yet to be established between *C/N* and BER obtainable from receivers in the field.

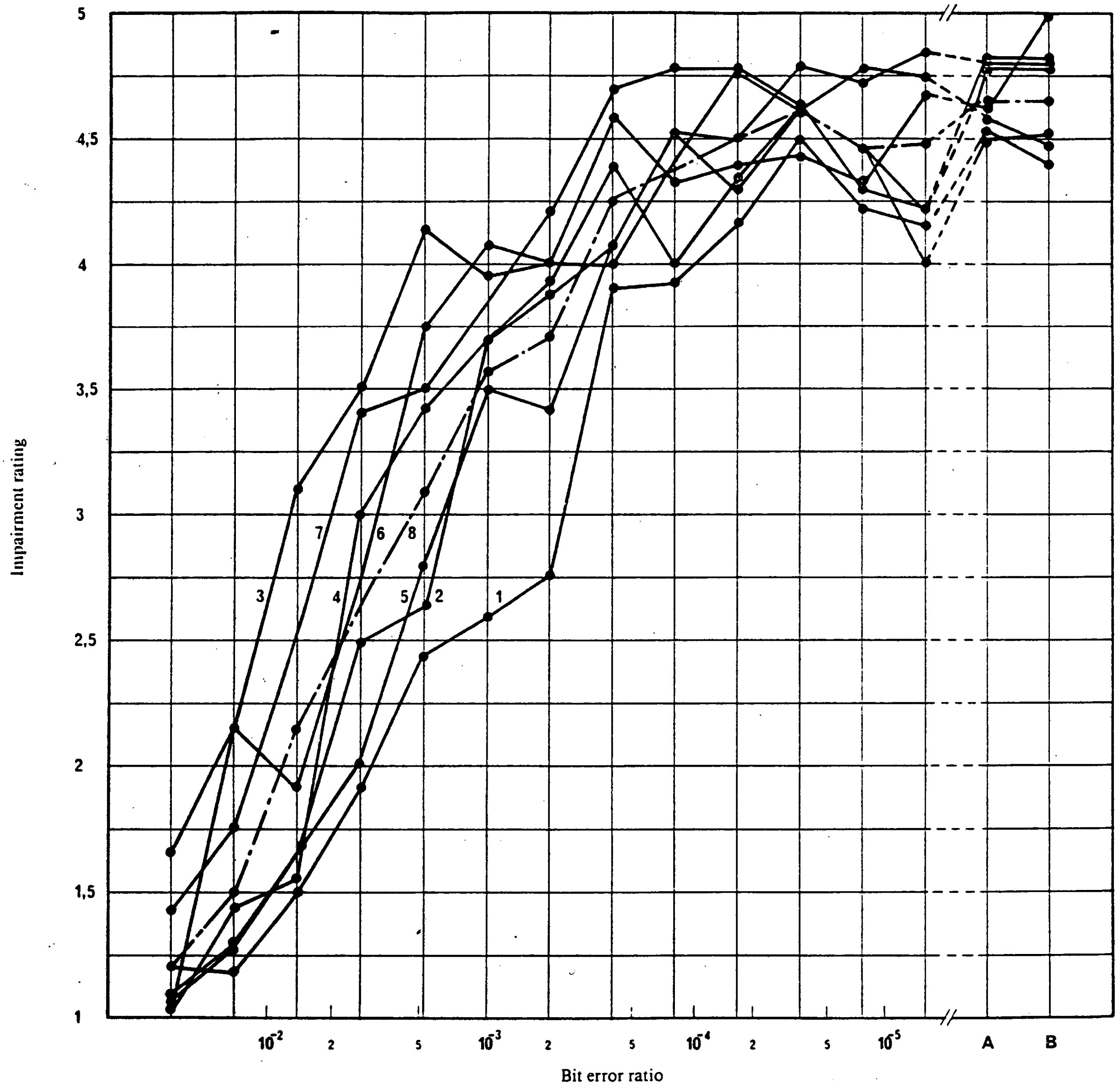

FIGURE 1 – *Impairment rating versus switch position, item by item*

Note 1. – Curves No. 1-7 are from programme selections indicated in Table I. Curve 8 is for overall (average) result.

Note 2. – In scale position A, signal is transmitted through Dolby ADM system without errors.

Note 3. – In scale position B, signal comes direct from analogue source (e.g.: PCM on VCR).

2. Subjective measurements conducted in Canada

2.1 *Subjective asssesment of a selection of ADM, linear and near-instantaneous codes*

In the process of identifying the relative merits of the various proposed coding schemes, a test programme was conducted in Canada.

The following coding schemes were covered by the measurement programme:

- 10-14 semi-instantaneous companding (NICAM 3) with CCITT Recommendation J.17 pre-emphasis;
- 10-14 instantaneous companding (A-law) with CCITT Recommendation J.17 pre-emphasis;
- 14 bit linear coding with CCITT Recommendation J.17 pre-emphasis;
- adaptative delta modulation (sampling rate = 330 kHz); and
- adaptative delta modulation (sampling rate = 204 kHz).

The first three coding schemes were modelled on a computer working in conjunction with a vectorial processor.

The pre-emphasis applied to the signal was changed through digital filtering. The sampling frequency was also changed to 32 kHz through digital processing. Companding and truncation to generate the proper number of bits was then performed to finally obtain the companded digital stream. Proper re-formatting was made to store the test sequence on video tape.

This process was not used for the ADM system which could not be modelled on the computer. Conversion to analogue signal was necessary before processing by the ADM. At the output of the ADM the signal was converted back from analogue to 16 bits/sample for insertion in the recorded test sequence.

The source material was either read from compact laser discs or generated by the computer itself:

- Cardozo, Pájaro Campana (Indian Harpsichord)
- Orff, Carmina Burana (Lyrics)
- synthetic gong generated at 44 kHz simulating the sound of a triangle on the first 4 notes of "Frère Jacques" (4.2 kHz, 4.7 kHz, 5.3 kHz and 4.2 kHz). (Attack: $T = 3$ ms, decay: $T = 300$ ms.)
- synthetic gong generated at 44 kHz simulating a bass guitar on the first 4 notes of "Frère Jacques" (65.4 Hz, 73.4 Hz, 82.4 Hz and 65.4 Hz). (Attack: $T = 3$ ms, decay: $T = 300$ ms.)

Tests were made according to the suggested CCIR comparison method (Recommendation 562) where sequence A-B is presented twice and then 15 s is left for scoring also according to the CCIR comparison scale. Audiometric measurements were taken with each subject before the subjective tests. On average, three listeners were accommodated in a well-calibrated listening room. A total of 25 listeners performed the tests.

All comparisons were repeated in reverse order to have a measure of the listener's consistency. Accordingly, 4 listeners were discarded from the analysis of the results. Furthermore, when the two scores of a same listener for the same comparison differed by more than two grades, these were discarded.

Due to uncontrollable vibrations and rattles induced in the listening room by the high-level low frequency synthesized gong, the test sequence was also assessed by 8 listeners using headphones. The results of this group are used for the low frequency gong.

In addition to the mean opinion score and the standard deviation obtained from the filtered data, a study of the statistical significance of the results was conducted using the one tail Student-t distribution. The level of confidence that, on average, the normal population will prefer codec "A" to codec "B"* was obtained.

Table II summarizes the results. The mean opinion score expressed on the −3, 0, +3 scale, the standard deviation as well as the level of confidence that "codec A is better than codec B" are given in each case. In the table, the 10-14 near-instantaneous companding as described in Report 953 is noted as NICAM 3.

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* "Codec" = "coder-decoder".

TABLE II – *Results of the subjective tests conducted in Canada*

Codec "A"	Codec "B"	Harpsichord	Lyrics	HF gong	LF gong
		$\bar{X}$ / S / % Conf	$\bar{X}$ / S / % Conf	$\bar{X}$ / S / % Conf	$\bar{X}$ / S / % Conf
NICAM 3, CCITT Rec. J.17	ADM (330 kHz)	0.1 0.7 88%	0.2 0.9 91%	–0.1 1.3 28%	1.1 0.8 99.95%
NICAM 3, CCITT Rec. J.17	ADM (204 kHz)	0.0 0.8 50%	0.2 0.9 92%	1.8 1.0 99.999%	1.4 0.5 99.995%
ADM (330 kHz)	A-law, CCITT Rec. J.17	0.0 0.6 50%	–0.2 0.8 6%	0.9 1.4 99.99%	–1.2 0.5 0.01%
NICAM 3, CCITT Rec. J.17	A-law, CCITT Rec. J.17	0.0 0.7 50%	–0.1 1.0 27%	0.8 1.1 99.975%	0.1 0.3 88%
NICAM 3, CCITT Rec. J.17	14 bits linear, CCITT Rec. J.17	–0.1 0.7 18%	–0.1 0.8 19%	–22 0.8 0.001%	0.1 1.0 60%

$\bar{X}$: mean opinion score on a scale – 3 to + 3 as per Recommendation 562.
S: standard deviation.
% Conf : statistical confidence level that codec "A" is preferred to codec "B".

As can be seen from the table, no significant difference was found between these two encoding systems when the ADM was sampled at 330 kHz except in the case of the critical low frequency gong where a noise spectrum shaping was perceived. This was mostly noticeable during the decay time of the gong. When the ADM was sampled at 204 kHz, a degradation in the reproduction of the high frequency gong could also be perceived, giving worse performance than the NICAM 3. For these two cases, however, no significant difference could be perceived between the two codecs for normal programme material.

2.2 *Quality assessment of a near-instantaneous differential code and a near-instantaneous PCM code*

An objective and subjective evaluation of two coding schemes, proposed in Report 1075 for HDTV broadcasting by satellite, was done in Canada. The coding schemes considered were:

- 15-to-8 Near-Instantaneous Companded DPCM (NI-DPCM) proposed for MUSE;*
- 14-to-10 Near-Instantaneous Companding (NICAM) as per Recommendation 651.

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* The NI-DPCM scheme used in MUSE is based on a leakage factor of 0.9375 as compared with a leakage factor of 0.975 used in the simulations reported here. Simulations with leakage factor values between 0.95 to 0.99 showed only minor differences in signal-to-noise ratios.

2.2.1 Objective evaluation

Both coding schemes were simulated on a computer in accordance with the descriptions given in Report 953-1 for the NICAM and in Report 1075 ———— for the NI-DPCM. A leak factor of 0.975 was used in the simulated NI-DPCM. The following audio test signals were applied to each encoder:

a) variable frequency sinusoidal signal
b) low and high frequency synthetic sounds
c) natural harp

The input test signals to the encoders consisted in 32 kHz digital audio samples uniformally quantized to 15 bits/sample for the NI-DPCM encoder and to 14 bits/sample for the NICAM encoder. For each test signal and for each encoder, signal-to-noise ratios were calculated over successive blocks of 256 samples (8 msec) and plotted as a function of time.

The variable frequency sinusoidal signal consisted in a sequence of ten sinusoids of constant amplitude and variable frequency ranging from 30 to 15360 Hz. Figure 2a shows an excerpt of this test signal and the SNR curves obtained are plotted in Fig. 2b and 2c. It can be seen from Fig. 2c that an instantaneous quantizing scheme such as the NICAM has an SNR which is independent of the frequency. A differential coding scheme like the NI-DPCM will yield better SNR values at low frequencies (up to 1 kHz). However, the SNR values deteriorate at higher frequencies, to become smaller than those obtained with the NICAM.

The synthetic sound test signal consisted in the first four notes of "Frère Jacques" (Do-Re-Mi-Do) synthesized both at low (60-80 Hz) and high frequency (4-6 kHz). Figure 3a shows the resulting signal shape in the time domain and the SNR curves obtained for the low frequency sound are plotted in Fig. 3b. The superiority of the differential coder (NI-DPCM) is apparent for a high level low frequency signal despite its lower number of bits-per-sample (8 against 10 for NICAM). Both coders exhibit decreasing SNR for decreasing signal levels. The SNR curves obtained with the high frequency synthetic sound are shown in Fig. 3c. The SNR values obtained for the NICAM are superior, for high level signals, to those obtained with the NI-DPCM.

The natural harp sound, shown in Fig. 4a, exhibits a very large dynamic range as well as large variations of level over short time periods. The SNR curves obtained with this test signal are shown in Fig. 4b and 4c. These two curves are comparable with, perhaps, a slight advantage for the NI-DPCM over the NICAM when the input signal reaches the peaks of its dynamic range.

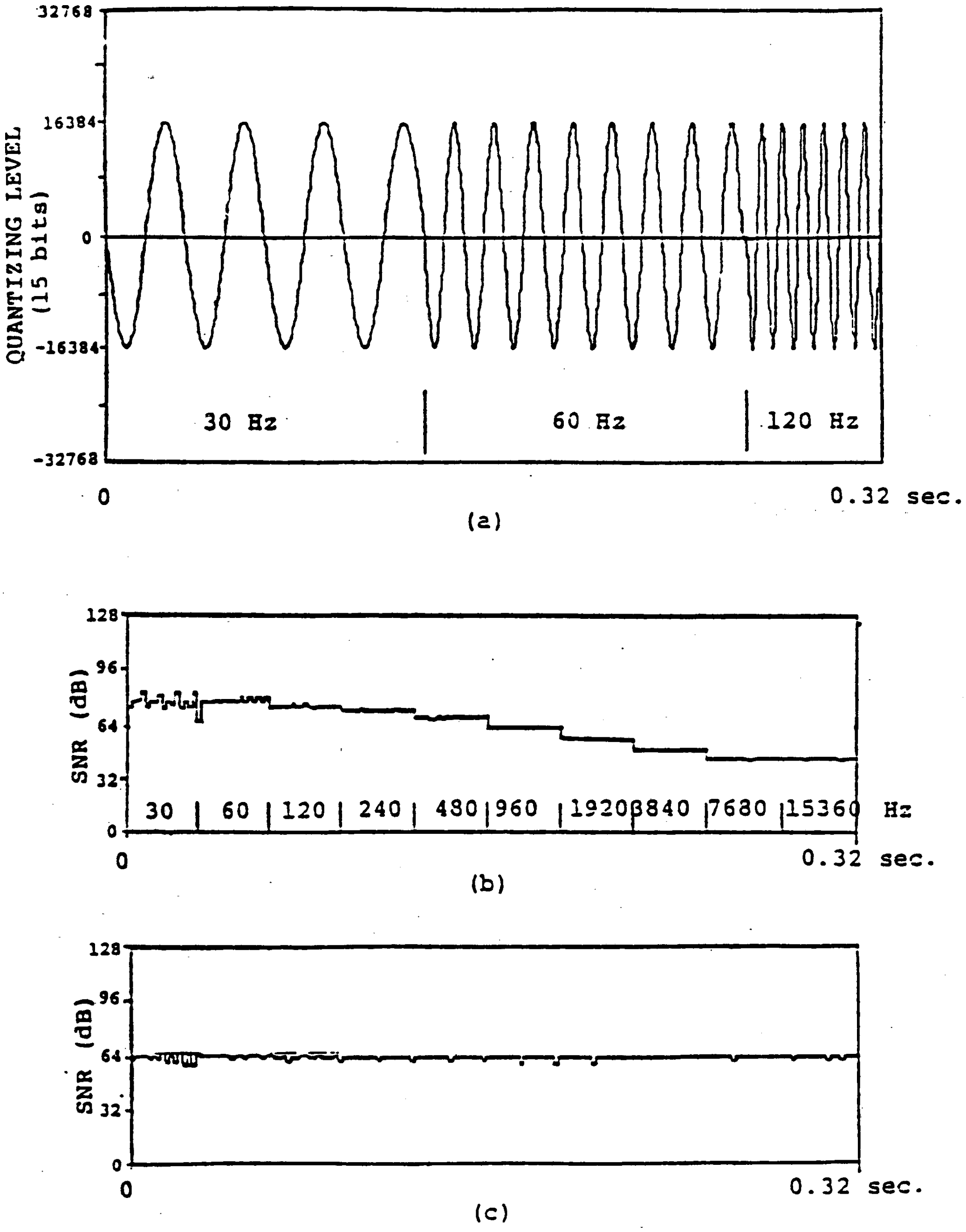
2.2.2 Subjective evaluation

An informal listening test using headphones was conducted with 4 sound broadcast engineers and 2 student engineers as listeners. Tests were made according to the suggested CCIR comparison method (Recommendation 562-2) where sequence A-B is presented twice and then about 15 sec. is left to the listener for scoring between -3 (coder A much worse than coder B) to +3 (coder A much better than coder B).

The test material consisted in excerpts from a harp solo, an organ solo, a female solo and performances from a chamber music ensemble, a jazz quartet and a pop music band. The low and high frequency synthetic sounds described in section 2.2.1 were also included in the test material. The 50/15 us pre-emphasis/de-emphasis law described in Recommendation 651 was used with both NI-DPCM and NICAM encoders.

The listening test, although informal, yielded consistent results. The listeners found no significant differences between the NI-DPCM and the NICAM encoders for the six natural music excerpts. The average opinion score for these six sequences was 0.2 in favor of NI-DPCM with a standard deviation of 0.8.

The listening panel clearly preferred the NI-DPCM encoder for the low frequency synthetic sound (average score of 2.2, standard deviation of 0.7) and the NICAM for the high frequency synthetic sound (average score of -1.8 with a standard deviation of 0.7). These results are in agreement with the objective evaluation results of section 2.2.1 where the NI-DPCM encoder had yielded better SNR values than the NICAM for low frequency signals but poorer SNR at high frequency."



Figure[2] Variable frequency sinusoidal signal
a) test signal excerpt
b) NI-DPCM: SNR vs frequency of sine wave
c) NICAM : SNR vs frequency of sine wave

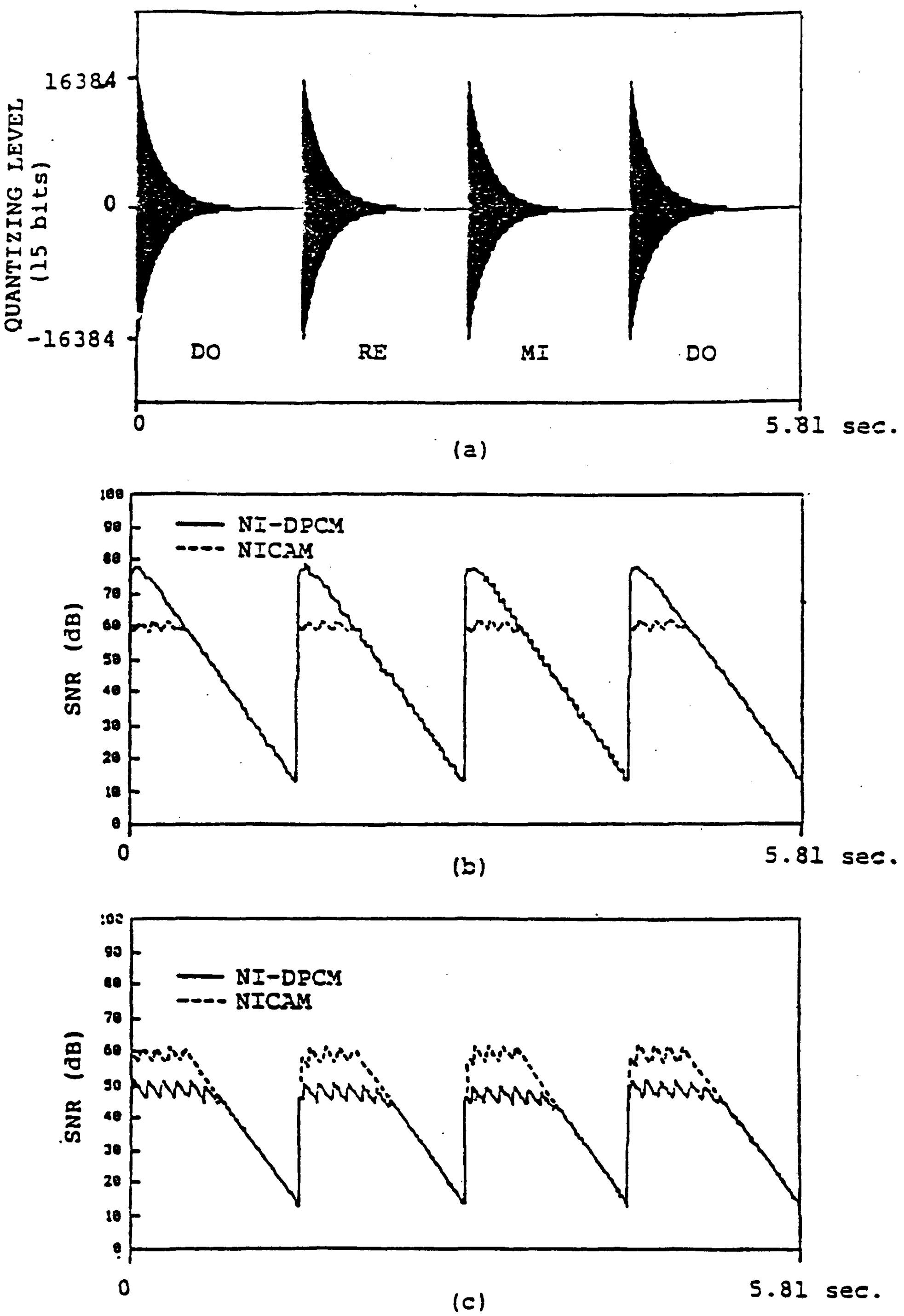
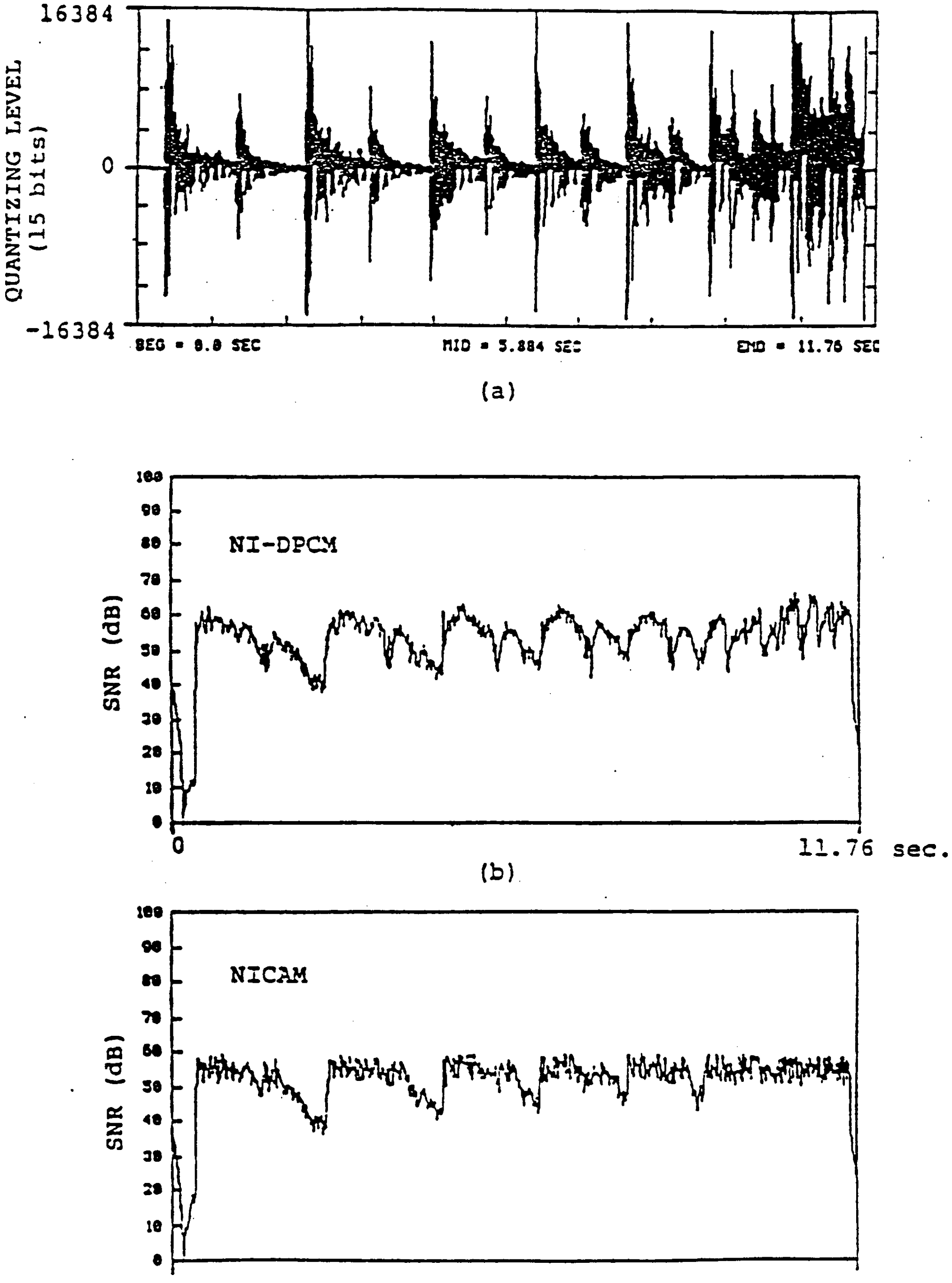


Figure [3] Low and high frequency synthetic sounds
a) test signal waveform
b) SNR curves for low frequency sound
c) SNR curves for high frequency sound



(a)

(b)

(c)

Figure[4] Natural harp sound
a) test signal waveform
b) SNR curve for the NI-DPCM coder
c) SNR curve for the NICAM coder

3. Subjective measurements conducted in the United States

Carefully controlled listening tests using trained auditors were conducted to evaluate the adaptive delta modulation (ADM) system described in Report 953-1. The experiment tested and compared the ADM system (sampling rate = 300 kHz) against a full dynamic range compact disc.

Twenty-four well-motivated and highly-qualified listeners, whose hearing was clinically normal as confirmed by an audiometric evaluation performed by a licensed and certified audiologist, were hired for these tests. The listeners' ages ranged from 16 to 27 years to ensure the probability of normal hearing. They were all experienced or expert listeners who were instructed to "vote" for the system which sounded superior in quality. No further details of what to listen for were provided. Fifteen listeners were male, nine were female, and they were paid in order to enhance motivation.

The listening conditions (environment) were kept in close agreement with those in Recommendation 562. The tests were conducted in a listening studio which had carpet and drapes, had a mid-frequency reverberation time of approximately 0.25 second, and was 16 x 22 feet. The loudspeakers were placed approximately 10 feet apart. A single listener at a time was tested.

The listening level in the center of the room was set to 85 dB on loud music passages. This level was chosen because at lower levels, differences between systems might not be perceptible.

The 10 CD selections, which are shown in TABLE III, were chosen from the European Broadcasting Union (EBU) Sound Quality Assessment Material (SQAM) Compact Disc (CD) as critical test material:

TABLE III - Programme Segments

Electronic Tune	Frère Jacques
ABBA	Pop Music
Triangles	Single Instrument
Grand Piano	Single Keys & Brief Musical Selection
Bells	Single Instrument
Eddie Rabbitt	Country Music
Soprano	Solo
Wind Ensemble	Brief Musical Selection
Xylophone	Single Keys & Musical Selection
Male Speech	German

These stereo selections used for test purposes have wide variations in dynamic range, spectrum, and temporal characteristics. They represent typical and atypical sound programme material. They were chosen to be especially problematical for the ADM type of processing under test, and to reveal coding artifacts. System performance flaws which might be audible include: A/D and D/A linearity, aliasing distortion, bit-rate reduction and programme-modulated noise.

The excerpts were 20 to 140 seconds in duration, and the total subjective-test time was 1/2 hour.

The classic two-alternative forced-choice (2 AFC) psychophysical method was employed. (The method of Recommendation 562 was not appropriate since this was a signal detection task, not a quality scaling task.) The ten selections were presented four times each, in two random orders. Listeners switched back and forth between systems in a pair and then voted for the one of "superior sound quality" immediately after each selection ended. Approximately five seconds separated the segments.

The initial-test results are presented in TABLE[IV] such that for each selection both the number of judgements and the percentage which that number represents are reported for each audio selection. This format allows an examination of the influence, if any, of the audio segment selection on the choice of the listeners and it also allows a direct comparison of the two audio paths. When there is no perceptible difference, this test produces results which are randomly distributed with a mean of N/2 (50%), and a standard deviation of $\sqrt{N/4}$ (where N is the number of trials).

Each listener made 40 judgments, four votes on each of ten selections. The total group of twenty-four, therefore, made judgments of each selection for a total of 960 judgments. Random selection would yield (per selection) 48 votes (50%) for the CD player, with a standard deviation of 4.9 votes (5.1%)

The overall initial-test result (Table [IV]) is 52.5% for ADM and 47.5% preference for the CD player, a very slight difference, if any. From this overall view alone, it could be concluded that the compander is acoustically transparent. However, there were five selections in which a preference more than 5% different from 50% occurs (45 to 55%): the electronic tune, 55.2% for CD; ABBA, 65.6% for ADM; the triangles, 61.5% for CD; the soprano solo, 59.4% for ADM; and the xylophone, 62.5% for ADM, and there appeared to be 3 to 5 listeners who were the primary cause of this result.

Since a few listeners were able to detect differences on these critical selections (although there was no preference for either audio path) a follow-on study was conducted to determine if small audio level differences might be responsible for the results. Level matching of the two paths (direct CD and CD via ADM codec) was improved from approximately 1.0 dB to better than 0.5 dB). All test conditions were kept the same. The results are shown in TABLE V.

The ADM codec, after the additional level matching adjustments, became even more difficult to distingush from the direct CD signal path by the expert listners. Three of the five audio program segments shifted approximately 10 percentage points toward true random results (50/50) and ended at 44, 50, and 52%. The results for the remaining two selections did not change appreciably (2 to 3 percentage points).

A carefully controlled test has shown that experienced and expert listeners showed no preference for the sound of critical programme material reproduced from a direct compact disc source over that of the CD played through the ADM codec under the test conditions described above.

TABLE IV

PILOT LISTENING TEST RESULTS
AUGUST 1988

VOTES FOR CD PLAYER
24 test subjects
96 forced-choice judgments per selection

	TOTAL VOTES	PERCENT
1 - Electronic Tune #7	53	55.2
2 - ABBA #69	33	34.4
3 - Triangles #32	59	61.5
4 - Grand Piano #39	47	49.0
5 - Bells #34	48	50.0
6 - Eddie Rabbitt #70	49	51.0
7 - Soprano #44	39	40.6
8 - Wind Ensemble #66	47	49.0
9 - Xylophone #36	36	37.5
10 - Male Speech-German #54	45	47.0
TOTALS	456	47.5

The standard deviation of 96 random events = 4.9 (5.1%).

TABLE V

FOLLOW-ON LISTENING TESTS RESULTS
SEPTEMBER 1988

VOTES FOR CD PLAYER
20 test subjects
160 forced-choice judgments per selection

	TOTAL VOTES	PERCENT
1 - Electronic Tune #7	86	53.8
2 - ABBA #69	70	43.8
3 - Triangles #32	80	50.0
4 - Soprano #44	83	52.0
5 - Xylophone #36	65	40.6
TOTALS	384	48.0

The standard deviation of 160 random events = 6.3 (4%).

REFERENCE

AuBC [May, 1985] Australian Broadcasting Corporation Engineering Research and Development Report No. 139. Subjective Tests of Adaptive Delta Modulation with B-MAC for HACBSS.

REPORT 954-2

MULTIPLEXING METHODS FOR THE EMISSION OF SEVERAL DIGITAL AUDIO SIGNALS AND ALSO DATA SIGNALS IN BROADCASTING

(Question 2/10 and 11, Study Programmes 2C/10 and 11, 51D/10, 2F/10 and 11, 2N/10 and 11)

(1982-1986-1990)

1. Introduction

This Report contains the preliminary results of a comparison of the multiplexing methods that can be used for the emission of several channels carrying digital sound and possibly other information, either with or without an associated analogue television picture emission, for new broadcasting applications. In this context this Report deals primarily with the use of the satellite-broadcasting channel, although some of the information is also valid for terrestrial broadcasting channels.

The study of multiplexing methods for several audio signals and data must take due account of the two main methods of multiplexing the complete digital signal with the video, which are:

- "interrupted", i.e. digits in the line-blanking interval;
- "uninterrupted", i.e. digits on a sub-carrier.

In the latter case, for sound only in the absence of a video signal, the digits can be on a carrier, but this is only a special case of the sub-carrier. In the case of "interrupted", the case of digits in the field-blanking interval is not considered in this Report.

Regarding the multiplexing of the various digital sound and data signals, two basic techniques are envisaged here: "continuous" multiplexing and "packet" multiplexing; the advantages and disadvantages inherent in the principle of each system have been investigated for both cases mentioned above, i.e. the interrupted and uninterrupted multiplex. Further studies will be needed to optimise these types of systems.

2. Services to be offered

Sound services envisaged in broadcasting are:

- high quality (stereophonic or monophonic) fully encoded digital sound with an audio bandwidth of 15 kHz and a dynamic range of up to 98 dB [CCIR, 1982-86a, b] for sound broadcasting programmes only;
- high quality (stereophonic or monophonic) sound associated with video (audio bandwidth of 15 kHz);
- high quality (monophonic, stereophonic or even quadraphonic) sound for additional radio sound programmes (audio bandwidth of 15 kHz);
- monophonic high quality or medium quality sound for various purposes (e.g. for multilingual commentaries in association with the international sound, etc.);
- commentary quality signals;
- telephone quality signals.

Additional data services envisaged could include:

- data information (e.g. service information, coded text, sub-titling, computer software and programme labelling);
- special information for pay TV service;
- paging.

This list is not exhaustive: in the future, other applications may be possible in accordance with the evolution of needs and technology. The requirements may vary from country to country and from time to time.

For this reason, some flexibility in the use of the digital bit stream is desirable. At the same time, it is necessary that the multiplexing techniques used should be standard and as simple as possible, in order to minimize receiver complexity and reduce costs while facilitating the reception of the various services even if they are not presently identified.

In the case of satellite broadcasting with a video signal, the sound requirements are for a capacity giving the equivalent of two to eight high quality monophonic sound channels. In the absence of a video signal, this requirement can rise to the equivalent of thirty to forty monophonic sound channels.

3. Multiplexing of the digital signal in the television channel

Two principal methods for the multiplexing of the digital signal in the television channel have been identified. They are:

- "interrupted multiplexing" corresponding, for example, to the inclusion of digital pulses in the line synchronisation, either in baseband (system B, see § 4.3.1 of Report 632), or at radio frequency (system C, see § 4.3.3 of Report 632); this method corresponds to the principle of time-division multiplexing, which is used in a generalised manner if the image signal is based on the coding of time-compressed components (MAC system);
- "uninterrupted multiplexing" corresponding, for example, to digital pulses on a sub-carrier (system A, see § 4.2.2 of Report 632); this method corresponds to the principle of frequency-division multiplexing, which is used in a generalised manner if the image is based on the coding of a composite signal with a colour sub-carrier.

The case of sound with no video is considered to be a special case of the uninterrupted multiplex. Before considering the multiplex of sound with data, it is necessary to consider the implications of the bearer channel on services being carried.

Services fall into four categories:

(a) those in which the data is generated at a regular rate and which must be recovered at a regular rate and for which propagation time is critical (e.g. digital sound);

(b) those in which the data is generated at an irregular rate, but for which propagation time is critical (e.g. coded sub-titles for an accompanying television programme);

(c) those in which data is generated at an irregular rate and for which the propagation time is, within limits, unimportant (e.g. service messages);

(d) those in which the data is broadcast cyclically at a rate such as to fully occupy the spare capacity of the system (e.g. certain forms of coded text and computer software broadcasting).

It is clear from this that the most important service, sound, is also the most critical as far as the bearer channel is concerned, and will therefore be considered here in more detail.

Sound samples can be considered as being generated regularly (e.g. at 32 kHz rate). At the receiver, it is necessary to recover the regularity of the audio samples in order to avoid distortion or "wowing" of the sound. This operation requires the recovery of the audio clock, which can be achieved by the following two methods:

- when the characteristic frequencies of the bearer channel are asynchronous and completely unrelated to the sampling frequency of the audio, it is necessary to use some form of elastic "first-in, first-out" store and clock rate with sufficient precision, with or without feedback, such that the rate of reading out from the store is made equal to the average rate of filling the store;
- when the characteristic frequencies of the bearer channel are synchronous with or related by a rational fraction to the sampling frequency of the audio, then the bearer channel itself may be used to convey the audio clock frequency. In the case where a relationship between the sampling frequency and the bit rate of the bearer channel is in the form of p/q, the clock recovery can be obtained by a phase locked loop. As an example, for interrupted digital signals, the 32 kHz can be recovered if related to line frequency by the ratio of 256:125. If the relationship is in the form of $1/n$, a simple division is sufficient and reduces the receiver costs. As an example, for uninterrupted digital signals, the sound clock can readily be recovered if the overall bit rate is an integer multiple of 32 kHz (e.g. 2048 or 1792 kbit/s).

The first method places much of the complexity in the domestic receiver design while giving a relatively simple transmitter design. The process of such asynchronous clock recovery can also lead to timing jitter on recovered clocks, particularly in a domestic design where cost must be minimised.

The second method requires that all the sampling frequencies of the audio channels are synchronised to the bearer channel, leading to complexity at the transmitter in requiring sampling rate synchronisers, but results in the simplest and most stable system design for domestic receivers.

The inherently intermittent nature of a TDM channel and the basic principles of the packet multiplexing system prevent the direct signalling of precise time or phase relationships such as those needed for some types of control signals or multi-channel sound. In such or similar cases, coding efficiency may be preserved by taking advantage of the television synchronizing signals to provide a reference timing grid, and using the relationship between the sound coding blocks and the timing reference. Such a method is described in Part 3, Chapter 3, of the CCIR Special Publication "Specification of Transmission Systems for the Broadcasting-Satellite Service".

The timing problems of data services (b), (c) and (d) (as categorized above) are rather less critical than for the sound services and therefore do not present any special problems.

It is clear from this that synchronous operation of the sound channels with the bearer channel is an advantage irrespective of the method by which the sound and data channels are themselves multiplexed to form the digital signal.

4. Multiplexing of the sound and data channels

The single digital channel considered in § 3 above for multiplexing with the video is itself produced by time division multiplex of the various sound and data signals. Two basic multiplexing concepts are possible, which will be described as "continuous" and "packet".

4.1 *Continuous multiplexing*

In conventional continuous multiplexing, a given fixed number of digits (called a frame) consists of bits, each of which is assigned a specific purpose according to its position in the frame. Thus, particular bits are dedicated to convey the information relating to one input signal. A predetermined pattern of bits (a frame alignment word) enables the receiver to identify and extract the particular bits which convey each signal in the multiplex.

The simplest form of such a multiplex has input signals whose bit rate is a precise sub-multiple of the final serial bit rate. This is known as synchronous multiplexing. When this condition does not apply, a process of asynchronous multiplexing is possible by arranging certain bits within the frame to carry either real or dummy information according to a control signal. This process is known as justification. An alternative method can be used for sound signals in which the sampling rate is adjusted by means of a synchroniser so that synchronous multiplexing can be used. Proposals have been made to use continuous multiplexing in the asynchronous mode, by use of justification, to insert audio signals sampled at 32 kHz in the line-blanking interval, but other methods are also possible. It is clear from § 3 that the synchronous form of multiplexing has many advantages.

Continuous multiplex systems require only a small proportion of the total bit rate for "overheads" such as framing. An example of the efficiency which can be obtained in a regular multiplexing system is given by NICAM 3 [Caine *et al.*, 1980] which only uses 7 kbit/s out of the total 2048 kbit/s for framing. The typical reframing time after loss of synchronization for this system is 2 ms.

In normal service, sound channel re-assignment will be relatively infrequent because of the continuous nature of sound. A continuous multiplexing system is therefore particularly suited to this application with a relatively low overhead required for secure definition of the sound channel structure. A small capacity can be used for signalling to indicate change of use of channel and thus provide flexibility. The capacity of any channel not used for sound can be assigned to data. In the case of data, the detailed structure can be carried in the data channel in a way similar to that used in packet multiplexing with a constant length of packets (see § 4.2). This method does not therefore involve any increase in the multiplex overheads to indicate the presence of data. The aim of such a structure is to exploit to the utmost the channel capacity for the useful information with a reasonable degree of flexibility, as well as simplicity and stability in the receiver design.

An advanced form of continuous multiplexing studied in Europe involves the transmission, in the digital frame, of coded information known as a "structure map"; this indicates the particular configuration of the multiplex. The addresses and service information are carried in this structure map and they serve to control the demultiplexer which selects the required bits and feeds them to the appropriate decoders. This method enables the provision of the desired flexibility in a continuous multiplex, the configuration of which may thus be revised frequently. A typical useful channel efficiency of 99% is possible. Other forms of continuous multiplexing are described in [CCIR, 1982-86a, c].

The digital subcarrier NTSC system (see Report 1073 (MOD F) has a continuous multiplexing structure for sound and data channels, with control codes in a digital frame indicating the structure of the frame. The system also has a packet multiplexing structure within the data channel area [CCIR, 1986-90a].

4.2 *Packet multiplexing*

In this case, the final bit stream is composed of successive blocks, called packets, with two parts: *heading* and *data.* Each packet conveys data from only one input signal and the selection in the receiver is realised by detection in the heading of the address of the desired service: this method does not impose a predetermined content on the final bit stream [CCIR, 1978-82a].

In the form of the system designed for broadcasting applications, the length of each packet is constant. The packets are transmitted "synchronously" which means that there is continuity of phase of the binary sequence and of the modulated carrier, between packets or groups of packets. The packets are also transmitted with regular periodicity. The checking process then becomes a synchronisation process similar to that used in a continuous multiplex structure. This synchronisation can be done in a conventional manner by the use of a loop locked to a synchronisation flag in the heading of each packet. This restriction of fixed overall packet length does not imply a fixed length of the section containing useful data.

Within the constraints of periodic packet transmission, the rate at which packets are transmitted for a particular service is related directly to the bit rate of the input signal of the associated service. In packet multiplexing, it is possible to operate synchronously or asynchronously. In the latter case, the bit rates of the various input signals do not need to be related directly to the final serial bit rate. Thus, no special provisions are necessary for accommodating asynchronous signals. The content of the multiplex does not need to be predetermined or fixed and can be changed at any time to be adapted to the needs. In the case of asynchronous operation for sound services (e.g. for insertion of sound signals in the line-blanking interval), packet multiplexing inherently permits the asynchronous insertion into the final bit stream but the recovery of the sampling frequency needs resynchronisation processes as described in § 3.

A packet is formed of two parts:

- a section containing useful data,
- a heading, specific to the transmitter, which serves to synchronise the receiver and to identify the source of the data inserted in the packet and for the transmission of other information. The heading contains a synchronisation flag followed by a prefix.

The synchronisation flag enables the receiver to extract the bytes comprising the packet. It has a role equivalent to that of a locking word in the case of a continuous multiplex. In a periodic transmission, it can also be used for the synchronisation of the loop which serves for the checking process. We should note also the possibility of using this flag to remove the ambiguity due to certain demodulation processes; such an arrangement is advantageous in that it avoids the coding of transitions and, hence, a certain propagation of transmission errors.

The role of the prefix is to characterise and identify the semantic content of the packet and, more especially, the source of the data inserted in the useful data section. Several prefix configurations can be envisaged. In particular, it may be possible to use the prefix configurations considered for data broadcasting [CCIR, 1978-82b].

The increased flexibility to the data of the packet multiplex system is obtained at the price of increased channel overhead for the packet headers which includes, in normal operation, the insertion of programme identifiers. A typical useful channel efficiency of 97% is possible.

4.3 *Sensitivity of continuous and packet multiplex systems to errors*

4.3.1 *Continuous multiplexing*

The continuous multiplexing process is susceptible to two sorts of impairments:

- bit errors,
- frame synchronisation loss.

Errors introduced into multiplex signals can cause loss for a certain number of consecutive frames of synchronism at the demultiplexer, when the framing pattern is not recognised. Careful attention to the design of framing circuits can minimise the risk of losing synchronism; for example, the decoding equipment for the NICAM 3 system mentioned earlier remains synchronised until the bit error ratio approaches 1 in 10. A very rugged synchronisation of framing can be achieved by using special type synchronisation codes (i.e. the class of Barker codes). With this implementation a very rapid, as well as a very stable synchronisation locking at BER of 10^{-1} is feasible [CCIR, 1982-86a].

4.3.2 *Packet multiplexing*

The packet broadcasting process is susceptible to two sorts of impairments:

- bit errors,
- packet loss.

In effect, for each source there is a digital channel identification carried in the packet prefix. In the demultiplexer, the packets are selected by analysis of this identification. Errors in this information, despite its protection, are likely to result in poor recognition of the address of the transmission source and hence, in the loss of the packet, this being apparent at service level as the loss of a certain number of successive bytes (which depends on the format of the data section of the packet(s) lost).

This phenomenon must result in an interruption in the sequence of the service frame and in a loss of synchronisation in the service terminal. Nonetheless, since the length of the *service frame* is a sub-multiple of a *fixed packet* length, there will be a loss of information without a loss of synchronisation.

In this case the packets associated with a given sound source will always have a fixed and pre-determined length which is known to the demultiplexer. It is for this reason that it is preferable to use a prefix configuration without a format byte in these applications.

Several tests of broadcasting digital sound signals with packet multiplexing and with modulation appropriate for satellite broadcasting (with television pictures) have been made in the laboratory as well as with the OTS satellite [EBU, 1981]. Some results are also given in Annex I to Report 632. It has been shown that the packet losses appreciably degrade the sound quality only at levels of the carrier-to-noise ratio that are below the FM threshold, when the television picture is already severely impaired.

4.4 *Experimental results*

Demonstrations of the continuous multiplex with structure map and of the packet multiplex have been carried out by the EBU in association with modulation systems A and C envisaged earlier for satellite broadcasting. More recently, tests have also been made on the packet multiplex in association with the D2 modulation system (see Report 632). The experimental multiplexing systems were designed to provide the greatest possible capacity, taking account of the bit rate imposed for the modulation system. The tests were concerned in particular with the various methods for ensuring protection against errors and with the possibilities for reconfiguring the multiplex with a change in the number and nature of the sound channels and the insertion of data services. The conclusions are summarized in § 4.4.1 and 4.4.2.

It is noted that:

- system capacity is expressed as an equivalent number of high-quality sound channels using near-instantaneous companding (see Report 953) and with a simple error-protection system;
- the available bit rate was 2048 kbit/s with type A modulation (sub-carrier) and about 3 Mbit/s (mean value) with type C modulation (RF time multiplex with an instantaneous bit rate of 20.25 Mbit/s) and about 1.5 Mbit/s (mean value) with type D2 modulation (baseband time multiplex with duobinary coding and instantaneous bit rate of 10.125 Mbit/s).

A continuous multiplex with rigid structure has been employed in a B type modulation system (described in Report 1073, Table III). With this multiplex technique the structure is essentially predefined and fixed by hardware implementation. The capacity is determined by the modulation and coding technique only, as no additional overhead is required to define the multiplex structure. The characteristics of this system are summarized in § 4.4.3.

For type B modulation (baseband time multiplex with four-state coding and an instantaneous bit rate of approximately 14.25 Mbit/s) the available bit rate is 1.57 Mbit/s.

4.4.1 *Continuous multiplex with structure map*

4.4.1.1 *Capacity*

In a type C system, with video, the structure map system offers capacity equivalent to 8 high-quality compressed sound channels.

Any combination of sound channels with linear coding or with companding or other types of sound channel are possible, provided that the total capacity is not exceeded. Any remaining capacity may be used for data.

In a type A system, the multiplexing permits the broadcast transmission of 6 companded audio channels with reduced error-protection (one parity bit for every two samples).

4.4.1.2 *Flexibility of the multiplex*

It is easy to accommodate the sampling frequencies and coding methods recommended for the sound. Other sampling frequencies and other coding methods could also be used. Any form of error protection may be adopted.

The data channels can have a capacity increasing in steps of 100 bit/s and ranging from the lowest values up to the entire available bit rate.

Modifications to the multiplex structure can be made rapidly and with security, so that at any moment the broadcast channel can be used in the optimum fashion for the combined transmission of sound and data. Changes in structure are synchronous and cause neither a variable delay nor an interruption in any channel.

In the case of a system C not carrying a video signal, it is possible to increase the capacity available for the sound and data to about 20 Mbit/s.

4.4.1.3 *Quality and continuity of the audio channels*

The multiplexing technique preserves all the synchronisation and timing information. Phase coherence is therefore assured between all present and future channels. Different error-protection strategies may be used for each of the audio or data channels.

An error in the decoding of the map, which may cause failure of all the channels, cannot occur except well below the failure point of the audio channels.

4.4.1.4 *Simplicity of the demultiplexer*

Construction of the demultiplexer may take the form of a circuit providing all the protection and demultiplexing functions, or an autonomous integrated demultiplexer/decoder for each channel. The logic needed will be the same for all types of channels, including those carrying the structure map.

4.4.1.5 *System ruggedness*

It has been demonstrated that the system synchronisation operates satisfactorily at bit-error ratios slightly lower than 10^{-1}.

4.4.2 *Packet multiplexing*

4.4.2.1 *Capacity*

For system A, the packet multiplex offers a capacity equivalent to 5 companded high-quality monophonic audio channels.

In the case of system C, the specifications of the packet multiplexing system given in Report 1073 offer capacity equivalent to 8 companded high-quality monophonic audio channels. For the D2 system specified in the same Report the offered capacity is equivalent to 4 companded high-quality monophonic audio channels.

Any combination of sound channels with linear coding or with companding or other types of sound channel are possible, provided that the total capacity is not exceeded. Any remaining capacity may be used for data.

4.4.2.2 *Flexibility of the multiplex*

This multiplex system meets the requirements set out in Report 953 on sound coding. As regards the data, it permits the insertion of synchronous or asynchronous services, without any limit on the bit rate (in particular, for low values). Changes in configuration can be assured rapidly and with security. In the case of system C, it is possible, in the absence of a video signal, to increase the capacity available for the sound and data to about 19.5 Mbit/s.

In principle, any form whatsoever of error protection can be used. Two levels of protection are provided in the system specified in Report 1073.

4.4.2.3 *Sound quality and continuity*

Even at high bit error ratios it has been shown that the quality and continuity of the sound are preserved and that modifications in the form of the sound signals to meet operational requirements are effected without impairment to the audio quality. Timing coherence between audio channels is assured.

4.4.2.4 *Simplicity of the demultiplexer*

The selection of a given channel is independent of its content (sound or data) and therefore it can be effected in the same manner for decoders for all types of service.

This feature may be used to implement a simple demultiplexer for existing services and for those yet to be defined.

4.4.2.5 *System ruggedness*

The packet multiplexing system with the specification defined in Report 1073 has been tested. Its capability to broadcast different sound and data channels has been verified for different bit error ratios. Table I gives information concerning the efficiency of the protection against errors on the header field.

TABLE I

Measured bit error ratio (during 30 s)	Packet loss rate	
	Measured	Calculated from the measured bit error ratio
6.6×10^{-5}	0	0
3.2×10^{-4}	0	10^{-10}
1.2×10^{-3}	0	1.6×10^{-8}
3.6×10^{-3}	0	1.4×10^{-6}
9.2×10^{-3}	7.4×10^{-5}	5.5×10^{-5}
2×10^{-2}	1.2×10^{-3}	1.05×10^{-3}
3.8×10^{-2}	10^{-2}	1.03×10^{-2}
6×10^{-2}	5.3×10^{-2}	4.6×10^{-2}
8.8×10^{-2}	1.7×10^{-1}	1.38×10^{-1}

4.4.3 *Continuous multiplex with rigid structure*

4.4.3.1 *Capacity*

In a type B system the rigid structure offers 6 independent audio channels (using ADM coding (see Report 953)). Additionally a data channel of 62 kbit/s is available.

4.4.3.2 *Flexibility of the multiplex*

Any audio channel may be reconfigured into a data channel with a data rate of 204 kbit/s.

4.4.3.3 *Sound quality and continuity*

Timing coherence between audio channels is assured. It has been demonstrated that audio quality is impaired to a quality rating of 4.4 at a BER of 10^{-4}, and impaired to a quality grade of 3.5 at a BER of 10^{-3}.

4.4.3.4 *Simplicity of the demultiplexer*

The rigid structure allows for the simplest possible demultiplexer.

4.4.3.5 *System ruggedness*

It has been demonstrated that system synchronisation occurs satisfactorily at bit error ratios worse than 1×10^{-1}. Both two-state and four-state coding is provided for flexibility in terms of capacity versus ruggedness. (The capacity drops to one-half of that shown in § 4.4.3.1 when two-level coding is being used.) In both cases system synchronization is two-state encoded.

5. Conclusions

This Report has outlined two basic methods of multiplexing digital sound and other signals together for broadcasting.

Summarising, continuous multiplexing offers, in the context of rigid structure, a system which is most efficient for sound transmission and results in a simple receiver. In the context of flexible structure, continuous multiplexing offers a system with adequate flexibility at the price of a greater receiver complexity and some increase of the bit rate overhead. The packet multiplexing system inherently offers a great flexibility with a receiver of medium complexity at the price of bit rate overhead. Both systems require only simple synchronisation circuits at the receiver if the sampling frequencies of the signals to be combined are synchronous or can be synchronised. Each system is in principle vulnerable to the effects of error, but frame loss and/or packet loss are not likely to occur in normal operation.

For the broadcast transmission of a group of digital audio and data signals accompanying the television image, the choice of multiplexing system depends principally on the nature and diversity of services, even if these have not yet been identified. Factors influencing the choice are efficiency, flexibility and receiver complexity. The two multiplexing systems that have been examined in Europe each provides a satisfactory solution to the overall requirements that have been expressed. In view of all the relevant factors, the packet multiplexing has been fully specified for satellite broadcasting at 12 GHz with 625-line television standards. The detailed specifications of the chosen packet multiplex (in association with type C and D2 modulation) are given in Report 1073.

The continuous multiplex with rigid structure has been fully specified for satellite broadcasting at 12 GHz, and is identical for either a 525-line or 625-line system. The detailed specifications for this multiplex (in association with type B modulation) are given in Report 1073, Table III.

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REPORT 1227*

SATELLITE BROADCASTING SYSTEMS FOR ISDB (INTEGRATED SERVICE DIGITAL BROADCASTING)

(Question 2/10 and 11, Study Programme 2N/10 and 11)

(1990)

1. Introduction

The growing popularity of such digital products as compact discs, digital audio tapes, video games, digital television, personal computers and digital facsimiles has made the general public more and more accustomed to high-quality, reliable and easy-to-use consumer digital devices. This, as a matter of course, has likewise prompted consumers to seek the advantages inherent in the digitization of broadcasting. The concept of integrated service digital broadcasting (ISDB) thus was born. It enables the transmission of various kinds of information, digitally encoded and systematically integrated on a single digital broadcasting channel.

This Report discusses,the basic concept and technical considerations of the ISDB system, and at the same time seeks to advance some ideas for its future development via satellite.

2. Concept of ISDB system

In the ISDB system, many kinds of information such as sound, teletext, stillpictures, facsimile, computer software and even television signals, from different originating sources, are digitally encoded, systematically integrated, and transmitted by a single digital broadcasting channel. Digitization in the ISDB system not only makes possible high-quality transmission but also allows greater flexibility and efficiency in operation. It also makes possible the provision of multi-media services, and simplifies both information selection and access for the user.

It should become possible at some point in the future to incorporate into ISDB almost all kinds of broadcasting services now or under development.

Supplementary services using television and narrow bandwidth channels identified in Report 802, such as teletext, "telesoftware" and broadcast facsimile, can be transmitted on relatively small-capacity channels.

Where it is possible to employ a 20 - 30 Mbps broadcasting channel, multi-programme high-quality sound broadcasting and still-picture broadcasting

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* This Report should be brought to the attention of JIWP 10-11/5.

providing high quality sound with high-definition stillpictures can be incorporated into the system, in addition to the capabilities mentioned above.

Bit rate reduction techniques used to reduce the bit rate below 100 Mbps should enable incorporation of conventional and high-definition television services in the ISDB systems.

3. Technical considerations

3.1 Transmission aspects

Use of a direct broadcasting satellite is considered an effective means for transmission of ISDB. The service requires a wide bandwidth channel and at present almost all of the terrestrial broadcasting frequencies are in use. Satellite transmission would also more effectively serve ISDB's goal of economically providing consistent high-quality, reliable services over broad geographical areas.

Incorporation of conventional television or HDTV moving pictures into the ISDB service would necessitate transmission capacities in excess of 100 Mbps, which may require a broadband channel plan for broadcasting.

3.2 Methods of multiplexing*

ISDB requires a multiplexing system that can handle the differing characteristics of the various services it will incorporate. Some of those factors are as follows:

- transmission speeds required by the various services differ greatly;
- some services must be transmitted continuously, while others only require intermittent transmission;
- for some services, time of transmission is restricted, while for others time of transmission is largely optional; and
- changes in and addition to the services would be frequent occurrences.

There are primarily two multiplexing methods to handle a variety of service data under conditions of a fixed transmission capacity (see Report 954).

One method is called continuous multiplexing. In this method the data of the various services are assigned a fixed position within a given fixed number of digits called a frame. While the assignment status for each service can be indicated using control bits, the flexibility of this system is generally low. However, in this method the overhead required for the control bits is also low.

Another method is packet multiplexing. In this method, data are transmitted in "packets" of a specific length, regardless of the type of service from which they originate. Recognition of the type of service

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* Attention is drawn to CCITT Recommendation I.121. CCITT practice is to use the terms "asynchronous time division multiplexing (ATD)" instead of "packet multiplexing" and "cell" instead of "packet". "Packet" is also used, but in another sense.

that the data belongs to is carried out by means of an identification code included in the header of each packet. While the overhead required for the header is somewhat higher than that of the continuous system, it does offer superior flexibility and expandibility. It also allows the formation of a highly transparent transmission channel.

The packet method, for its flexibility and expandibility, is considered best suited as the multiplexing system for ISDB; however, consideration should also be given to combining the two methods for use depending on the requirements of the individual services.

As an example, the MAC/packet family of systems operating in the full-channel digital mode (see Report 1228) —— is considered by the EBU as a system which allows maximum flexibility and multiple usages with varying bit rates. The packet multiplexing and service identification techniques used in MAC/packet accommodate a variety of services using the same BSS channel, including television, multiple sound and data. Thus a universal receiver for all these services may be considered.

3.3 Information identification function

ISDB makes it possible not only to integrate and transmit a large variety of services but also to provide services using a number of different media.

Such features underscore the importance of identification and index capabilities. These would enable the user easily to receive, select, use directly, or store automatically and retrieve the required information.

3.4 Other aspects

Other aspects are also expected to be studied and combined in an optimum manner to develop ISDB. These would include:

- source/channel coding;
- error protection;
- digital modulation;
- conditional access; and
- the concept of a universal receiver.

4. Modeling of data broadcasting

As ISDB, in its service repertoire, would include data broadcasting services in large part, attention should be given to Report AC/11 which describes activities for the development of a common reference model for data broadcasting. A well organized model would be necessary to facilitate the introduction of various services and to enjoy the flexibility and expandibility of ISDB fully.

5. Conclusion

While the realization of an ISDB system still lies in the future, its foundations of transmission and service technology are gradually being developed.

REPORT 1228

HIGH QUALITY SOUND/DATA STANDARDS FOR THE BROADCASTING SATELLITE SERVICE IN THE 12 GHz BAND

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

(1990)

1. Introduction

According to the current Radio Regulations, satellite channels in the 12 GHz band are assigned to each administration over which television programmes but also, alternatively, other services may be broadcast, as long as the transmitted signals do not cause more interference than conventional FM-TV signals. The appropriate TV standards are recommended in Rec. 650 and specified in Rep. 1073 and the relevant parts of the CCIR Special Publication, *Transmission Systems for the BSS.*

The introduction of digital sound recording and reproduction techniques constitutes a challenge to the broadcasting organizations in so far as to pass on such a quality to the subscribers which has been beyond the possibilities of conventional transmission methods (e.g. FM stereo). Besides this, in a number of countries there is a need for the emission of a large number of high-quality sound channels over a coverage area as large as possible. In addition, the growing requirements for data broadcast facilities resulted in investigations of systems suitable to transmit both, sound and data in a flexible way.

Several alternatives are in various stages of development within different administrations. This Report briefly describes the basic characteristics of three systems developed in Germany (Federal Republic of), by the EBU and in Japan.

2. Summary description of the systems

This section gives the summary description of the main features of each of the systems considered. Table I gives the list of relevant parameters of each system in a comparative way.

2.1 *The Digital Satellite Radio (DSR) System*

The DSR system [Technische Richtlinien ARD, 1985] was developed in the Federal Republic of Germany to allow simultaneous transmission of 16 stereophonic or 32 monophonic high-quality sound channels (or any combinations of stereophonic or monophonic channels) over a wide coverage area. In line with Rec. 561, the sampling frequency is 32 kHz and the resolution equals 16 bits, preserving a quantizing noise performance comparable with that of the compact disc. For bit error correction/detection a 63/44 BCH code was chosen, capable to correct two errors and to detect five errors per block. In combination with the scale factor (see Annex I) this bit error protection scheme offers a good subjective sound quality to a BER of 2×10^{-3}. 4-PSK, differentially encoded, serves as the modulation method.

Although the DSR system is mainly intended for high-quality sound transmission, it is also capable of transmitting high-speed data in one or more stereophonic or monophonic channels [Assmuss, 1989] in addition to the already existing auxiliary low-bit rate data channel accompanying each sound channel.

Since the regular service, based on DSR, in Germany (Federal Republic of) commenced in August 1989, the transmit and receive devices, the latter being based on VLSI technique, are already commercially available.

The detailed specification of the DSR system is given in Annex I.

2.2 *MAC/packet family full-channel digital mode*

Report 1073 and the CCIR Special Publication ***Transmission Systems for the BSS*** provide the specification of the MAC/packet family of systems when operating in normal television mode. When the area of the television frame, normally reserved for the MAC vision signal (and its field-blanking interval), is replaced by data bursts, the MAC/packet is said to operate in the full-channel digital mode [CCIR, 1986-90a].

The three members of the family (i.e., the C-MAC/packet system, the D-MAC/packet system with FM and the D2-MAC/packet system with FM) can be used in the full-channel digital mode providing the following sound/data capacity:

C-MAC/packet full-channel mode: nearly 20 Mbit/s or up to 53 high-quality sound channels with 15 kHz bandwidth, with near-instantaneous 14/10-bit companding and protected by one parity bit per sample.

D-MAC/packet full-channel mode: identical capacity as C-MAC/packet.

D2-MAC/packet full-channel mode: nearly 10 Mbit/s or up to 26 high-quality sound channels with 15 kHz bandwidth, with near-instantaneous 14/10-bit companding and protected by one parity bit per sample.

The extension of the MAC/packet family specification with the full-channel digital mode provides the possibility of a variety of facilities (i.e., sound or television data broadcasting, etc.). Within this concept it is possible to design and implement universal receivers to accommodate either television reception in the normal MAC/packet mode or sound/data reception in the full-channel digital mode.

The extent to which all possible facilities will eventually be available to the public will depend both upon which of these services are transmitted and which of them the receivers are designed to receive.

For MAC/packet full-channel digital mode, the decoders and integrated circuits are expected to be available at the start of such a service.

Digital sound coding is described in Report 953 and the multiplexing methods used in the full-channel mode are outlined in Report 954.

The detailed description of the MAC/packet full-channel digital mode is given in Annex II.

2.3 *The Multichannel Digital Sound/Data (MDSD) System*

The MDSD system has been studied in Japan for future high quality sound and data broadcasting throughout the country by the broadcasting satellite operating in the 12 GHz band. This system has two modes. In Mode *A*, using 14/10 near-instantaneous companding, the same sound quality as FM broadcasting is available. In Mode *B*, sound quality not lower than that of the compact disk is possible (20 kHz bandwidth and 16-bit resolution) [CCIR, 1986-90b], [Kawai *et al.*, 1988].

TABLE I - *Relevant parameters of satellite sound/data broadcasting standards for the 12 GHz BSS band*

Parameter	Digital Satellite Radio (DSR)	MAC/packet family full-channel digital mode		Multi-channel Digital Sound/Data satellite broadcasting (MDSD)
		D2	C/D	
Multiplex structure	Synchronous time division multiplex (STD)	Asynchronous time division multiplex (ATD)		Sound : STD multiplex Data : ATD multiplex
Total bit rate (Mbit/s)	20.48	10.125	20.25	24.576 Mbit/s
Useful bit rate[1] (Mbit/s)	19.2	9.576	19.242	18.62 Mbit/s (Mode A) 21.50 Mbit/s (Mode B)
Sound coding[7]	32 kHz sampling frequency	32 kHz sampling frequency (16 kHz for medium quality)		Mode A : 32 kHz sampling frequency 14/10 bit near-instantaneous companding
	16/14 bit floating point technique	First coding law: 14/10 bit near-instantaneous compander (HQI)[2]		Mode B : 48 kHz sampling frequency 16 bit linear coding
		Second coding law: 14 bit linear coding (HQL)		
	No pre-emphasis	Pre-emphasis per CCITT Recommendation J17		Pre-emphasis 50 µs(zero) + 15 µs(pole)
Dynamic range	According to 16-bit resolution (equal to compact disk)	According to 14 bit resolution		Mode A : According to 14 bit resolution Mode B : According to 16 bit resolution
Bit-error protection	(63,44) BCH code: corrects 2 errors in 63 bits or detects 5 errors. Additional protection by the scale factor.	First protection level: 1 parity bit applied to the 6 MSB (HQI) or to the 10 MSB (HQL case) (error concealment only)		(63,56) BCH code: Corrects 1 error and detects 2 errors. Additional protection by the 8 ranges.
		Second protection level: Hamming code (11,6) for HQI and Hamming code (16,11) for HQL: corrects 1 error or detects 2 erroneous bits. Additional protection by scale factor for both protection levels.		(63,50) BCH code: Corrects 2 errors and detects 3 errors. Additional protection by the range information.
Number of sound configurations (i.e. combination of sound coding and error protection scheme)	One (see above)	Four high quality configurations[2, 3] HQI1 HQL1 HQI2 HQL2		Two high quality configurations Mode A Mode B
Sound channel capacity (monophonic)	32	HQI1: 26 HQL1: 19 HQI2: 19 HQL2: 14	HQI1: 53 HQL1: 40 HQI2: 40 HQL2: 30	Mode A : 48 (maximum) Mode B : 24 (maximum)

TABLE I (Continued)

Parameter	Digital Satellite Radio (DSR)	MAC/packet family full-channel digital mode		Multi-channel Digital Sound/Data satellite broadcasting (MDSD)
		D2	C/D	
Modulation	4-PSK differentially encoded	for D and D2: FM of duo-binary coded data signal for C : 2-4 PSK, differentially encoded		Minimum shift keying (MSK)
C/N for BER = 10^{-3} (overall link with reference to 27 MHz bandwidth)	7.5 dB[4]	8 dB[5]	for D : 9.5 dB[5] For C : 8.0 dB[6]	8.0 dB
Limit for perceptibility	2×10^{-3}	1st-level protection : 10^{-5} 2nd-level protection : 10^{-3}		1×10^{-3}

Notes:

1) Useful bit rate (for sound transmission)
= total bit rate minus sync, additional data and packet headers.

2) HQI1 = High quality, near-instantaneous companding, 1st protection level
HQL1 = High quality, linear coding, 1st protection level
HQI2 = High quality, near-instantaneous companding, 2nd protection level
HQL2 = High quality, linear coding, 2nd protection level.

3) In addition to high quality configurations, MAC/packet full-channel digital mode allows four medium quality configurations using 16 kHz sampling.

4) Measured with a domestic receiver (first series of mass-production).

5) Values for 27 MHz IF filter; improvements of around 2 dB are possible by using narrower filters and/or applying Viterbi decoding.

6) Typical value for differential demodulation. With coherent demodulation improvements are possible.

7) All coding schemes used follow Rec. 651.

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The signal format of the MDSD system is constructed in two multiplexing stages. The lower multiplexing stage has the same format as the sound/data signals of the digital sub-carrier/NTSC system (Report 1073) with a transmission bit rate of 2.048 Mb/s. In this format, four Mode *A* sound channels with 480 kb/s data signals or two Mode *B* sound channels with 224 kb/s data can be selected. The data rate can be expanded to 1760 kb/s maximum, depending on the mode and number of sound channels. It allows data broadcasting using packet transmission other than sound.

At the higher multiplexing stage, 12 of these signals are further multiplexed. The transmission bit rate at this stage is 24.576 Mb/s (2.048 Mb/s x 12).

In order to maintain high-quality digital signal transmission performance, the same error correction schemes used for digital sub-carrier/NTSC signals, such as BCH (63,56) SEC-DED code and 3-bit range codes are applied. For more efficient error correction performance, the BCH (63,50) DEC-TED code may be considered.

The carrier is MSK, QPSK or OQPSK-modulated by the above-described multiplexed bit stream. The MSK modulation method with AFC is likely to be used because of its higher performance and the lower cost of the receiver.

Transmission experiments of the MDSD system were carried out via the broadcasting satellite BS-2. The received carrier-to-noise ratio (27 MHz signal bandwidth) to obtain just-perceptible sound degradation is about 8 dB (BER = 1×10^{-3}), as confirmed using home-type receivers.

3. **Conclusion**

Presently, three high-quality sound/data broadcasting systems are known for the use in the 12 GHz broadcasting-satellite service. Two of them (i.e. the DSR system and the full-channel digital mode of the MAC/packet family systems) are already available at standardization level. Both systems fulfil the requirements for the broadcasting of very high-quality sound/data signals. Consequently, the two systems are the subject of Recommendation 712 for Region 1.

The issue of a sound/data standard for the broadcasting-satellite service in the 12 GHz band is still under consideration in Regions 2 and 3 and thus the MDSD system is not yet the subject of a Recommendation.

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ANNEX I

SPECIFICATIONS OF THE DSR SYSTEM

1. Introduction

Television broadcasting satellites will not only be used for the transmission of television programmes but also for the high-quality, exclusively digital transmission of 16 stereophonic sound broadcasting programmes over a transponder channel reserved solely for that purpose. Several studies and development projects funded by the Ministry for Research and Technology of the Federal Republic of Germany have defined the main parameters for the reception quality and the coverage area for a given number of channels so that it was possible to identify the requirements imposed on the transmission system. Experiments involving field tests have successfully been conducted.

The finalized system specifications are set out below. The time sequence of all bit sequences in this Annex is shown from left to right.

The analogue modulation and RF transmission parameters refer to the nominal specifications. The equipment and operating tolerances at the transmitting end are given elsewhere.

2. Encoding of the sound signal

2.1 *Source signal*

Uniformly quantized audio signals with a resolution of 16 bits and a sampling frequency of 48 kHz will be available at digital sound studios.

Since neither the terrestrial link to the earth station nor the satellite channel will have the necessary capacity for the transmission of the source signal in this particular form, the signal will have to be adapted to the bit rate of 14 bits × 32 kHz/audio channel available both on the terrestrial links and the satellite channel. The necessary adaptation of the sampling frequency from 48 kHz to 32 kHz does not lead to a noticeable degradation of the quality. For various reasons, however, it would be desirable to obtain a dynamic range of the sound signal corresponding to 16 bits. This can in fact be achieved by appropriate measures. The signal at the end of the overall transmission is hence characterized by the parameters 16 bits and 32 kHz.

2.2 *Formation of sound signal blocks*

If, in addition to the sound signal, data are transmitted about the sound signal's range of amplitude (scale factor), these data can be used at the receiving end to limit the amplitude errors caused by bit errors in the sound signal to the indicated amplitude range. Additionally, the scale factor permits a 16/14-bit floating-point system to be applied.

The scale factor does not need to be transmitted with each sample. Tests have shown that it suffices to determine a single scale factor for blocks of 64 samples (≙ 2 ms) for describing the range of amplitude of the largest of the 64 samples.

2.3 *Transmission format*

The 16 bit samples of the sound signal are available as dual numbers in a 2s complement. The first bit of each word is the MSB (sign bit, 0 ≙ +), and the last the LSB. Using a floating point system, the 16 bit samples are converted into 14 bit code words for transmission.

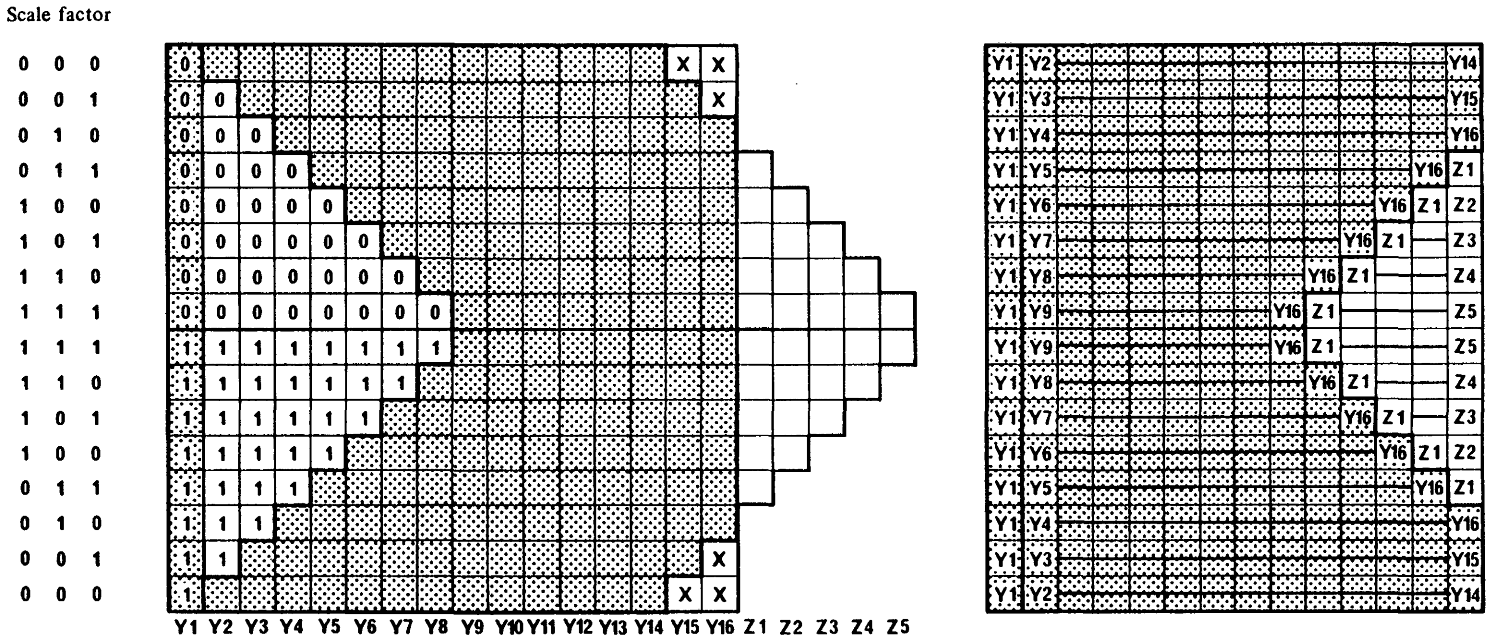
A 3 bit scale factor applying to a block of 64 samples indicates how many of the bits (0 ... 7) following the sign bit (y_1) in all sampled words have the same value as the sign bit **(Fig. 1a)**. The redundancy indicated by the scale factor does not need to be transmitted. Instead, the samples and their relevant information must be shifted towards the sign bits (floating-point system). This allows the 15th and 16th bits of the source code words to be transmitted in the case of low signal amplitudes. The bits marked Z1 to Z5 have not yet been assigned **(Fig. 1b)**.

At the receiving end the scale factor is used to shift the bits of the samples back to their original value. This yields 16 bit samples and limits the effects of unrecognized bit errors to the amplitude range indicated by the scale factor.

3. Multiplexing

3.1 *General*

All the information to be transmitted, i.e. audio signals, programme-related data and associated data for bit error protection, is contained in two identical synchronous main frames initiating modulation of two orthogonal carriers (4-PSK modulation). Each of the two main frames contains 16 of the audio channels described under § 2, and related information. Two audio channels can be used as one stereophonic channel. Stereophonic channels 1 ... 8 are contained in main frame A, stereophonic channels 9 ... 16 in main frame B **(Fig. 2)**.



a) Coding scheme

b) Transmission format

▨ relevant sound signal code word range of the 16 bit source signal words

X X non-transmittable bits of the 16 bit source signal words

FIGURE 1 - *16/14 bit floating-point method*

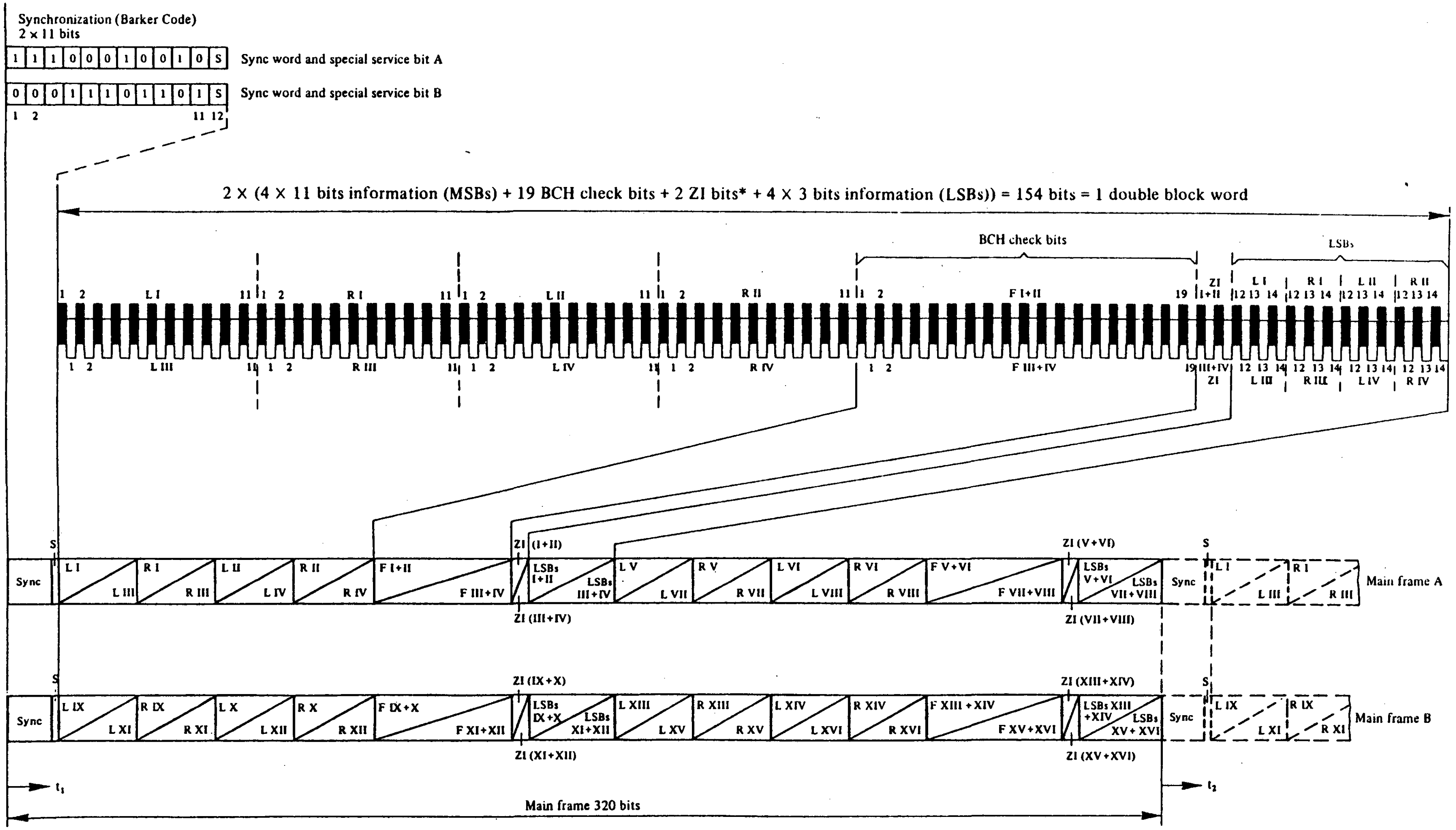


FIGURE 2 – *Format of the main frame*

1 : MSB
14 : LSB
I, II, XVI : stereophonic channel number

L : left channel
R : right channel
* Additional information

3.2 *Structure of the main frame*

A main frame consists of 320 bits (**Fig 3**). The frame repetition frequency is 32 kHz. This provides a data rate of 10.24 Mbit/s.

The frame begins with a frame sync word, followed by a bit for special services and four blocks of 77 bits each, of which the first two consecutive blocks are bit-interleaved and the second two consecutive blocks are bit-interleaved as well (**Fig. 2**). This mode of bit interleaving eliminates the effects of double bit errors in the receiver when differential modulation is used.

3.2.1 *Main frame sync word*

An 11 bit Barker code word with the following structure serves as the sync word for main frame A:

1 1 1 0 0 0 1 0 0 1 0

The inverse of this 11 bit Barker code is used for main frame B:

0 0 0 1 1 1 0 1 1 0 1

The Barker code word allows a correlation analysis to be performed in the receiver, ensuring correct bit clock recovery and bit allocation and enabling the recognition of loss of synchronism (cycle skips and bit slips). Inversion of the Barker code word in main frame B ensures unambiguous allocation of the two demodulated bit streams to main frames A and B even in the case of differential demodulation.

3.2.2 *77-bit block*

To ensure trouble-free reception in the event of unfavourable conditions, a (63,44) BCH code is used systematically at the receiving end for error correction or error recognition with error concealment. The 19 BCH check bits are each derived from a set of 11 MSBs of the 14-bit code word of four audio signal channels. They are fully described by the generator polynomial:

$$g(x) = x^{19} + x^{15} + x^{10} + x^{9} + x^{8} + x^{6} + x^{4} + 1$$

Beginning with the check bit corresponding to the highest power, the check bits are appended to the 4 × 11 MSBs of the 14 bit audio signal code words to form the 63 bit BCH code word. Together with the 4 × 3 LSBs of the 14 bit audio signal code words and two additional information bits used for a channel-related transmission of the scale factors and the so-called programme-related information (PI), the 63 bit BCH code word forms a 77 bit block for two stereophonic channels. The first additional information bit is always allocated to the first, the second additional information bit always allocated to the second stereophonic channel. The exact arrangement is shown in **Fig. 4.**

3.2.3 *Special service bit*

The special service bits (**Fig.3**) of 64 consecutive A main frames are combined to form a special service frame (SA) (**Fig. 5**). The use and structure of this particular frame is described under § 3.3 and 3.4. The use of the special service bit in main frame B has not yet been defined and is provisionally set at "0".

3.3 *Structure of the superframe*

3.3.1 *General*

One audio signal code word from each of the 16 audio channels is transmitted in a main frame. In accordance with § 2.2, 64 audio signal samples (≙ 2 ms) from one channel are combined to form a sound signal block for the determination of the scale factor. To make sure that this structure is retained on the transmission path for all audio channels, a superframe is formed from 64 consecutive main frames. The superframe must likewise begin with a sync word.

3.3.2 *Superframe synchronization*

The first 16 bits of the special service frame formed by the special service bits of main frame A are used to ensure correct synchronization of the 2 ms audio signal blocks in all 32 audio channels (including all additional information) of the two main frames. A Williard code with the following structure is implemented as the sync word:

0 0 0 0 0 1 0 1 1 1 0 0 1 1 1 1

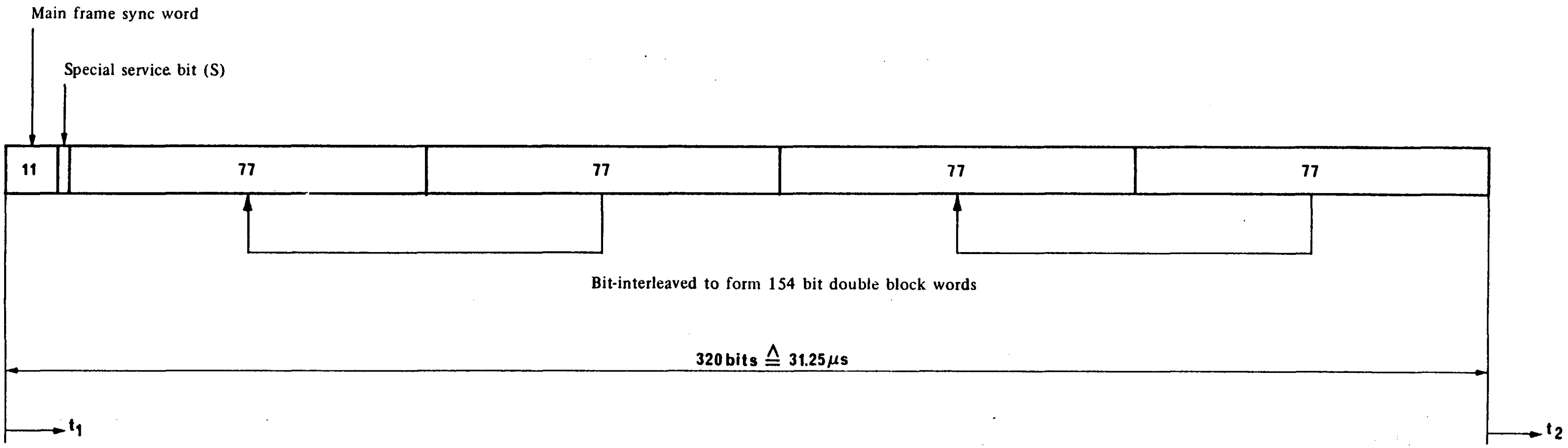


FIGURE 3 – *Structure of main frame (principle; details in* Figs. 2 and 4)

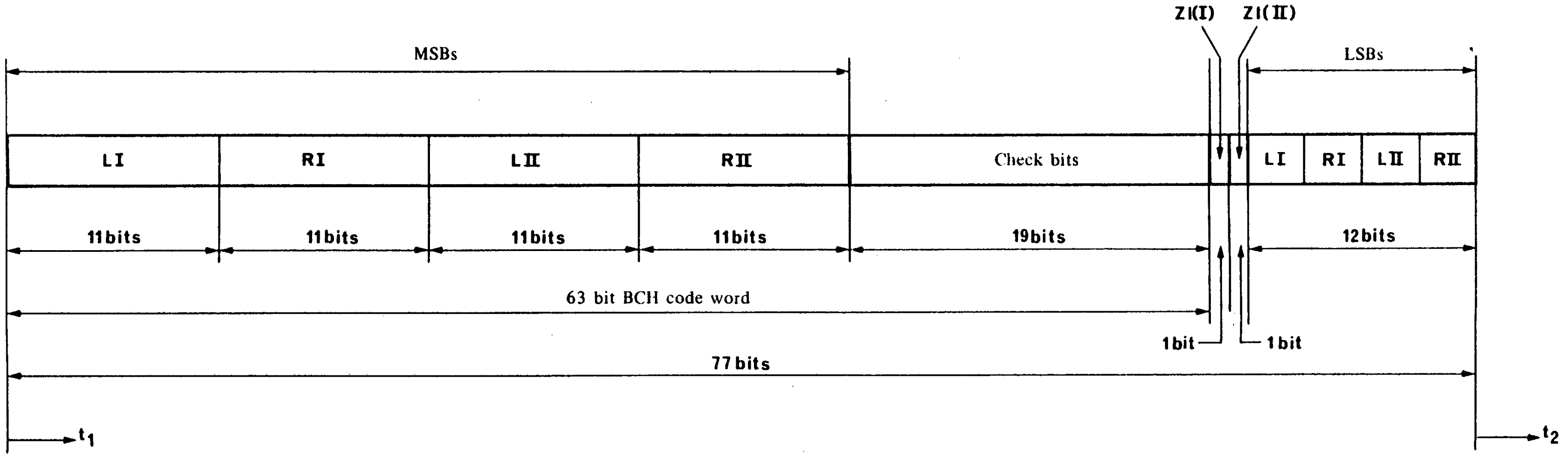


FIGURE 4 – *Structure of the 77 bit block (details in Fig.* 2)

I, II : stereophonic channel numbers
L : left channel
R : right channel
ZI : additional information

If a stereophonic channel is split into two monophonic channels :

L → monophonic channel 1
R → monophonic channel 2

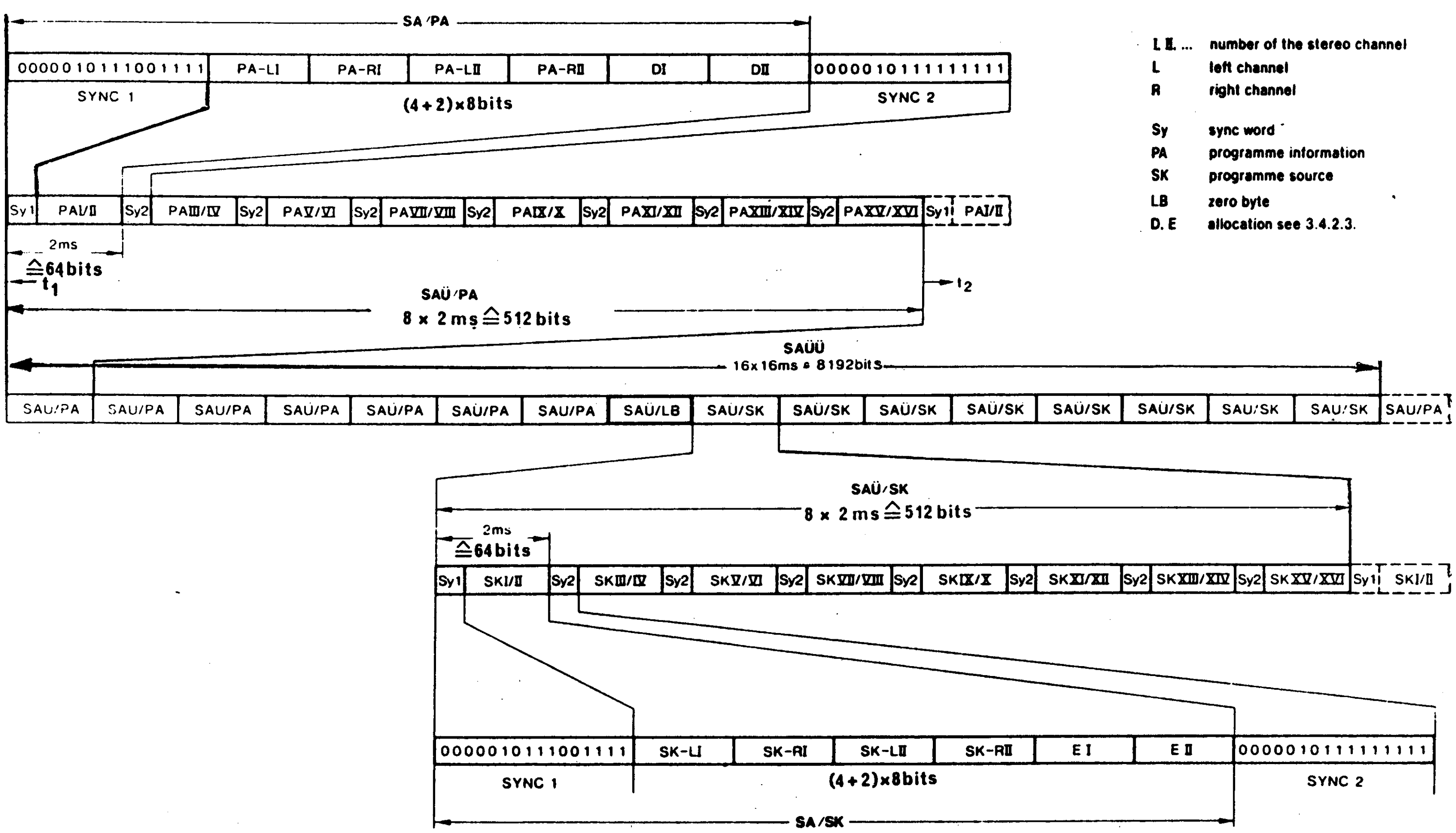


FIGURE 5 - Structure of the special service frames (SA), the special service super frames (SAÜ) and the SAÜÜ frame

The main frame A whose special service bit contains the last bit of the above sync word is followed by all 2 ms audio signal blocks (including additional information Z1) of main frames A and B. In view of the utilization of the remaining 48 bits of the special service frame SA, superframes SAU and SAUU are required for the special service as well (see also § 3.4.3 and 3.4.4).

3.4 *Use of the special service bits*

3.4.1 General

After deduction of the 16-bit sync word, 48 of the 64 bits of the special service frame remain. The 48 bits are available at 2 ms intervals and are used to identify the programmes supplied (programme information PA and programme source SK). The PA-information indicates the mode (mono/stereo)* of the various channels, the type of programe (0 ... 15) and whether music or speech is broadcast. It is therefore possible to provide a continuous overview of all available programmes and to control the switching functions in the receiver. By means of the SK-information the programme source is identified. This information can be interpreted and displayed by the receiver. It consists of 8 alphanumeric characters**.

3.4.2 Structure of the special service frame

The 48 bits available within a period of 2 ms are divided into six bytes (Fig. 5). The first 4 of these are used for the transmission of the PA-information (SA/PA) as well as for the programme-source-code (SA/SK). Bytes 5 and 6 of the SA-frames (Dn- or En-bytes) are used for identification of the 77-bit block or are available for other future applications.

3.4.2.1 Programme Information (PA)

In the case of *monophonic* broadcasts, the programme information for monophonic channels 1 ... 4 (PA-L I, PA-R I, PA-L II, PA-R II) is contained in the first four bytes after the sync word. The coding scheme for the programme information is then as follows:

Programme type No.					Speech/music	Mode		Parity
0	0	0	0	0	K	0	1	P
1	0	0	0	1	K	0	1	P
2	0	0	1	0	K	0	1	P
3	0	0	1	1	K	0	1	P
4	0	1	0	0	K	0	1	P
5	0	1	0	1	K	0	1	P
6	0	1	1	0	K	0	1	P
7	0	1	1	1	K	0	1	P
8	1	0	0	0	K	0	1	P
9	1	0	0	1	K	0	1	P
10	1	0	1	0	K	0	1	P
11	1	0	1	1	K	0	1	P
12	1	1	0	0	K	0	1	P
13	1	1	0	1	K	0	1	P
14	1	1	1	0	K	0	1	P
15	1	1	1	1	K	0	1	P

K: identification for music/speech
  1: music
  0: speech
P: parity bit
  0: even number of "1" in bits 1 ... 7

---

* The designation "stereo" means that two channels are used for the transmission of the programme even if the programme signal is not a stereophonic one.

** The programme source SK corresponds to the "programme-source" code PS in the radio Data System (RDS).

The programme type numbers stand for the following*:

Number	Programme type	**	
0	No programme type or undefined		
1	News	(NEWS)	SPEECH
2	Current Affairs	(AFFAIRS)	
3	Information	(INFO)	
4	Sport	(SPORT)	
5	Education	(EDUCATE)	
6	Drama	(DRAMA)	
7	Culture	(CULTURES)	
8	Science	(SCIENCE)	
9	Varied	(VARIED)	
10	Pop Music	(POP M)	MUSIC
11	Rock Music	(ROCK M)	
12	M.O.R. Music	(M.O.R. M)	
13	Light classical	(LIGHT M)	
14	Serious classical	(CLASSICS)	
15	Other Music	(OTHER M)	

In the case of **stereophonic** broadcasts, a **double identification for the programme type** can be used. In this way programmes which can be allocated to two different programme types are better to characterize (e.g. Sport/Pop) and furthermore a larger number of programmes can be found during the searching process in the receiver. A double identification consists of a primary and a secondary identification. Both have to be taken from the table of programme type numbers above.

The primary identification of the programme-type and of the identification music/speech is transmitted in the left channel PA-L, the secondary identification in the first 4 bits of the right channel PA-R. If there is no need for transmitting a secondary identification the primary identification shall be repeated as secondary identification.

---

* This is the allocation laid down in the EBU's recommandation Doc. Tech.-3244 on the radio data system (RDS) for terrestrical VHF sound broadcasts.

** The terms in brackets are the recommended short terms which can be used on an 8 character display or on the front panel of the radio receiver.

To indicate the stereophonic mode additionally the remaining bits of the right channel PA-R are used. The right channel's occupation (PA-R) for stereophonic broadcasts is as follows :

X X X X 0 1 0 P

where :

X : bits for coding of the secondary identification
P : parity bit (0 = even number of "1" in bits 1 ... 7)
Bits 6 and 7 : If 01 in PA-L and PA-R → two independent monophonic channels
If 01 in PA-L and 10 in PA-R → stereophonic pair.

If **one channel is not occupied** this will be indicated by the bit sequence

0 0 0 0 1 0 0 1

in the corresponding 8-bit codeword of the programme information identification. The audio-signal samples, scale factors and additional information are set to "permanent 1" in this case.

3.4.2.2 Programme source (SK)

In the case of **monophonic** broadcasts the first four bytes following the sync-word contain the SK-information for the monophonic channels 1 ... 4 (SK-LI, SK-RI, SK-LII, SK-RII). In the case of **stereophonic** broadcasts the same programme source code is transmitted in both the left and the right channel.

The coding-law for the SK-data is based on the list of characters in the RDS-specifications EBU Doc. Tech. 3244, Appendix 5, Fig. 21. In order to maximize the distance to the sync-word (to avoid simulation of sync-word) the code-word 0111 1111 must not be transmitted. The code-words 1110 XXXX and 1111 XXXX cannot be used for the same reason; the characters in the EBU-Doc. assigned to these code-words are therefore transmitted by the code-words 0000 XXXX and 0001 XXXX, respectively (see **Table II**).

In all bytes bit No. b8 is always transmitted first. The transmission always starts with the utmost left character in the display. The number of all characters including possible spaces is always 8.

3.4.2.3 Utilization of Dn- and En-Bytes

In order to maximize coding distance to the chosen sync-word (Sync 1; Sync 2) the following rule must be observed when Dn- and En-Bytes are used :

X X X X X 0 X P

TABLE II - *Code table for 218 displayable characters forming the complete EBU Latin-based repertoire**

Additional displayable characters for:

Displayable characters from the code table of ISO Norm 646

EBU common-core (7 languages)

Complete Latin-based repertoire (25 languages)

				b8	0	0	0	0	0	0	1	1	1	1	1	1	0	0
				b7	0	0	1	1	1	1	0	0	0	0	1	1	0	0
				b6	1	1	0	0	1	1	0	0	1	1	0	0	0	0
				b5	0	1	0	1	0	1	0	1	0	1	0	1	0	1
b4	b3	b2	b1		2	3	4	5	6	7	8	9	10	11	12	13	0	1
0	0	0	0	0		0	@	P		p	á	â	ª	º	Á	Â	Ã	ã
0	0	0	1	1	!	1	A	Q	a	q	à	ä	α	¹	À	Ä	Å	å
0	0	1	0	2	"	2	B	R	b	r	é	ê	©	²	É	Ê	Æ	æ
0	0	1	1	3	#	3	C	S	c	s	è	ë	‰	³	È	Ë	Œ	œ
0	1	0	0	4	¤	4	D	T	d	t	í	î	Ǧ	±	Í	Î	ŷ	ŵ
0	1	0	1	5	%	5	E	U	e	u	ì	ï	ě	İ	Ì	Ï	Ý	ý
0	1	1	0	6	&	6	F	V	f	v	ó	ô	ň	ń	Ó	Ô	Õ	õ
0	1	1	1	7	'	7	G	W	g	w	ò	ö	ő	ű	Ò	Ö	Ø	ø
1	0	0	0	8	(	8	H	X	h	x	ú	û	π	µ	Ú	Û	Þ	þ
1	0	0	1	9	)	9	I	Y	i	y	ù	ü	₠	¿	Ù	Ü	Ŋ	ŋ
1	0	1	0	10	•	:	J	Z	j	z	Ñ	ñ	£	÷	Ř	ř	Ŕ	ŕ
1	0	1	1	11	+	;	K	[(1)	k	{ (1)	Ç	ç	$	°	Č	č	Ć	ć
1	1	0	0	12	,	<	L	\	l		Ş	ş	←	1/4	Š	š	Ś	ś
1	1	0	1	13	–	=	M	] (1)	m	} (1)	β	ğ	↑	1/2	Ž	ž	Ź	ź
1	1	1	0	14	.	>	N		n		¡	ı	→	3/4	Đ	đ	Ŧ	ŧ
1	1	1	1	15	/	?	O		o	▨	Ĳ	ĳ	↓	§	Ŀ	ŀ	ð	

▨ Modification - see text

---

* The characters shown in positions marked (1) in the table are those of the "international reference version" of ISO 646 that do not appear in the "complete Latin-based repertoire" given in Appendix 2 of EBU document Tech. 3232 (2nd edition, 1982).

where :

X : unallocated bits
P : parity bit (0 = even number of "1" in bits 1 ... 7)

The **Dn-Bytes** describe the utilization of the four monophonic channels within one 77-bit block. For each monophonic channel two bits are available for that purpose. The allocation of these identification bits to the monophonic channels is :

Dn (odd) 5th byte in the SA/PA-frame

Dn (even) 6th byte in the SA/PA-frame

X	X	X	X	X	0	X	**P**	X	X	X	X	X	0	X	**P**

Mono 1 Mono 2 Mono 3 Mono 4

LI RI ← example → LII RII

Bits No. 5 and 7 of each Dn-byte are held in reserve for possible extension of identifications and are provisionally set to "0".
By means of the two bits four different modes can be identified.

mode	meaning
00	monophonic sound channel within a 77-bit block according to Fig. 4 Sound coding as described in § 2 additional information as described in § 3.5
01	not yet defined
10	not yet defined
11	data transmission according to APPENDIX V

With an identification other than "0 0" bytes 1 ... 4 of the SA/PA- and the SA/SK-frames **(Fig. 5)** are not occupied by programme information or programme source data and are free for other use. A safe evaluation of the Dn-bytes is ensured by 7 consecutive transmissions of the SA/PA-frames and a majority decision.

The utilization of the **En-bytes** (bytes No. 5 and 6 in the SA/SK-frame) has not yet been fixed. They are set to :

0 0 0 0 0 0 0 0

3.4.3 *Structure of the special service superframe SAU*

One special service frame SA contains the programme identification (PA) and the programme source information (SK) of four monophonic or two stereophonic programmes. To cater for all 32 monophonic or 16 stereophonic programmes, eight special service frames SA/PA and SA/SK must be combined to form one special service superframe SAU/PA or SAU/SK.

The beginning of this superframe is marked by the 16-bit Williard code word described above (see § 3.3.2)(Sync 1). The remaining seven special service frames within the superframe all start with the following modified sync word (Sync 2) :

0 0 0 0 0 1 0 1 1 1 1 1 1 1 1 1

(see also Fig. 5.)

3.4.4 Structure of the SAUU-frame

The special service superframe SAU/PA and SAU/SK are transmitted in alternate groups. To this end another superframe (SAUU) is formed containing 7 consecutive SAU/PA-frames and 8 consecutive SAU/SK-frames. Both groups are separated by a SAU/LB frame (Fig. 5),which has the structure of a SAU-frame in which all bytes of the enclosed 8 SA-frames are set to "0".

The 8 SAU/SK-frames following the SAU/LB-frames contain the 8 characters of the programme source information starting with the utmost left character of the display. In case of sound transmission the 7 consecutive SAU/PA-frames carry identical information thus ensuring data protection.

3.5 *Use of the additional information bits*

3.5.1 *General*

The process of combining 64 main frames into superframes (see § 3.3) also leads to the formation of frames for the additional information bits ZI. Such a ZI frame contains the scale factors for two audio channels. The remaining capacity is reserved for the future transmission of programme-related information (PI)(see Fig. 6).

3.5.2 *Scale factor*

The position of the scale factors of two audio channels in an information (ZI) frame is shown in Fig. 6. Figure 1 indicates the allocation of the scale factors to the amplitude ranges. In view of their importance, the scale factors require greater protection against bit errors than the audio signal code words. To this end, the two 3 bit scale factors of a left and a right channel are inserted, starting with the MSB, into a systematic abbreviated BCH (14,6) code. The BCH code word is transmitted in triplicate (thus occupying 42 bits of the information frame). To obtain the abbreviated BCH code word, the following steps have to be carried out:

a) the two 3 bit scale factors are preceded by a seventh bit with the value 0;

b) eight check bits are obtained by the generator polynomial of a BCH (15,7) code

$$g(x) = x^8 + x^7 + x^6 + x^4 + x^0$$

and are appended to the six scale factor bits. The sequence of the check bits is determined by the power of the associated generator polynomial (those with the lowest value are at the end).

To facilitate decoding on the receiving side, the scale factor must be received before the sound signal block from which it was derived. For technical reasons, the scale factor should in fact have a lead of two sound signal blocks, i.e. transmission of the scale factor in the information frame ZI should commence 4 ms before the transmission of the first sound signal code word of the associated sound signal block.

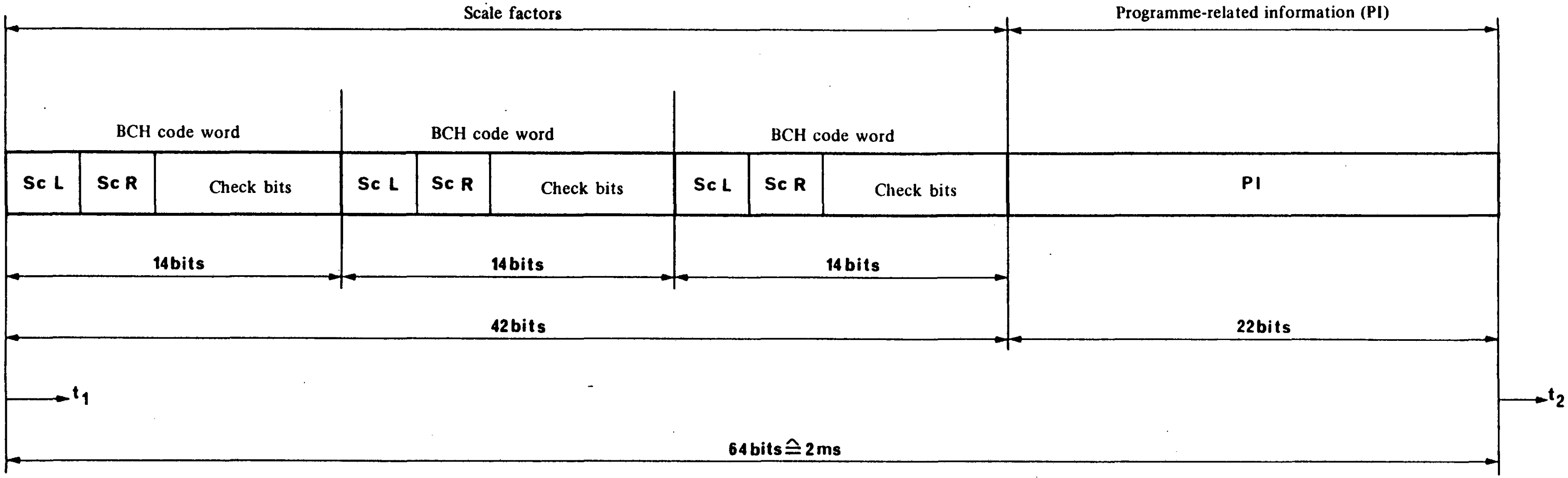


FIGURE 6 – *Structure of the information frame ZI*

3.5.3 *Programme-related information (PI)*

At 2 ms intervals, resulting from the determination and transmission of the scale factors, a data capacity of 22 bits per stereophonic channel is available in the information frame for the transmission of additional programme-related information. These 22 bits should be used bit transparently, i.e. the 22 bit words transmitted in bursts every 2 ms by the ——— earth station should reach the interface* at the receiving end in bursts of 22 bits**.

The 22 programme-related information bits of monophonic programmes are allocated to the two monophonic channels on an alternating basis, i.e. a 22 bit programme-related information block is only transmitted every 4 ms. The synchronization of the special service super frame (SAU) is used to determine the allocation of the 22 programme-related information bits to the appropriate monophonic channel. The 22 programme-related information bits following the SAU sync word of the special service superframe are consequently assigned to monophonic channel 1.

4. Modulation and RF transmission

4.1 *Modulation technique*

To make efficient use of the bandwidth of the transponder channel even at low C/N values, coherent 4-PSK modulation without bit offset of a carrier is applied. The two 10.24 Mbit/s bit streams derived from the two main frames form the input signals. The overall bit rate of 20.48 Mbit/s permits 16 stereophonic or 32 monophonic sound programme signals to be transmitted. Differential encoding of the two bit streams allows both synchronous and differential demodulation at the receiving end. A commonly used modulation method is described in Appendix III.

4.2 *Scrambling*

Scrambling is applied for energy dispersal and reliable clock recovery in modulation pauses or in the case of stationary signals for protection against sync word imitation. As shown in **Fig. 7**, the bit streams of main frames A and B, with the exception of the sync words and the special service bits, are scrambled by means of a combination with the pseudo-random sequence of a scrambling generator. This is technically possible using a 9 digit feedback shift register. The generator polynomial is:

$$g(x) = x^9 + x^4 + 1$$

A 308 bit sequence showing a minimum imitation probability with respect to the Barker frame sync word is selected from the binary sequence of 511 clocks ($2^9 - 1$). The 308 bit sequence is determined by the initial value:

$$r_8, r_7 \ldots r_0 = 0\ 1\ 0\ 1\ 1\ 1\ 1\ 0\ 1$$

From the thirteenth bit of the main frame onwards, the remaining 308 bits are combined with the pseudo-random modulo-2 as follows:

- main frame A with the contents of shift register cell r_0, and
- main frame B with the contents of shift register cells r_3 and r_0.

Subsequently, the shift register cells are reset to the aforementioned initial value. Scrambling then restarts with the thirteenth bit of the next main frame.

4.3 *Differential coding*

To be able to provide differential phase demodulation instead of the more complicated synchronous modulation at the receiver, differential encoding should be applied to all bits of main frames A and B after scrambling. To do so, the two scrambled bit streams A′ and B′ of main frames A and B are combined by means of a differential encoder. The combination process applied is based on the following principle:

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[*] A proposal for a standardized programme-related (PI) information interface in the DSR receiver is contained in Appendix I to this Annex.

[**] Appendix II ——— describes a possible packet structure for the transmission of programme-related information.

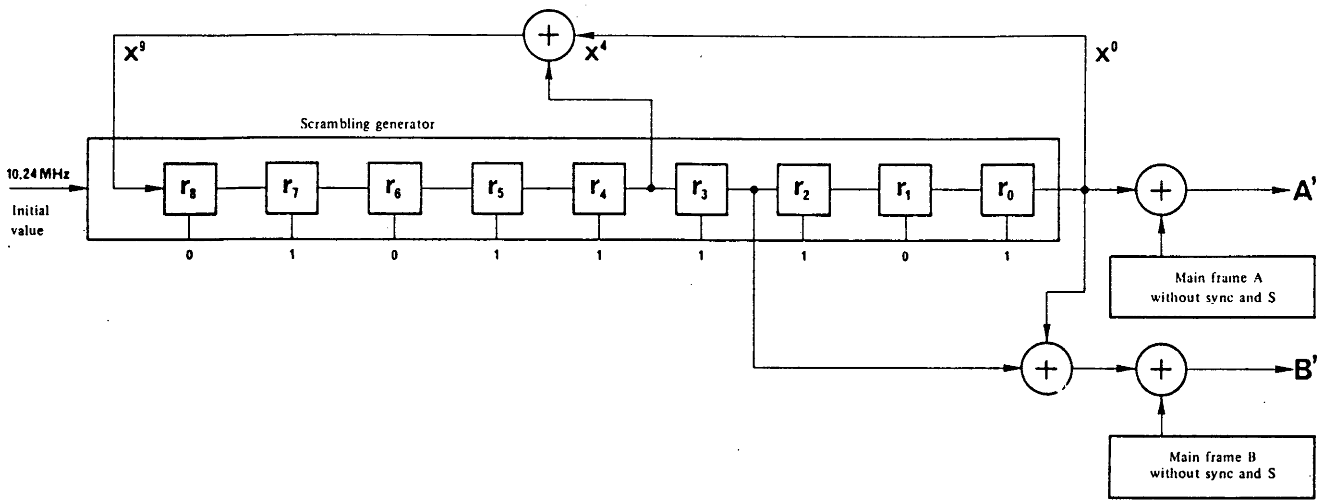


FIGURE 7 – *Scrambling in main frames A and B*

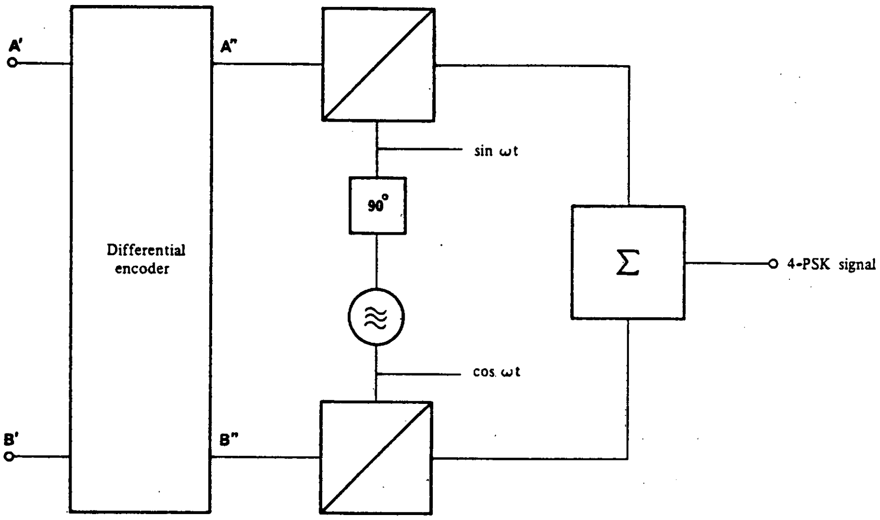


FIGURE 8 – *Notional block diagram of the coherent 4-PSK modulator with an encoder for differential encoding*

for $A'_n \oplus B'_n = 0$ $\quad A''_n = A''_{n-1} \oplus A'_n$

$B''_n = B''_{n-1} \oplus B'_n$

for $A'_n \oplus B'_n = 1$ $\quad A''_n = B''_{n-1} \ominus A'_n$

$B''_n = A''_{n-1} \oplus B'_n$

$\oplus$: EX-OR,

X_n : logical state at time n,

X_{n-1} : logical state at time $n-1$, i.e. 1 bit earlier.

The two output signals A″ and B″ of the differential encoder form the modulated signal **(see also Fig. 8)**.

4.4 *Spectrum shaping*

The signal spectrum* provided by the earth station (linear amplification portion) is described by the equivalent representation at baseband (50% cos roll-off):

$$S(f) = 1 \qquad \text{for } 0 \leqslant f \leqslant \frac{1}{4\tau}$$

$$S(f) = \sqrt{\frac{1}{2}\left\{1 + \cos\left[2\pi\left(f - \frac{1}{4\tau}\right)\tau\right]\right\}} \qquad \text{for } \frac{1}{4\tau} \leqslant f \leqslant \frac{3}{4\tau}$$

$$S(f) = 0 \qquad \text{for } f > \frac{3}{4\tau}$$

$$\tau = \text{bit pair (dibit) duration} = \frac{2}{20.48} \cdot 10^{-6}\ \text{s}$$

(The IF/RF spectrum is obtained by amplitude modulation of the two orthogonal carriers with a signal corresponding to the above baseband representation.)

4.5 *Modulation states*

The bit pairs (dibits) of the scrambled bit streams A′ and B′ (prior to differential encoding) in the modulated 4-PSK signal correspond to the following bit phase allocation:

Bit information		**Phase change (degrees)**
A′	**B′**	**Δφ**
0	0	0
1	0	90
1	1	180
0	1	270

The phase change is related to the phase position of the carrier signal at each preceding dibit.** **Counting** should take place in an anti-clockwise direction (mathematically positive).

---

* Definition of the out-of-band emission in the earth station specifications should conform to the Radio Regulations and the planning principles for up links (WARC-ORB). The spectrum mask applicable to the 4-PSK signal is shown in Appendix IV.

** The phase changes and bit allocations indicated here apply to the spectrum of the signal in normal position. The receiver should automatically recognize whether the spectrum of the signal appears in reverse position as a result of the conversion of the signal from the RF range to the IF range at the receiving end and should be able to process the signal accordingly (e.g. by exchanging A′ and B′ according to the associated sync word in the case of differential demodulation).

APPENDIX I

PROGRAMME-RELATED INFORMATION (PI) INTERFACE IN THE DSR SOUND BROADCAST RECEIVER

To be able to identify the programme-related information of the programme received, the receiver for sound broadcasts will comprise a special serial interface. Three different output signals will be applied to the interface. The logical combination of these output signals will permit the reading of the programme-related data.

Figure 9 shows the output format of the three signals and their relationship in time for stereophonic programmes:

- data stream of the additional information relating to the stereophonic channel;
- window signal;
- 32 kHz clock.

The logical combination of these signals ensures that the 22 bit words containing the programme-related information (PI) are transmitted in bursts every 2 ms.

The window signal changes in the case of monophonic programmes. It only appears every 4 ms; consequently, a 22 bit PI word is only transmitted at 4 ms intervals. Allocation to the appropriate monophonic channel is described in § 3.5.3.

The choice of plug and its pin allocation is left to the manufacturers of the receivers.

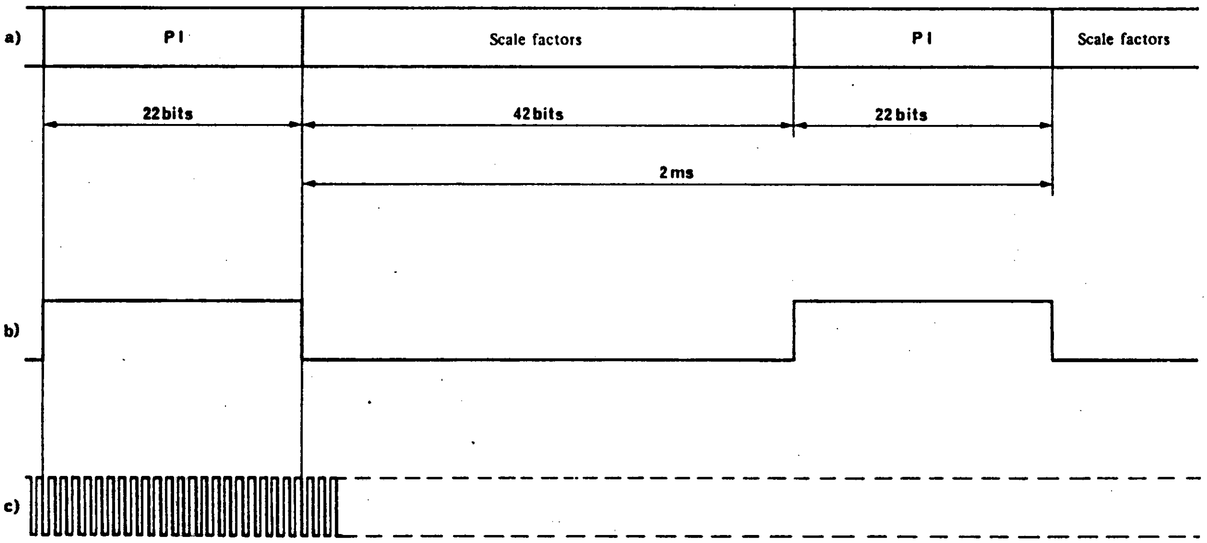


FIGURE 9 – *Programme-related information (PI) interface, output format and correspondence in time (stereo)*

a) Additional information (ZI) data stream

b) Window signal, start of word with positive slope

c) 32 kHz clock, data output with negative clock slope

APPENDIX II

PACKET STRUCTURE FOR PROGRAMME-RELATED INFORMATION (PI)

The 22 bit programme-related information words occurring every 2 ms (every 4 ms in monophonic programmes) are used as follows:

1. The programme-related information (PI) is structured in *packets* whose length corresponds to integral multiples of 22 bits.

2. A *packet* consists of a *header* (2 × 22 bits) and the *packet contents* (*n* × 22 bits).

3. The structure of the header is illustrated in **Fig. 10**. The header begins with a 12 bit initial word

0 0 0 0 0 0 1 1 1 1 1 1

The initial word is followed by two bytes for *packet length indication* and ends with two bytes for *packet contents identification.*

4. Eight bits of the two bytes for *packet length indication* are used for indicating 256 different packet lengths. Consequently, the maximum packet length, including the header, corresponds to 255 × 22 bits + 2 × 22 bits = 5654 bits and is transmitted over a stereophonic link in 514 ms (1028 ms in the case of monophonic programmes). The other 8 bits of the packet length indication are used for bit error protection (Hamming (8,4) code). The encoding and decoding scheme for half-bytes is given in **Table III.**

5. The two bytes for *packet contents identification* have the same structure as the packet length indication and use the same bit error protection. 256 different packet contents identifications are thus possible.

6. The *packet contents* are transmitted in 22 bit words. The actual number of 22 bit words is determined by the packet length indication. Length 0 is a "dummy packet" consisting only of a header. Length 255 indicates the maximum length of 255 × 22 bits for the packet contents. The structure and bit error protection of the 22 bit words are left to the user of the various possible services and need to be specified when a new service is introduced.

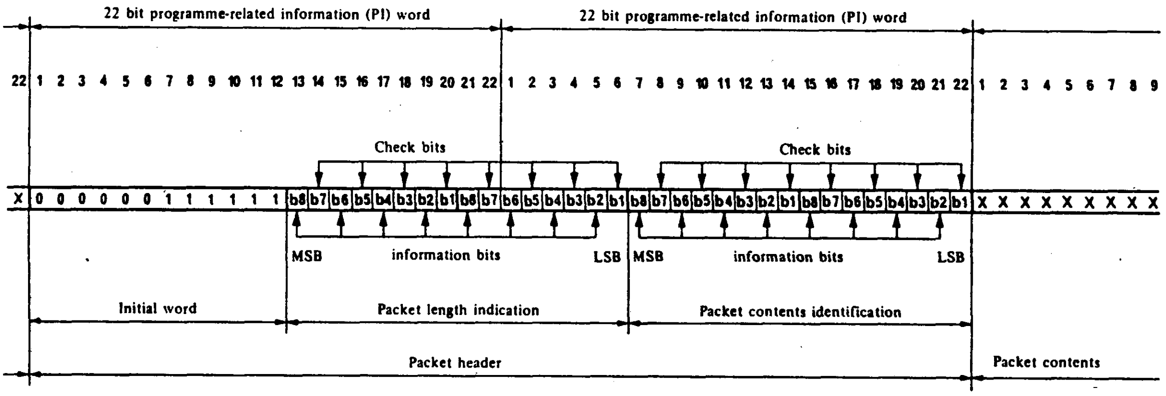


FIGURE 10 – *Structure of the header of the programme-related information (PI)*

APPENDIX III

MODULATION

4-PSK modulation can be generated by, for example, two phase quadrature carrier oscillations A and B which are 2-PSK-modulated by bit streams of 10.24 Mbit/s and finally added.

Main frame A generates a continual data stream of 10.24 Mbit/s on carrier signal A, whereas main frame B generates a continual data stream of 10.24 Mbit/s on carrier signal B. By adding the two 2-PSK-modulated carrier signals, which have the same amplitude, the 4-PSK signal is obtained (**Fig. 8**).

TABLE III – *Encoding and decoding scheme for the bytes protected by a Hamming code*

ENCODING

information bits: b8, b6, b4, b2

hexadecimal number	decimal number	b8	b7	b6	b5	b4	b3	b2	b1
0	0	0	0	0	1	0	1	0	1
1	1	0	0	0	0	0	0	1	0
2	2	0	1	0	0	1	0	0	1
3	3	0	1	0	1	1	1	1	0
4	4	0	1	1	0	0	1	0	0
5	5	0	1	1	1	0	0	1	1
6	6	0	0	1	1	1	0	0	0
7	7	0	0	1	0	1	1	1	1
8	8	1	1	0	1	0	0	0	0
9	9	1	1	0	0	0	1	1	1
A	10	1	0	0	0	1	1	0	0
B	11	1	0	0	1	1	0	1	1
C	12	1	0	1	0	0	0	0	1
D	13	1	0	1	1	0	1	1	0
E	14	1	1	1	1	1	1	0	1
F	15	1	1	1	0	1	0	1	0

protection bits: b7, b5, b3, b1

$b7 = b8 \oplus b6 \oplus b4$

$b5 = b6 \oplus b4 \oplus \overline{b2}$

$b3 = b4 \oplus \overline{b2} \oplus b8$

$b1 = \overline{b2} \oplus b8 \oplus b6$

DECODING

$\oplus$ = EXCLUSIVE-OR

$\overline{b2}$ = b2 inverted

$A = b8 \oplus b6 \oplus b2 \oplus b1$

$B = b8 \oplus b4 \oplus b3 \oplus b2$

$C = b6 \oplus b5 \oplus b4 \oplus b2$

$D = b8 \oplus b7 \oplus b6 \oplus b5 \oplus b4 \oplus b3 \oplus b2 \oplus b1$

A	B	C	D	interpretation	information
1	1	1	1	no error	accepted
0	0	1	0	error in b8	corrected
1	1	1	0	error in b7	accepted
0	1	0	0	error in b6	corrected
1	1	0	0	error in b5	accepted
1	0	0	0	error in b4	corrected
1	0	1	0	error in b3	accepted
0	0	0	0	error in b2	corrected
0	1	1	0	error in b1	accepted
$A \cdot B \cdot C = 0$			1	multiple errors	rejected

APPENDIX IV

SPECTRUM MASK FOR THE EARTH STATION

To avoid adjacent channel interference, the RF spectrum at the output of the power amplifier of the earth station should not exceed the tolerance mask shown in Fig. 11.

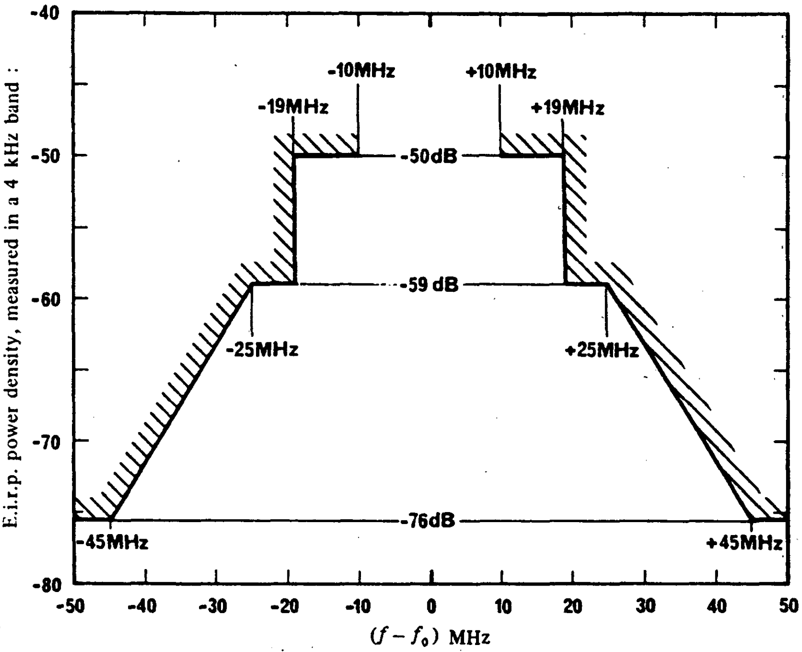


FIGURE 11 – *Tolerance mask for the Earth station*

Out-of-band spectrum mask for the 4-PSK signal at the output of the transmitting earth station (4 kHz measuring filter), related to the maximum planned e.i.r.p., measured with a pseudo-randon sequence of $2^{15} - 1$ in length, which modulates the two carriers.

APPENDIX V

DATA TRANSMISSION

Without changing its structure the DSR-system can also be used for data transmission. Each monophonic channel provides a data rate of 448 kbit/s. Each 14-bit code-word for transmission of sound signals consists of 11 BCH-protected MSB's and 3 unprotected LSB's (Fig. 4). Hence the total capacity of a monophonic channel consists of 352 kbit/s (BCH-protected) plus 96 kbit/s (unprotected). This has to be taken into account when using the channel for data transmission. Possible schemes for data transmission are described in [Assmus, 1989] and [Assmus (EBU Review), 1989].

For a detailed description of the data transmission service the bytes in the SA/PA- or SA/SK-frame allocated to the corresponding monophonic channel can be used. The first 4 bits of the SA/PA-bytes can be used to describe different data transmission structures. Details have not yet been defined.

X X X X X 0 1 P

Bit No. 5 may also be used for future identification purposes. Bits No. 6 and 7 are set to "01" in order to maximize coding distance. Bit No. 8 is the parity bit.

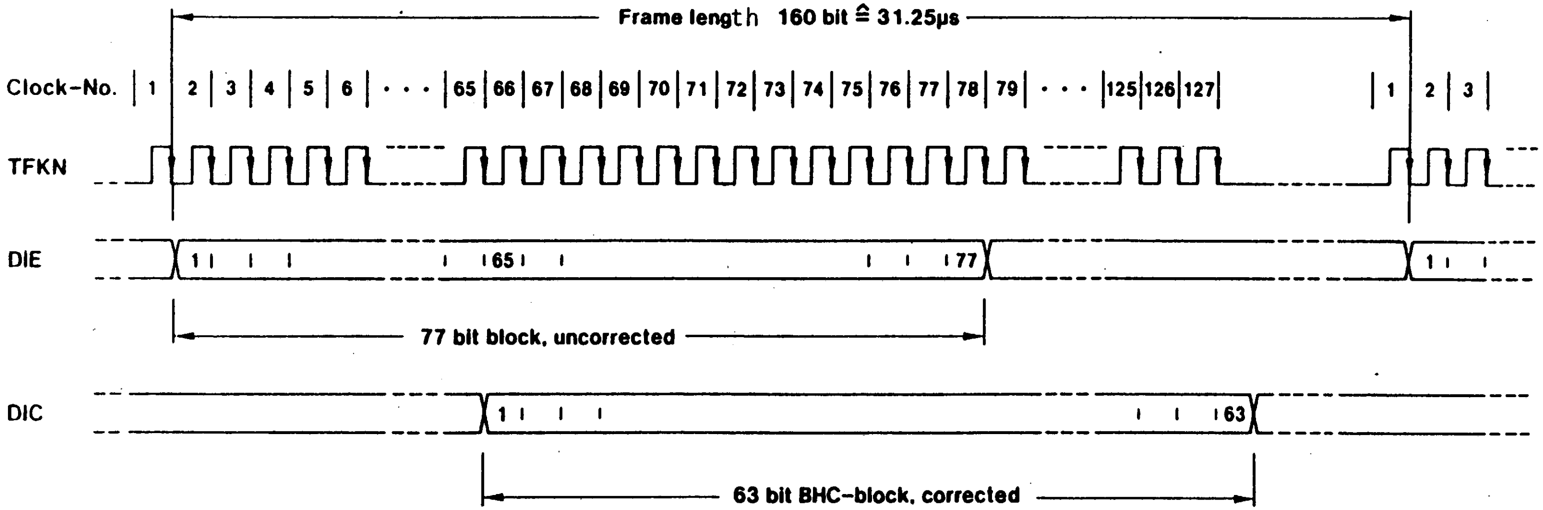
Two adjacent monophonic channels can be combined in order to obtain a total data rate of 896 kbit/s (704 kbit/s protected, 192 kbit/s unprotected). The occupation of the corresponding SA/PA-bytes then is :

X X X X X 0 1 P	X X X X 0 1 0 P

The capability of identification by means of bit No. 5 in the first channel then refers to the pair of channels.

The use of the SA/SK-bytes has not yet been specified. If there is no other request they may still be used for programme source information. The structure would be as explained under 3.4.2.2.

At the receive end an interface has to be prepared for the whole 77-bit blocks (uncorrected) as well as for 63 bit BCH blocks (corrected) and the clock burst. The output format and the time relations of this interface are shown in Fig. 12.



There is a fixed relation between the start of the clock burst TFKN, the start of the uncorrected 77 bit block and the start of the corrected BHC-block. This relation does not depend on the position of the chosen BHC-block of the main frame.

TFKN, DIE and DIC are test outputs of the VALVO DECODER for DIGITAL BROADCASTING SAA 7500

Fig. 12 Interface for data transmission, output format and time relations

REFERENCES

ASSMUS, U. [1989] Datenübertragung im DSR. *Rundfunktechnische Mitteilungen*, 33, Vol. 1, 1-7.

ASSMUS, U. [February, 1989] Data transmission in DSR channels. *EBU Rev. Tech.* 233, 2-8.

ANNEX II

TECHNICAL DESCRIPTION OF THE FULL-CHANNEL DIGITAL MODE OF THE MAC/PACKET FAMILY SYSTEMS

1. Introduction

General description of the MAC/packet family is given in Report 1073 and the CCIR Special Publication on the transmission systems to be used in the 12 GHz BSS band. When the MAC vision signal and its field-blanking interval are replaced by one or several data bursts, the MAC/packet system operates in the full-channel digital mode. This mode of operation has been recently proposed by the EBU and was introduced in the Specification of the systems of the MAC/packet family [CCIR, 1986-90a].

This Annex describes only those elements of the Specification which are specifically related to the full-channel digital mode of operation. Sound coding, signalling and modulation parameters etc are specified in the Special Publication and are not repeated here.

2. The time-division multiplex structure

In the case of full-channel digital mode of operation, the time-division multiplex structure for each line is shown in Fig. 13.

This Figure assumes that the first data burst is of normal length. If the first data burst is reduced in length, the clamping period and the start of the second data burst are moved forward accordingly. The first data burst must end not later than shown in the Figure.

Examples of multiplex structure for full-channel digital mode of operation of C/D- and D2-MAC/packet are given in Figures 14 and 15, respectively. The basic television multiplex structure used for normal television transmissions is retained for full-channel digital mode of operation, except that the analogue vision signal is replaced by digital signals. The data stream of full-channel digital mode is divided in time-division multiplex (TDM) components. Each of the TDM components may occupy lines 1 to 623*, inclusive, of each frame, leaving line 624 free for insertion of a clamp marker and reference signals, and line 625 free for insertion of a frame synchronization word and the special data burst (as specified in the Special Publication).

In principle, the digital TDM components of the C and D systems are divided in two subframes, one of them being intended to be handed over to a D2 system. These TDM components are identified by TDMCID codes 01-0E.

However, certain operational requirements for the C and D systems, such as high-speed data services, may demand a multiplex structure which is not compatible with the above general principle, i.e the TDM components are not divided in two subframes. In this case, a D2 subset of the C and D systems may not exist. These components are identified by TDMCID codes 40-4F.

3. Data transmitted in line 625 relevant to the full-channel digital mode

Overall structure of line 625 data is given in the Special Publication. Specific information related to the full-channel digital mode of operation is included in the static data frame (SDF) and the repeated data frame (RDF) as follows:

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* In the case of full-channel digital mode of operation, the vision insertion test line signals and teletext signals in the field blanking interval should be omitted.

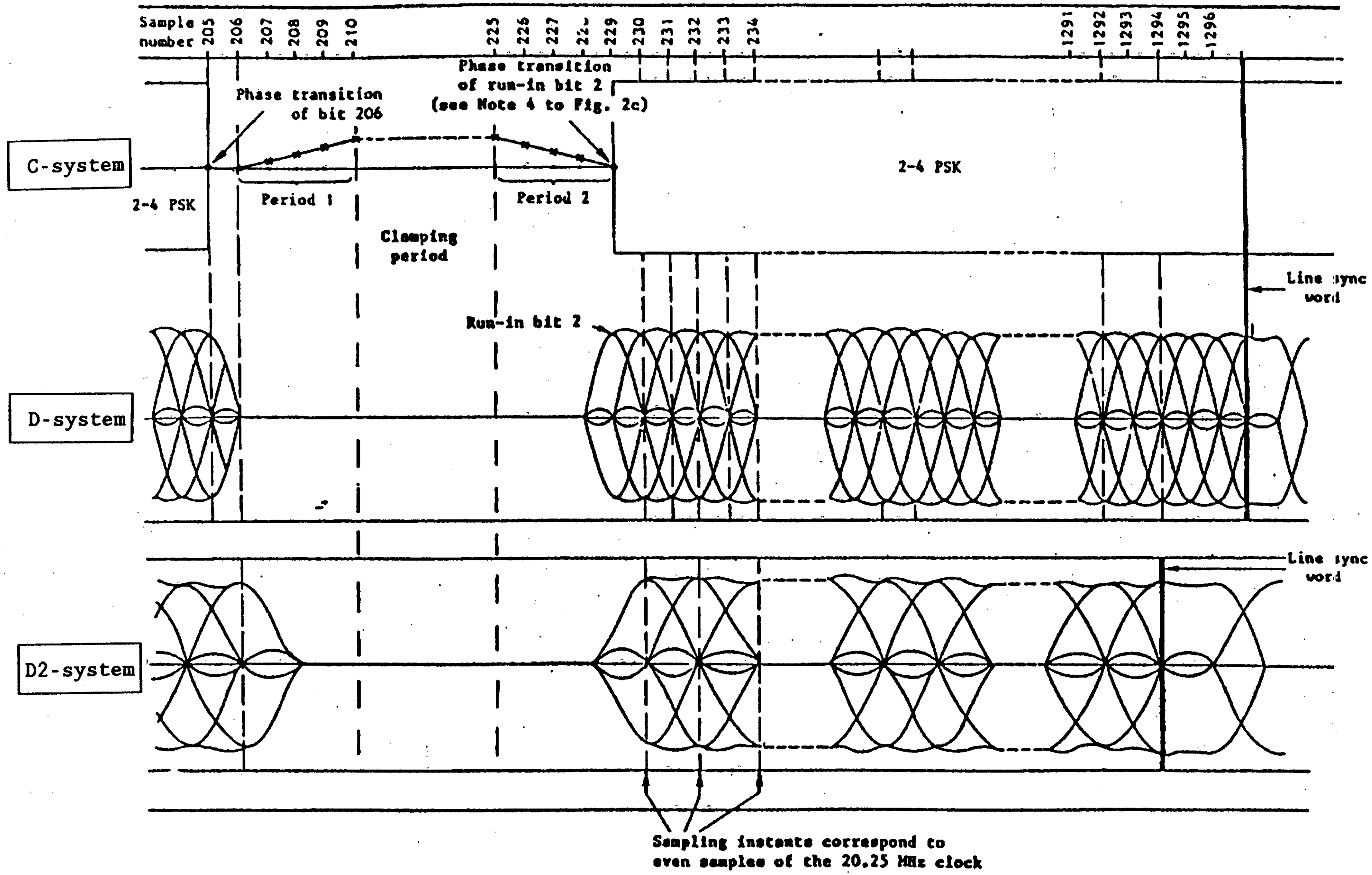
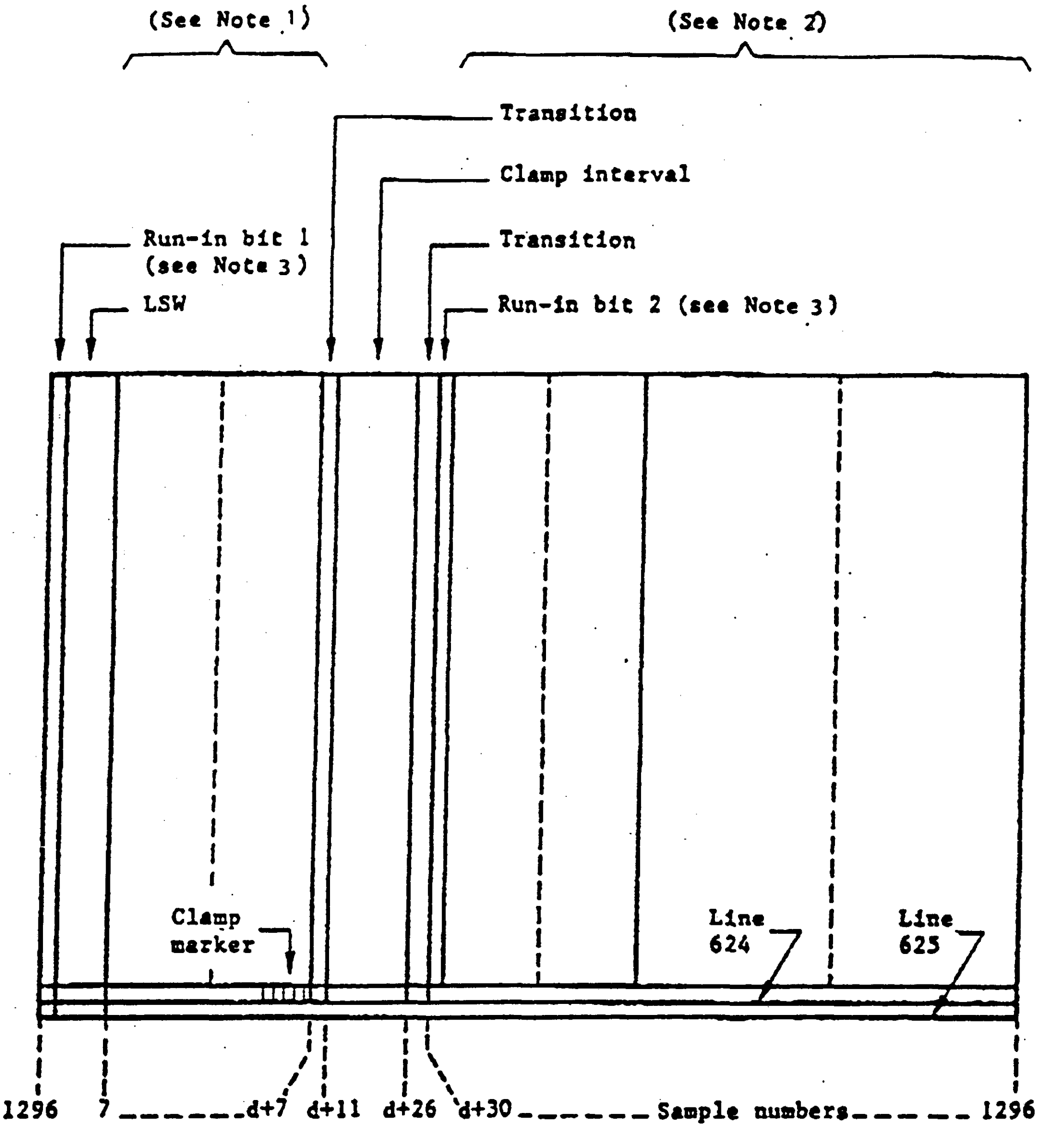


FIGURE 13 – Relationship between the bits of data and the sampling structure in the case of full-channel digital mode of operation for the C, D and D2-MAC/packet systems.



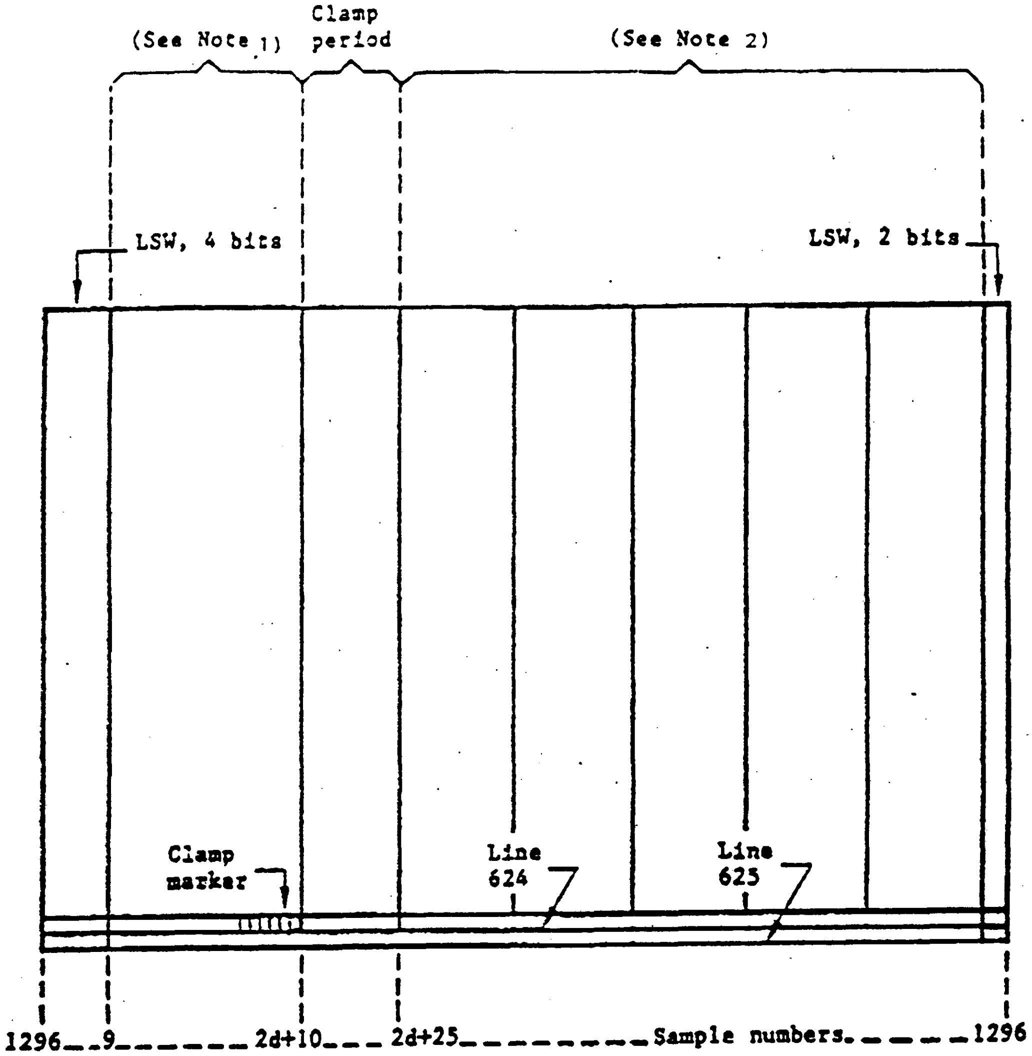
d: duration in bits of the first data burst
LSW: line synchronization word (6 bits)

FIGURE 14 - Example of multiplex structure for C and D full-channel digital mode of operation (not to scale)

Note 1: This part of the frame consists of TDM components with TDMCID codes 01 and 02. Its total duration is 198 bits (+ one spare bit) or less. It may contain a single TDM component.

Note 2: This part of the frame consists of TDM components divided in two subframes or not. The TDMCID codes are 03 to 0E and 40 to 4F respectively. The duration of the TDM component is signalled in line 625.

Note 3: In the case of full-channel digital mode of operation, a differential demodulator for the C system should use run-in bit 2. Run-in bit 1 is not used for that purpose and can be the last useful bit of the last digital TDM component as signalled in line 625.



d = duration in bits of the first data burst
LSW: line synchronization word (6 bits)

FIGURE 15 - Example of multiplex structure for D2 full-channel digital mode of operation (not to scale)

Note 1 This part of the frame consists of TDM components with TDMCID codes 01 or 02. Its total duration is 99 bits.

Note 2 This part of the frame consists of TDM components with TDMCID codes in the range 03 to 0E and/or 40 to 4F. The duration of the TDM component is signalled in line 625.

3.1 *Static data frame (SDF)*

(MVSCG) *Multiplex and video scrambling control group* gives information on the physical signal organisation within the satellite channel. Bits 1 to 4 constitute the Time division multiplex configuration (TDMC) sub-group and take the following values in the full-channel digital mode:

Bit 1: $b_j = 0$

Bit 2: b_m = sound/data multiplex format: if $b_m = 1$, the sound/data multiplex is compatible with decoders intended for the normal burst multiplex, defined in this specification; if $b_m = 0$, the sound/data multiplex is not compatible.

Bit 3: b_T = sound/data multiplex transcoding recommendation; if this bit is "1", then the subframe characterised by TDMCID = 01 is the only one that is recommended by the broadcaster to be handed on from C or D-MAC/packet system into a D2-MAC/packet system; if this bit is "0", then either of the subframes with TDMCID codes 01 and 02 may be handed on at the choice of the cable operators. For satellite broadcast of a D2-MAC/packet signal, bit 3 has no significance. *For full-channel digital mode of operation, this bit is only relevant to the first data burst.*

Bit 4: $b_A = 0$

For full-channel digital mode, bits 5-8 of MVSCG have no function in the user's decoder.

3.2 *Repeated data frame (RDF)*

The repeated data frame transmits *Time Division Multiplex Control* (TDMCTL) information that describes the individual components of the time division multiplex. In particular, parameter TDMCID (TDM component identification) carries a unique code for every type of TDM component as follows (hexadecimal notation):

01-0E: For C- or D-MAC/packet systems, these codes are allocated to areas reserved for data bursts organized as two related subframes; the odd TDMCID codes refer to the first subframe in each data burst, the even codes to the second subframe. For a D2-MAC/packet system, these codes are allocated to areas reserved for data bursts.

The data burst immediately following the line synchronization word is always identified by TDMCID codes 01 and 02 for C- or D-MAC/packet systems, and by the codes 01 or 02 for the D2-MAC/packet system.

For C- or D-MAC/packet systems, the data bursts following the clamping interval are labelled by TDMCID code pairs, i.e. 03 and 04, ..., 0D and 0E. For the D2-MAC/packet system, these data bursts are labelled with TDMCID codes 03 or 04, ..., 0D or 0E.

40-4F: Allocated to areas reserved for data bursts not divided in two related subframes.

Parameter TDMS *(Time Division Multiplex Structure):* defines the horizontal and vertical boundaries of subframes* allocated to a TDM component in terms of line numbers and clock periods, respectively. One TDM component may

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* A subframe is any rectangular shaped area within the television frame.

comprise one or more subframes, and each TDMS field can define two separate subframes, if required. These must occupy identical clock periods (e.g. in the definition of the luminance component in fields 1 and 2 of the television frame). The format of the TDMS field is as follows:

(FLN1) 10 bits: first line number of TDM component subframe 1
(LLN1) 10 bits: last line number of TDM component subframe 1
(FLN2) 10 bits: first line number of TDM component subframe 2
(LLN2) 10 bits: last line number of TDM component subframe 2
(FCP) 11 bits: first clock period of TDM component subframe(s)
(LCP) 11 bits: last clock period of TDM component subframe(s)

Line number 1 is coded as binary 0, clock period 1 is coded as binary 0; higher numbers are coded correspondingly. All 1's in FLN1, FLN2, etc. represent invalid codes and are used to signal undefined subframes. Thus, a TDMS field defining only one subframe has all 1's in FLN2 and LLN2.

Parameter LINKS *(Linked structure):* one-bit switch used to link the group of TDMS field(s) needed to fully define one TDM component. This bit changes on each repetition of the linked TDMS field(s).

TDMCTL data for different TDM components can be sent in any order in successive television frames. Linked structures must be described in increasing order of FLN1. TDMS fields having the same value of FLN1 must be transmitted in increasing order of FCP. The maximum number of different TDM components in one satellite channel must never exceed 128*.

Any change of the TDM configuration is synchronized by the frame counter. New TDMS data, which is flagged by the UDF (up-date flag) bit, is transmitted prior to the change. New and old TDMS data can be interleaved in any order in successive data frames. The actual change of configuration starts from the beginning of line 1 of the second frame following the frame in which FCNT (frame counter) code 0 (modulo 128) is sent.

A TDM component that is to be deleted is flagged by the UDF bit, and the TDMS data is set to all 1's. The component is deleted after the next change of configuration as described above. The procedure can be repeated several times to increase the probability that no receiver has failed to recognize the deletion.

It is recommended that new TDMCTL data be sent shortly before any change of configuration in order tó minimise the acquisition delay for those receivers which are turned on during this process.

4. Service identification (SI) channel in the full-channel digital mode

Chapter 5, part 5 of the Special Publication gives the specification of the data broadcast in the service identification channel. This channel is formed by packets in the sound/data multiplex with the packet address "0". For normal television transmissions, the information broadcasting this channel gives the user access to the various television, sound, and data services, that may co-exist in a channel carrying a signal of the MAC/packet family. *In the case of full-channel digital mode of operation, each digital TDM component carries its own SI channel. It provides the information needed by the user to access the sound services and the data services present in that TDM component.*

REFERENCES

CCIR Documents

[1986-90] **a.** JIWP 10-11/3-51 (EBU)

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* This number corresponds to a maximum acquisition time of about 5 seconds for a particular TDM component.

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SECTION 10/11C: TECHNOLOGY

REPORT 810-3*

BROADCASTING-SATELLITE SERVICE (SOUND AND TELEVISION)

Reference patterns and technology for transmitting and receiving antennas

(Question 2/10 and 11, Study Programme 2D/10 and 11)

(1978-1982-1986-1990)

1. Introduction

The WARC-BS-77 agreed to reference patterns for satellite transmitting and earth-station receiving antennas for planning the 12 GHz broadcasting-satellite service in Regions 1 and 3. The adopted patterns are contained in Annex 8 to the Final Acts of the WARC-BS-77. Similarly, antenna reference patterns were adopted at the RARC SAT-83 for planning the 12 GHz broadcasting-satellite service in Region 2. These patterns are found in Annex 5, § 3 of Part I of the Final Acts of the RARC SAT-83. (See also § 3 of Annex 5 of Appendix 30 (ORB-85) of the Radio Regulations.)

The purpose of this Report is to introduce new reference antenna patterns for spacecraft transmitting and ground receiving equipment. This information can be used in system planning. The reference patterns are presented in § 2 and a description of the present state of technology, including experimental data which justifies the reference patterns, is presented in § 3.

2. Reference patterns

For planning the broadcasting-satellite service, it is necessary to make certain assumptions concerning the maximum gain of the antenna (both for transmitting and receiving), and the way in which the gain decreases as a function of the angle measured from the axis of the beam. This information is essential for calculating interference between the transmissions for different service areas.

This section proposes reference patterns which can be used for this purpose. They are not intended to represent specifications of the best performance which may be possible, but they are reasonable practical targets which should be feasible when good design techniques are used.

The patterns are given as functions of the relative angle φ/φ_0, where φ is the angle measured from the axis of the beam, and φ_0 is the angular width of the beam measured between the -3 dB levels. The levels are expressed in dB relative to the maximum (on-axis) gain of the antenna.

Patterns are specified separately for the co-polar and the cross-polar component. They apply equally to linear and circular polarization. It is intended that they should be applicable throughout the whole of the broadcasting band under consideration, and for all angles of azimuth.

2.1 *Satellite transmitting antenna*

It is likely that initial planning will be based on the assumption that the beams emitted from the satellite have elliptical or circular cross-sections, and the reference patterns in this Report are based on this case.

Note. – Nevertheless, antennas with specially-shaped beams may be very useful for broadcasting satellites, because they would facilitate the suppression of undesirable spillover to neighbouring countries, while maintaining an effective coverage in the intended area. Information on one such antenna is given in § 3 and in Report 676.

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* This Report should be brought to the attention of the IEC.

2.1.1 *Co-polar component*

It is convenient to consider the reference pattern as comprising three sections, namely:

- the main lobe, corresponding approximately to $0 < \varphi/\varphi_0 < 1.6$;
- the near sidelobes, corresponding approximately to $1.6 < \varphi/\varphi_0 < 3.2$;
- the far sidelobes, corresponding approximately to $\varphi/\varphi_0 > 3.2$.

As discussed in Report 558, the envelope of the main lobe can be satisfactorily approximated by a curve of the form $-12(\varphi/\varphi_0)^2$ (dB). This is confirmed by measurements on a number of antennas already produced in the USA [CCIR, 1974-78a].

The level of radiation in the region of the near sidelobes is particularly important for broadcasting satellites, because it will have a significant effect upon the interference between different service areas. For this reason, it will be essential to employ antennas which are designed to reduce the level of the near sidelobes.

Through the use of offset-feed configurations, such as a Cassegrain horn, sidelobe levels less than −30 dB can be achieved [Janky and Barewald, 1977].

For the far sidelobes, the measurements made in the USA show that, with current technology, the level can be kept within an envelope defined by the curve:

$$-[17.5 + 25 \log (\varphi/\varphi_0)] \qquad \text{dB}$$

The studies made by ESA show that, if necessary, it would be possible to design antennas in which the level of the far sidelobes falls off more rapidly, with respect to φ/φ_0, than indicated by the above expression.

It is recognized that, in practice, there must be some lower limit to which the level asymptotes. For the reference pattern, this is taken as being equal to minus the on-axis gain of the antenna.

Taking account of the above discussion, the proposed reference pattern for the co-polar component of the satellite transmitting antenna is defined in Fig. 1. In practice, the values near $\varphi/\varphi_0 = 1.5$ may be difficult to achieve [CCIR, 1978-82a]. One method to improve this situation is to use a larger reflector with tapered illumination.

2.1.2 *Cross-polar component*

A study by the European Broadcasting Union [CCIR, 1974-78b] suggests that the upper limit for the cross-polar component can be expressed in the form:

$$-(a + b \log |(\varphi/\varphi_0) - 1|) \qquad \text{dB} \qquad (1)$$

where a and b are constants.

Account is taken of the discontinuity which occurs at $\varphi/\varphi_0 = 1$ by applying a limit to the permitted values of the envelope.

Theoretically, the level can be kept arbitrarily low at all angles, and some studies have indicated that this could be as low as −40 dB [CCIR, 1974-78c]. However, until more practical experience is obtained in the design and construction of antennas with a very low cross-polar radiation, it is prudent to adopt, for a reference pattern, a somewhat less stringent specification.

In practice, the level of cross-polar response depends primarily on the characteristics of the feed. If the feed for the transmitting antenna is used exclusively for transmission and does not have to be part of a multi-function feed assembly, then excellent cross-polar responses can be obtained in the range of −35 to −40 dB over the main beam [Janky and Barewald, 1977].

Taking account of the limited amount of information on measured results which is so far available, it is proposed to make a and b equal to 40, in expression (1), with an upper limit of −33 at $\varphi/\varphi_0 < 1.5$, and a limit equal to minus the on-axis gain at $\varphi/\varphi_0 > 1.5$.

This proposed pattern is shown in Fig. 1. In practice, the values around boresight may be difficult to achieve [CCIR, 1978-82a].

If the feed assembly is used for both transmitting and receiving, or if a multiple-feed assembly is used to generate an irregularly-shaped beam, then it may not be possible to achieve the cross-polar performance indicated in Fig. 1.

2.2 *Earth-station receiving antenna*

2.2.1 *Co-polar component*

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.

It is suggested that, to take account of the pointing error, the reference pattern should correspond to a relative gain of 0 dB for relative angles up to $\varphi/\varphi_0 = 0.25$. Thereafter, the curve may be expected to follow a square-law (that is, the relative level is equal to $-12\ (\varphi/\varphi_0)^2$ dB), in the same way as in the case of the transmitting antenna discussed above in § 2.1, to a level of -6 dB.

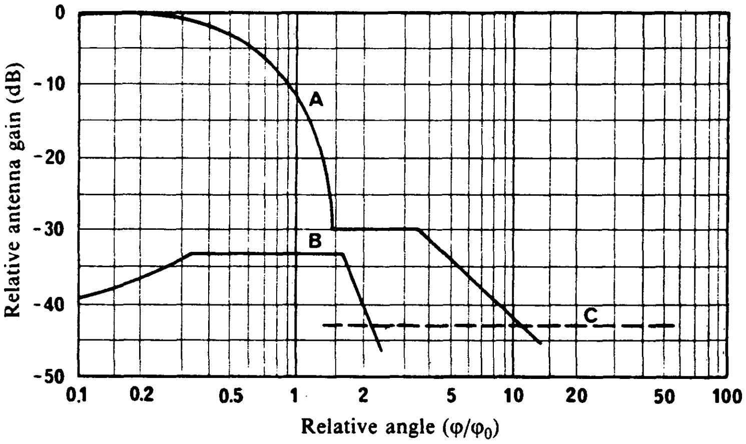


FIGURE 1 – *Reference patterns for co-polar and cross-polar components for a single-feed satellite transmitting antenna producing a beam of circular or elliptical cross-section*

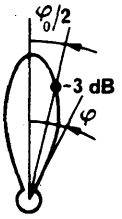
Curve A: Co-polar component (dB)
- $12\ (\varphi/\varphi_0)^2$ for $0 \leq \varphi \leq 1.58\ \varphi_0$
- 30 for $1.58\ \varphi_0 < \varphi \leq 3.16\ \varphi_0$
- $[17.5 + 25 \log (\varphi/\varphi_0)]$ for $3.16\ \varphi_0 < \varphi$

After intersection with Curve C: as Curve C

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

After intersection with Curve C: as Curve C

C: minus the on-axis gain (dB)



At larger angles, the relative level will depend on the degree to which sidelobe reduction techniques are used.

For individual-reception antennas, without the use of such techniques, the upper limit of the relative level decreases from the -6 dB point at a rate given by the expression

$$-[9 + 20 \log (\varphi/\varphi_0)] \qquad \text{dB},$$

up to $\varphi/\varphi_0 = 1.26$, and from this point decreases at a faster rate given by

$$-[8.5 + 25 \log (\varphi/\varphi_0)] \qquad \text{dB}$$

up to $\varphi/\varphi_0 = 9.55$. Beyond this point, a constant level of -33 dB is taken for the remainder of the envelope.

According to the WARC-BS-77, Curve A of Fig. 2 for individual reception (in Region 2) is extended up to a value of $\varphi/\varphi_0 = 15.14$ and has a constant value of -38 dB beyond that (see Annex 8 to the Final Acts of the WARC-BS-77).

For community reception, without sidelobe-suppression techniques, the relative level is given by the expression

$$-[10.5 + 25 \log (\varphi/\varphi_0)] \qquad \text{dB}$$

starting from $\varphi/\varphi_0 = 0.86$, and continuing until the level corresponding to minus the on-axis gain is reached. The pattern corresponding to a community receiver without sidelobe-suppression is given in Curve A′ of Fig. 2.

If sidelobe-suppression techniques are employed, the curve $-12 (\varphi/\varphi_0)^2$ could be continued to a relative angle of $\varphi/\varphi_0 = 1.44$, corresponding to a relative level of -25 dB. The sidelobes could be contained at less than this level to a relative angle of $\varphi/\varphi_0 = 3.8$, and thereafter the level falls according to a curve defined by

$$-[10.5 + 25 \log (\varphi/\varphi_0)] \qquad \text{dB}$$

The pattern corresponding to the use of sidelobe-suppression is shown as curve A″ in Fig. 2. This curve may be feasible for both individual and community reception when sidelobe-suppression techniques are used.

2.2.2 *Cross-polar component*

The level of the cross-polar component can be defined in the same way as in the case of the transmitting antenna, but a less stringent performance must be expected. Moreover, account must be taken of the probable pointing inaccuracy of the antenna. Thus, it is proposed that the level should be -25 dB to a relative angle $\varphi/\varphi_0 = 0.25$. It then rises according to the curve

$$-(30 + 40 \log |(\varphi/\varphi_0) - 1|) \qquad \text{dB}$$

to a maximum of -20 dB, which is maintained to a relative angle $\varphi/\varphi_0 = 1.4$. It then decreases according to the curve

$$-(30 + 25 \log |(\varphi/\varphi_0) - 1|) \qquad \text{dB}$$

to a level of -30 dB. It maintains the -30 dB level until it intersects with the co-polar component curve which it then follows. The resultant pattern is shown in Fig. 2 as Curve B. It may be taken as applying to both individual and community reception.

2.3 *Suggested values of* φ_0

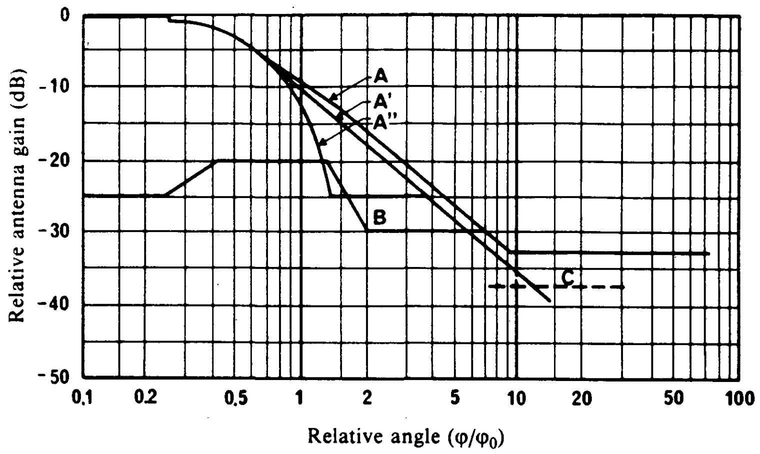
The suggested values of φ_0 to be assumed for different types of broadcasting service are given in Table I.

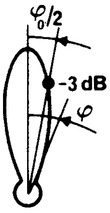
Higher-gain antennas may be used in some receiving installations, for example, to obtain a better signal-to-noise ratio, but the Table is intended to indicate the values of φ_0 for the types of antenna expected to be used in the majority of receiving installations.

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.

3. **Antenna technology and experimental data**

This section presents a summary of the documents submitted on spacecraft and ground-station antenna technology. New sidelobe envelopes have been presented in § 2, and the salient experimental data justifying these envelopes are also included.





Relative antenna gain (dB):

Co-polar component

A: individual reception without sidelobe suppression
0 for $0 \leqslant \varphi \leqslant 0.25\ \varphi_0$
$-\ 12\ (\varphi/\varphi_0)^2$ for $0.25\ \varphi_0 < \varphi \leqslant 0.707\ \varphi_0$
$-\ [9.0 + 20 \log (\varphi/\varphi_0)]$ for $0.707\ \varphi_0 < \varphi \leqslant 1.26\ \varphi_0$
$-\ [8.5 + 25 \log (\varphi/\varphi_0)]$ for $1.26\ \varphi_0 < \varphi \leqslant 9.55\ \varphi_0$
$-\ 33$ for $9.55\ \varphi_0 < \varphi$

A′: community reception without sidelobe suppression
0 for $0 \leqslant \varphi \leqslant 0.25\ \varphi_0$
$-\ 12\ (\varphi/\varphi_0)^2$ for $0.25\ \varphi_0 < \varphi \leqslant 0.86\ \varphi_0$
$-\ [10.5 + 25 \log (\varphi/\varphi_0)]$ for $0.86\ \varphi_0 < \varphi$
After intersection with curve C: as curve C

A″: feasible for community and possibly for individual reception when sidelobe-suppression techniques are used
0 for $0 \leqslant \varphi \leqslant 0.25\ \varphi_0$
$-\ 12\ (\varphi/\varphi_0)^2$ for $0.25\ \varphi_0 < \varphi \leqslant 1.44\ \varphi_0$
$-\ 25$ for $1.44\ \varphi_0 < \varphi \leqslant 3.8\ \varphi_0$
$-\ [10.5 + 25 \log (\varphi/\varphi_0)]$ for $3.8\ \varphi_0 < \varphi$

B: *Cross-polar component (both types of reception)*
$-\ 25$ for $0 \leqslant \varphi \leqslant 0.25\ \varphi_0$
$-\ (30 + 40 \log |(\varphi/\varphi_0) - 1|)$ for $0.25\ \varphi_0 < \varphi \leqslant 0.44\ \varphi_0$
$-\ 20$ for $0.44\ \varphi_0 < \varphi \leqslant 1.4\ \varphi_0$
$-\ (30 + 25 \log |(\varphi/\varphi_0) - 1|)$ for $1.4\ \varphi_0 < \varphi \leqslant 2\varphi_0$
– 30 until intersection with co-polar component curve; then as for co-polar component

C: *Minus the on-axis gain*

FIGURE 2 – *Reference patterns for co-polar and cross-polar components for receiving antenna*

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

TABLE I – *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) (Regions 1 and 3)	2.0° (Regions 1 and 3) (0.9 m) 1.7° (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 the WARC-BS-77 for planning of the 12 GHz broadcasting-satellite service in Regions 1 and 3 and at the RARC SAT-83 for planning of the 12 GHz broadcasting-satellite service in Region 2.

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

3.1 *Spacecraft transmitting antennas*

3.1.1 *Sidelobe levels*

Effective spectrum utilization of the geostationary orbit for broadcasting satellite transmission depends to a large extent upon directional control of the antenna radiation. The most effective means of serving a desired broadcasting service area with the required e.i.r.p. while maintaining low levels of radiation outside of this area is through active or passive control of the satellite antenna radiation pattern, particularly in the areas of the near-in sidelobes. This applies to both the co-polar and cross-polar patterns. (The Earth's disc as seen from the geostationary orbit subtends approximately 17.5 degrees, and it is in this region that the reduction of sidelobes is most advantageous.) Much effort has been directed toward this vital aspect of effective spectrum usage.

3.1.2 *Reflectors and lenses*

It is a standard practice to taper the illumination of parabolic reflectors to increase sidelobe suppression. Extension of this technique in conjunction with other techniques has shown [Thomas *et al.*, 1970] that with deliberate design, first sidelobe levels can be held to the −40 dB level relative to the main beam through application of aperture blockage compensation and active zone suppression techniques.

Passive techniques are also used to control sidelobe levels in reflectors. A common technique uses a stepped zone in the reflector, usually at the centre or outer edge. The height of the step produces the desired phase change and determines the width and position of the desired cancellation pattern.

In principle, any desired degree of lobe suppression can be obtained with these techniques. Practically, however, cumulative errors in amplitude, phase and position, limit the degree of lobe suppression to approximately −40 dB referred to the peak of the main beam. This degree of suppression, however, has not been demonstrated in space qualified hardware. For this reason, a higher level has been adopted in the reference pattern.

An effective design technique for a horn-reflector antenna of arbitrary beam cross-section has been recently presented [Katagi and Takeichi, 1975]. The technique is simple in nature. The shape of the wave-front near the aperture is first determined, for a desired beam shape, and the reflector shape is then based on optical path considerations. Such antennas may be useful in the design of broadcasting satellites.

3.1.3 *Beam shaping*

Several studies have been performed concerning the applicability of satellite-borne multi-element arrays to the solution of broadcast and communication coverage requirements.

Active arrays appear to offer a capability of providing greatly reduced interference effects and increased spectrum re-usability because of the greater flexibility and efficiency with which they can be made to operate.

Phased arrays allow virtually unlimited control over the amplitude and phase of aperture illumination, and a single aperture can be used to provide any desired number of parallel beams (assuming a separate phasing matrix for each beam to be generated). Arbitrarily shaped portions of the aperture can be selected to provide arbitrarily shaped beam cross sections such that a geographical boundary may be closely approximated. Arrays appear to be capable of providing first sidelobe isolation to the −40 dB level from the main beam [Hult *et al.*, 1968].

Other approaches to the shaped beam antenna involve the use of multiple-feed reflectors and lenses. In these devices, each feed element of a multiple-element feed array separately illuminates the reflector or lens to generate a component beam in the far field. By properly adjusting the main aperture distribution phase and amplitude from each feed and summing the feed inputs in hybrids, the secondary pattern can be shaped to provide arbitrary area coverage. Several engineering models of these antennas have been built, and satellite antennas now in orbit (Intelsat IV-A) and planned (DSCS-III) make use of such techniques. There are a number of sophisticated computer programs available for calculating phase and amplitude distribution for the feed element array. Additional information on development of these techniques in the USA is given in Report 676.

An antenna with specially-shaped beams developed in Japan for the Broadcasting Satellite for Experimental Purposes (BSE) consists of an elliptical reflector and three primary feed horns to conform to the shape of the service area in which the mainland and the remote islands of Japan are included [CCIR, 1974-78d]. The frequency of the down link is 12 GHz. The measured patterns were in good agreement with the theoretical calculations. Such an antenna would facilitate the suppression of undesirable spillover to neighbouring countries, while maintaining an effective coverage in the intended area.

Another study indicates that an improvement in sidelobe suppression can be obtained by the use of offset feed horns for this type of antenna [CCIR, 1974-78e]. A circularly polarized shaped beam antenna which is similar to the above configuration has also been developed. Measured results show that cross-polar discrimination of better than 33 dB (referenced to the boresight co-polar gain) could be maintained in most directions.

However, it was found that a requirement of 40 dB discrimination around the boresight is difficult considering current technology for medium scale broadcasting satellites [CCIR, 1978-82b]. Further study of this matter is desirable.

It is possible to use beam-shaping techniques with multiple feeds to achieve a main lobe pattern which is different from the conventional Gaussian shape. Specifically, it is possible to maintain a more uniform amplitude level over the intended service area. Such equalization of the radiation pattern may have distinct advantages under some circumstances. The principal advantage is that less spacecraft prime power is needed to provide the minimum e.i.r.p. required at the edge of the service area. This means that a smaller transmitter and smaller solar cell panels could be used, with consequent economic savings. For some applications, these savings could be significant.

A disadvantage of this technique is that the more uniform pattern may slightly exceed the present Gaussian envelope within the desired service area, but not outside the intended −3 dB contour. In this event, an administration which desired to use such beam-shaping techniques would have to co-ordinate with its neighbour in advance. Further study of this technique is desirable.

Analytical and measured results at 12 GHz [Chen and Franklin, 1980] were obtained for a shaped beam coverage of the US Eastern Time Zone (ETZ) using linear polarization. The 25-horn feed reflects the use of additional horns at the zone periphery for sidelobe cancellation. Comparisons of calculated and measured results for transmit frequencies at 11.7 and 11.95 GHz showed excellent agreement.

The antenna implementations covering the 11.7 to 14.5 GHz band provided quite uniform performance. For the 12.2/18.1 GHz receive/transmit band, use of the same antenna would result in some performance compromise. Although the reflector could be compensated by making the outer 1/3 portion dichroic (i.e., transparent) to the frequencies near 18 GHz, the bandwidth limitation of the feeds and polarizer would result in degraded performance.

Broadcast systems generally are not amenable to relocation of satellites to new orbital locations because of the change of coverage area in size and shape. If the longitude shift is small, say less than 5°, and specified during antenna development, then the coverage can be designed for the composite pattern (which is larger than either one) at a small loss in gain of 0.3 to 0.5 dB. The spacecraft can easily be repointed in the east-west direction to provide additional flexibility.

If the change in orbital longitude is large, say a shift from 100° W to 115° W, it may be impractical to design using the composite pattern because of the loss in gain. The difference in gain for an antenna designed for 115° and used at 100° could be as large as 3 dB for selected areas. This effect will generally be less severe for a broader coverage shaped-beam antenna, i.e., where coverage is provided at the -2 dB contour rather than at the -3 to -4 dB contour or with a shaped beam not as closely matched to the coverage contour.

If two discrete longitudes are specified, a design could be synthesized using some combination of variable power dividers or switchable horns to reconfigure the antenna feed in orbit. This is generally undesirable from the standpoint of complexity and reliability.

3.1.4 *Multiple beams*

The use of multiple beams to provide multiple independent coverages within a desired service area has been shown to increase the total spectrum capacity through frequency re-use.

Multiple beams can be produced from a single aperture by employing reflector, lens or array technologies.

Multiple off-set horn feeds operating in conjunction with a reflector or a lens provide a viable solution to the broadcasting-satellite service's performance requirements, for spacecraft as well as earth station antennas. Allowing a separate beam to be devoted to each group of users permits the desirable re-use of frequency bands. A proposed multi-beam microwave antenna [Ohm, 1974] using an off-set multiple horn feed system and Cassegrain reflector has been shown to essentially eliminate aperture blockage, reduce coma aberrations and provide good isolation between beams (40-45 dB).

Much effort has been devoted to studies of the zoned lens for producing multiple independent beams. Analytical techniques and some experimental results of a wave guide lens antenna have been presented [Dion and Ricardi, 1971] indicating the capability of providing a variable coverage radiation pattern. This variable coverage is obtained through selective excitation of derived feeds to produce the proper aperture illumination and phase distribution.

Phased arrays offer good potential for future satellite antennas in the higher frequency ranges. Multiple independent beams can be produced through selective element excitations.

Phased array antennas of the lens type have been developed for ECM and telemetry applications, and designs producing several independently steerable beams over octave bandwidths have been demonstrated. Selective summing of groups of beams produces even narrower beams which are independently "steerable".

3.1.5 *In-orbit satellite antenna reconfiguration* [CCIR, 1982-86a]

Most communication satellite systems in operation today employ spacecraft antennas which provide footprints which straddle the service area, and the generation of their footprints is orbit-location dependent. In the future a need will arise to change the footprint shape or size while the satellite is in orbit and at a fixed location. Another more complicated footprint change would be required if the satellite is to be relocated (while in orbit) to another location, or a spare built whose location in orbit may not be known since it would replace one of several satellites already there. Both of these situations would require an in-orbit antenna reconfiguration in order to match the footprint to the service area.

In the discussion which follows, it is assumed that a shaped beam(s) will be used and the antenna aperture is driven by a cluster of feed horns.

The first form of reconfigurable antenna would be to service several areas from a single orbital position. For example, the sketch in Fig. 3a shows three possible service areas which can be served from a single orbital position. That is, the antenna power can go to footprint A or footprint B or the composite footprint C. The power division between area A and area B is generally not equal, with the larger area receiving more power to equalize the pfd. Another scenario would be that one area receives more power to reduce the earth station requirements in that area.

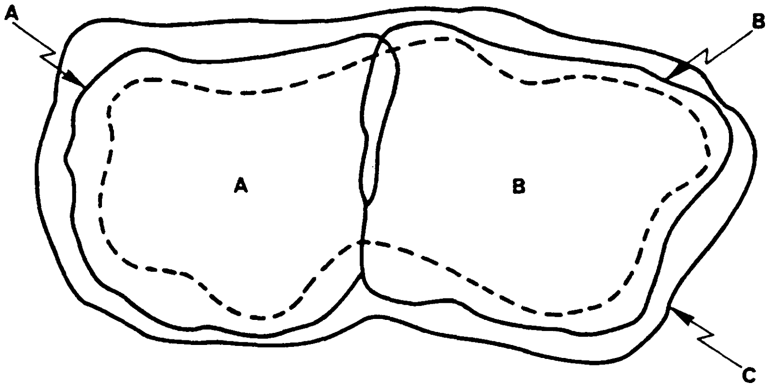
Implementation of these ground illumination patterns can be made by the beam forming networks and feed clusters shown in Fig. 3b. The ground-controlled variable power divider (VPD) partitions the power to the two sub-arrays which individually produce footprints A and B. Suitable power division between the two sub-arrays produces footprint C. There may be additional circuitry in the labyrinth such as phasing devices to ensure uniform phasing across the aperture. A schematic diagram of a VPD is shown in Fig. 3c. The phase shifters have a maximum phase shift of $\pi/2$ radians and are incrementally stepped to this value with a resolution of 4 bits. This corresponds to $\pi/32$ radians. The output power at each port will be the same when the phaser states are identical. The output of either port will be zero when the phase difference is 90°. Therefore, all divisions are possible within the increments set by the number of bits.

Another form of reconfigurable antenna, which presents more practical problems than the structure above, is for use in the case in which reconfiguration is required when a satellite is relocated from its present longitude, or a spare is required which can assume several possible orbital positions. The final orbital position is not known *a priori*, since which satellite will fail first is unknown.

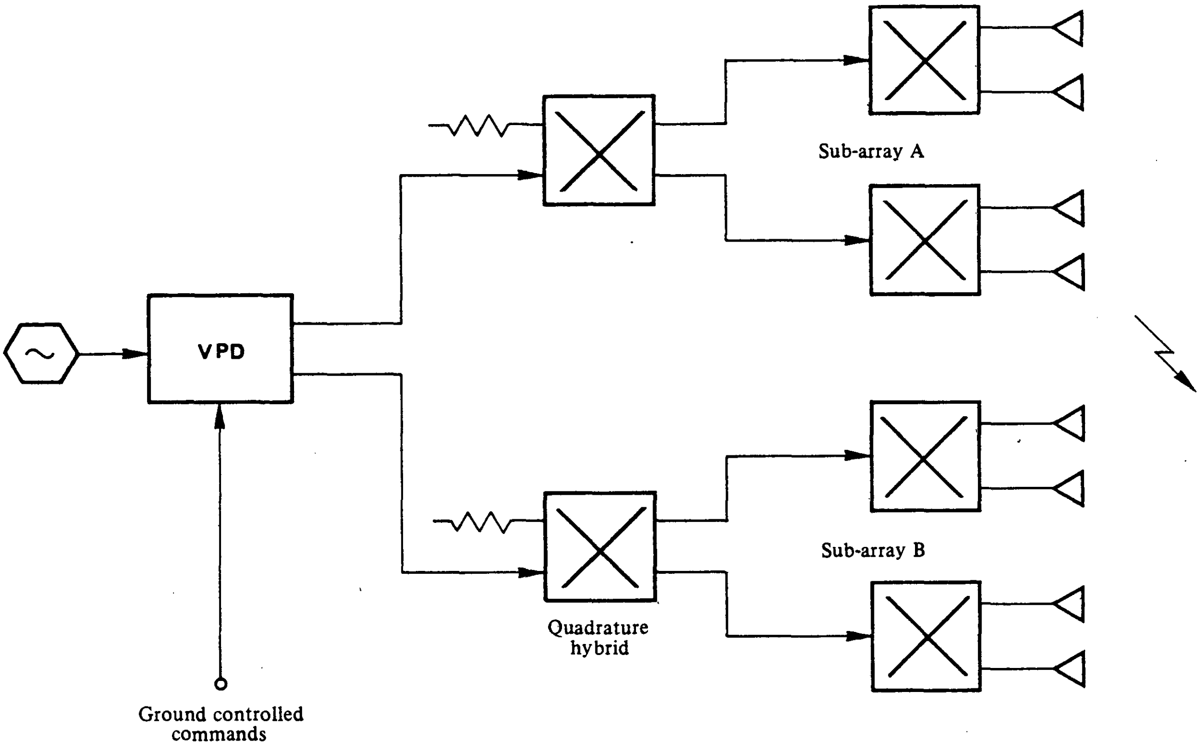
For antennas which are designed to follow the contour of the service area and produce little radiation outside this area, the migration of the satellite will no longer produce an optimum shaped footprint for that area. This is because the satellite "sees" the service area from a different perspective. Especially for shaped beams, the service area coverage at the beam periphery is satellite location sensitive. It would therefore be necessary to reconfigure the antenna feed arrangement to return it to the optimum illumination of the service area. It is clear that dividing up the power amongst the feeds is not adequate since the original footprints would prevail, as indicated in the previously-described antenna reconfiguration. It is therefore necessary to have a multiplicity of feeds in the feed cluster which can be driven by varying amounts of power. Some feeds, depending on the satellite location and area to be contoured, may receive more power or less power or none at all.

A reconfigurable antenna system is being investigated in the United States which can be programmed to provide optimum footprints to the 50 states for a satellite location in the range of 66° W to 129° W longitude. Typical footprints which can be generated for three different locations are depicted in Fig. 4.

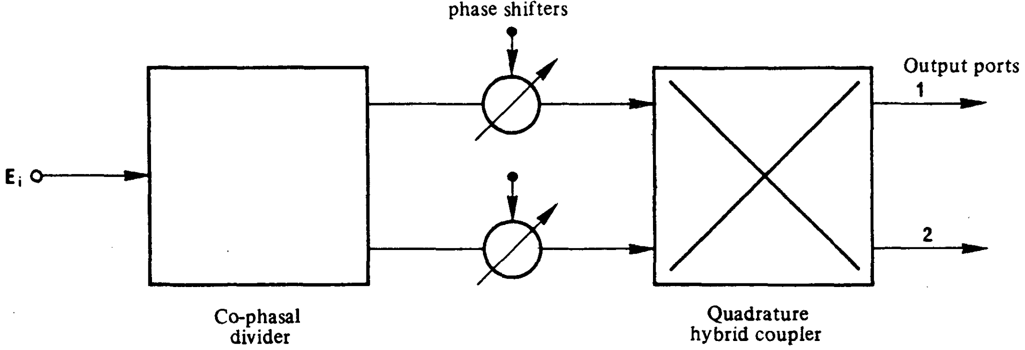
It is noticed that the reconfigurable antenna network will generally be more complicated and may contribute more weight than a simpler beam shaping network. Another factor to consider is that the added circuitry will introduce more losses in parts of the transponder where losses are critical. In addition, one would expect an additional cost to the spacecraft, but this is less important than the weight and performance factors.



a) Assumed service areas

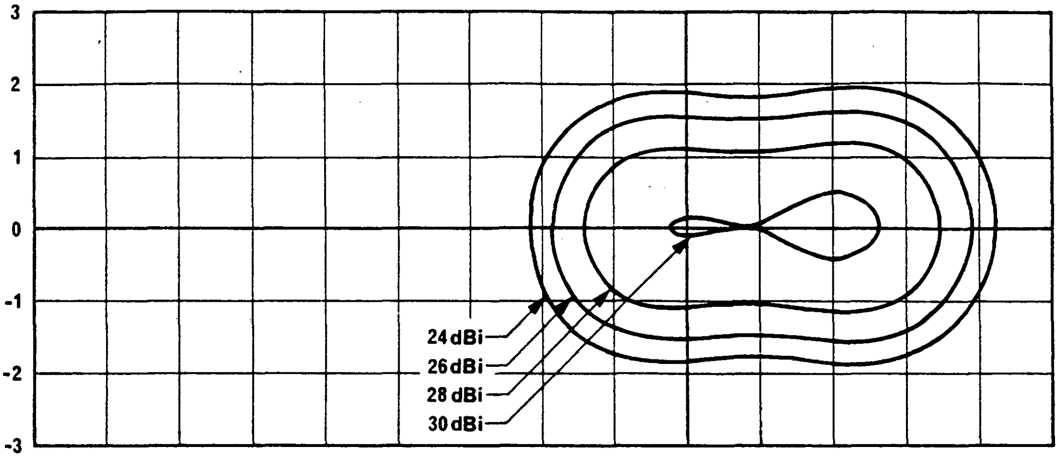


b) Beam-forming network

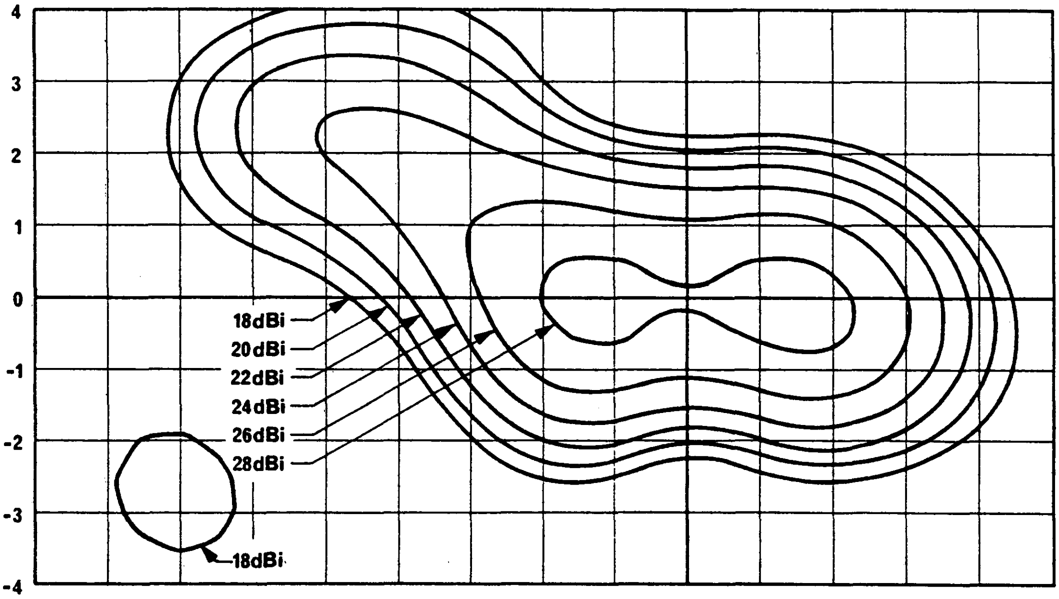


c) Variable power divider (VPD)

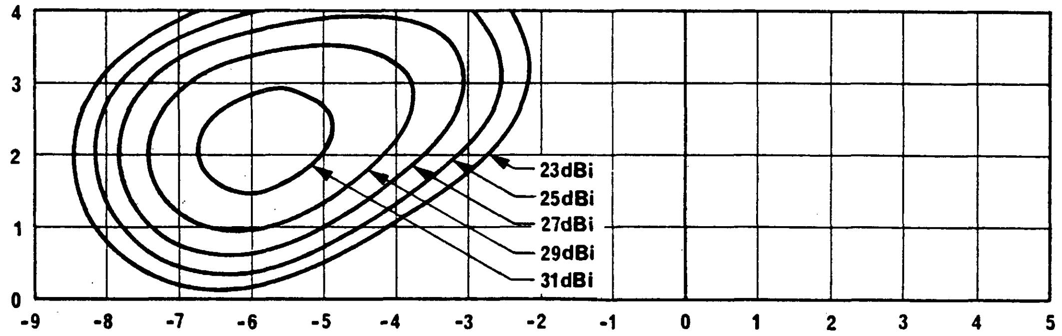
FIGURE 3 – *Reconfigurable antenna to service several service areas from a single orbital position*



a) 96° W (CONUS)



b) 119° W (CONUS/Alaska/Hawaii)



c) 139° W (Alaska only)

FIGURE 4 – *Typical footprints for different orbital positions*

CONUS: contiguous United States

3.2 *Antennas for earth receiving equipment*

This section gives the results of some measurements on antennas of a type suitable for individual or community reception. In addition, the results of some sidelobe-suppression experiments are presented to justify the recommended −25 dB level for community-reception in the reference pattern.

3.2.1 Antenna sizes and types

In the 12 GHz band, a common form of antenna for individual reception is one with a conventional or offset parabolic reflector 0.3 to 1 m in diameter. Larger diameters may, however, be used for community reception. Two feed arrangements are possible; either an antenna with direct illumination, or a dual reflector assembly. The choice of diameter and of feed device may depend on economic considerations since for a given figure of merit (G/T), a lower antenna gain would necessitate a lower noise temperature for the receiving equipment. The antenna may be either of aluminum or a composite moulding, e.g., of plastics with a conductive coating or an embedded wire mesh. An effective surface accuracy of about 1 mm r.m.s. under all weather conditions is adequate, and the mounting must be sufficiently rigid to maintain correct pointing, e.g. better than 0.5° or 0.6° for the antenna dimensions envisaged (0.3 to 1 m).

"Flat-plate" antennas are also now of interest. They may have broadside or steerable beams. The advantage of such antennas is that they may be easier to support and maintain correctly pointed in high winds, and less susceptible to loss of gain from snow deposits on the antenna face. This would be particularly true of an antenna with a steered beam to provide the required elevation angle while the antenna is mounted in a vertical plane. A further refinement, whereby a phased-array antenna has a beam which may be steered away from broadside, permits the antenna to be mounted flat against the most suitable wall or roof of a building having arbitrary orientation. This arrangement would be less obtrusive and simple to install.

Broadside-beam flat-plate antennas have reached the stage whereby they are likely to be an economic alternative to dish antennas, and, in the smaller sizes at least, can offer an antenna efficiency comparable to that of a dish of similar size. At present the efficiency of larger arrays and steerable arrays tends to be lower than that of comparable dishes. In the future the low-noise amplifier may be incorporated into the antenna, with the first amplifier stages distributed through the feed structure to improve the loss performance.

The broadside-beam flat-plate antenna can offer gain and side lobe performance equivalent to that of a parabola of comparable size. For many home installations, it also provides advantages over a parabolic antenna in terms of unobtrusive appearance, light weight and ease of installation.

Recent development work in the United States, the United Kingdom and Japan has led to BSS receiving antenna designs using planar phased arrays [Sorbello et al., 1988; Wells, 1989; Sorbello and Zaghloul, 1989; Griffiths et al., 1989; Maddocks, 1988]. The characteristics of these "flat antennas", including measured data on their co-polar and cross-polar patterns are described in § 3.2.3.

Along with various types of offset parabolic antennas, some flat-plate antennas have appeared in the market in Japan. The flat antenna offers advantages in shape and in convenience of installation to the wall of the houses, preventing snow accumulation, although there are many items to be studied, such as efficiency.

3.2.2 Measured data for parabolic antennas

Data extracted from measured antenna patterns for the co-polar component of parabolic antennas are shown in Fig. 5a. All the antennas were linearly polarized. The list of antennas from which the data was taken is given in Table II. The data is presented in groups. Each group is represented by a vertical bar spanning the range of gain variation of the sample of data points in that group. Such partitioning into groups is done with due caution to ensure that sufficient data is encompassed by each group. The upper circle on each vertical bar represents that point above which 20% of the data lies. The lower circle is the corresponding lower 20% point. The median is shown as an open circle. In addition to the measured data, Fig. 5a also includes a plot of the reference antenna pattern given in § 2.

Similar data extracted from a group of 3.3 m antennas at 12 GHz are shown in Fig. 5b. The antennas were linearly polarized. Median values fall well below curve A of Fig. 2 at all angles measured, and peak values fall below the reference pattern out to six or eight times the half-power beamwidth. These data were generated with no efforts made toward sidelobe suppression.

For antennas in the size and cost range considered suitable for broadcasting-satellite applications, it is unlikely that gains below isotropic will be consistently achieved in the far sidelobes and backlobes.

Measurement of radiation patterns of linearly polarized receiving antennas with a diameter of 40 cm to 1.6 m were carried out in Japan [CCIR, 1974-78f]. Figure 6 shows some measured data for a parabolic antenna with a diameter of 60 cm.

These results, and the test results obtained by the measurements of the patterns of antennas with 1.0 and 1.6 m diameters, which were manufactured with the objectives of high efficiency, light weight and low cost, show that the patterns for the co-polar components fall within the reference pattern for individual reception.

Measurements of the cross-polarized component were made on various kinds of parabolic antennas for D/λ between 40 and 100. The results are shown in Fig. 7. The data are presented in the same way as in Figs. 5a and 5b.

Measurements were performed in Canada on a centre-fed parabolic antenna. The antenna had a diameter of 1.2 m and was linearly polarized. The sidelobe patterns were measured in 1982 for the frequency band 11.7-12.2 GHz. The mid-band efficiency was found to be 72% and a scatter plot of the sidelobe peaks is shown in Fig. 8. The antenna sidelobe patterns were taken at 3 frequencies (edge and centre of the frequency band) and for two azimuthal profiles (E-plane and H-plane). The reference pattern adopted for Region 2 at the RARC SAT-83 is also shown for purposes of comparison [CCIR, 1982-86b].

Analysis of limited data on the cross-polarized response of small-aperture antennas, where no special attention was paid to sidelobe levels, indicates that a minimum discrimination level of 20 dB is attainable, and the maximum level is 32 dB both on-axis and elsewhere. In the case where sidelobe suppression techniques are employed, the minimum level of discrimination can be reduced to 25 dB.

3.2.3 Characteristics and measured data for flat-plate antennas

The basic, single-polarized flat-plate antenna is constructed from three layers, as shown schematically in Figure 9. There are two etched layers, one containing the receiving elements and the other the power divider or combining

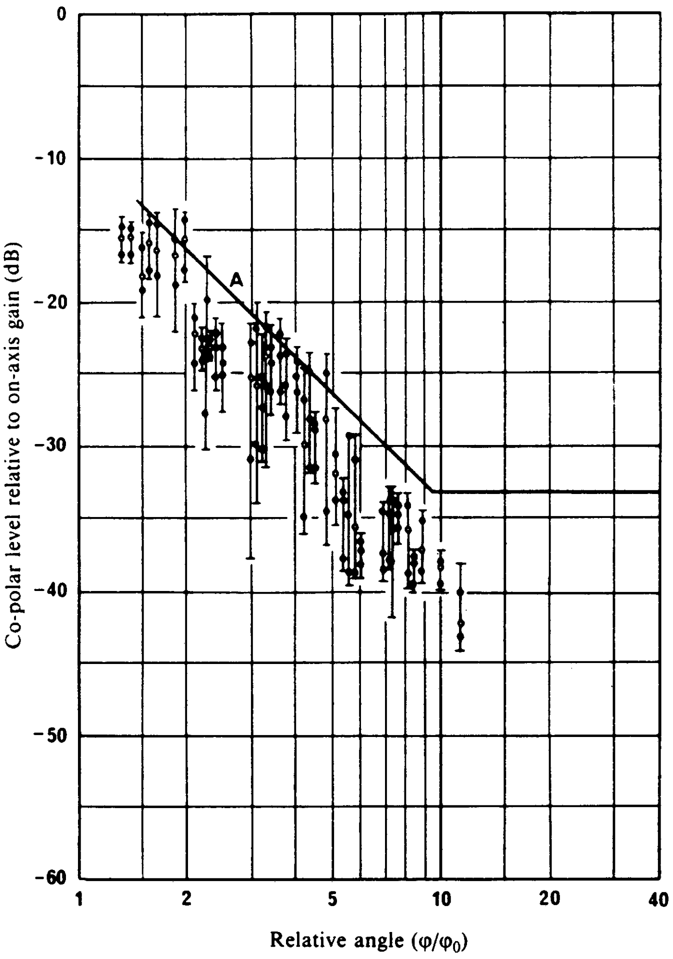
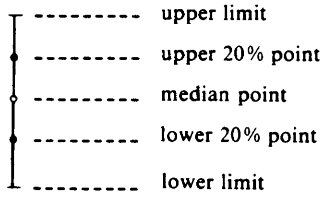


FIGURE 5a – *Measured co-polar peak sidelobe levels and reference antenna pattern*



Curve A: reference pattern for individual reception

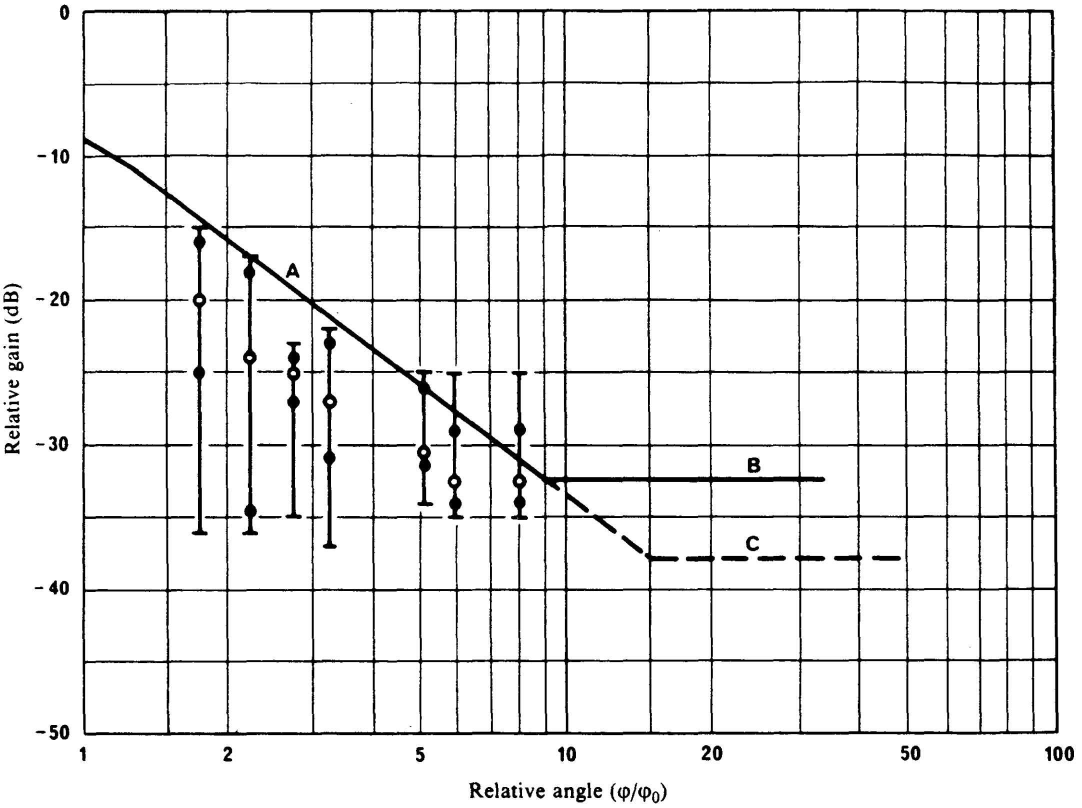


FIGURE 5b – *Measured co-polar peak sidelobe levels and reference earth station antenna pattern at 12 GHz*

Curves A: reference pattern for individual reception
B: Regions 1 and 3
C: Region 2

┬ — upper limit
● — upper 20% point
○ — median point
● — lower 20% point
┴ — lower limit

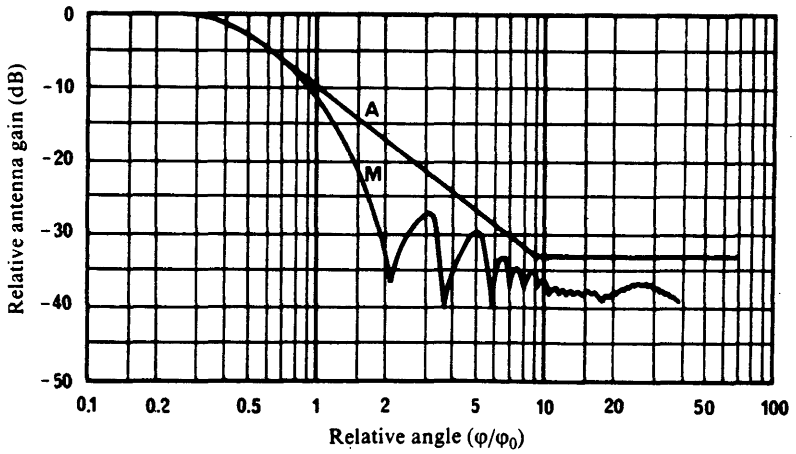


FIGURE 6 – *An example of co-polar pattern of a terrestrial parabolic antenna (12 GHz)*

Curves A: reference pattern for individual reception
M: measured results for a 60 cm parabolic antenna

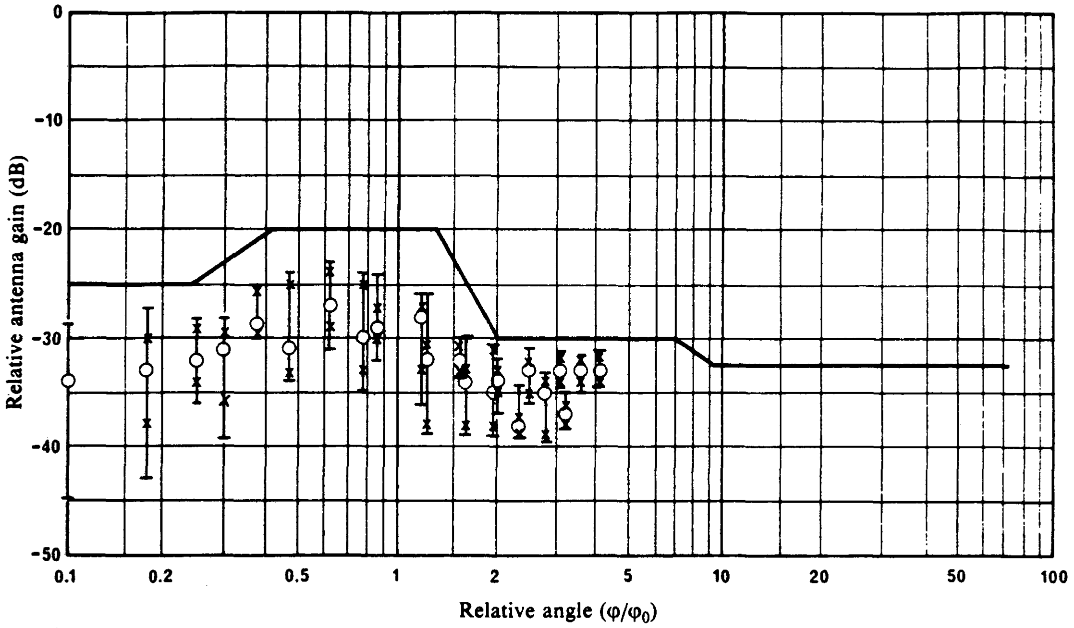


FIGURE 7 – Measured data for cross-polar response

reference pattern
upper limit
upper 20% point
median point
lower 20% point
lower limit

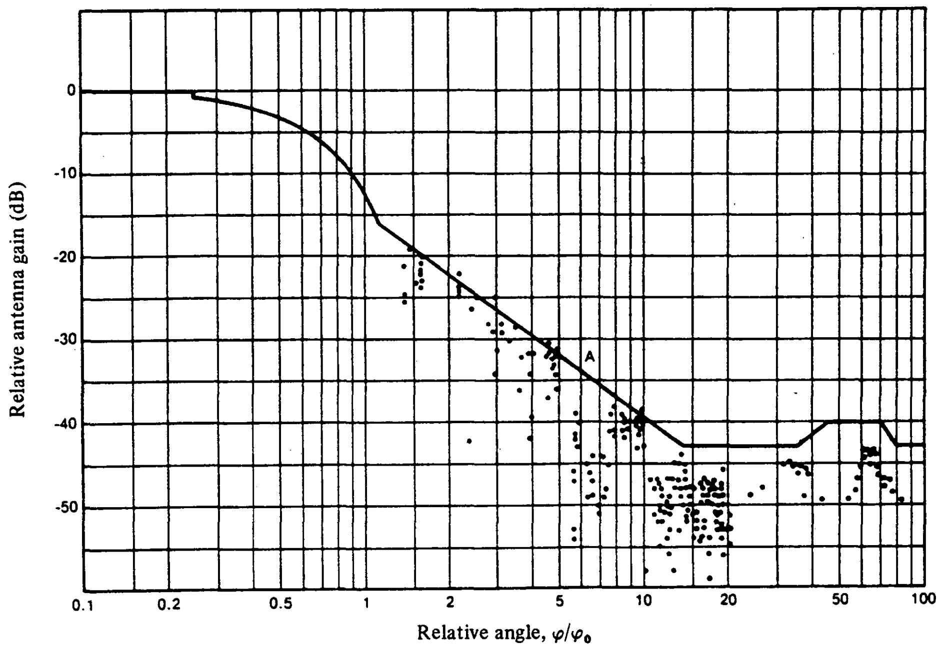


FIGURE 8 – *Co-polar sidelobe levels measured on a 1.2 m centre-fed antenna at 12 GHz (φ_0 = 1.46°)*

Curve A: co-polar component of the antenna reference pattern
adopted at the RARC SAT-83 for Region 2

network. These layers are separated by plastic foam spacers, and a foam spacer also separates the power divider network layer from the ground plane.

Two aspects of this construction lend themselves to the low manufacturing costs that are essential for a consumer electronics product. One is the etched layers, which are easily mass produced. The other is the capacitive coupling between the receiving elements and the power divider, which avoids the requirement of physical connections.

The physical and principal electrical characteristics of a family of commercially available models of the flat-plate antenna are given in Table II. It will be noted that the gain and efficiency of these antennas are comparable to those of parabolic antennas of the same cross-section. Sidelobe performance is also comparable to that of parabolic antennas as discussed below.

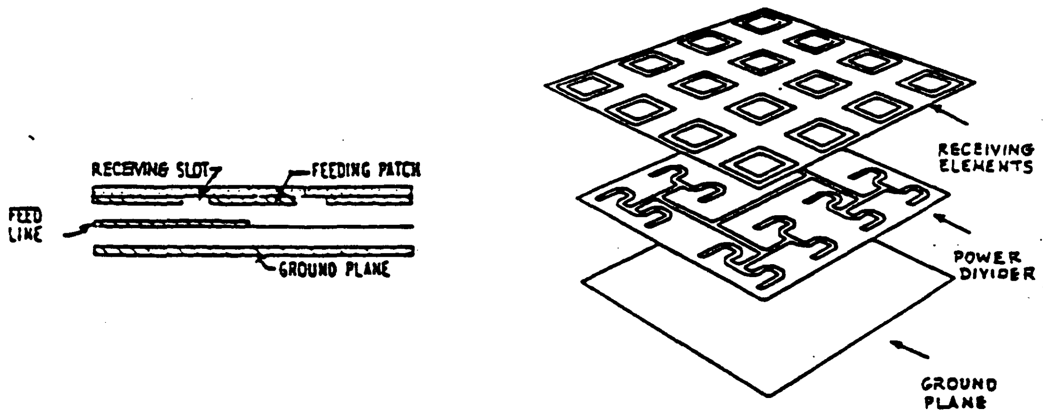


FIGURE 9

Schematic representation of the construction of a flat antenna array for reception of satellite broadcasts

Measured data on the co-polar and cross-polar patterns of production models of the 256-element, 41 cm square array are shown and compared with the reference patterns of Rec. 652 in Figure 10. The 256-element antenna is chosen for illustration because, as the smallest of the family of flat-plate arrays, it is the one most vulnerable to interference from adjacent satellites.

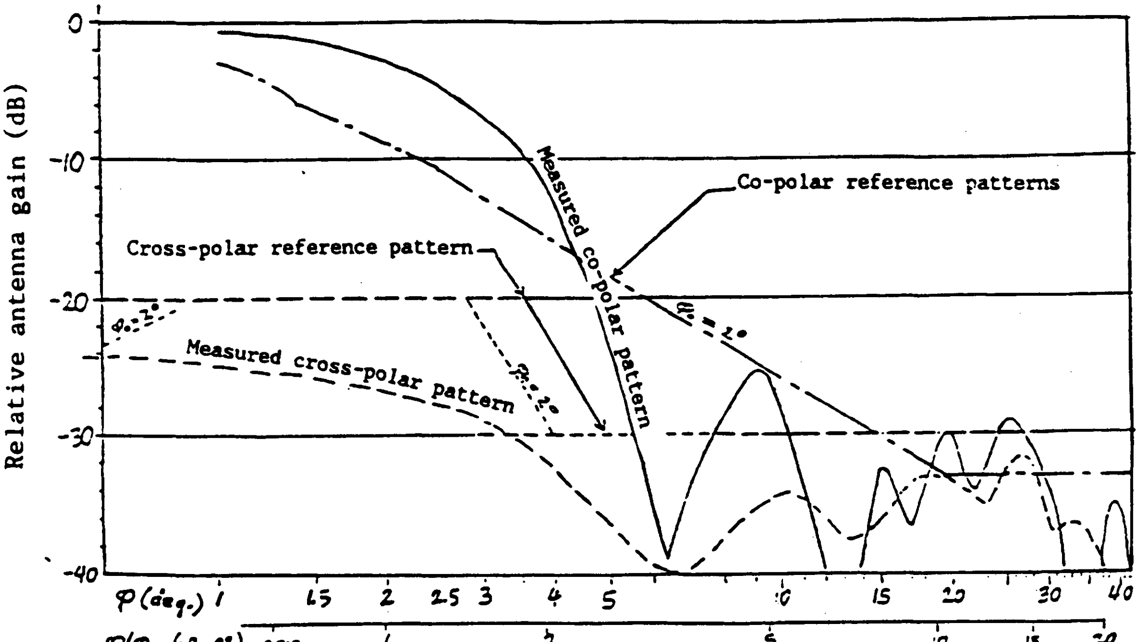
The patterns in Figure 10 are measured in a plane that contains the beam axis and is 45° to the principal planes of the array. They are representative of the patterns measured in all planes containing the beam axis that are more than 15° away from the principal planes. These are the patterns of most interest from an interference standpoint because, with circular polarization as prescribed in the Plans for the BSS at 12 GHz, the antenna can always be mounted so that all significant sources of satellite interference lie at least 15° from the principal planes. Indeed, this will normally be the case if the antenna is mounted with its edges horizontal and vertical, because the orbital position assigned to each country in the BSS Plans lies from 15 to 40° west of the longitude of the service area for that country.

TABLE II - Characteristics of a family of flat-plate antennas

Characteristic	Number of radiating elements 256	384	256	1024
Frequency range (GHz)	11.7-12.2	11.7-12.0	11.7-12.5	11.2-11.45
Dimensions of panel (cm)**	41 x 41	42 x 60	41 x 41	78 x 78
Thickness (cm)	2	2.5	2	2.5
Weight (kg)	2.3	5	2.3	9
Gain (dBi)	32.5	34.5	31	37
Efficiency (%)	> 65	> 60	> 55	> 50
Polarization*	R or L	R or L	R or L	V & H
On-axis cross-pol discrim (dB)	-20	-20	-25	-25
Beam squint angle (°)	0	0 or 12	0	0
Half power beam widths (°)	4 x 4	4 x 2.7	4 x 4	2 x 2
Noise figure of LNB (dB)	1.6	1.6	1.6	1.6
G/T ant $(dB(K)^{-1})$	9.8	11.4	8.5	13.2

* R = right-hand circular; L = left-hand circular; V = vertical linear; H = horizontal linear.

** These are the overall dimensions of the panel including the supporting frame; the dimensions of the active area of the array are about 4 cm less.



Angle and relative angle (φ/φ_0)

FIGURE 10

Measured side lobe patterns of 256-element flat antenna in a plane which contains the beam axis but is 45° to the principal planes of array

Figure 10 also displays the co-polar and cross-polar reference patterns for individual reception earth station antennas in Regions 1 and 3 as given in Recommendation 652 and section 3.7.2 of Appendix 30 (ORB-85) of the Radio Regulations.

These reference patterns assume a half-power beamwidth $\varphi_0 = 2°$, the half power beamwidth assumed for interference calculations in constructing the Regions 1 and 3 Plan at WARC-77.

It is seen that, even though the 256-element flat-plate antenna has a half-power beamwidth of 4°, its cross-polar side lobe pattern conforms to the $\varphi_0 = 2°$ reference at all off-axis angles greater than 0.5° (except at 27° where it exceeds the reference by 1.6 dB), and the co-polar pattern conforms out to an off-axis angle of 18°. Even beyond this angle, where adjacent satellite power flux-densities are expected to be low, the flat-plate antenna exceeds the reference by only about 3 dB.

3.2.4 *Sidelobe suppression techniques* for parabolic antennas

There are numerous ways to reduce sidelobes, ranging from extremely simple to extremely complicated [Han, 1972].

A reduction can be achieved by increasing the taper of the feed pattern across the aperture of the reflector [Han, 1972; Silver, 1949]. The penalty paid is a loss of on-axis gain, but overall efficiencies of 50% are still achievable. With simple under-illumination, the sidelobe levels are reduced in all planes of rotation about the boresight.

Recent analyses in Italy have demonstrated the effect of using corrugated surfaces on the performance of parabolic antennas. With such surfaces, it is possible to obtain radiation patterns equal in the two main planes, high cross-polar isolation, reduced side lobes, low spillover, and correspondingly lower antenna noise temperatures and higher aperture efficiencies (sometimes higher than 70%).

The computed co-polar radiation pattern for a 60 cm parabolic antenna with a corrugated flange is shown in Figure 11. This pattern is seen to lie at least 3.5 dB below the corresponding WARC-77 reference for all relative angles φ/φ_0 greater than 1 [Pacini, 1985].

In theory, a circular aperture with uniform illumination results in sidelobes some 15 dB below the peak of the secondary pattern. With an aperture distribution proportional to $(1 - \gamma/2)$, where γ is the radial function normalized to the aperture radius, the sidelobes drop to 24.5 dB below the pattern peak. Patterns at 6 GHz using a 1.22 m dish with an aperture edge illumination of −12 dB, show first sidelobes 26 dB below the mainlobe peak [Silver, 1949]. If the feed remains at the focus of the reflector and a portion of the reflector is removed, thereby creating an offset-fed reflector, the sidelobes can be lowered an additional several dB because the aperture blockage is reduced. However, the aperture is also reduced so that the main beam is broadened and reduction in gain occurs. This can be compensated for by increasing the size of the reflector. Sidelobe data measured on several offset-fed reflectors is shown in Fig. 12. The curves represent the peak sidelobe envelope for each antenna. All of the data lies substantially below Curve A′ of Fig. 2. The antennas had efficiencies ranging from 63% to 70% [CCIR, 1982-86c].

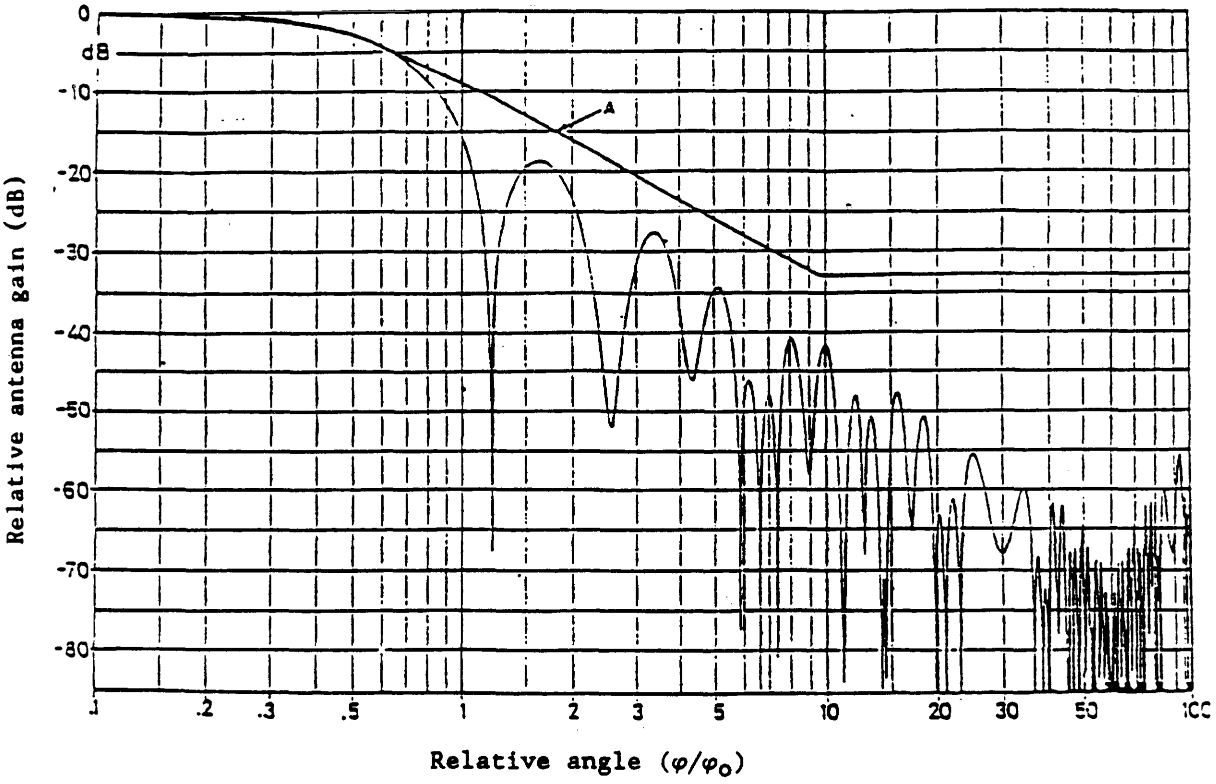


FIGURE 11

Radiation pattern computed for a 60 cm diameter parabolic dish implemented with corrugated flange

Note - Curve A is the WARC-77 co-polar reference pattern for individual reception.

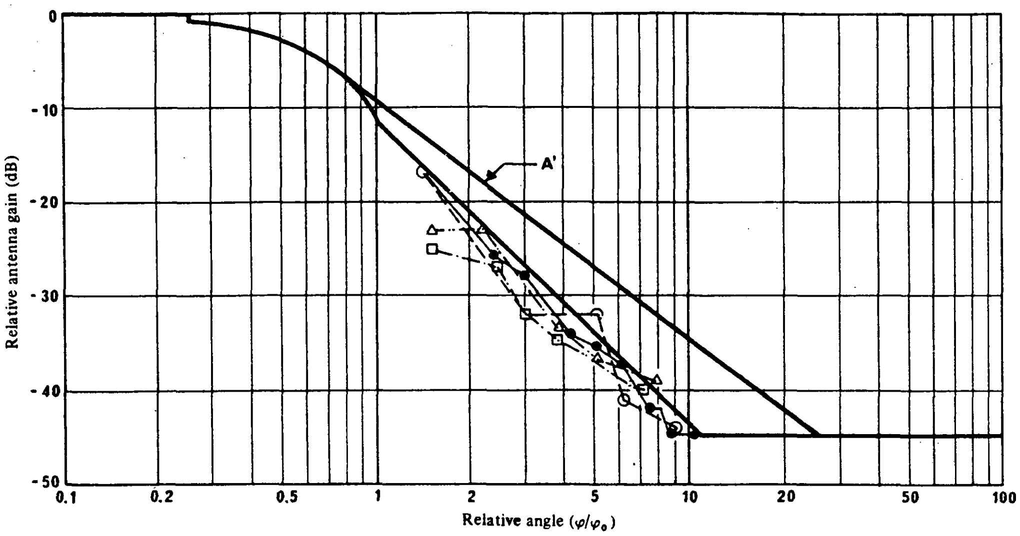


Figure 12 – *Composite sidelobe envelopes for offset-fed reflectors*

○— — —○ 1.22 m offset, linear polarization
●———● 1 m offset, linear polarization
□-·—·—·-□ 0.75 m offset, linear polarization
△··—··—··△ 0.75 m offset, circular polarization

Another method of sidelobe reduction in one plane is through the use of a duopod feed support. The duopod is a two-armed rigid feed support oriented in one plane with guy-wire support in the orthogonal plane. In operation, the low sidelobe plane is aligned with the equatorial plane, thus reducing sidelobe levels in the direction of neighbouring satellites. This duopod construction provides low sidelobes in the plane of the supports because the blockage discontinuity in the aperture plane is smallest in this plane [EDUTEL, 1977]. Envelope A″ of Fig. 2 can be met easily in the equatorial plane with a duopod-supported feed antenna.

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REPORT 473-5*

CHARACTERISTICS OF RECEIVING EQUIPMENT FOR THE BROADCASTING-SATELLITE SERVICE**

(Question 2/10 and 11, Study Programme 2H/10 and 11)

(1970-1974-1978-1982-1986-1990)

1. Introduction

The characteristics to be adopted for 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 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. The present Report gives information about the most important of these characteristics on the basis of the results presented in the documents listed in the references of this Report. Many of the contributions received relate to equipment operating in the 12 GHz frequency band.

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.

As satellite broadcasting is capable of delivering a high quality TV signal to the general public, comparable to that of the studio, it seems practicable to set a higher quality target for receivers.

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

2. Overall characteristics of receiving equipment [CCIR, 1982-86a, b and c]

A typical receiving system for individual reception is comprised of an antenna, a low-noise receiver front end, an indoor unit containing intermediate frequency stages, programme selector, demodulation or adaptor stages, and a television monitor or television receiver.

As an example, major target performance objectives of a composite video system for a satellite broadcasting chain and receiving equipment are shown in Table IV of Report 215.

It would seem desirable to specify the overall characteristics of receiving equipment by the figure of merit G/T, which is the ratio expressed in dB(K^{-1}), between the gain of the receiving antenna (including losses) and the total noise temperature expressed in Kelvin, referred to the point of measurement of the antenna gain. The advantage of introducing the figure of merit parameter is that it is no longer necessary to specify separately the performance of the various parts of the installation, such as the noise figure, coupling loss, antenna gain, etc. The latter parameters may then be chosen by the receiver manufacturers so as to obtain the required overall performance at lowest cost.

Two different types of figure of merit (G/T) are considered:

- the "nominal G/T" is considered as a parameter characterizing the intrinsic quality of the equipment. It can be directly obtained by measuring the on-axis gain of the antenna, the "clear-sky" antenna temperature at a given elevation angle, the total receiver noise temperature and the coupling loss. No operational margins are included. This figure of merit, widely used in fixed-satellite service earth stations, is defined in Report 390. It corresponds to the highest value of the G/T ratio and allows a qualitative comparison between different receivers;

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* Section 11 of this Report (*Susceptibility to certain types of interference*) should be brought to the attention of Study Group 8.

** It is noted that work of IEC-TC12, especially SC12A, D and G is related to receiver characteristics for satellite broadcasting.

- the "usable *G/T*" is considered as the parameter directly characterizing the in-service performance of the receiving system. It therefore takes into account operational factors such as the effects of pointing errors, ageing and the increase in sky noise temperature for a given percentage of the time. This figure may thus be used directly in a link budget. Care should be taken to specify the conditions assumed for the evaluation.

A detailed definition of the figure of merit (*G/T*) and an example of how to calculate it are given in Annex I to this Report.

Receiving equipment suitable for Japan's satellite broadcasting system is commercially produced by many manufacturers. Most receivers are constructed as stated above. Antennas used are of the offset-feed type with diameters of less than 1 m. The outdoor unit is directly connected to the primary radiator of the antenna without exception. The indoor units are mostly of an adaptor type. Some units are incorporated in the main TV receiver.

Annex II indicates preferred characteristics of satellite broadcasting receivers now being produced in Japan and their present average performance .

Annex III shows examples of characteristics for receiving equipment in Italy and also gives the signal quality obtained in a satellite bandwidth of 27 MHz.

A range of equipment has come onto the market following the launching of TDF-1 in France. The antennas used are either parabolic with diameters of 30 to 55 cm, or slightly larger flat antennas. The D2-MAC/packet decoding equipment for indoor use is either housed in a separate unit or incorporated in the television set itself.

Annex IV gives examples of the characteristics of receiving systems used for reception of TDF-1.

3. **Antenna systems** [CCIR, 1982-86a;]

In the 12 GHz band, a common form of antenna for individual reception is one with a conventional or offset parabolic reflector, 0.3 to 1 m in diameter. Large diameters may, however, be used for community reception. Small, flat-plate antennas are also now of interest and becoming available for direct reception. Antenna technology is discussed in Report 810.

Any antenna is subject to mispointing caused by ageing and wind pressure as well as the unavoidable pointing error referred to above. The relationship between the antenna diameter and the "usable" figure of merit was studied by taking into account the loss in gain introduced by the antenna pointing error and is indicated in Fig. 1. From this figure, it is apparent that the use of antennas larger than 1 m in diameter may have significant disadvantages if the total pointing error due to the ageing, wind pressure, and other factors which produce a deflection of about ± 1°, is taken into account. The larger the antenna diameter, the greater its mispointing under wind pressure. In addition, a large antenna requires additional space for installation.

Receiving systems using a relatively small diameter antenna are now capable of offering the figure of merit and directivity established in the 12 GHz Plans. This capability has been achieved because:

- the noise figure of the low-noise front end has been improved far below (e.g. 1.8 dB is a typical value, currently available) the level previously expected at the WARC-BS-77;
- the antenna efficiency has been enhanced from 55% to 70%; and
- the side-lobe level has been markedly reduced through the use of the offset-feed type antenna.

For example, in the case of the BS-2 in Japan with maximum satellite e.i.r.p. of about 58 dBW, 45 to 60 cm diameter antennas are generally used for home receiving equipment.

In the case of a linearly polarized system it will also be necessary to ensure correct rotational orientation, better than 2°, for example, in order to provide adequate protection against orthogonally polarized signals. From the point of view of aligning the antenna, it will be advantageous to use circular polarization. In this case, the antenna feed may be a little more complex to manufacture than if linear polarization were used.

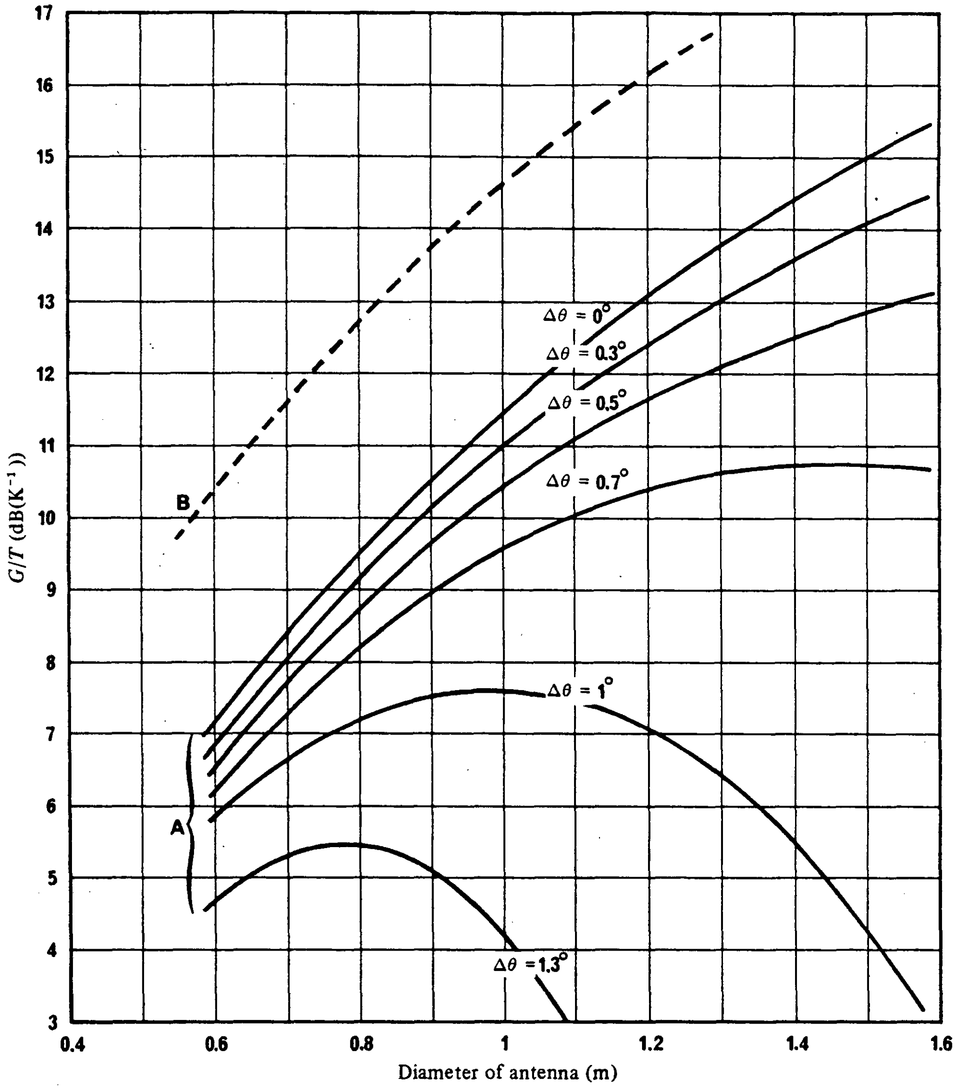


FIGURE 1 – *"Usable" figure of merit (G/T) considering various causes of pointing error*

$$G/T = \frac{a\beta G_r}{aT_a + (1 - a)\,T_0 + (n - 1)\,T_0}$$ (These parameters are defined in Annex I)

where for curves A: a = 0.9
β = losses due to overall pointing error $\Delta\theta$ (see Note 1)
T_a = 150 K
T_0 = 290 K
n = 2.51 (noise figure = 4 dB)
f = 12 GHz
η = 0.6 (see Note 2)

and for curve B: a = 1
β = 1($\Delta\theta$ = 0)
n = 1.78 (noise figure = 2.5 dB)
η = 0.7

Note 1. – Overall pointing error includes positioning error of the satellite (±0.16°), setting error of the antenna (approximately 10 to 20% of the half-power beamwidth of the antenna) and additional pointing error due to wind pressure and ageing etc.

Note 2. – The effect of antenna efficiency on G/T for a given antenna diameter is given by 10 log (η/0.55) (dB), i.e., increasing the antenna efficiency from 0.55 as given in Table IV of Annex I to 0.70 will increase the G/T by 0.4 dB.

Receiving antenna diagrams for various frequency ranges are given in Report 810 indicating the upper limit of the relative gain as a function of the angle, to be assumed for planning purposes.

The choice of the feed arrangement may also be influenced by the associated feeder losses. In the 12 GHz band, to minimize the feeder loss, it is likely that the input stages will be located at or near the focus of the antenna. Thus a dual reflector or offset antenna could be preferred because of high aperture efficiency (65 to 70%) and low feeder losses. On the other hand, with developments in microwave electronics, similar efficiencies are now possible with a normal focal feed. Successful designs in respect of cost and reliability were used in Canadian experiments at 12 GHz with linear polarization (Hermes and Anik-B experiments), a field-effect transistor (FET) amplifier and frequency changer unit are mounted at the focal point with a high-efficiency feed. Units with 1.2 m and 1.8 m diameter reflectors gave worst-case values of G/T of 11 dB(K^{-1}) and 15 dB(K^{-1}) respectively, including losses and an ageing allowance of 1 dB [CCIR, 1978-82a]. With the same technology the corresponding G/T for a 0.9 m reflector would be 9 dB(K^{-1}). These values are significantly greater than the 6 dB(K^{-1}) value used for planning at the WARC-BS-77. This Conference adopted the use of circular polarization for broadcasting satellites at 12 GHz. A short microwave feeder may be desirable to establish the polarization and/or give useful first-converter image attenuation; this would contribute a small additional coupling loss.

4. Input stages

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 and a local oscillator.

If low noise pre-amplifiers are required, the field effect transistor (FET) is now widely used. For higher frequency bands such as 23 GHz, the low noise high electron mobility transistor (HEMT) has been developed, and because the cost has been greatly reduced, they are being introduced.

Hybrid MIC (microwave integrated circuit) amplifiers are generally used for low noise amplifiers to achieve lower noise figures and stable performance. In addition to this technique, monolithic GaAs FET amplifiers have been developed which will reduce the cost in the case of mass production.

Various data have been reported at present concerning noise performance for low noise elements, amplifiers and receivers for satellite broadcasting as shown in Annex V . As a summary, Table I shows the noise figure of receivers for frequency bands assigned to the BSS.

TABLE I

Summary of typical noise figures reported for present-day receivers (1989)

Frequency band (GHz)	0.7	2.6	12	23
Typical noise figure (dB)	1.5	1.5	1.8	5.0

It is noted that the configuration used to obtain the value of the noise figure should be clearly identified because the noise figure may be expressed for various configurations, e.g.: single element, amplifier or receiver. It is also noted that for consumer equipment used in the home, after ageing, characteristics such as the noise figure may be different from those available in laboratories.

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 in 1980. As for distribution of the noise figure, results show that the initial value was 4.1 dB on average with a standard deviation of 0.25 dB. The degradation during two years was 0.15 dB [CCIR, 1978-82b].

For the first local oscillator, a solid state direct local oscillator source, such as a Gunn device, or a field-effect transistor (FET), may be used. To stabilize oscillator frequency, a phase locked oscillator (PLO) referenced by a crystal controlled oscillator or dielectric resonator oscillator (DRO) with high Q dielectric resonator is commonly used. However, even if some form of automatic frequency control of this or any subsequent local 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.

There is a prospect of reducing the number of components in the outdoor unit and hence the cost of the receiver, by applying such technologies as use of active mixers, and/or self-oscillating mixers which eliminates a separate oscillator. Introduction of planar geometries to the integrated type of antenna and low noise input stages using microstrip lines with co-planar and slot structures would facilitate the manufacturing process [CCIR, 1986-90a].

5. **Intermediate-frequency stages** [CCIR, 1974-78b, d, f and g]

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 significant 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 first intermediate frequency may be chosen within the band 900 to 1700 MHz. However, as summarized in § 11.3, it may be helpful in some countries to use a higher intermediate frequency (e.g. 1500-2300 MHz) to avoid interference from radionavigation radars.

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 § 11.2).

Another factor in determining the first intermediate frequency is the selection of the first local oscillator frequency. In Japan, a first local oscillator frequency of 10.678 GHz is considered appropriate for the following reasons:

- emission of radio waves in the band 10.68 GHz to 10.7 GHz is prohibited, as a general rule (Article 8, Nos. 833 and 834 of the Radio Regulations, 1988);
- the maximum leakage power of the first local oscillator is assumed to be −40 dBW as the worst case, when a conventional direct converter is used;
- in Japan, radio-relay systems operating above 10.7 GHz and outside broadcasting links operating in the band 10.55 GHz to 10.675 GHz should be protected from possible interference by the leakage power of the first local oscillator.

In France, the frequency 10.750 GHz is normally used as first local oscillator; this corresponds to a first IF of between 950 and 1 750 MHz.

In the event that a radionavigation radar should cause interference to reception of a satellite channel, the frequency of the first local oscillator would be displaced by a multiple of 19.18 MHz.

A further discussion of unwanted radiation from receiving equipment is given in § 12.

Another item to be considered is the selection of the second intermediate frequency. The frequency must be chosen so as to avoid interference by terrestrial broadcasting and other transmitters. In this regard, use of frequencies near 130, 400 MHz and other possibilities are studied. The home receiver designed mainly for individual reception may possibly be applied to group reception; in this case a common front end is connected to more than one indoor unit. When the selected value of the second intermediate frequency is smaller than the value of the total frequency bandwidth at 12 GHz allocated for satellite broadcasting in a service area, local oscillator frequencies coincide with part of the first intermediate frequency band. Depending on the level of the received signal and leakage power, attention has to be given to mutual interference between indoor units caused by the local oscillator leakage. To make this interference as low as possible by arranging the second local oscillator frequencies between any two adjacent channels allocated to that area, the following relationship is desirable for the second intermediate frequency:

$$f = 38.36\,(n + 1/2)\ \text{MHz (in Regions 1 and 3)}$$

$$f = 29.16\,(n + 1/2)\ \text{MHz (in Region 2)}$$

where n is an integer.

This relationship is valid when the selected frequency f is smaller than the value of the total frequency bandwidth to that area. However, if $2f$ is smaller than the total bandwidth there is the possibility of image frequency interference, and a small adjustment of the value of f may be beneficial.

The second intermediate frequency, having a bandwidth of 27 MHz, might be chosen in the vicinity of 70 to 400 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 [CCIR, 1978-82c].

Recent designs of home terminal receivers have shown that it may be practical to use surface acoustic wave (SAW) filters for the second IF. These filters are practical in the frequency range between 35 and 600 MHz and have very desirable properties of linear phase and sharp filter roll-off. Examples of the achievable amplitude versus frequency response of SAW filters are shown in Figs. 2a, b and c.

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 [CCIR, 1978-82d].

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 [CCIR, 1978-82c]. 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 [CCIR, 1978-82d].

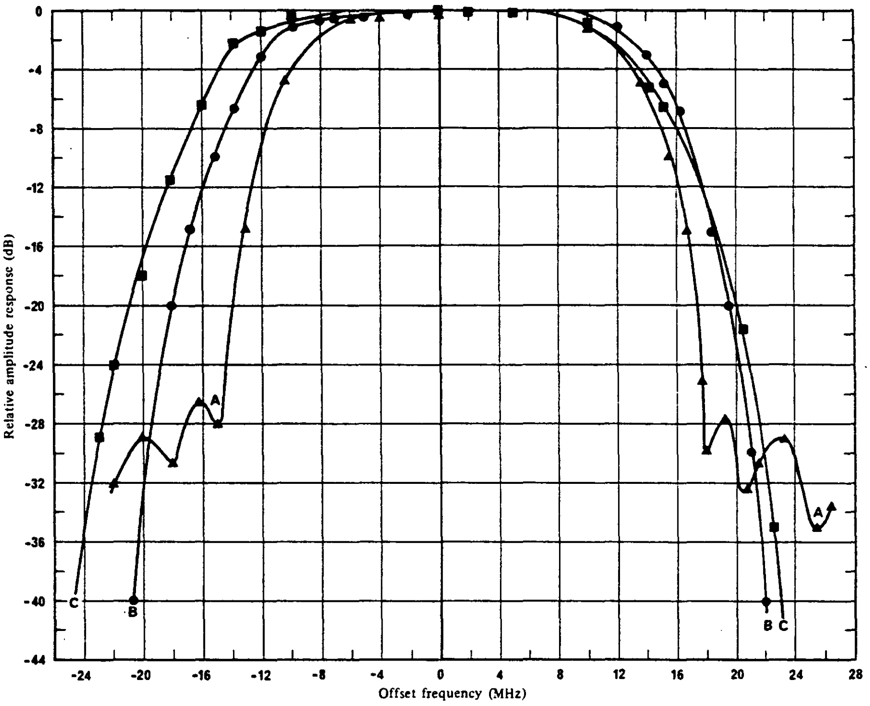
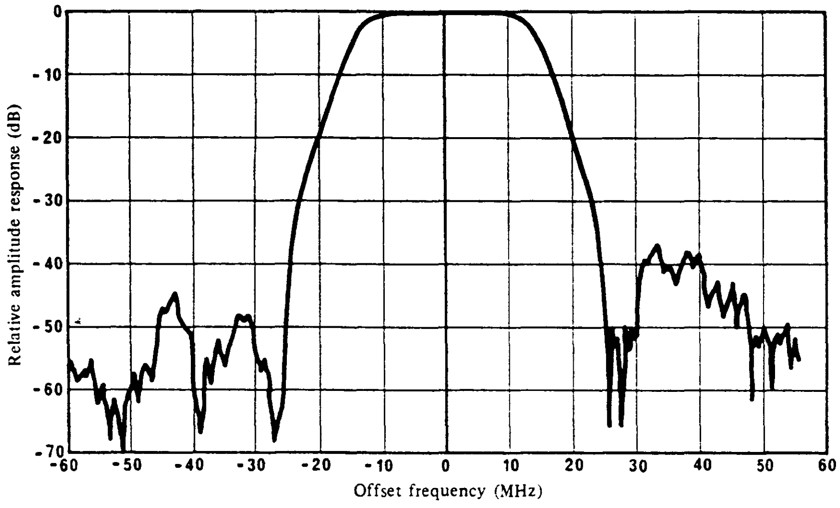


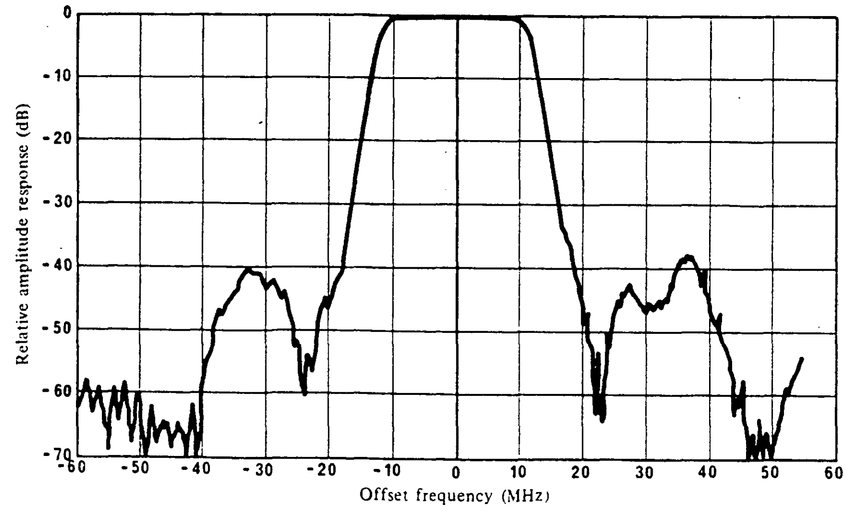
FIGURE 2a – *Amplitude versus frequency response of SAW filters (second IF)*

Curves	Centre frequency (MHz)	Equivalent slope
A	260	6-pole Chebychev
B	130	6-pole Chebychev
C	130	5-pole Chebychev



Centre frequency = 134.3 MHz
Bandwidth = 27 MHz

FIGURE 2b – *Amplitude versus frequency response of SAW filter*



Centre frequency = 140 MHz
Bandwidth = 23 MHz

FIGURE 2c – *Amplitude versus frequency response of SAW filter*

6. Demodulation or adaptor stages

For television, use can be made of a frequency demodulator which will deliver the video signal (and possibly frequency- or digitally-modulated sound signals on sub-carriers, if sub-carriers are 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, would be incorporated into television receivers designed for reception of both frequency-modulation satellite and amplitude-modulation 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.

Integrated circuit and discrete component threshold extension demodulators comparable in complexity to conventional FM demodulators but using phase lock loops, FM feedback or tracking filters may be cost effective for some BSS applications. Dynamic thresholds occurring at carrier-to-noise ratios of approximately 8 dB are presently achievable with average programme level modulated colour signals.

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 an 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 [CCIR, 1978-82b].

The demodulation stages of home receivers intended for reception of a digitally-modulated sub-carrier system may consist of an FM demodulator, a 4-PSK demodulator and a PCM signal processor.

The sound sub-carrier signals are fed to the PSK demodulator through the bandpass filter. The PSK demodulator, performing phase lock detection of the 4-PSK signal, regenerates PCM signals and the clock frequency synchronized to them. The PCM signal processor performs de-interleave, error correction and other PCM signal processing, if necessary, and then converts digital signal into analogue signal through the D/A converter. And if necessary, all PCM bit-stream signals with error correction may be provided for the use of independent data and sound broadcasting, in order to meet the needs of the various services of satellite broadcasting.

There is a trend to provide an increasing number of consumer television receivers equipped with RGB interfaces. Demodulators and decoders generating RGB signals are now made available to provide high picture quality.

7. Community reception and distribution techniques

In satellite broadcasting, the concept of signal reception, not only for individual reception but also for community receiving installations, has been established. To this end it is necessary to use suitable reception and distribution techniques satisfying, as much as possible, the requirements of maximum commonality between individual and community receivers.

For example, in Japan about half of the 1.7 million households that were receiving satellite-broadcasting programmes in mid-1989 were receiving these programmes via cable networks using either AM or FM distribution techniques. Moreover, small community reception installations using FM distribution techniques are increasing in number.

7.1 Distribution techniques

According to studies conducted in Italy and Japan, two possible FM distribution techniques for community reception can be envisaged [Mussino, 1984; REEA, 1987; CCIR, 1982-86c]:

(a) Distribution in the first IF band (e.g.: 0.95-1.75 GHz) of up to 20 FM channels spaced 38.36 MHz (or more), without changing the RF modulation parameters of BSS signals.

This technique is applicable to the case where constraints from spectrum occupation or use of high frequencies do not exist.

(b) Distribution in the VHF or UHF TV broadcasting bands including the extended UHF band (e.g: 230-470 MHz) of a few selected FM channels, spaced 38.36 MHz (or more), without changing the RF modulation parameters of BSS signals.

This technique can be used when the availability of a limited number of channels is acceptable to the users.

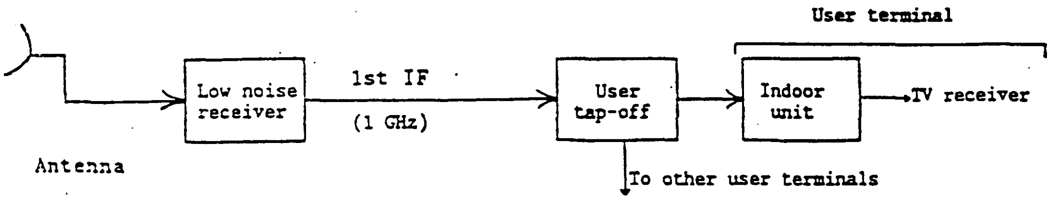
Appropriate safeguards may be necessary against accidental leakage in order to prevent interference to other services, in particular in the allocation for emergency position-indicating radiobeacons (EPIRBs) at 243 MHz and 406-406.1 MHz.

Examples of practical implementation of distribution techniques (a) and (b) are shown in Figs. 3a) and b) and 4a) and b), respectively.

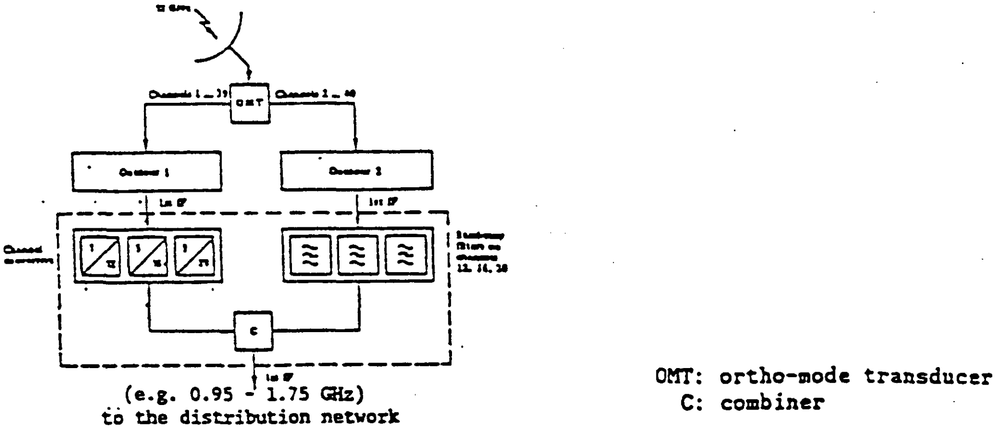
For the techniques illustrated in Fig. 3(b), channel converters and **band-stop** filters are used to select an combine the 20 wanted channels among those (up to 40) received from each satellite orbital position. In this example, channels 1, 5 and 9 are converted and distributed in place of channels 12, 16 and 20, which are suppressed by the band-stop filters. For the techniques illustrated in Fig. 4(b), channels 1, 5 and 9 and channels 24, 28 and 32 are converted into the band 230-470 MHz. In the indoor unit, the 230-470 MHz band is selected and converted into a suitable part of the first IF band.

In the case of community-receiving installations, where the above distribution techniques (a) and (b) cannot be used, the use of AM/VSB remodulation may be necessary in order to minimize the channel bandwidth.

Reference should be made to Report 482 and the relevant texts of Volume XI-1.



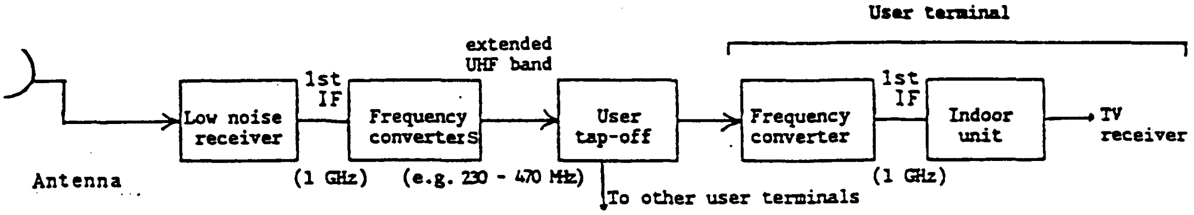
(a) Method of providing all channels transmitted on the same polarization



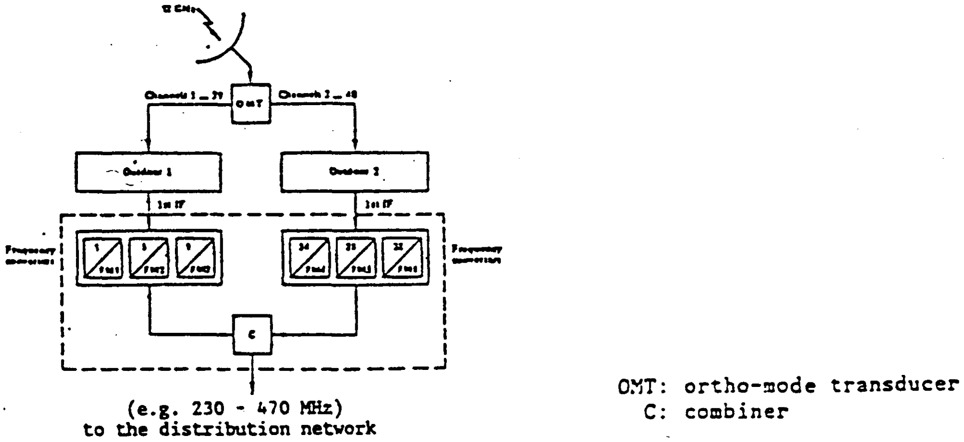
(b) **Method of providing selected channels from both polarizations**

FIGURE 3

Examples of the distribution technique in the first IF band



(a) **Method of providing selected channels transmitted on the same polarization**



(b) **Method of providing selected channels from both polarizations**

FIGURE 4

Examples of the distribution technique in the extended UHF band

7.2 Impairments affecting the distributed signals

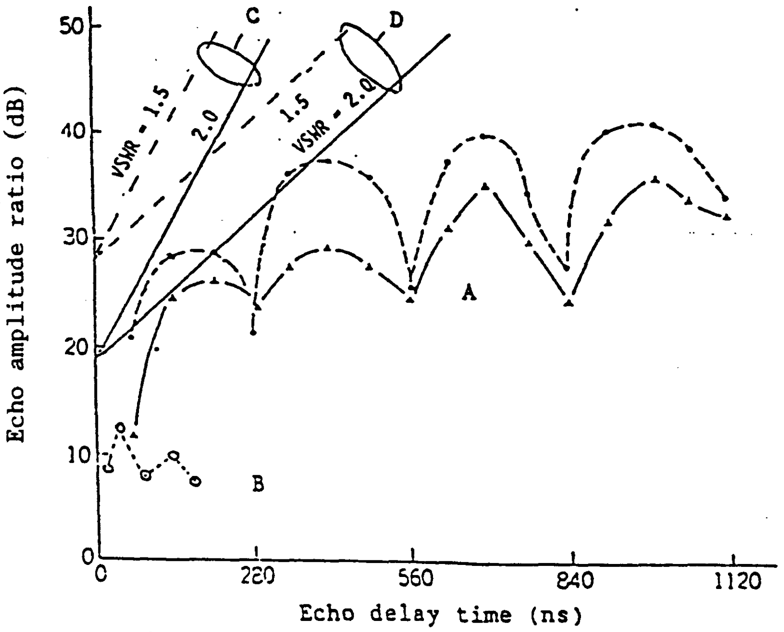
In small collective antenna systems, the BSS signals, distributed according to FM techniques (a) and (b)(see § 7.1), can be impaired with respect to direct reception, because of imperfect matching between the various parts of the installation, especially the distribution network. Other impairments can be introduced because of imperfect alignment of the head-end unit devices (e.g. channel and frequency converters, band-stop filters, amplifiers, etc.).

The corresponding alterations of the frequency response (amplitude and group delay) at the user outlets affect the spectral distribution of both signal and noise. The C/N ratio, at the receiving filter output, is then changed with respect to direct reception, depending on the carrier frequency of the BSS signals distributed in the network. Consequently, the demodulated signal is affected by waveform distortions, impairments of the S/N ratio and increase of impulse noise at low C/N ratios.

Theoretical studies, as well as laboratory and field tests, were carried out on the cable distribution systems in Japan [CCIR, 1986-90b]. Based on these studies, it is shown that both AM and FM distribution techniques are practical. As for FM distribution techniques, it is considered that some care regarding the mismatching of impedances of components is necessary to avoid echoes. Figure 5 shows an example of the relationship between the echo amplitude ratio and delay time in the cable distribution system which gives just perceptible flicker impairment. This also shows that mismatches resulting in a VSWR of 1.5 would be acceptable in such systems.

Results of the field tests show that there are no major problems of applying FM distribution techniques to the cable distribution systems if selected distribution units with appropriate characteristics are used.

For further information, see Annex VI.



Legend

Curves A - Just perceptible flicker
-·-·-·-·- for the colour bar signal
—▲—▲— for the test pattern of the kitchen scene
Curve B - Measured BER for 10^{-8}
Lines C - Cable loss 0.4 dB/m
Lines D - Cable loss 0.2 dB/m

FIGURE 5

Echo amplitude ratio vs. echo delay time which gives just perceptible flicker impairment

Laboratory tests have been carried-out in France [CCIR, 1986-90c] on D2, D, C-MAC/packet signals, in order to evaluate the impairments on both sound/data and vision components introduced by a single echo added to the direct signal at the second IF of 230 MHz.

With regard to the sound/data component, Table II gives the values of C/N measured at a bit error ratio of 1 x 10^{-3}.

The C/N impairments with respect to direct reception, measured for an echo level of -15 dB were 1 dB for D2, 1.5 dB and 1.7 dB for C (with FM and 2-4 PSK demodulation, respectively) and 2 dB for D signals. The D signals showed higher sensitivity than D2 and C signals to frequency offset.

With regard to the MAC vision component, the main effect of a short echo, less than 100 nsec delayed, was the impairment of the S/N ratio of the demodulated signal.

For a C/N ratio of 16 dB in 27 MHz, 1 dB and 2 dB impairments of the luminance S/N ratio (weighted) were measured for echo levels of -20 dB and -15 dB, respectively. For a C/N ratio of 12 dB, an echo level of -15 dB corresponded to the visibility threshold of impulsive noise. Details of these laboratory tests are given in Annex VII.

Experimental investigations have been carried out in Italy [Cominetti and Stroppiana, 1986; CCIR, 1986-90d] to evaluate the impairments introduced on C-MAC/packet signals by the distribution network of collective antenna systems implemented according to technique (b) of section 7.1, in the extended UHF band (230 - 470 MHz), assuming ideal performance of the head-end unit devices.

With regard to the sound/data component, Table III gives the measured C/N ratio in 27 MHz corresponding to a bit error ratio of 1 x 10^{-3}, at the receivers where the worst reception quality was found, for the cases of differential demodulation and conventional frequency demodulation of the 2-4 PSK C-type signal. Maximum C/N impairments of 1.8 dB and 2.3 dB were measured for the two types of demodulation, respectively.

TABLE II

C/N ratio (dB) measured in 27 MHz corresponding to a bit error ratio of 1 x 10^{-3}

Type of modulation	Type of demodulation	Bandwidth of receiving filter	Frequency offset in receiving filter	C/N (dB) for echo level		
				None	- 20dB	- 15dB
D2	limiter-discriminator	27 MHz	$\Delta f = 0$	8	8	9
	limiter-discriminator	27 MHz	$\Delta f = 2.5$ MHz	8.4	9.0	9.5
C	limiter-discriminator	27 MHz	$\Delta f = 0$	9.5	10.3	11
	limiter-discriminator	27 MHz	$\Delta f = 2.5$ MHz	10.3	11.5	11.8
	differential	21 MHz	$\Delta f = 0$	7.3	8.5	9.0
D	limiter-discriminator	27 MHz	$\Delta f = 0$	10.5	11.2	12.5
	limiter-discriminator	27 MHz	$\Delta f = 2.5$ MHz	10.9	12.2	14.2

TABLE III

C/N ratio (dB) measured in 27 MHz corresponding to a bit error ratio of 1 x 10^{-3} for 2-4 PSK C-MAC/packet sound/data signals with differential and frequency demodulation

Condition		C/N (dB) for type of demodulation:	
		Differential	Limiter/discriminator
Modulator-demodulator, direct connection		7.6	10.1
Distribution network	Best condition	7.6	9.3
	Worst condition	9.4	12.4

With regard to the MAC vision component, no significant waveform distortions were found. The main impairment was due to the reduction of the C/N ratio, reaching at most 2 dB.

Details of the laboratory implemented installation are given in Annex VII.

According to the results obtained in France and Italy, referring to FM distribution of BSS MAC/packet family signals, a C/N ratio of about 2 dB higher than that achieved by an ideally matched receiving system should be necessary in order to overcome the impairments due to the distribution network.

Further studies are necessary to evaluate the additional impairments introduced by the other components of the receiving installations.

8. Reception of sound broadcasts

For individual reception at 12 GHz of sound-only broadcasts or of supplementary sound channels associated with television broadcasts, it would seem desirable to be able at least to use the same input stages as for the reception of television signals. To avoid the need for a highly stable local oscillator in the input stages and to simplify the demodulation stages, it is possible that a number of sound programmes may be multiplexed within a video signal bandwidth, and used to frequency modulate a 12 GHz transmission, having a power and bandwidth comparable with that used for a satellite television transmission. This multiplexing could be achieved with analogue FM frequency division multiplex or with digitally modulated signals in frequency or time division multiplex (see Report 215 for system examples). Although less efficient than separate FM carriers in terms of use of bandspace and power, such arrangements would have significant advantages for tuning. Studies of such possibilities are in progress.

9. Effect of channel grouping

The interdependence of receiver design, channel grouping and sharing criteria may have a considerable influence on the development and the implementation of a plan for the broadcasting-satellite service (Recommendation No. 712 of the WARC-79).

Measurements were carried out in Japan using down-converter type receivers with a double conversion structure, compatible with the technical characteristics and with the plan which was adopted at the WARC-BS-77. The results indicate that the channel grouping of the plan for the broadcasting-satellite service in the 12 GHz band is unlikely to cause deterioration in the reception of television; measured levels of intermodulation were fairly low and the rejection characteristics of adjacent channels were satisfactory.

Further study of this matter is desirable.

10. Cost consideration

The relationship between cost and the overall performance of receiving equipment, measured by the figure of merit, *G/T*, involves other factors, such as the quality of workmanship, the extent of the tests carried out after manufacture, the reliability objective, installation costs, etc. Cost studies both for items of equipment and for complete installations have shown substantial differences between the estimates obtained from various sources; even after these estimates have been adjusted for a similar basis and for similar performance factors.

Installation tests, carried out in Sweden [CCIR, 1978-82e] show that the installation costs for individual TVRO terminals for 12 GHz, installed by installation engineers, are about 1 to 1.5 times the estimated factory cost for 12 GHz terminals for quantities of 10^5 units, Although these cost estimations are primarily valid for Sweden they indicate that the installation cost should not be ignored when determining the overall costs of the broadcasting-satellite system [CCIR, 1978-82e].

11. Susceptibility to certain types of interference

A receiver having the characteristics suggested in § 5 would be expected from theoretical considerations to be susceptible to the following forms of interference; experience and measurements in practical situations are required to assess the true extent of any interference problem.

11.1 *Harmonics of certain emissions falling into the broadcasting-satellite band*

This risk has its origin in harmonics radiated by ISM equipment and in particular domestic microwave ovens. A study [CCIR, 1978-82c] has shown that the risk remains slight, if the ISM equipment does not exceed the limit of parasitic radiation recommended by the CISPR, namely 57 dB(pW). That limit ought to be interpreted as applying to the total power in a bandwidth of 27 MHz. The population of domestic microwave ovens is now sufficient in many places to permit realistic measurements to be made in the field. In many urban areas, however, a microwave oven may be located near the receiving antenna in the broadcasting-satellite service. Limitation on the location of the oven for prevention of possible interference into receivers is given in Annex VIII. The computed distances are based on, among other things, an assumed 5th harmonic effective radiated power (e.r.p.) of 57 dB(pW) and may not represent the worst case value [CCIR, 1978-82b].

11.2 *Emissions in the first image band (9.1 to 10.3 GHz in Region 1)*

This risk, which arises if the first local oscillator frequency is below the signal frequency, has its origin in certain very-high-power radar stations. A study [CCIR, 1978-82c] has shown that the range of the interference may reach 27 km. Thus the problem is a serious one and could be resolved at the level of the receiver by choosing the frequency for the first local oscillator above that of the signal, to avoid the disadvantage given in § 5 of requiring, in some areas, an image rejection of 80 dB [CCIR, 1978-82f].

11.3 *Emissions in the band of the first intermediate frequency*

If the intermediate frequency band lies in the range 900 to 1700 MHz, there is a serious risk of extraneous interference, mainly from radionavigation transmitters which may produce an e.i.r.p. of several kilowatts.

Measurements were carried out in France that confirmed the presence of a field strength of the order of 10 V/m a few metres above the ground up to at least 10 km away. The field strength was in fact found to depend on the height of the point of measurement and, considering that a number of users of broadcasting-satellite services will be connected by cables to distribution networks running inside buildings or tower blocks, the actual interference zone may be considerably larger and may extend as far away as 20 km [CCIR, 1982-86d]. Another study [CCIR, 1978-82g] has shown that a separation distance of 11 km may be required, assuming the screening of the IF interconnection and circuits to be typical of present practice for UHF broadcast receivers.

Measurements made in Australia [CCIR, 1982-86e] showed that certain receivers displayed interference with a radar field strength of 0.35 V/m. The interference disappeared when the wanted signal level was increased by 6 dB above FM threshold. During the same test another receiver showed interference in field strengths above 1.6 V/m. One receiver that could only be tuned such that the radar frequency and the wanted IF signal were separated by 10 MHz was able to operate in field strengths up to 39 V/m [DOC, 1985].

In order to avoid picture impairments due to such interference problems, there are at least two solutions:

- use of receiving equipment with protection against this risk by using a suitable well-screened construction and suitably designed components: in particular the SHF converter (which should have a high gain but low intermodulation levels) and the down-lead conveying the signals at intermediate frequency. This may call for the development of specific components and for the IEC to establish appropriate methods of measuring interference immunity [CCIR, 1978-82h]. However for the mass market, it may be too expensive to equip all receiving stations with a perfectly screened and decoupled selector/demodulator, and the manufacture of specially screened versions is not necessarily compatible with the consumer market;
- choice of the band 1500-2300 MHz as an intermediate frequency. This raises problems of technology that may be solved in the future with foreseen improvements in electronic components.

11.4 *Intermodulation*

Attention has been drawn to a possible problem arising from the large number of third-order intermodulation products that could be present in the wanted signal channel when using a wide-band first converter (e.g. over a hundred products for a case when twenty equally-spaced signals might be present in an 800 MHz band) [CCIR, 1978-82i].

Linearity requirements in the converter and IF amplifiers must therefore take into account the number of television signals of significant amplitude that may be present within the first IF bandwidth.

12. **Unwanted radiation from receiving equipment** [CCIR, 1982-86f]

A potential source of unwanted radiation from BSS receiver terminals is the first local oscillator (LO). Front-end receiver designs using a direct mixer approach could have local oscillator levels as high as −50 dBW at the antenna flange. Receivers with pre-amplifiers as the first stage will typically have levels of −65 to −70 dBW. Further reduction of these levels would be required to prevent possible interference into FS and FSS bands if the frequency selected for the first LO fell in bands allocated to these services. The following are two possible methods for reducing the impact of local oscillator radiation:

- select a frequency for the local oscillator for all BSS home terminals that will not cause unacceptable interference to other services. An example of such a frequency would be 11.2 GHz that is at the centre of the guard band between the low band and high band of the 10.7 to 11.7 GHz fixed service allocation;
- use a single conversion receiver for BSS home terminals thus keeping the local oscillator frequency within the BSS band.

Although this latter approach is commonly used in the FSS at 4 GHz, it is really not suitable for the BSS since it would require a tunable local oscillator in the outdoor unit. In addition, this approach would require careful satellite frequency channelization to ensure that the in-band image frequency falls on cross-polarized channels.

Careful selection of the local oscillator frequency at some point either above or below the receive band could minimize image rejection requirements depending upon which signals fall into the image band. Other technical factors need to be considered in selecting the best approach to minimizing unwanted radiation, for example:

- other spurious responses created in the receiver by the local oscillator frequency selected; and
- benefits from waveguide cut-off.

Another potential source of unwanted radiation is the clock frequency oscillators in the decoders used in the receiving equipment. The highest clock frequency in MAC/packet decoders used in 625-line/50 Hz domestic television equipment is 3/2 times that of the digital television coding standard, i.e. 20.25 MHz. Certain harmonics of this clock frequency coincide with the centres of the emergency frequency channels at 121.5 MHz and 243 MHz in the aeronautical mobile and mobile satellite frequency bands.

The electromagnetic radiation limits for mass produced equipment are the subject of existing specifications, CISPR Recommendation 13-1975 (Applying to broadcast receivers) and CISPR 22-1985 [CISPR, 1985] (Applying to information technology equipment). These recommendations are intended to ensure electromagnetic compatibility between such equipment and radiocommunication services.

CISPR Recommendation 13-2-1989 [CISPR, 1989] is a new issue of Recommendation 13 which applies to broadcast recievers and associated digital equipment and specifies radiation limits on aeronautical maritime distress frequencies (121.5 MHz and 243 MHz) indentical to CISPR Recommendation 22.

This is consistent with the conclusions of a study on potential interference from MAC/packet equipment into, inter alia, the SARSAT system on aeronautical maritime distress frequencies (121.5 and 243 MHz) made by the EBU [CCIR 1986-90e] which have been incorporated together with input from Study Group 8 into Report 1101. However, a study by the United States relating to interference to SARSAT operations on these frequencies concluded that a decrease in the radiation limits defined by CISPR might be required to protect the SARSAT system [CCIR, 1986-90f].

This matter should be the subject of further consideration in Study Groups 1 and 8.

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[1978-82]: a. 10-11S/59 (Canada); b. 10-11S/113 (Japan); c. 10-11S/8 (EBU); d. 10-11S/141 (USA); e. 10-11S/125 (Sweden); f. 10-11S/45 (France); g. 10-11S/62 (Japan); h. 10-11S/47 (France); i. 10-11S/46 (France).

[1982-86]: a. 10-11S/137 (Japan); b. 10-11S/171 (France); c. 10-11S/175 (Italy); d. 10-11S/13 (France); e. 10-11S/192 (Australia); f. 10-11S/17 (USA).

[1986-90]: a. 10-11S/145 (Italy); b. 10-11S/104 (Japan); c. 10-11S/56 (France); d. 10-11S/25 (Japan); e. 10-11S/4 (EBU); f. 10-11S/167 (USA).

ANNEX I

EXAMPLE OF CALCULATION OF THE FIGURE OF MERIT OF RECEIVING EQUIPMENT FOR INDIVIDUAL RECEPTION IN THE 12 GHz BAND

For the present example, the figure of merit, G/T, is defined by the following formula, which allows for pointing error, polarization effects, and ageing:

$$G/T = \frac{\alpha\beta G_r}{\alpha\ T_a + (1-\alpha)\ T_0 + (n-1)\ T_0}$$

where:

α : the total coupling losses, expressed as a power ratio,

β : the total losses due to the pointing error, polarization effects and ageing, expressed as a power ratio,

G_r : the effective gain of the receiving antenna, expressed as a power ratio and taking account of the method of feeding and the efficiency,

T_a : the effective temperature of the antenna (either clear sky or for a given percentage of the time),

T_0 : the reference temperature = 290 K,

n : the overall noise factor of the receiver, expressed as a power ratio.

Relatively inexpensive receivers can be produced having a maximum noise figure of 4 dB (438 K). An example of the calculation of "nominal" and "usable G/T", using this noise figure and assuming an antenna diameter of 90 cm and an efficiency of 55%, is given in Table IV [CCIR, 1982-86a]. The following expression may be used to calculate the pointing loss P in dB:

$$P = -12\left[(\theta_1^2 + \theta_2^2 + \theta_3^2)/\theta_0^2\right]$$

where:

θ_1 : the initial pointing accuracy of the fixed-mount receiving equipment in the direction of the satellite (degrees),

θ_2 : the pointing stability of the receiving equipment under the influence of the climatic environment (degrees),

θ_3 : the orbital drift of the satellite (degrees),

θ_0 : the half-power beamwidth of the receiving antenna (degrees).

It is also possible to obtain the same result with other combinations of parameters. Figure 6 shows an example of how the antenna gain, the antenna diameter and noise figure may have a range of values. It is interesting to note that as the value of noise figure is reduced, the influence of the increase in antenna noise temperature on the antenna gain and diameter required for a given "nominal" and "usable G/T" is magnified.

The effective antenna noise temperature is determined by its size and elevation angle, external noise sources, and atmospheric propagation effects. The smaller the antenna, the greater the relative gain of the pattern pointing to the Earth (side-lobes also intersect the ground at a higher antenna elevation angle). Consequently, the smaller the antenna, the higher the elevation angle at which its noise temperature approaches 290 K.

The effect of atmospheric attenuation of the signal is also to raise the effective antenna noise temperature, T_a, according to the relationship:

$T_a = T_m(1 - 1/L)$ (T_a is effective antenna noise temperature)

where:

T_m = 280 K, and

$L = 10^{0.1A}$ (A is the atmospheric attenuation in dB)

Thus, for high atmospheric attenuation, T_a approaches 280 K even for high angles of elevation.

TABLE IV – *Example of the calculation of the figure of merit (G/T)* *

		"Nominal G/T"		"Usable G/T"	
Gain of receiving antenna G_r (90 cm diameter, 55% efficiency)	(dB)		38.2		38.2
Coupling losses α	(dB)		−0.5		−0.5
Net gain αG_r	(dB)		37.7		37.7
Antenna temperature T_a (clear sky)	(K)	80		80	
Temperature referred to the input αT_a	(K)	71		71	
Coupling noise $(\alpha - 1)\ T_0$	(K)	35		35	
Increase in antenna temperature for 99% of the worst month	(K)	–		70	
Receiver noise temperature	(K)	438		438	
Total effective noise temperature	(K)	544		614	
	or (dBK)	⟶	27.4	⟶	27.9
Initial pointing accuracy of the antenna θ_1	(degrees)	–		0.4	
Pointing stability of the antenna θ_2	(degrees)	–		0.4	
Orbital drift of the satellite θ_3	(degrees)	–		0.1	
Aperture of half-power beamwidth of the antenna θ_0	(degrees)	–		1.8	
Pointing loss $P = -12\left[(\theta_1^2 + \theta_2^2 + \theta_3^2)/\theta_0^2\right]$	β (dB)		–	⟶	−1.0
Ageing and polarization losses			–		−1.0
G/T	(dB(K^{-1}))		10.3		7.8

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* Calculated at 11.7 GHz.

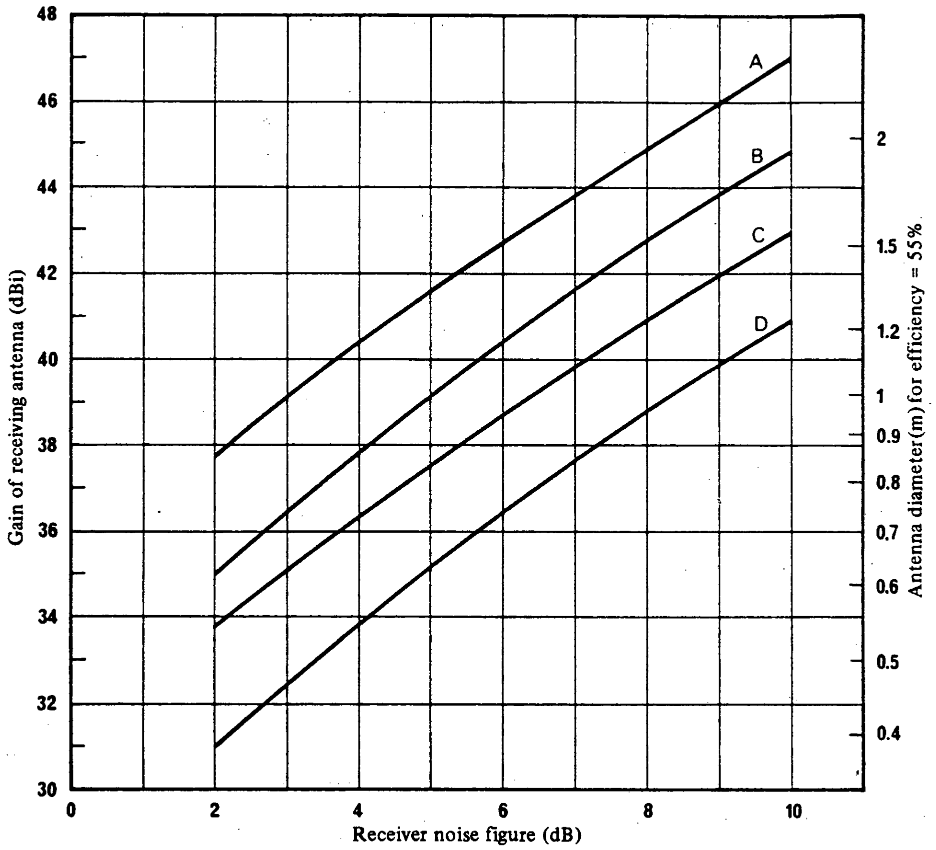

FIGURE 6 – *Relationship between noise figure, antenna diameter and antenna gain for "nominal" and "usable G/T" = 6 dB(K^{-1}) or 10 dB(K^{-1}) with losses and antenna temperature as in the example of* Table IV

A : "usable G/T" = 10 dB
B : "nominal G/T" = 10 dB
C : "usable G/T" = 6 dB
D : "nominal G/T" = 6 dB

REFERENCES

CCIR Documents

[1982-86]: a. 10-11S/171 (France).

BIBLIOGRAPHY

CCIR Documents

[1978-82]: 10-11S/141 (USA).

ANNEX II

CHARACTERISTICS OF HOME RECEIVING EQUIPMENT FOR SATELLITE BROADCASTING AT 12 GHz IN JAPAN

Television satellite broadcasting at 12 GHz has started in Japan and small-size high-quality home receiving equipment which consists of an antenna and receiver, is in practical use [CCIR, 1982-86a].

Table V shows the characteristics being established as a baseline for design and mass production. For the characteristics, the following are taken into consideration:

- minimization of interference with other services, as well as mutual interference between indoor units;
- standardization of electrical and mechanical interface parameters in order to ensure interchangeability of units;
- maintenance of high reception quality and ensuring flexibility with respect to the extension of broadcasting services in the future.

Several circuit technologies are used to construct mass-production type outdoor and indoor units. Offset feed type antennas are exclusively used for the smaller sizes.

In August 1989, more than 1.7 million of the households were receiving programmes via the BS-2 satellite either by direct or by community reception and this number is rapidly increasing.

Table V also gives the average performance of mass produced receiving equipment available in the marketplace in the beginning of 1989. This is based on the experiences of nine manufacturers in Japan.

REFERENCES

CCIR Documents

[1982-86]: **a.** 10-11S/137 (Japan).

TABLE V – *Summary of basic characteristics of home receiving equipment in Japan*

<table>
<tr><th>Item</th><th colspan="2">Preferred characteristics (1)</th><th colspan="2">Results of measurements (2)</th></tr>
<tr><td>1. <i>General:</i>
– Receiving frequency (GHz)</td><td colspan="2">11.7-12.1</td><td colspan="2">–</td></tr>
<tr><td>– Figure of merit (dB(K^{−1}))</td><td colspan="2">6 (3)</td><td colspan="2">14.5 for 75 cm type</td></tr>
<tr><td>2. <i>Antenna:</i></td><td>Effective diameter (cm)</td><td>Gain (dB)</td><td colspan="2"></td></tr>
<tr><td>– Effective diameter and gain</td><td>45</td><td>32.0</td><td colspan="2">–</td></tr>
<tr><td></td><td>75</td><td>36.5</td><td colspan="2">37.7 (Efficiency = 68%)(4)</td></tr>
<tr><td></td><td>90</td><td>38.0</td><td colspan="2">–</td></tr>
<tr><td></td><td>100</td><td>39.0</td><td colspan="2">–</td></tr>
<tr><td></td><td>120</td><td>40.0</td><td colspan="2">41.2 (Efficiency = 65%)</td></tr>
<tr><td>– <i>Directivity:</i>
– half-power beamwidth</td><td colspan="2" rowspan="2">Fig. 2 of Report 810</td><td colspan="2">2°20'(for 75 cm type)</td></tr>
<tr><td>– side-lobe relative gain</td><td>6°: −31 dB
12°: −40 dB
18°: −45 dB</td><td>(for 75 cm type)</td></tr>
<tr><td>– polarization</td><td colspan="2">Circular polarization (RHCP)</td><td colspan="2">–</td></tr>
<tr><td>3. <i>Outdoor unit:</i>
– Noise figure (dB)</td><td colspan="2">< 4</td><td colspan="2">1.8</td></tr>
<tr><td>– Image frequency suppression (outdoor unit) (dB)</td><td colspan="2">> 31</td><td colspan="2">40</td></tr>
<tr><td>– Overall gain (dB)</td><td colspan="2">48 ± 4</td><td colspan="2">48 ± 2</td></tr>
<tr><td>– 1st local oscillator:
– frequency (GHz)</td><td colspan="2">10.678</td><td colspan="2">–</td></tr>
<tr><td>– stability (MHz)</td><td colspan="2">± 1.5 (4)</td><td colspan="2">± 1.0</td></tr>
<tr><td>– leakage power (dBm)</td><td colspan="2">< −30 (5)</td><td colspan="2">< −45</td></tr>
<tr><td>– 1st intermediate frequency (GHz)</td><td colspan="2">1.036-1.332</td><td colspan="2">–</td></tr>
<tr><td>4. <i>Indoor unit:</i>
– Leakage power at 2nd local oscillator (dBm)</td><td colspan="2">< −55</td><td colspan="2">< −60</td></tr>
<tr><td>– IF bandwidth (MHz)</td><td colspan="2">27</td><td colspan="2">–</td></tr>
<tr><td>5. <i>Performance:</i>
– Signal-to-noise ratio of the video signal (dB)</td><td colspan="2">> 37 peak-to-peak/r.m.s. (unweighted)</td><td colspan="2">38 peak-to-peak/r.m.s. (<i>C</i>/<i>N</i> = 14 dB)</td></tr>
<tr><td>– Bit error ratio of PCM signal</td><td colspan="2">< 3 × 10^{−4}
(before error correction, <i>C</i>/<i>N</i> = 9 dB)</td><td colspan="2">1.5 x 10^{−4}</td></tr>
</table>

(1) All characteristics shown in this table are considered to be satisfied within the standard environmental conditions which are specified individually.

(2) The values indicated are the mean value of samples at 11.85 GHz.

(3) Different figures may be selected dependent on system performance such as satellite e.i.r.p. and received quality.

(4) With automatic frequency control (AFC).

(5) This value is applicable when harmful interference to other services due to local oscillator leakage can be eliminated by an appropriate frequency arrangement.

ANNEX III

EXAMPLES OF CHARACTERISTICS OF RECEIVING EQUIPMENT IN ITALY [CCIR, 1986-90a]

TABLE VI

Item	Characteristics
1. Receiving frequency range (GHz)	11.7-12.5
2. Antenna diameter (cm)	60-90
3. Image frequency attenuation (dB)	> 90
4. Stability of local oscillator (LO) frequency (MHz)	± 1.6 for an LO frequency of 10.750 GHz
5. Maximum radiated power at the LO frequency (dBm)	−42
6. Output frequency range (GHz)	0.95-1.75
7. Noise figure of the outdoor unit (dB)	$\leqslant$ 2.0
8. Demodulation threshold of the indoor unit (dB)	$\leqslant$ 10
9. Clear sky C/N received from Olympus (dB)	**18.5-22**

REFERENCES

CCIR Documents

[1986-90]: a. 10-11S/145 (Italy)

ANNEX IV

EXAMPLES OF CHARACTERISTICS OF RECEIVING EQUIPMENT FOR TDF-1 (FRANCE)

TABLE VII

Type of antenna	C/N measured in clear sky (dB)	Calculated G/T in clear sky (dB(K^{-1}))	Stated noise figure (dB)
30 cm Ø dish focal feed on the axis of revolution	18	6.8	1.3
33 cm Ø dish rear feed helical source	18.2	7	1.8
Flat antenna 72 x 72 cm	20.5	9.3	2.3
49 cm Ø dish offset feed	21	9.7	1.8
55 cm Ø dish offset feed	21.7	10.4	2.9

Note - The nominal frequency of the first local oscillator is 10.750 GHz, and the first intermediate frequency is selected between 950 and 1 750 MHz.

ANNEX V

NOISE FIGURE DATA

Various data have been reported convering the input stages of receivers for satellite broadcasting. Table VIII is a summary.

TABLE VIII

Reported noise characteristics for satellite broadcasting receivers

No	Reference	Freq.	Low noise element	Noise Figure	Remarks
1	CCIR, 1978-82a(USA)	700MHz		1.5dB	
2	CCIR, 1978-82a(USA)	2.5GHz		1.5dB	
3	CCIR, 1978-82b(F)	12GHz	FET	3.6dB	BW=400MHz
4	CCIR, 1978-82c(J)	=	Direct conv.	4.1±0.25dB	2 years degradation 0.15dB
5		=	FET, NF=1.8dB	2.5dB	carefully adjusted
6		=		3.5dB	expected
7	Konishi, 1979,80	=	Dir. conv./FET	4dB	BW=800MHz
8	=	=		3.4-3.6dB	BW=300-500MHz
9	CCIR, 1978-82a(USA)	=		4dB	soon obtainable
10	=	=		4.5dB	reduce cost
11	Hirata, 1983	=	Monolithic MIC	4dB	
12	CCIR, 1982-86a(J)	=	GaAsFET MIC	2.5-3.0dB	BW=300MHz
13	CCIR,1986-90a(J)	12 GHz	HEMT	1.8 dB average	BW=300MHz
14	CCIR,1986-90b(J)	23 GHz	HEMT	5 dB	

REFERENCES

HIRATA, S. *et al.* [April, 1983] SHF receiver for satellite broadcasting. Proc. National Convention of IECE Japan, S7-14 (in Japanese).

KONISHI, Y. [June, 1979] Home receiver for broadcasting-satellite service. 11th International Television Symposium, Montreux, Switzerland.

KONISHI, Y. [May, 1980] Satellite broadcasting receiver – present and future. IEEE MTT-S International Microwave Symposium, Washington, DC, USA.

CCIR documents
[1978-82]: a.10-11S/141 (USA); b. 10-11S/16 (France); c. 10-11S/62 (Japan)
[1982-86]: a.10-11S/137(Japan)
[1986-90]: a.10-11S/104(Japan) b. 10-11S/25 (Japan);

ANNEX VI

RESULTS OF THE FIELD EXPERIENCES FOR SATELLITE BROADCASTING CABLE DISTRIBUTION SYSTEM IN JAPAN

Operational satellite broadcasting in Japan commenced in 1984 using the BS-2 satellite. At the end of August 1989, about 800,000 households were receiving satellite broadcasting programmes employing either AM or FM cable distribution. FM distribution techniques have advantages of transmission quality for both picture and digitally modulated sound and data programmes. Approximately 8,000 installations using FM distribution techniques were operating at that time and this number is increasing.

Studies concerning satellite broadcasting signal distribution by cable were carried out several times at different phases of development in Japan. Results show that one of the possible significant impairments in cable distribution systems is a flicker disturbance relating to the 15 Hz dispersal signal due to the echo resulting from mismatches in cable connections. Theoretical analysis, as well as laboratory and field tests predicted these effects and help identify practicable limits for the echo amplitude due to cable mismatches.

Figure 5 shows the relationship between the echo amplitude ratio and delay time in an FM distribution system which gives just perceptible flicker impairment for different picture patterns (Curves A) and also gives bit error ratio for the digital signal for sound and data (Curve B). Lines C and D show calculated echo delay and amplitude ratio in the cable connection predicted by the indicated loss and VSWR. According to these results, it is considered that a permissible value of VSWR for cable connections will be between 1.5 and 2, as compared with 2.5 for the case of individual reception.

A possible cause of worst case echoes may be due to open or short circuit conditions at the tap-off terminal. To keep reflections at the connection points to a minimum, it is necessary to define a minimum value of isolation at the tap-off terminal. For example, preferred characteristics of a trunk line tap-off unit is a VSWR of less than 1.2, and isolation between trunk line and receiver port more than 14 dB.

Compared to the requirements of an AM distribution system for conventional television systems, FM distribution systems require less stringent characteristics for most parameters except for the above-mentioned echo characteristics. If sufficient bandwidth is available and components such as signal combiners, distribution amplifiers and dividers with appropriate characteristics are chosen, FM cable distribution systems can provide acceptable performance.

According to the above field experience , it is confirmed that there are no major problems of applying FM distribution techniques to cable distribution systems.

ANNEX VII

MEASUREMENT RESULTS ON BSS SIGNALS DISTRIBUTED IN COMMUNITY RECEIVING INSTALLATIONS

1. Laboratory tests in France

Laboratory tests have been carried out in France [CCIR, 1986-90a] on D2, D, C-MAC/packet signals, with the modulation parameters specified in those of Report 1073, using a satellite simulator with characteristics very close to TDF-1, in order to evaluate the impairments on both sound/data and vision components introduced by a single echo, of different levels, added to the direct signal at the second IF of 230 MHz. The echo delay was equal to the bit interval of each system, i.e. 100 nsec for D2 and 50 nsec for both C and D. The phase difference between direct and delayed signals was adjusted to cause maximum impairment.

The tests included a 2.5 MHz offset of the carrier frequency with respect to the receiving filter, which corresponds to the operation of an AFC circuit based on the average picture content. For the C type signals both frequency demodulation by limiter/discriminator and 2-4 PSK differential demodulation were adopted.

The impairments on the sound/data component were measured in terms of C/N ratios, in 27 MHz, corresponding to a bit error ratio of 1×10^{-3}. For the MAC vision component the impairment was expressed by the decompressed luminance S/N ratio, using weighting network given in Recommendation 567-2 (1982).

2. Laboratory tests in Italy

In the experimental investigations carried out in Italy [Cominetti and Stroppiana, 1986]; [CCIR, 1986-90b] the C-MAC/packet signals were injected into the distribution network shown in Figure 7, which was laboratory implemented. This type of network structure, frequently found in existing installations, uses resistive dividers not perfectly matched to the main line, which are responsible for multiple reflections moving towards the head-end unit. The maximum impairments, due to the alterations of the amplitude and group-delay/frequency responses, were therefore measured at the fifth floor outlets.

Better matching would be achievable by adopting directional coupler dividers, generally used only in new installations. In order to assess the maximum expected impairments with respect to the ideal matching condition, in terms of C/N ratios, in 27 MHz, for a bit error ratio of 1×10^{-3} on the sound/data component, and in terms of C/N variations for the vision component, the carrier frequency was initially set to f_0 = 387 MHz, where significant irregularities affected the frequency response; and then offset step-by-step in the range of ± 10 MHz.

REFERENCES

COMINETTI, M., STROPPIANA, M. [November 1986] - Distribution of DBS signals of the MAC-family in collective antenna systems", Third International Conference on New Systems and Services in Telecommunication, Liége.

CCIR Documents

[1986-90]: a. 10-11S/56 (France); b. 10-11S/34 (Italy).

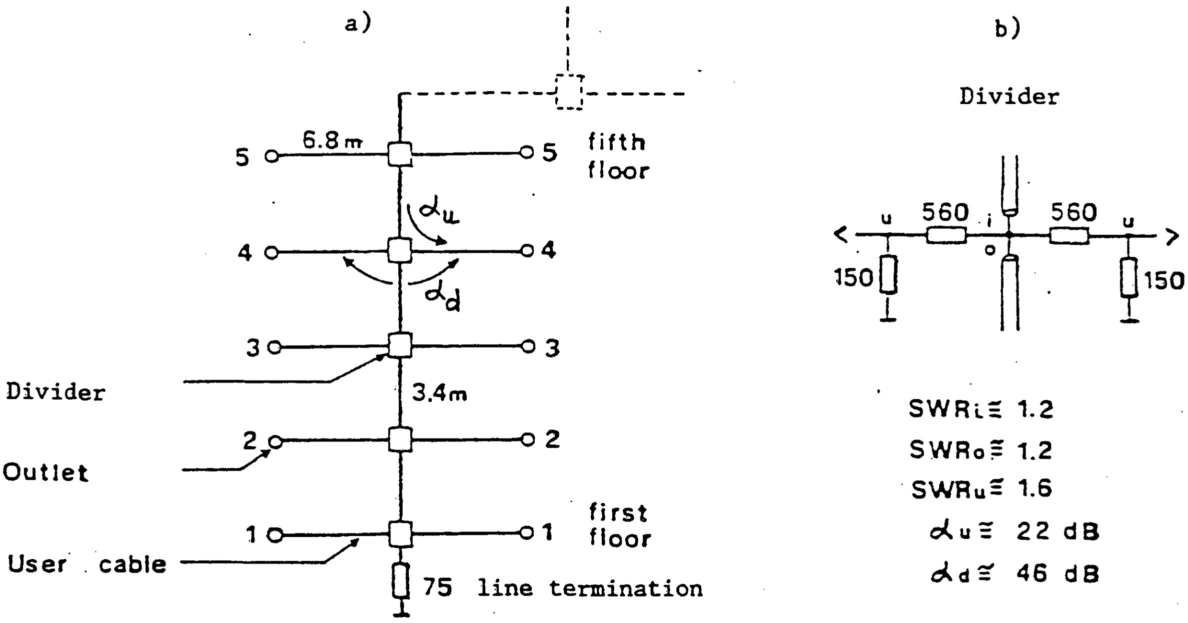

FIGURE 7

a) Typical distribution network used in small community antenna systems and adopted in the laboratory tests

b) Structure and characteristics of the user divider

ANNEX VIII

[CCIR, 1978-82a]

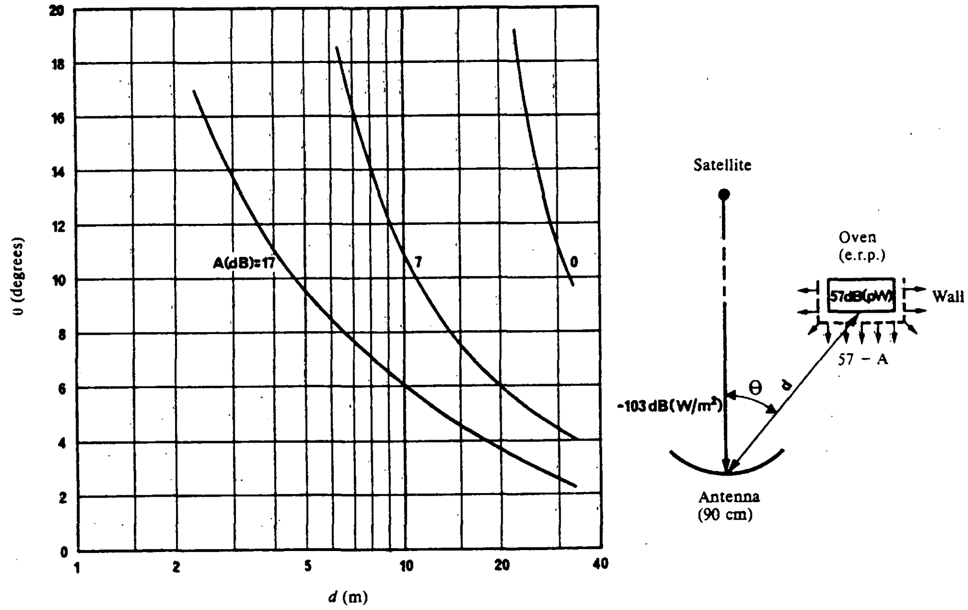

FIGURE 8 – *Limitation on the location of a receiver against the 5th harmonic radiation of a microwave oven including the shielding loss (A) due to the wall* (C/I = 30 dB)

REFERENCES

CCIR Documents

[1978-82]: **a.** 10-11S/113 (Japan).

REPORT 808-3*

BROADCASTING-SATELLITE SERVICE

Space-segment technology

(Question 2/10 and 11, Study Programme 2K/10 and 11)

(1978-1982-1986-1990)

1. Introduction

1.1 *General*

The large coverage area possible from a satellite-borne radio transmitter, especially on a satellite in the geostationary orbit, and the supporting technology which is available at present, will make possible the establishment of a broadcasting service to the general public. An earth-station transmitter could direct programme material to the satellite which, in turn, would broadcast this material over a wide area to individual or community receivers.

The technology applicable to the space segment of the broadcasting-satellite service is similar in many respects to the technology applicable to other satellite services. In a few areas, however, the technology needed for the broadcasting-satellite service will differ from that required in other services, and will require specialized research and development. These specialized areas include the generation of high RF power, high efficiency radio frequency generators, effective methods of heat conduction and dissipation from these high power RF sources, and the design and development of spacecraft antennas having low side-lobe levels and asymmetrically shaped beams.

The following sections of this Report are confined to discussions of these aspects of satellite design technology, apart from the last three mentioned above.

2. **Primary power** (see also Report 673)

2.1 *Solar arrays*

As a result of the increase in power requirements, attention has been directed to the use of light-weight sun-oriented arrays. Most of the interest is centred around photo-voltaic cells mounted on a flexible substrate which is either folded, or rolled on a drum during launch and transfer orbit [Ray and Winicor, 1966]. Deployment methods take several forms, as indicated in Annex I.

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 summarized in Annex I.

The ratio of primary power capability to the mass of broadcasting satellites in the geostationary orbit is dependent to some extent upon the attitude stabilization utilized (spin stabilized or 3-axis stabilized). A spin stabilized spacecraft in general will require more mass than a 3-axis stabilized spacecraft to provide equal prime power. Figure 1 shows the beginning of life; prime power and in-orbit mass for several representative spacecraft. The ratio of "beginning-of-life" to "end-of-life" power for a lifetime of 7 years is of the order of 1.3 to 1. The figure also indicates the approximate date at which the particular design was "frozen". The higher ratio of prime power capability-to-mass for the CTS and BSE spacecraft compared with the other examples results from the fact that they do not carry multiple transponders and the associated filters.

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 (see Fig. 2). 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.

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

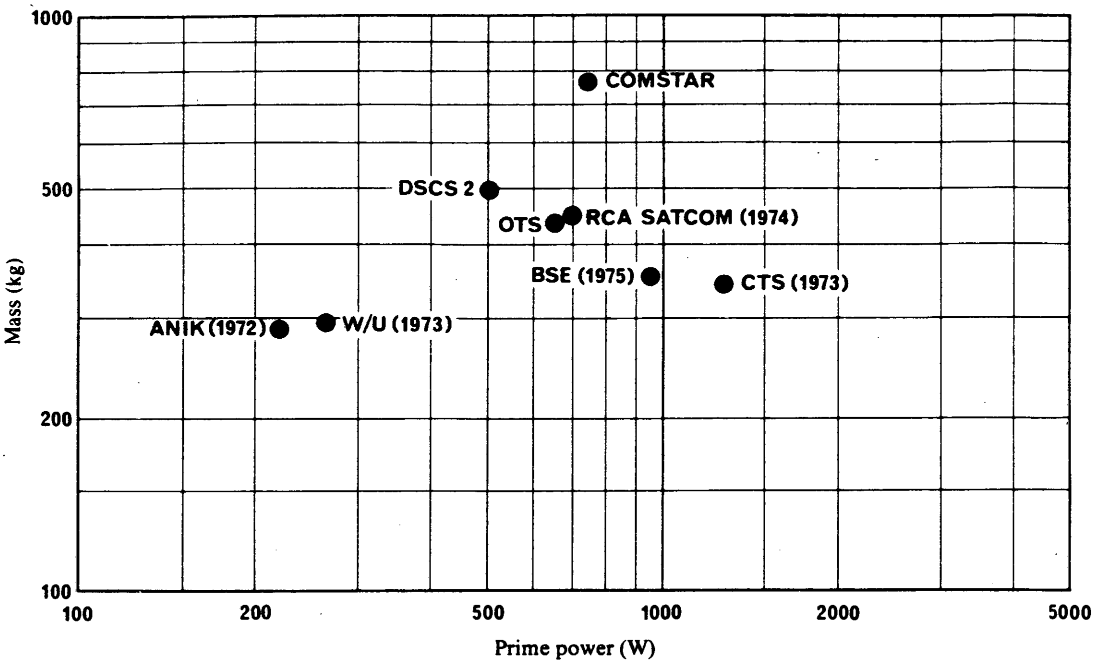

FIGURE 1 — *Relationships between in-orbit mass and prime power at beginning of life*

COMSTAR	(COMSAT General + AT&T satellite)
CTS	(Communications Technology Satellite)
BSE	(Japanese experimental broadcasting satellite)
W/U	(Western Union WESTAR)
ANIK	(Canadian communications satellite)
DSCS	(Defense Satellite Communications System)
OTS	(Orbiting Test Satellite)
RCA SATCOM	(RCA Americom satellite)

Note. – Dates in parentheses indicate approximate date at which the design was finalized.

Eclipses due to Moon shadow are not as regular in terms of times of occurrence, duration, and depth as Earth solar eclipses. 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. Table I gives a prediction for the period 1981 to 1990 for orbital position 110° longitude. 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; CCIR, 1978-82a; Siocos, 1981]. Table II gives the timetable of Moon solar eclipse occurrences for 19° W for the 18-year period, 1983-2000, while Fig. 3 provides information on their distribution of occurrence in terms of time of day and duration [CCIR, 1982-86a].

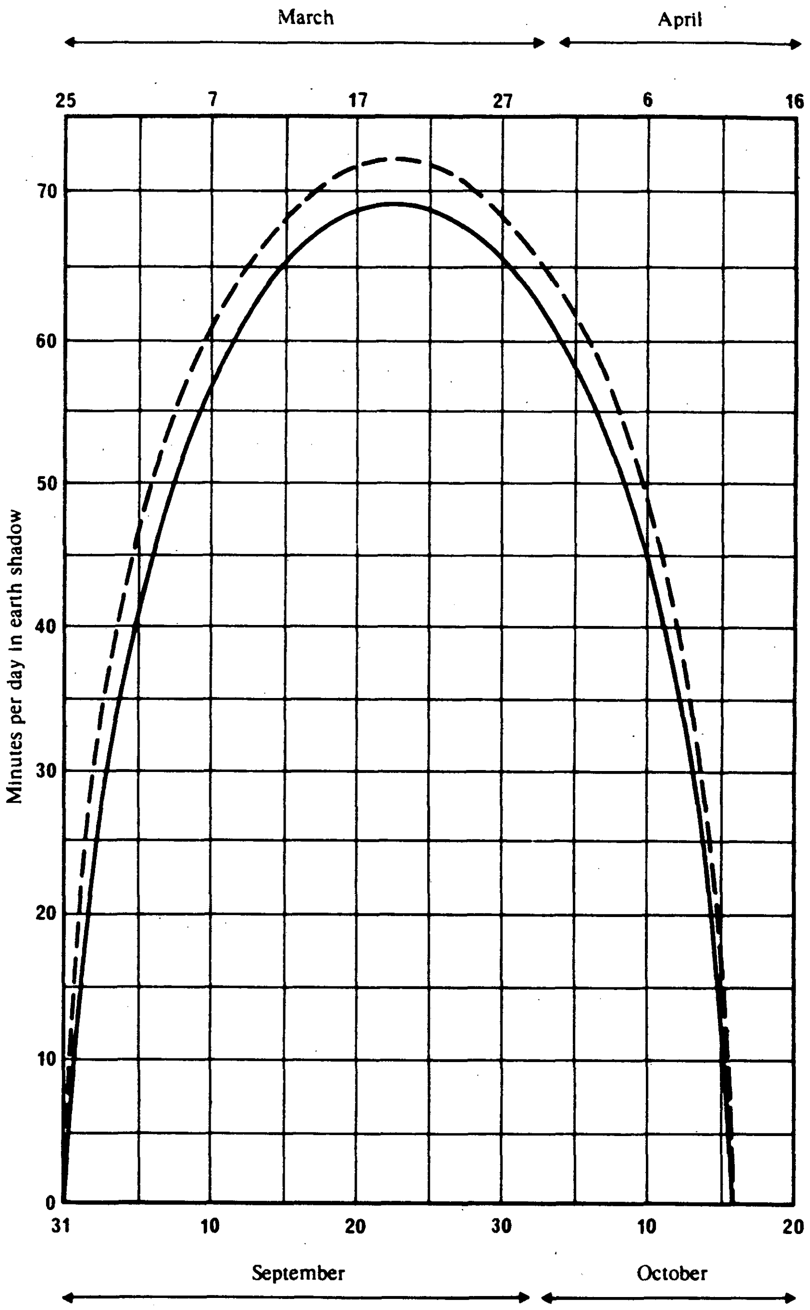

FIGURE 2 — *Shadow time during equinoctial periods in the synchronous orbit*

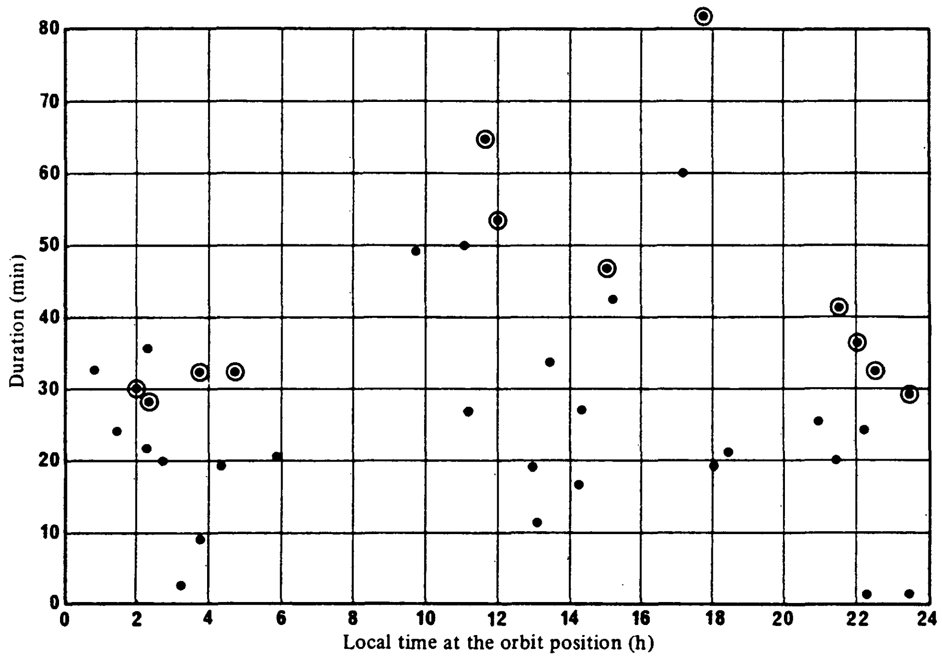

FIGURE 3 – *Distribution of Moon solar eclipses (19° W)*

● 0-50% shadowing

◉ 50-100% shadowing

TABLE I – *Predicted Moon solar eclipses at geostationary-satellite orbit. Position: 110° E longitude*

Date			Entrance time (UT)	Duration (min)	Shadowing (%)
1981	January	6	0252	56	85
	February	5	0832	102	86
	July	30	1924	30	39
	December	26	0134	66	96
1982	January	24	1926	32	35
1983	January	13	1926	22	11
	January	14	1330	38	61
	July	10	1524	14	9
	November	5	0802	140	62
1984	May	1	0516	44	40
1985	April	20	0450	20	4
	October	14	1250	38	69
1986	April	9	1354	34	43
1987	February	28	1054	66	44
	March	29	1538	28	59
	April	27	1856	26	19
	September	23	0448	42	47
1988	August	12	1516	32	69
	September	11	0404	44	56
1989	August	1	1622	10	3
	August	31	0340	38	30
1990	July	21	1902	28	48

TABLE II – *Timetable of Moon solar eclipses for geostationary satellites*

Position: 19° W longitude

Date	Entrance time (UT)	Duration (min)	Shadowing (%)
1983 January 14	0208	22.5	26
July 10	0410	18.2	19
July 10	2138	19	17
1984 January 3	0210	28.2	68
June 29	0146	23.5	45
October 24	1410	26.4	20
1985 May 19	0845	19.2	8
1986 May 9	0049	32.6	32
October 3	2330	28.1	65
1987 March 29	1337	31.9	32
August 24	2129	41.1	72
October 22	0632	17.7	7
1988 April 16	0429	32.4	68
September 11	0202	35.7	36
1989 February 6	1744	83.2	88
1990 June 22	2339	1	1
August 20	1257	11.5	8
1991 February 14	0626	14	7
February 14	1050	64.6	70
December 6	0154	27.2	66
1992 February 3	1006	47.5	18
November 24	0313	1	6
1993 May 21	2234	31.2	70
December 13	1516	21.8	10
1994 June 9	1525	42.7	36
November 3	2202	35.3	63
1995 April 29	1119	25.4	13
September 24	0606	21	23
1996 March 19	0358	8.6	8
October 12	1254	18.1	11
October 12	2215	1	2
1997 April 7	1456	44.2	50
April 7	2057	26.3	35
1999 January 17	1203	51.4	100
February 16	0239	19.2	24
February 16	1716	60.1	37
August 11	0344	31.4	84
2000 January 6	1055	50.4	27

Arrays of silicon solar cells have served quite satisfactorily as the prime power source in satellites and are likely to be employed in this application for many years to come. The theoretical limit (approximately 25%) on the efficiency of silicon solar cells is much higher than the efficiencies now being realized. Therefore, several efforts are under way to improve the efficiency of the silicon solar cell [Lindmayer and Allison, 1973; Revesz, 1973; Arndt, 1974; Statler and Treble, 1974; Haynos *et al.*, 1974].

2.2 *Batteries*

Batteries can be employed to provide a limited operational capability during eclipse. However, to provide full operational capability for the high power requirement would greatly increase the weight of the satellite. The practical consequences of Earth solar eclipse outage can be minimized by having the service break occur after prime viewing time (normally taken after midnight) in the service area, by placing the satellite to the west of its service area. However, it will not be possible to overcome the effects of the Moon solar eclipse occurrences by such techniques, as this phenomenon is not as regular in times of occurrence, duration and depth as Earth solar eclipses (see § 2.1).

The elimination of eclipse protection constraints may significantly enhance planning flexibility and could increase the orbit-spectrum resources available for planning.

State-of-the-art battery technology makes it feasible to support eclipse operation of a significant number of channels for small service areas using the lowest capacity, low-cost spacecraft being considered for the broadcasting-satellite service. As an example, analysis has shown that STS/PAM-D class spacecraft* can support a communication payload capacity of 350 W RF power at the high power amplifier (HPA) output by battery operation through the full Earth solar eclipse period.

Table III illustrates the number of eclipse-operated channels for two typical levels of maximum e.i.r.p. for 7 to 10-year service lifetime. A TWT efficiency of 45% was assumed in the analysis [CCIR, 1982-86b].

TABLE III – *Eclipse operation capability for 7-10 year service lifetime using STS/PAM-D class spacecraft*

Beam diameter (degrees)	Maximum e.i.r.p. (¹) 58 dBW		Maximum e.i.r.p. (¹) 62 dBW	
	HPA output power per channel (W)	Maximum number of channels	HPA output power per channel (W)	Maximum number of channels
0.8	19	18	48	7
1.2	43	8	108	3
1.6	76	4	191	2
2.0	119	2	300	1
2.2	138	2	350	1

(¹) Assumes 1.5 dB of TWT output circuit loss.

2.3 *Other power sources*

Nuclear reactors and fuel cells are possible sources of primary power, but additional development will be required before they will be competitive with solar arrays in terms of cost, mass and reliability.

Thermoelectric junctions and thermionic cells may also be considered as a means of converting heat from the Sun or from isotope sources into electrical energy, and offer the possibility of less total mass in the power unit for a given electrical output. Work is in progress on the development of such devices and their application to spacecraft [IEE, 1968].

3. **Radio-frequency power**

3.1 *Summary of radio-frequency power limits*

The final stage of the broadcasting transmitter is the major consumer of power on the satellite. Solid-state transmitter modules for a frequency of about 860 MHz and at power levels of about 100 W have been demonstrated by the USA on the Applications Technology Satellite-6 (ATS-6). Twenty watt solid state transmitters at 2.6 GHz have also been demonstrated on ATS-6. Appreciably higher powers, particularly at higher frequencies, will require vacuum tubes. For the frequency range 2 to 20 GHz, travelling-wave tubes or klystrons might provide maximum powers in the range of 1 to 7.5 kW, depending on the frequency. An efficiency of 35 to 65%, including any loss in power conditioning units, can be achieved with these systems. A 200 W travelling-wave tube with an efficiency of about 50% at 12 GHz was used in the US/Canadian Communications Technology Satellite Programme. For the 12 GHz band, Table IV provides pertinent parameters for existing travelling-wave tubes (TWTs) applicable for broadcasting satellites.

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* STS/PAM-D class spacecraft: spacecraft generally having a mass of 1250 kg in transfer orbit.

The total radio-frequency output power is limited by the solar array power, the losses in the power conditioning sub-system, and the transmitter efficiency. The output power of a single tube is limited by cathode loading and beam compression. The power in a waveguide component is limited by radio-frequency breakdown and heating. Other factors which impose practical constraints on spacecraft transmitter power include spacecraft weight, power flux-density limits applicable in particular frequency ranges, and the consequences of interference on the efficient use of the geostationary arc.

TABLE IV – *Travelling-wave tubes for broadcasting satellites*

	20-30 W	100-110 W	120-140 W	230 W	235 W	230-260 W	100 W	200 W	450 W
RF circuit	Helix	Helix	Helix	Helix	Helix	Helix	Coupled cavity	Coupled cavity	Coupled cavity
Number of collectors	1-3	4	4	4	5	5	3	10	5
Nominal efficiency (%)	35-40	50	50	52	50	49	50	48	50
Instantaneous bandwidth (MHz)	200	200	300	105-200	400	105-200	180	85	100-200
Design lifetime (years)	7-10	7-10	7-10	7-10	10	7-10	3	3	7-10
Collector cooling	Conduction	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation
Collector/body dissipation (%)	–	70/30	70/30	70/30	70/30	70/30	40/60	40/60	70/30
Mass (kg)	1.0	3.0	3.2	2.5	4.5	3.5	6.8	11.9	6.8
Programme	OTS, ECS, TDRSS and others	BS-2	BS-3	TDF-1 & TDF-2	OLYMPUS	TV SAT TDF-1 TDF-2 Tele-X	BSE	CTS/HERMES	–
Status (1989)	Flown and qualified	Flown	To be flown 1990	Flown	Flown	Flown	Flown	Flown	Engineering model

3.2 *Equivalent isotropically radiated power and its stability*

For a given zone of coverage, say 2°, maximum values of e.i.r.p. of 75 dBW at 700 MHz and perhaps 70 dBW at 12 GHz can be expected with still higher powers likely to be technically feasible at a later date.

Based on measurements obtained from the BSE programme over a two-year period, the standard deviation of the variation of the transmitting power was determined to be less than 0.2 dB [CCIR, 1978-82b].

3.3 *Thermal control*

The major problems are associated with heat rejection from the power conditioning components and from the high-power stages of the transmitter. Solid-state components lend themselves to simple passive methods of control. However, the low operating temperatures (350 K to 390 K) require a significant amount of radiator area. Other devices, such as gridded tubes and microwave tubes, have high heat dissipation densities and high temperatures. The higher operating temperatures (470 K to 500 K) minimize the radiator area requirements.

The development of heat pipes provides a promising method of heat transfer from the source to the radiator. Heat pipes have been used for thermal control on spacecraft [Anand, 1968] and in heat rejection from high power tubes on the ground.

4. Station keeping and attitude control

This section treats the operational requirements for, and the status of technology relating to, station-keeping and attitude control of geostationary satellites.

The possibility of physical interference between spacecraft in the geostationary orbit, and the blockage of the emissions of one satellite by another, the countermeasures that could be employed, and the estimates of the increase in fuel mass that could be required, are discussed in Report 1004.

4.1 *Station keeping*

The slight inequalities in the gravitational field of the Earth, together with the gravitational forces due to the Sun and Moon have perturbing effects on satellites which otherwise would remain stationary, but these can be encountered by orbit correction or "station-keeping" techniques.

A geostationary satellite will experience extremely slight eastward or westward forces which change the longitudinal drift of the satellite.

Other perturbing forces tend to change the inclination of the orbital plane by approximately 0.8° per year, thereby causing the satellite to undergo corresponding daily variations in latitude.

Present station-keeping techniques develop corrective thrust to overcome the gravitational forces by the use of small propulsion jets on the satellite, operated by propellants stored on board. The extent to which correction is required depends upon the allowable displacement of the satellite.

East-west (longitudinal) station-keeping is usually essential, because the uncorrected drift may be relatively large and rapid. Fortunately, the required rate of propellant consumption is very low. North-south (latitudinal) station-keeping, to keep the orbit close to the plane of the equator, will become more important as satellites achieve longer life. Latitude station-keeping requires about ten times the amount of propellant as does longitude station-keeping.

For frequencies up to 1 GHz, where the required beamwidth of the receiving antenna is not expected to be less than 5°, a station-keeping accuracy of 1° will be sufficient to ensure that the satellite remains in the beam of receiving antennas. Above 1 GHz, accuracies of the order of 0.25° may be required. The longitudinal drift for satellites at present in the geostationary orbit can be held to 0.1° during a satellite lifetime of at least five years. Satellites now under construction will be capable of controlling the daily variation in latitude to the same accuracy. Station-keeping techniques for achieving the orbital accuracy required for a geostationary broadcasting satellite are, therefore, technically feasible.

Station-keeping of the order of 0.1° is desirable to maximize the efficiency of utilization of the geostationary satellite orbit spectrum space. As a general rule, satellite drift should be limited to 5% or less of the spacing between adjacent satellites.

4.2 *Attitude control*

The pointing accuracy of the satellite antenna beams is very important in satellite broadcasting in order to obtain the best utilization of the antenna directivity. On the other hand, solar pressure and thermal gradient are the causes of depointing of the satellite antenna beams. To maintain the pointing of the antenna, it is therefore necessary to control the attitude of the satellite with as high an accuracy as possible. This accuracy depends mainly on the type of sensor and on the system chosen for the attitude control.

Attitude control for all three axes of a geostationary satellite is generally required to maintain coverage of the desired service area and to minimize spillover. In some rare applications, it may be sufficient to provide control of only the pitch and roll axes [CCIR, 1978-82c]. However, this would require an axially symmetrical (i.e. circular) circularly polarized antenna beam pointed at the sub-satellite point (an unlikely situation that will not be treated further since the satellite is normally positioned west of the service area to delay the onset of solar eclipse) or pointed with radio-frequency sensors toward a beacon located at the centre of the service area. Generally, even this latter case would benefit by controlling all three satellite axes when solar array mispointing and propellant budget factors are considered.

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

Allowing for satellite attitude angle errors, the boresight error circle of the transmitting antenna should be capable of being maintained within 0.1° radius. With the introduction of improved systems (e.g. radio-frequency sensing; see Report 546) this error could be considerable reduced. Measurements made on the TDF-1 satellite have shown that a boresight error circle of 0.01° radius can be achieved.

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.

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 a combination of earth sensor and radio-frequency monopulse sensor, almost throughout the day [Shimizu *et al.*, 1980]. (An angle of approximately 7° was subtended between the earth station beacon transmitter and the sub-satellite point as viewed from the satellite.)

The relationships between attitude errors and movement of the antenna footprint on the Earth's surface are described in Report 546. A range of values is given, reflecting future developments in recognition of the critical effect of pointing error on planning.

5. Transmitting antennas

The maximum gain of an antenna and the way in which the gain decreases as a function of angle is important in interference calculations. Therefore, guidelines are required as to the probable performance of transmitting antennas for satellite broadcasting and of receiving antennas on the ground. A detailed examination of antenna patterns and technology is given in Report 810.

6. Coverage

The area of the Earth covered by a satellite antenna beam, and the shape of that area, depend on the satellite antenna pattern *per se*, and also on the pointing offset of the beam from the satellite nadir (the sub-satellite point). Since the satellite is not at the origin of the terrestrial co-ordinate system, the antenna pattern co-ordinates are not linearly related to the terrestrial co-ordinates. Methods for calculating Earth "footprints" of satellite antennas are available in the literature [for example, Jacobs and Stacey, 1971; Adamy, 1974].

7. Lifetime

Current system planning assumes a mean satellite life of about seven years. So far, studies and the performance of satellite systems encourage the view that a life expectancy of up to ten years can be achieved by careful design and provision of certain reserve equipments. In particular, the solar panels must be large enough to allow for the progressive deterioration that takes place in space. Fuel requirements for station-keeping and attitude stabilization may well be large, possibly of the order of 20% to 25% of the mass of the satellite if existing techniques are employed. With the advent of ion thrusters, less fuel will be required to realize the same manoeuvring functions. These thrusters may eventually replace traditional gas propulsion systems. However, these new thrusters are still in the developmental stage and full evaluation still has to be determined (see Report 843).

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[1978-82]: **a.** 10-11S/60 (Canada); **b.** 10-11S/114 (Japan); **c.** 10-11S/114 (USA).

[1982-86]: **a.** 10-11S/14 (France); **b.** 10-11S/59 (Canada).

ANNEX I

DEVELOPMENT OF LIGHT-WEIGHT SOLAR ARRAYS

The purpose of this Annex is to summarize the performance characteristics which might be expected from new developments in the technology of light-weight, deployed solar arrays. It provides a summary of development on light-weight solar arrays and may serve as a basis for determination of future research and development work in this area.

During the past several years there has been a considerable effort by a number of organizations to develop light-weight, deployed solar arrays. Two distinct types of solar arrays have been studied; namely, deployed, rigid arrays and deployed, flexible arrays.

The deployed, rigid arrays have been exclusively the fold-out type either folded around the satellite body during transfer orbit or contained in a flat pack, accordion fold, arrangement during transfer orbit. Deployment occurs in several steps usually commencing with the pyrotechnic release of latches or the cutting of cables. Depending on the type of array, the deployment continues with the solar panels unfolding, followed by the extension of a yoke mechanism to separate the array from the spacecraft. The deployed array is normally locked in place at the panel hinges. With a rigid array, transfer orbit power is readily obtained from the outer side of the stowed panels.

There are two basic types of deployable, flexible substrate arrays; fold-out and roll-out. The fold-out solar arrays use a flat pack concept to contain the solar cell blanket during launch. The deployment sequence begins with the pyrotechnic opening of a box or release of latches or cables holding the array against the spacecraft body. Deployment of the folded blanket takes place by extension of a pantograph, a boom, or a telescopic mast system attached to the blanket. During transfer orbit, the roll-out array is wrapped around a drum attached to the spacecraft. During deployment, the solar cell blanket is rolled out by the extension of a boom which is attached to the blanket. For both fold-out and roll-out systems a yoke is used to separate the array from the spacecraft.

A major advantage of flexible, fold-out systems over flexible, roll-out systems is their inherent higher packing density, since no drum is required. This allows for easier integration of a fold-out system to a spacecraft within a launch fairing. Usually for both types of flexible arrays an additional array is required to provide transfer orbit power during launch to geostationary orbit. In some advanced fold-out, flexible designs this power is provided by incorporating the transfer orbit panels into the flexible array.

Table V shows the weight-to-power and power-to-weight ratios for several deployed, rigid solar arrays. This Table is based on a one kilowatt wing of a two kilowatt solar array system. It first lists the weight-to-power at beginning of life, equinox conditions, including the array with its blanket, deployment, yoke, and stowage systems. The orientation mechanism weight-to-power ratio is broken out separately as is an estimated miscellaneous category to cover redundancy items such as redundant orientation mechanism motor windings and/or electronics, redundant latching, insulation, etc. The power-to-weight ratio at end of life (5 years) summer solstice conditions is also given. Finally, the effect of advanced cells on the power-to-weight ratio is shown. The end effect on the overall array of changing to advanced cells was estimated at 15 per cent which was assumed uniformly. It should be noted in Table V and later, in Table VI that in going from a designed or tested solar array system to a flight-qualified array, extra weight is estimated to provide for redundancy, temperature control, etc. It is even more evident when the Fleetsatcom or CTS and FRUSA numbers are compared to the typical early design numbers. Several examples of rigid solar arrays are shown. The first one listed which is being developed for an operational spacecraft is Fleetsatcom. The Fleetsatcom array is a rigid deployable array, initially folded around the periphery of the spacecraft. It uses conventional aluminium honeycomb substrates and solar cells.

TABLE V – *Comparison between deployable rigid solar arrays*

Type of array	FLEETSATCOM TRW - conventional, rigid foldout	MBB-ICS foldout (carbon fibre)		MBB-ULP (very light materials)		Matra foldout (glass fibre technology)		Flight type arrays Post 1980 (estimate)
		A	B(1)	A	B(1)	A	B(1)	
Array, including deployment and stowage, at beginning of life, Equinox (kg/kW)	54.0	31.0	31.0	18	18	28.6	28.6	
Orientation mechanism (kg/kW)	7.7	(4.3)	(3.4)	(4.3)	(3.4)	(4.3)	(3.4)	
Miscellaneous(2) (kg/kW)	Included in above	(1.5)		(1.5)		(1.5)		
Total at beginning of life, Equinox (kg/kW)	61.7	36.8	34.4	23.8	21.4	34.4	32.0	25
Total at beginning of life, Equinox (W/kg)	16.2	27.2	29.1	42.0	46.7	29.1	31.3	40
Total at end of life, 5 years, summer Solstice (W/kg)	11.4	20.9	22.4	27.7	30.8	20.4	21.9	26
Total at end of life (5 years), summer Solstice if advanced cells are used (W/kg)	13.1	24.1	25.8	31.9	35.4	23.5	25.2	Included in above
Reference	[1]	[2]		[3]		[4]		

( ) Assumed value, since a real value is not provided.

(1) Column B uses a lighter weight suggested by the Royal Aircraft Establishment (RAE) for the orientation mechanism and excludes any miscellaneous items.

(2) Includes any redundancy required in the orientation mechanism; for example, motor windings, any insulation required, redundant latches, etc.

The Messerschmitt-Bölkow-Blohm GmbH (MBB) improved composite structure (ICS) array uses aluminium honeycomb substrates and carbon fibre reinforced epoxy (CRFP) facesheets in a flat pack design with the deployment energy supplied by spiral springs on the panel hinges. This concept will be used on the ESA, OTS and Marots satellites. The ultra light-weight panel (ULP) is an advance on the ICS system using the same deployment approach but including a carbon fibre framework and very light-weight solar panels. The Matra system uses a flat pack design with aluminium honeycomb substrates and glass fibre faceskins. Deployment is by springs and hinges along with a cable and pulley system.

The MBB-ICS system shown utilizes 125 micron solar cells whereas the Matra analysis is based on 200 micron solar cells. Consequently, the MBB-ICS system is lighter and shows less degradation than the Matra system, at the end of five years. However, the availability of 125 micron cells in the large quantities necessary for production spacecraft is questionable. These systems may have to depend on the heavier cell.

The last column represents an estimate on weight-to-power for advanced flight-type systems for use in the post-1980 time period.

TABLE VI – *Comparison between deployable, flexible solar arrays*

Type of array	SNIAS flexible foldout	RAE flexible foldout	CTS flexible foldout	Hughes FRUSA flexible roll-out	Flight-type arrays Post-1980 (estimate)
Array, including deployment and stowage, at beginning of life, Equinox (kg/kW)	23.0	16.6	37.7	35.8	–
Orientation mechanism (kg/kW)	4.3	3.4	Included in above	Included in above	–
Miscellaneous (1) (kg/kW)	1.5	–	Included in above	Included in above	–
Total at beginning of life, Equinox (kg/kW)	28.8	20.0	37.7	35.8	18
Total at beginning of life, Equinox (W/kg)	34.7	50.0	26.5	27.9	56
Total at end of life, 5 years, summer Solstice (W/kg)	22.9	36.2	17.5	18.4	37
Total at end of life (5 years), summer Solstice if advanced cells are used (W/kg)	26.3	41.6	20.1	21.2	Included in above
Reference	[5]	[6]	[7]	[1]	

(1) Includes any redundancy required in the orientation mechanism; for example, motor windings or electronics; any insulation required; redundant latches, etc.

The data in Tables V and VI are based on the following sources:

[1] BILLERBECK, W. J. and CURTIN, D. J. [1974] Flexible solar array applications in communications satellites. Proc. Intersociety Energy Conversion Engineering Conference, San Francisco, California, USA.

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[6] TREBLE, F. C. [1974] The RAE lightweight solar array. Royal Aircraft Establishment Technical Report 73172. (Numbers contained in this report were upgraded to a 1 kW system by F. C. Treble.)

[7] SACHDEV, S. S., QUITTNER, E. and GRAHAM, J. D. [September, 1974] The Communications Technology Satellite deployable solar array sub-system. International Conference on Photovoltaic Power Generation, Hamburg, Germany (Federal Republic of).

Table VI is similar to Table V except that it concerns flexible substrate solar arrays. It includes data on several solar arrays. The array developed by AEROSPATIALE uses a pantograph, fold-out system with launch stowage in an aluminium honeycomb-walled box. The pantograph is spring loaded and self deploys when released. The rate is controlled by a winch and motor. The solar cells are mounted on a Kapton substrate designed in modular form to be usable for different power levels.

The Royal Aircraft Establishment solar array, based on the background of a 280 W hardware development programme, as proposed, would use a pneumatically actuated telescopic mast to deploy a light-weight flexible, foldout panel using 125 micron wrap around contact solar cells. The light-weight orientation mechanism is based on design estimates by Hawker-Siddeley Dynamics. RAE also indicates that transfer orbit power could be provided by a light-weight rigid panel which would be part of the flexible array. As with the MBB-ICS system, the RAE estimates are based on using the 125 micron cells; consequently, the degradation rate is less than with other systems.

The Communications Technology Satellite (CTS) array is a flexible, fold-out array deployed by a Bi-Stem boom. This satellite was launched in January 1976. The data given is based on direct scaling of the actual array. Since the CTS array consists of two wings with approximately one kilowatt total at end of life, it is not optimized as a one kilowatt/wing system. Consequently, the numbers shown are heavier than would be expected in a two-wing, one kilowatt per wing array. On the basis of one kilowatt per wing, the CTS system would be expected to achieve at least 20 W/kg at the end of life.

The flexible rolled-up solar array (FRUSA) system is a flexible roll-out solar array deployed by a Bi-Stem boom. The FRUSA array was built by Hughes Aircraft Company and launched in 1971. It performed successfully and provided several months of useful data.

The last column in Table VI is the estimate on weight-to-power for flight-type flexible solar arrays for use in advanced flight-type systems in the post-1980 time period. It must be stressed that in both Tables V and VI these are estimates based on information available at present. Particular missions or new, unique types of arrays could change these estimates.

ANNEX II

Annex II gives a representative summary of pointing accuracies obtained with American communication satellites in 1976.

TABLE VII

Item	Error (degrees)	
	North-South	*East-West*
Long-term variations:		
– station keeping	±0.02	±0.01
– attitude determination	±0.01	±0.01
– antenna thermal distortion	±0.04	±0.04
– attitude drift	±0.1	±0.1
Sum of square roots	±0.11	±0.11
Short-term variations:		
– spin (pitch)	not available	±0.035
– nutation	±0.04	±0.02
Total error	±0.150	±0.185

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SECTION 10/11D: PLANNING

Reports

REPORT 633-3

ORBIT AND FREQUENCY PLANNING IN THE BROADCASTING-SATELLITE SERVICE

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

(1974-1978-1982-1986)

1. Introduction

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

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

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

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

2. Guidelines toward efficient planning

2.1 *General principles*

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

2.1.1 *Orthogonal polarization*

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

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

2.1.2 *Frequency interleaving*

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

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

2.1.3 *Crossed-path geometry*

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

2.1.4 *Clustering*

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

2.1.5 *Homogeneity of systems*

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

2.1.6 *Feeder link considerations*

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

There may be cases where the feeder link and the down-link service areas are not coincident. For example, an administration whose territory spans several time zones may find it desirable to serve each time zone from a different orbital position in order to obtain better eclipse protection, and at the same time to be able to access each satellite from any point within its territory that has an adequate elevation angle. These matters received particular attention in the RARC SAT-83, which demonstrated the advantages of simultaneous planning of the feeder links and down links.

2.1.7 *Protection ratio*

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

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

2.2 *Geographic considerations*

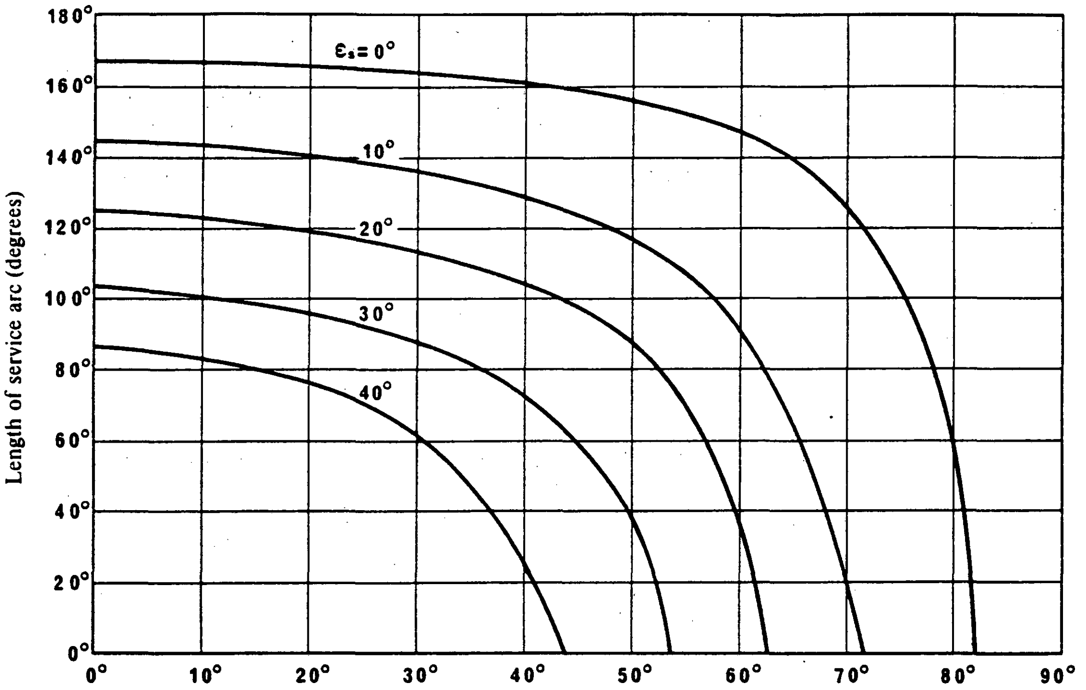
Geographic features affect the use of the geostationary orbit in two ways: they determine the usable service arcs for the given service areas, and they interact in various degrees with the three techniques employed for the re-use of the same frequencies.

2.2.1 *Service arcs*

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

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

- *Latitude:* For a single receiver and for an assumed minimum angle of elevation, the length of the service arc is a function of latitude only. Figure 1 shows the length of the service arc for such a point as a function of latitude for angles of elevation from 0° to 40°. For an area that is narrow in latitude, so that all of its points are approximately at the same latitude, this length is decreased by the distance (measured in degrees of longitude) between its easternmost and westernmost points;
- *Size and shape:* The service arc of an extended area of irregular shape is determined by the latitude and longitude of the two points in the area at which the elevation angle first falls below the given value as the satellite moves east or west, respectively. These points frequently are not obvious by inspection and must be determined by trial and error or by graphical means. In general, the larger the service area and the higher its latitude, the smaller its service arc. As far as shape is concerned, a long narrow service area has a smaller service arc than a roughly circular one of the same size. For a service area near the equator, the east-west dimension tends to be the determining one; for a service area nearer one of the poles, the east-west dimension at the highest latitude is critical.



Latitude (degrees)

FIGURE 1 – *Service arc of single receiver*

(ε_s: angle of elevation)

2.2.2 *Frequency re-use*

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

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

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

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

Service areas can be covered in three general ways:

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

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

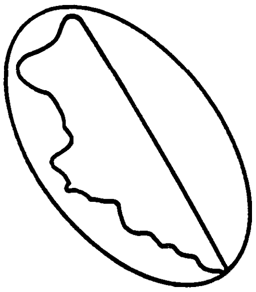


FIGURE 2 – *Single elliptical beam*

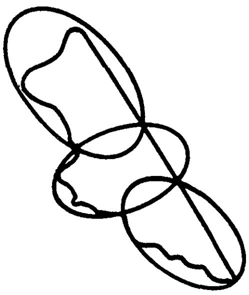


FIGURE 3 – *Multiple elliptical beam*

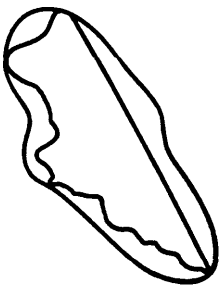


FIGURE 4 – *Shaped beam*

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

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

2.3 *Broadcasting-satellite systems for community reception*

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

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

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

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

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

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

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

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

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

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

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

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

3. Key elements

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

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

Each of the key elements will be discussed in turn.

3.1 *Service requirements*

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

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

3.1.1 *Examples of factors relating to the required service*

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

3.2 *Technical parameters and interference criteria*

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

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

3.2.1 *Examples of factors relating mainly to technical standards*

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

3.3 *Structure and allotments*

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

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

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

3.3.1 *Examples of characteristics determined by the plan*

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

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

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

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

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

3.4 *Modification*

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

4. Planning approaches

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

4.1 *Detailed orbital position and channel allotment plan*

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

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

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

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

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

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

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

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

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

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

4.2 *Detailed orbital position and block frequency allotment plan*

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

4.3 *Detailed frequency assignment and orbital arc allotment plan*

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

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

4.4 *Guaranteed access by means of multilateral coordination*

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

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

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

5. **Procedures for detailed a priori planning**

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

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

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

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

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

5.1 *Planning with regular channel distributions*

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

5.2 *Definition of regular distribution*

A regular distribution is characterized by:

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

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

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

The total number of channels C is given by:

$$C = tC_1 \tag{1}$$

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

The carrier spacing Δ is given by:

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

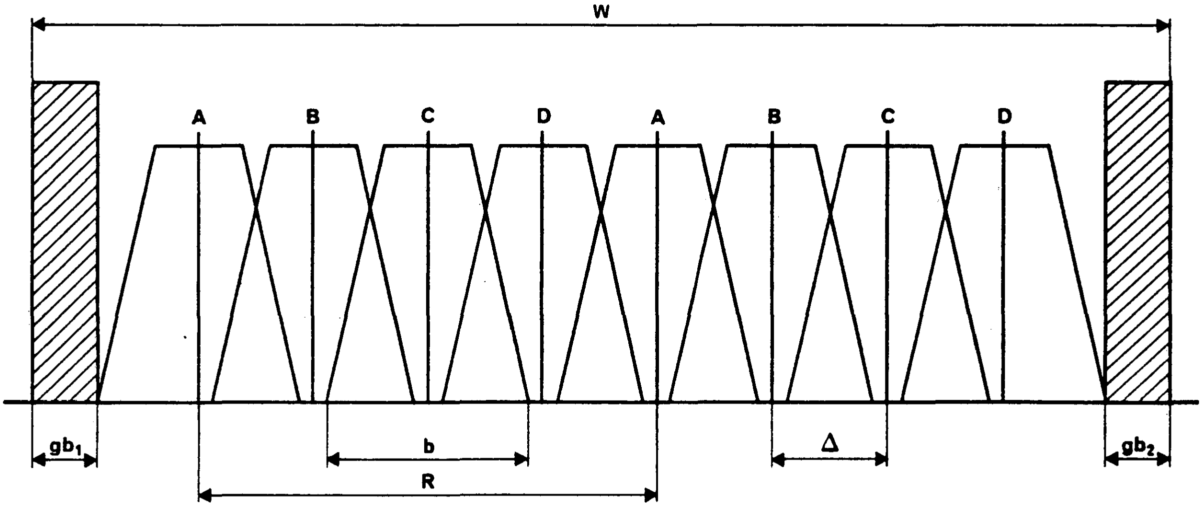
where:

W: the total bandwidth including the two guard bands;

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

b: necessary channel bandwidth.

This can readily be seen from Fig. 5.



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

FIGURE 5 – *Example of a regular channel distribution*

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

5.3 *Constraints on distributions*

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

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

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

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

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

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

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

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

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

5.4 *Non-regular distributions*

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

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

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

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

5.5 *Standardization of carrier position and spacing*

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

6. Calculation of the total interference

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

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

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

$$
\begin{aligned}
G &= G_1 \cdot \cos^2 \beta + G_2 \cdot \sin^2 \beta \qquad (4)\\
G_1 &= G_{tp} \cdot G_{rp} \cdot A + G_{tc} \cdot G_{rc} \cdot A + G_{tp} \cdot G_{rc} \cdot A \cdot X + G_{tc} \cdot G_{rp} \cdot A \cdot X\\
G_2 &= (\sqrt{G_{tp} \cdot G_{rc} \cdot A} + \sqrt{G_{tc} \cdot G_{rp} \cdot A})^2 + G_{tp} \cdot G_{rp} \cdot A \cdot X + G_{tc} \cdot G_{rc} \cdot A \cdot X
\end{aligned}
$$

where:

β : for linear polarization, is the relative alignment angle between the received signal polarization plane and the plane of polarization of the receive antenna, and, for circular polarization, $\beta = 0°$ is assumed to correspond to co-polar transmission and reception and $\beta = 90°$ is assumed to correspond to mutually cross-polarized transmission and reception;

G : gain (power ratio > 1);

A : co-polar attenuation on the interfering partial link (as a power ratio $\leqslant 1$);

X : cross-polar discrimination on the interfering partial link (as a power ratio $\lessdot 1$);

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

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

where:

f: frequency (GHz); and

ε_s : satellite elevation angle as seen from the earth station (degrees).

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

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

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

where:

P_R : power received (dBW),

P_T : transmitting antenna power (dBW),

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

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

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

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

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

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

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

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

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

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

where:

A : foul weather signal attenuation (dB);

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

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

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

7. Principal planning steps

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

These matrices can be used:

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

7.3 *Interference matrix for reception*

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

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

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

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

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

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

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

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

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

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

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

8. Criteria for planning approach selection and plan assessment

8.1 *Criteria for selection of a planning approach*

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

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

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

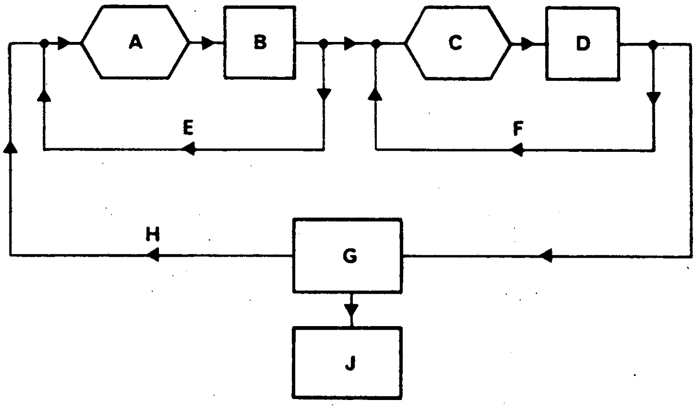


FIGURE 7a – *Process for planning the feeder links and down links in the broadcasting-satellite service*

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

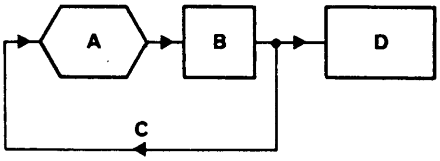


FIGURE 7b – *Simplified process for the simultaneous planning of the feeder links and the down links*

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

8.1.1 *Equitable access*

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

8.1.2 *Service requirements*

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

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

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

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

8.1.4 *Accommodation of existing systems*

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

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

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

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

8.1.6 *Restrictions due to sharing with other services*

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

8.1.7 *Efficient use of the orbit-spectrum*

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

8.1.7.2 Is there incentive to use optimum technical standards?

8.1.8 *Impact on satellite system costs*

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

8.1.9 *Administrative costs*

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

8.2 *Plan assessment*

8.2.1 *Introduction*

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

8.2.2 *Efficient use of the orbit-spectrum resource*

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

8.2.3 *Protection margins*

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

8.2.3.1 *Overall co-channel protection margin*

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

8.2.3.2 *Overall adjacent-channel protection margins*

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

8.2.3.3 *Overall equivalent protection margin*

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

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

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

8.2.4 *Worst-case scenario testing*

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

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

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

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

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

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

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

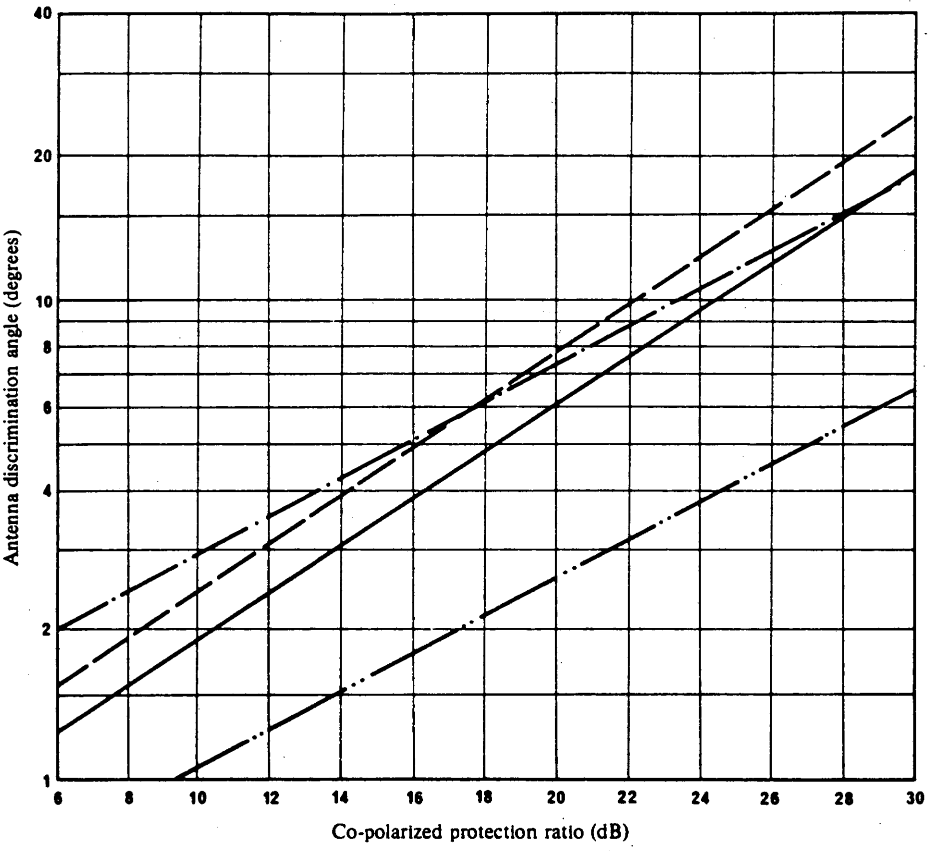


FIGURE 8 – *Protection ratio as a function of antenna discrimination angle for frequency sharing between broadcasting satellites*

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

10. Results of the Plan for Region 2

10.1 *The Plan*

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

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

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

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

10.2 *Special geographical features of Region 2*

10.2.1 *Boundaries*

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

10.2.2 *Division into sub-regions*

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

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

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

10.2.3 *Consequences*

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

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

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

11.1 *Introduction*

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

11.2 *2.6 GHz systems*[*]

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

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

TABLE II

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

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

Pattern B: $\Delta G =$ 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.

11.3 *700 MHz systems*[*]

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

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

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

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

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

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

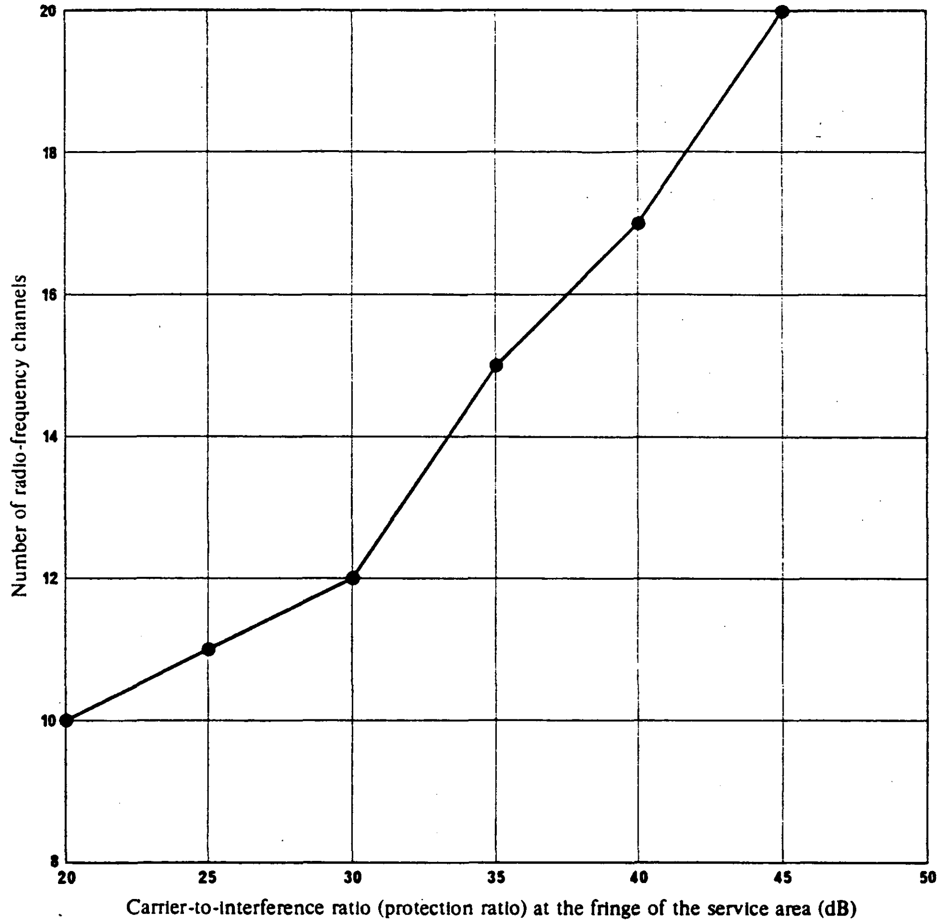

FIGURE 9 – *Number of radio-frequency channels required to provide one national programme to about thirty countries of a continent as a function of the carrier-to-interference ratio*

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

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

12. Spacecraft service functions

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

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

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

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

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

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

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

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REPORT 811-2

BROADCASTING-SATELLITE SERVICE

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

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

(1978-1982-1986)

1. Introduction

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

2. Planning elements

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

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

3. System characteristics

3.1 *Polarization*

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

3.2 *Angle of elevation*

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

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

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

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

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

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

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

TABLE I – *Summary of planning elements*

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

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

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

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

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

3.3 *Service quality and availability objectives*

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

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

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

3.4 *Figure of merit and type of receiver*

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

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

3.5 *Satellite transmit antenna beams*

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

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

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

3.6 *Antenna gain at edge of coverage area*

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

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

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

3.7 *Minimum channel spacing and satellite output multiplexer losses*

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

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

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

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

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

3.8 *Variations in output power*

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

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

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

3.9 *Pointing accuracy of the antenna beam*

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

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

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

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

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

4. Power flux-density required

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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REPORT 814-2

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

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

(1978-1982-1986)

1. Introduction

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

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

2. Comparison between linear and circular polarization

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

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

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

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

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

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

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

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

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

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

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

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

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

3. Experimental results

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

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

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

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

(¹) C: circular L: linear

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

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

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

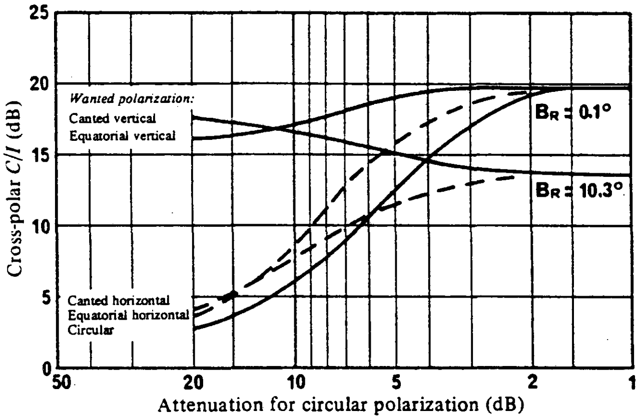

FIGURE 1 – *Availability of cross-polar C/I at edge of coverage area between co-located satellites serving adjacent beam areas.*
(The antennas are assumed to be perfectly aligned.)

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

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

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

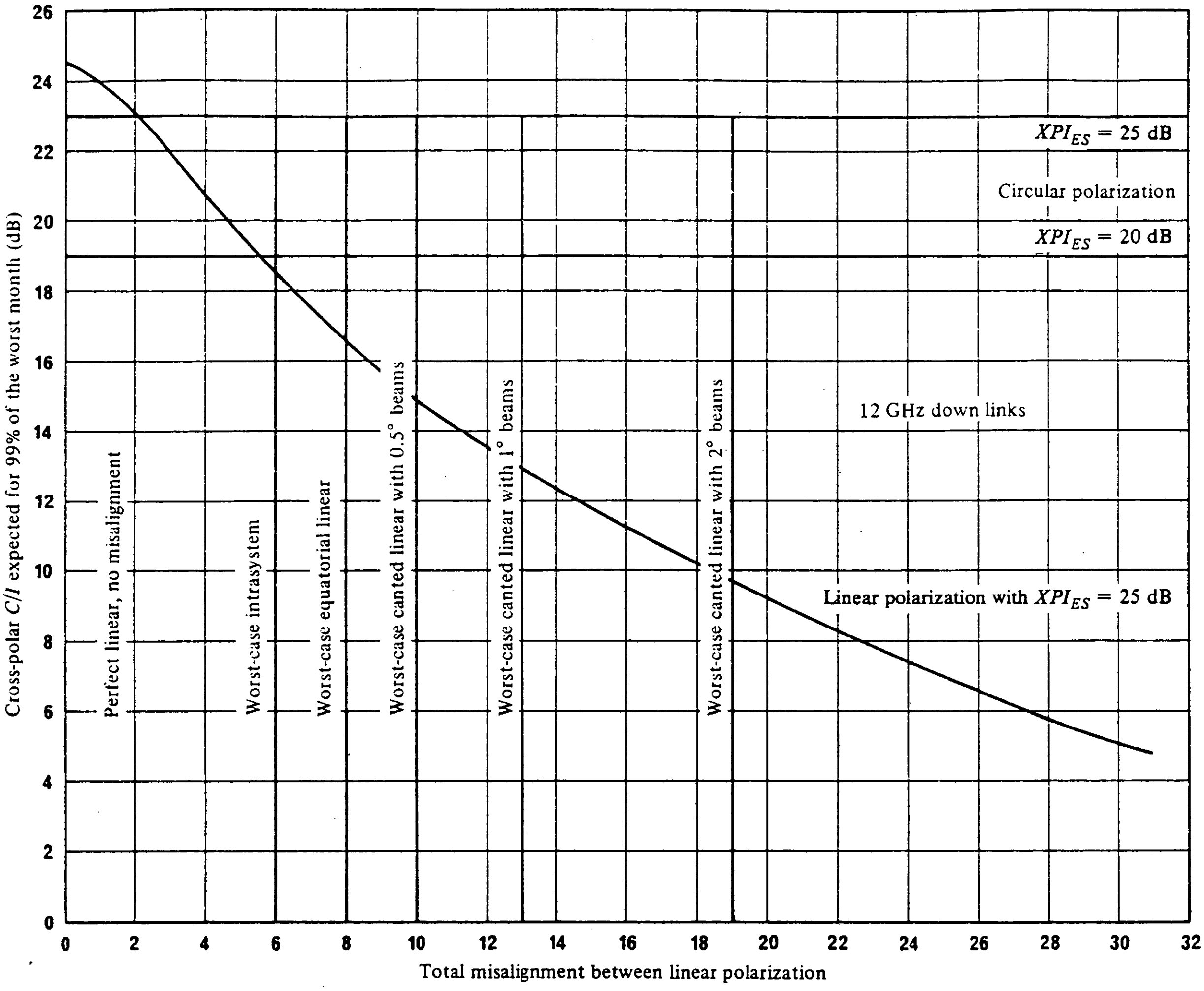

FIGURE 2 – *Clear sky cross-polar C/I between adjacent satellite beams transmitted from a satellite to an earth station located at the common point of the −3 dB contours*

(The best case of equatorial linear and circular polarization and the worst case of canted linear polarization are illustrated)

REFERENCES

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

CCIR Documents

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

ANNEX I

EFFECTS OF SYSTEM GEOMETRY ON LINEAR POLARIZATION

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

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

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

where:

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

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

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

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

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

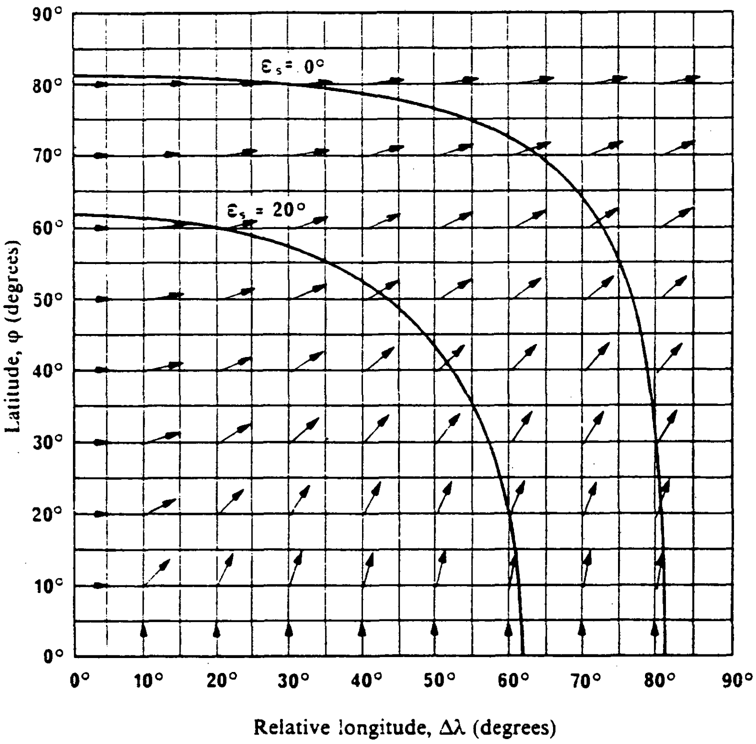

FIGURE 3 – *Variation of received angle of polarization on the Earth*

ε_s: angle of elevation

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

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

REPORT 952-2*

TECHNICAL CHARACTERISTICS OF FEEDER LINKS TO BROADCASTING SATELLITES

Elements required for the establishment of plans of frequency assignments and orbital positions for the broadcasting-satellite service and the associated feeder links – Sharing in the feeder-link bands

(Question 1/10 and 11, Study Programmes 1B/10 and 11, 2J/10 and 11)

(1982-1986-1990)

1. Introduction

The purpose of this report is to deal with the technical characteristics and operational constraints for the feeder links to broadcasting satellites.

This report examines exclusively the feeder links for 12 GHz broadcasting satellites, since feeder link Plans for the 12 GHz broadcasting satellite are established (see § 2) and very little is known about the problem related to feeder links for broadcasting satellites operating at frequencies other than 12 GHz.

2. 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 the feeder links to the 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).

The WARC ORB-85 selected the frequency bands 17.3-18.1 GHz and 14.5-14.8 GHz (for countries outside Europe and for Malta) for feeder-link assignment planning in Regions 1 and 3. It decided not to use the frequency band 10.7-11.7 GHz for the feeder-link assignment Plan.

A Plan for feeder links to Region 2 broadcasting satellites was developed for the 17.3-17.8 GHz band at the RARC SAT-83.

A Plan for feeder links to Regions 1 and 3 broadcasting satellites was developed in the frequency bands 14.5 - 14.8 GHz and 17.3 - 18.1 GHz at the WARC ORB(88) Conference. The 14.5 - 14.8 GHz band was used for certain countries outside Europe.

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* This Report should be brought to the attention of Study Groups 4 and 9.

3. System design and technical characteristics

3.1 *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 § 5 to 9, while further general system considerations are summarized below.

In some cases, broadcasting satellites will have a single, primary feeder-link earth station for each set of down links within a single service area. In other cases, it may be desirable to allow for the location of feeder-link earth stations anywhere within a predetermined feeder-link service area. Such feeder links will normally employ a primary earth station with a comparatively large antenna and high transmit power. This specificity as to the "primary earth station" was not considered in the planning of the feeder links in Region 2. Small fixed and transportable earth stations providing a direct connection to an experimental satellite have already been used and their number can be expected to increase as the broadcasting-satellite service develops [CCIR, 1978-82a].

Recognizing that the service quality objectives of these small earth stations could be less than those of the primary stations, their use should be taken into account to the maximum extent possible.

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 the feeder-link 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;
- 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.

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.

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.

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 under this light.

3.2 *Partitioning of noise between feeder links and down links*

The WARC-BS-77 adopted for the purposes of planning a maximum reduction of 0.5 dB of the overall carrier-to-noise ratio, to represent the contribution of the feeder link to that ratio for 99% of the worst month. That corresponds to a difference of about 10 dB (see Report 215) between the carrier-to-noise ratios of the down links and feeder links.

According to an EBU study [CCIR, 1978-82b], the contribution of the noise resulting from the feeder link may be rendered negligible by adopting a relatively small margin in the carrier-to-noise ratio of the down link, This study considered the case of automatic gain control in the satellite and was based on a statistical analysis of the attenuations on the feeder link and down link. The probability of having an overall carrier-to-noise ratio less than a given value is expressed by a general formula given in [CCIR, 1978-82b].

Numerical applications have been made assuming that the attenuations (in dB) follow a log-normal relationship for which the parameters fit measurements made in Europe. It is seen, first, that the results obtained assuming either total correlation or total independence between feeder-link and down-link fadings, are more or less identical. The influence of a margin of 0.5 dB on the down link, however, is crucial. The improvement due to this margin is better than that obtained by dimensioning the C/N ratio of the feeder link for 99.9% of the worst month instead of for 99%. Hence, if we take a down-link C/N ratio of 14 dB for 99% of the worst month, the noise contribution from the feeder link to the overall circuit makes the overall link C/N drop below 14 dB 50% to 10% more often (depending on whether the feeder link is dimensioned to give a C/N ratio of 24 dB for 99% or 99.9% of the worst month). If account is taken of the 0.5 dB margin on the down link, the percentage of the time during which the overall C/N drops below 14 dB, including the noise contribution of the feeder link, is still smaller than the specified 1% of the worst month in both cases.

This result confirms the suitability of the choice, made by the WARC-BS-77, to take account of the feeder link by means of such a margin, even at frequencies of the order of 18 GHz.

Similar studies were conducted in Canada on the effects of rain attenuation and satellite transponder characteristics as related to the partitioning of the noise contributions on the feeder links and down links in a broadcasting-satellite service [CCIR, 1978-82c].

Some of the results can be found in Fig. 1, where the same assumptions as in the above-mentioned study were made. The curves in this figure represent the degradation of the down-link C/N due to the noise contribution from the feeder link, $(C/N_d - C/N_t)$ as a function of the difference between the C/N of the feeder link and the C/N of the down link $(C/N_u - C/N_d)$. Full correlation and independence of the fadings on both links are illustrated. All C/N values are specified for 99% of the worst month.

Partitioning of noise need not be specified as a planning element for Region 2 because the overall carrier-to-noise ratio is the applicable criterion when planning feeder links and down links at the same time. However, some assumption of noise partitioning is required in order to determine feeder-link characteristics, such as e.i.r.p. needed to satisfy broadcasting-satellite service requirements.

As a guidance to the development of the Plans for Region 2 and Regions 1 and 3, the noise contribution of the feeder link to the overall link was assumed not to exceed 0.5 dB for 99% of the worst month.

3.3 *Feeder-link carrier-to-noise ratio*

Assuming that there is no transponder output back-off, a 0.5 dB noise contribution of the feeder link to the overall link requires that:

$$(C/N)_u = (C/N)_d + 10 \qquad \text{dB} \qquad (1)$$

is exceeded for 99% of the worst month. Under clear-sky conditions, the $(C/N)_u$ is then:

$$(C/N)_u = (C/N)_d + 10 + L_{Att} \qquad \text{dB} \qquad (2)$$

where:

$(C/N)_u$: feeder-link carrier-to-noise ratio,

$(C/N)_d$: down-link carrier-to-noise ratio, and

L_{Au} : feeder-link rain attenuation exceeded for 1% of the worst month.

A margin of 1 dB is also needed for planning purposes for possible mispointing of the earth-station transmitting antenna.

Furthermore, the high-power, non-linear amplifier of the repeater introduces, on account of its AM/PM conversion factor, a degradation by the thermal noise in the demodulated signal. The impairment caused to the frequency demodulated signal by the AM/PM phenomenon is given by:

$$D = \frac{\alpha + I}{1 + I} \qquad (3)$$

where:

D: decrease in post detection signal-to-noise ratio (S/N) (see Fig. 2) due to increase in post-detection noise in the presence of AM/PM conversion.

$I = (C/N)_u/(C/N)_d$

$\alpha = 1 + \left(\frac{K}{6.6}\right)^2$ (for frequency modulation).

K: AM/PM conversion factor.

K is of the order of 5 to 6 degrees/dB with present-day amplifier technology. This gives a value for α in the region of 2.0-2.6 dB, which has been demonstrated theoretically and experimentally [CCIR, 1982-86a].

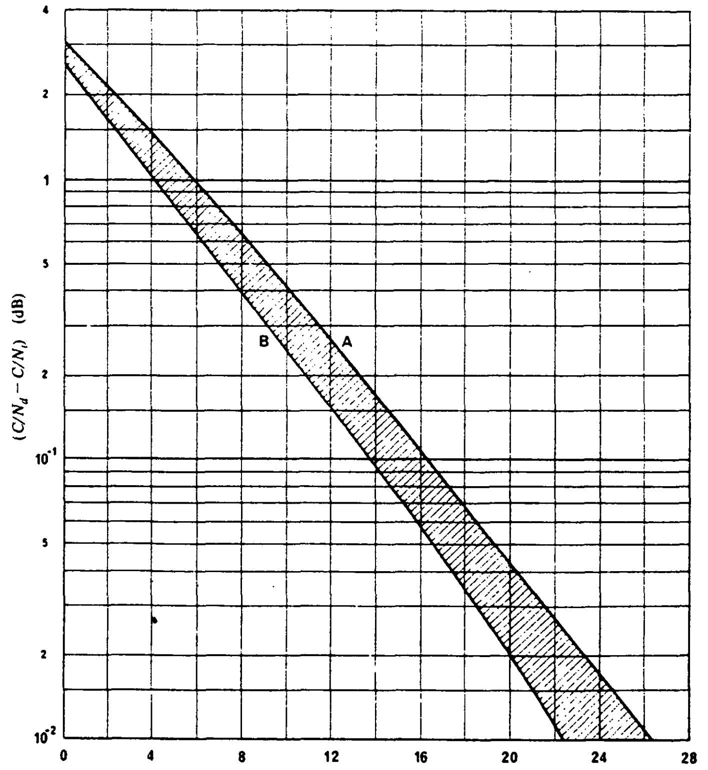

FIGURE 1 – *Noise contribution of the feeder link*

A: correlated
B: uncorrelated

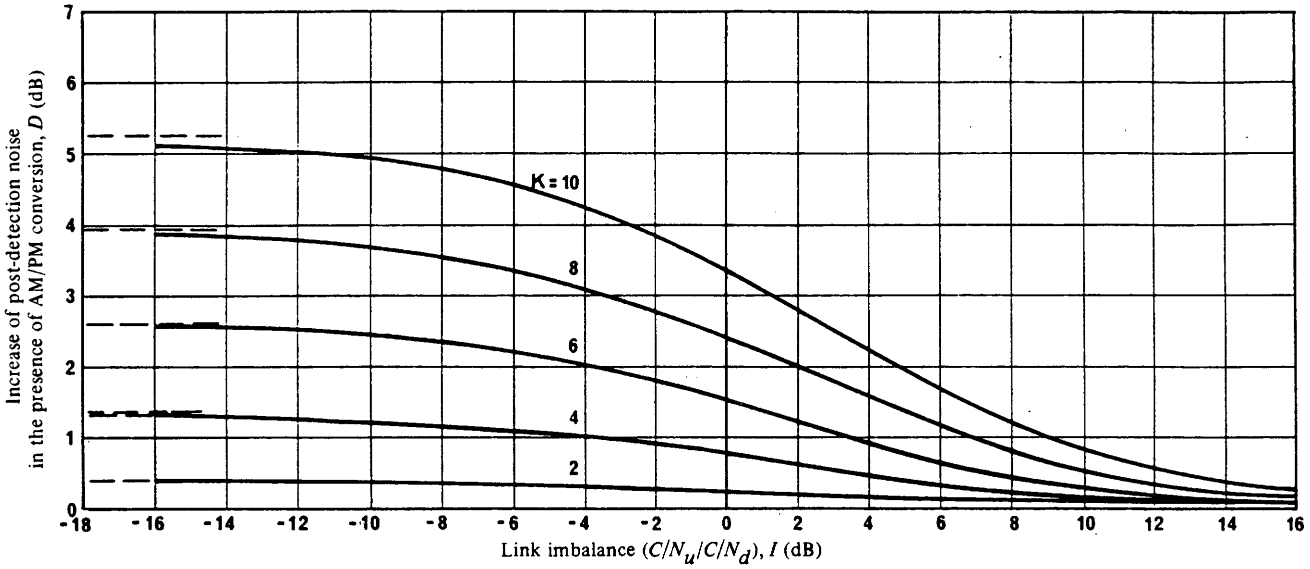

FIGURE 2 – *Effect of AM/PM conversion on the post-detection noise power*

K : AM/PM conversion factor (degrees/dB)

— — —: I → -∞ dB

The degradation caused by AM/PM conversion cannot be observed by means of direct radio-frequency carrier-to-noise ratio (C/N) measurements. However, this degradation can be measured by other means. It must be taken into account when calculating feeder-link budgets and can be compensated for by an increase in C/N_u of 10 log α dB. AM/PM conversion was not taken into account in the development of the Region 2 Plan.

In a plan based on homogeneous characteristics of feeder-link stations which in turn leads to homogeneous nominal (clear sky) power flux-densities at the satellites, the C/N_u varies with satellite receive antenna gain. In Region 2, the range of interest of the satellite receive antenna gain at the −3 dB edge of coverage area varies from about 28 dB for a large country-wide feeder-link beam of 3° × 8° to 46 dB for a small spot beam of 0.6°. With a system noise temperature at the satellite of 1500 K, which is readily achievable for satellite receivers at 18 GHz, the range of interest of G/T varies from −4 dB(K^{-1}) to 14 dB(K^{-1}) at the edge of coverage area. The choice of feeder-link power into the transmitting antenna may be in the range of 500 to 1000 W. The Region 2 feeder-link Plan is based on a maximum radio-frequency power of 1000 W delivered at the input of the feeder-link antenna. Table I gives a range of C/N_u at 17.5 GHz assuming an antenna efficiency of 65%, a filter bandwidth of 24 MHz and 1 dB gain loss due to mispointing of the earth-station antenna for 500 and 1000 W transmitted power. In Region 2, the Plan is based on a 5 m antenna diameter but larger and/or smaller antennas can be used.

For example, in the case of a 14.5 dB C/N_d on the down link and a possible 1 dB mispointing of the earth-station transmitter antenna, a very small number of cases in Table I would give a noise contribution of the feeder link greater than 0.5 dB to the overall noise of the communication channels. These few cases are italicized in the Table. In Regions 1 and 3, the Plan is based on 5 and 6 m antenna diameters for frequency bands 17 and 14 GHz respectively and 500 W transmitter power. These values correspond to an e.i.r.p. of 84 and 82 dBW respectively and aim to achieve a carrier-to-noise ratio (C/N) of 24 dB exceeded for 99% of the worst month.

TABLE I – *Range of carrier-to-noise ratio calculated for earth-station antenna mispointed by 1 dB and transmitting 500 or 1000 W of power* (Region 2)(1)

Earth-station antenna diameter (m)	Minimum G/T of satellite receive antenna (edge of coverage area) (dB(K^{-1}))	Carrier-to-noise ratio C/N_u (dB)					
		Clear sky		With 5 dB rainfall attenuation		With 10 dB rainfall attenuation	
		Transmitted power (W)					
		500	1000	500	1000	500	1000
2.5	– 4	*19.2*	*22.2*	*14.2*	*17.2*	*9.2*	*12.2*
	+ 2	25.2	28.2	*20.2*	*23.2*	*15.2*	*18.2*
	+ 8	31.2	34.2	26.2	29.2	*21.2*	*24.2*
	+14	37.2	40.2	32.2	35.2	27.2	30.2
5	– 4	25.2	28.2	*20.2*	*23.2*	*15.2*	*18.2*
	+ 2	31.2	34.2	26.2	29.2	*21.2*	*24.2*
	+ 8	37.2	40.2	32.2	35.2	27.2	30.2
	+14	43.2	46.2	38.2	41.2	33.2	36.2
8	– 4	29.3	32.3	24.3	27.3	*19.3*	*22.3*
	+ 2	35.3	38.3	30.3	33.3	25.3	28.3
	+ 8	41.3	44.3	36.3	39.3	31.3	34.3
	+14	47.3	50.3	42.3	45.3	37.3	40.3
11	– 4	32.1	35.1	27.1	30.1	*22.1*	25.1
	+ 2	38.1	41.1	33.1	36.1	28.1	31.1
	+ 8	44.1	47.1	39.1	42.1	34.1	37.1
	+14	50.1	53.1	45.1	48.1	40.1	43.1

Note 1 - In case of the feeder link Plan for Regions 1 and 3, the figures in Table I should be reduced by 0.5 dB with a reference bandwidth of 27 MHz.

3.4 *Influence of the atmosphere*

3.4.1 *Rainfall attenuation*

The feeder-link signal will suffer attenuation 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.

Rainfall attenuation will result in decreased values for C/N and C/I on the feeder link. In addition, C/N on the down link will decrease unless automatic gain control is used on the satellite to maintain the satellite transponder at or near saturation.

The propagation model for feeder links in Regions 1 and 3 using circularly polarized signals is based on the value of rain attenuation for 1% of the worst month.

WARC-ORB(88) adopted the method for calculation of the rainfall attenuation as follows:

The mean zero-degree isotherm height h_F is:

$$h_F = 5.1 - 2.15 \log \left[1 + 10^{\frac{(|\zeta| - 27)}{25}} \right] \quad \text{(km)}$$

where ζ is the latitude of the earth station (degrees).

The rain height h_R is:

$$h_R = C \cdot h_F$$

where $C = 0.6$ for $0° \leq |\zeta| < 20°$

$C = 0.6 + 0.02\ (|\zeta| - 20)$ for $20° \leq |\zeta| < 40°$

$C = 1$ for $|\zeta| \geq 40°$

The slant-path length, L_s, below the rain height is:

$$L_s = \frac{2(h_R - h_o)}{\left[\sin^2 \theta + 2 \dfrac{(h_R - h_o)}{R_e} \right]^{\frac{1}{2}} + \sin \theta} \quad \text{(km)}$$

where h_o = the height above mean sea level of the earth station (km)

θ = the elevation angle (degrees)

R_e = the effective radius of the Earth (i.e. 8,500 km).

The horizontal projection, L_G, of the slant path is:

$$L_G = L_s \cos \theta \quad \text{(km)}$$

The rain path reduction factor $r_{0.01}$ for 0.01% of the time is:

$$r_{0.01} = \frac{90}{90 + 4\ L_G}$$

The specific attenuation γ_R, is determined from:

$$\gamma_R = k \, (R_{0.01})^{\alpha} \quad \text{(dB/km)}$$

where $R_{0.01}$ is given in Table II for each rain climatic zone. The frequency dependent coefficients k and α are given in Table III. The rain climatic zones are given in Report 563.

Table II - Rainfall intensity $R_{0.01}$ for the rain climatic zones (exceeded for 0.01% of an average year)

Rain climatic zone	A	B	C	D	E	F	G	H	J	K	L	M	N	P
Rainfall intensity $R_{0.01}$ (mm/h)	8	12	15	19	22	28	30	32	35	42	60	63	95	145

Table III - Frequency dependent coefficients

Frequency* (GHz)	k	α	
14.65	0.0327	1.149	For Regions 1 and 3
17.5	0.0521	1.114	For Region 2
17.7	0.0531	1.110	For Regions 1 and 3

---

* Mean frequencies of the feeder-link bands.

The rainfall attenuation exceeded for 1% of the worst month is:

$$A_{1\%} = 0.223 \, \gamma_R L_s \, r_{0.01} \quad \text{(dB) for Regions 1 and 3}$$

$$A_{1\%} = 0.21 \, \gamma_R L_s \, r_{0.01} \quad \text{(dB) for Region 2.}$$

For the calculation of power control described in Section 5.4.4, the rainfall attenuation for 0.1% of the worst month is used. It can be calculated as follows:

$$A_{0.1\%} = 3.3 \, A_{1\%}$$

3.4.2 *Depolarization*

Both rain and ice can cause depolarization of signals and thereby reduce the carrier-to-interference ratio, C/I, at co-located 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.

The CCIR rain model (see Report 564) predicts that rain depolarization, *XPD*, varies with attenuation and elevation angle as illustrated in Fig. 3 for circular polarization. For any given value of rainfall attenuation, A_p, the *XPD* value decreases with decreasing elevation angle.

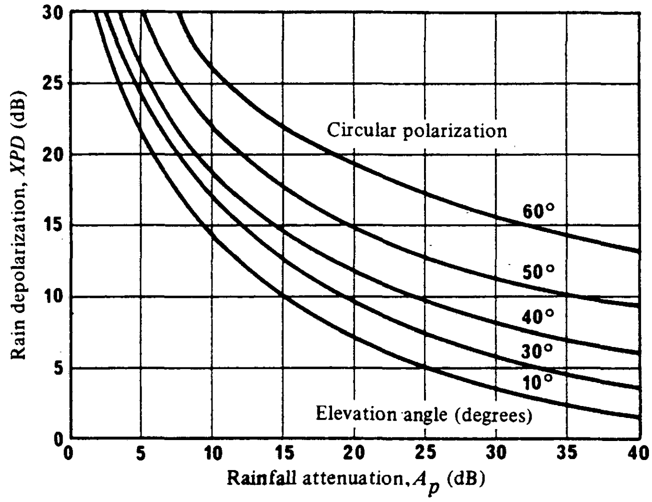

FIGURE 3 – *Rain depolarization and attenuation predicted for circularly polarized signals (14 GHz)*

The WARC-ORB(88) Conference adopted the following method for the calculation of depolarization (XPD), not exceeded for 1% of the worst month:

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

where $V = 20$ for 14.5 - 14.8 GHz

and $V = 23$ for 17.3 - 18.1 GHz

where A_p : co-polar rain attenuation exceeded for 1% of the worst month

f : frequency (GHz)

θ : elevation angle (degrees).

For values of θ greater than 60°, use $\theta = 60°$ in the above equation.

3.4.3 *Rain scatter*

Rain scatter, as a potentially important short-term interference mechanism at 17 GHz, is analyzed [CCIR, 1982-86b] for sharing between feeder links. Further study is required since several simplifying assumptions have been made and the rain scatter model that was used is specifically applicable to terrestrial scatter paths. The provisional analysis shows that:

- rain scatter interference contributions should not be a problem at 17 GHz but, however, can greatly exceed the interference on the direct earth station (side-lobe)-to-victim satellite path;
- rain scatter interference is highest, relative to the direct earth station (side-lobe)-to-victim satellite interference, at large angular separations between the victim and intended satellites;

- in some cases, the net interference during rain might exceed that which is present during clear-sky conditions. However, all such cases are associated with situations where this interference is negligibly small;
- further study is needed to assess the magnitude of precipitation scatter interference from around and above the 0°C isotherm. 10 GHz radar reflections from the melting layer at this altitude are typically substantially greater than those from somewhat lower altitudes.

3.5 *Propagation margin*

The propagation margin at 17 GHz (L_{Au} in equation (2)) depends primarily on the rain climatic zone and the elevation angle. Rainfall attenuation not exceeding 10 dB is predicted for 1% of the worst month in many rain climatic zones with little or no restriction on elevation angle. In rain climatic zones *M*, *N* and *P*, it might be desirable to locate the satellites so as to limit the minimum elevation angle and thus minimize the cases where rainfall attenuation could exceed 10 dB for 1% of the worst month. The minimum elevation angles in rain climatic zones *M*, *N* and *P* are approximately 12°, 35° and 60°, respectively, for 10 dB of rainfall attenuation exceeded for 1% of the worst month.

Possible techniques to compensate for rainfall attenuation include site diversity and power control. These subjects are discussed in § 5.6 and 5.4, respectively.

3.6 *Practical feeder-link earth stations*

It is useful to obtain information on the technical characteristics and operation of operating feeder links, in particular, based on overcoming the problems of heavy rain attenuation, and on increasing the effectiveness of transportable earth stations.

According to the experience with the feeder-link operations of the Japanese broadcasting satellite (BS-2), Annex II to this report gives information on the following two aspects of the actual feeder link [CCIR 1986-90a]:

- feeder-link operation in rainy conditions (section 1 of Annex II);
- systems of transportable earth stations (section 2 of Annex II).

4. **Interference**

Since the sources of interference in the satellite-to-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 satellite-to-Earth path should be 90% of the total interference.

The WARC-BS-77 approach requires that the feeder links have protection ratios about 10 dB greater than those of the down link. However, it must not be forgotten that the WARC-BS-77 specified more stringent conditions for the protection against interference than for that against noise. It may be expected that, under clear-sky conditions, a C/N ratio in the vicinity of 30 dB could be obtained on the feeder link. Even under those conditions, the received noise power would still be ten times greater than the interference power, assuming a protection ratio of 40 dB.

The feeder-link C/I ratio need not be specified as a planning element when feeder links and down links are planned at the same time because the overall carrier-to-interference ratio is the applicable criterion.

4.1 *Co-channel, co-polar interference*

A single entry protection ratio (C/I_u) of 40 dB between co-polarized feeder links transmitted from adjacent service areas is readily achievable for 99% of the worst month. Under clear-sky conditions a C/I_u of 40 dB requires satellite separation of about 3° for feeder-link antennas having 5 m diameters. When considering the worst case of aggregate interference and a 10 dB rain fade at the wanted transmitting earth station, the required minimum orbital separation between satellites serving adjacent services areas is about 10°. Orbital separations of less than about 10° would require some separation of feeder-link service areas, just as some separation is required for down-link service areas when orbital separations are less than 15°. Satellite separations will normally be determined by down-link interference considerations. However, feeder-link interference might be the determining factor when the feeder-link service area is larger than, or outside, the down-link service area. A value of 40 dB for C/I_u appears suitable as guidance in development of feeder-link plans.

Experiments conducted with the OTS satellite were used to measure the perceptibility threshold of an interferer for a total link [CCIR, 1978-82d]. The tests show that for a 625-line television signal in conformity with the WARC-BS-77 Plan, the value of 30 dB is confirmed for co-channel protection ratio.

Measurements were carried out in Canada on the effect of the non-linearity of the satellite TWTA on the co-channel interference. It would seem that the commonly known "small signal suppression" phenomenon does not take place in this case and that no decrease in the interference level was observed at the output of a saturated TWTA. The satellite should therefore be considered as transparent in the calculation of the overall co-channel carrier-to-interference ratio.

A value of 40 dB for the feeder link co-channel protection ratio was used in establishing the Regions 1 and 3 Plan.

4.2 *Adjacent-channel interference*

For other than co-polar, co-channel interference, the required C/I is much reduced from 40 dB and satellite and/or service area separations can be much smaller. For common or adjacent service areas the satellites can be nearly co-located and still protect the adjacent and second adjacent channels.

Experiments conducted with the OTS satellite were used to measure the perceptibility threshold of an interferer (co-channel or adjacent channel) for a total link [CCIR, 1978-82d]. The tests show that for a 625-line television signal in conformity with the WARC-BS-77 Plan, a lower value (7 dB instead of 14 dB) may be acceptable for the adjacent-channel protection ratio in Regions 1 and 3. A very likely explanation for this qualitative reduction may be found in the improved channel selectivity due to filtering at the transmitting station. However, a reduction of adjacent-channel interference due to the filtering on the feeder links is somewhat limited by the requirement for a rather low-selectivity filter in order to transmit signals with minimum impairment. If, as it seems, the value adopted by the WARC-BS-77 for the adjacent channel in the down link is a little too high, it would be interesting to continue experiments to see whether, for the adjacent channel, a lower corresponding value (for example 17 dB) could be adopted for feeder-link planning.

Laboratory experiments in France in which feeder-link interference was simulated using 625-line television signals in conformity with the WARC-BS-77 Plan have indicated that, in addition to confirming the protection ratio of 30 dB for co-channel interference, for adjacent-channel interference, transmission filtering at the feeder-link station and the operation of the satellite amplifier tube at saturation lead to a subjectively apparent decrease of 4 dB in the adjacent-channel interference.

For the 525-line NTSC system, studies of the adjacent-channel protection ratio have been carried out in Japan, in particular taking into account the effects of the AM/PM conversion factor of satellite transponders. Results of subjective measurements of signals passed through a 12 GHz TWTA and computer simulation of saturated amplification, including AM/PM conversion, agree and indicate that the adjacent channel protection ratio required for just perceptible interference can be reduced to 11 dB, after taking into account an AM/PM conversion factor of 6 degrees/dB (see § 3.3 of this Report).

Considering the differing experimental results presented, it appears that a unified planning value of the order of 21 dB would be appropriate for the feeder link adjacent-channel protection ratio irrespective of the television system used.

A value of 21 dB for the feeder link adjacent channel protection ratio was used in establishing the Regions 1 and 3 Plan.

4.3 *Second adjacent-channel interference*

Because of the relatively limited out-of-band rejections of the receiver filters expected to be used in practice, the second adjacent channel interference can become a non-negligible contributor to the interference level. The protection ratio is found to be in the neighbourhood of −10 dB for frequency modulated NTSC signals with two sound sub-carriers and with simple lumped-element 4-pole filters.

Some measurements with C-MAC signals indicate a protection ratio in the range 0 to −8 dB to be appropriate with the same type of filter [Shelswell, 1984].

The major contributors to this second adjacent channel interference are the feeder links. The contribution of the down link is negligible since the e.i.r.p. differential towards a given point in the service area due to beam overlap is limited to a few decibels. The contribution from the feeder links is found to be more important and the worst case occurs when the feeder links for the two channels, wanted and second adjacent interfering channels, are from the same service area towards the same orbital location. A difference in antenna gain towards the two wanted and interfering stations as well as a rain fade at the wanted transmission site where clear-air conditions are found at the interfering site can produce a relatively large differential in the levels received at the satellite.

In the case of the Region 2 planning at the RARC SAT-83, this feeder-link level differential could be found to be as high as 16 dB giving a second adjacent channel margin of −6 dB for a corresponding protection ratio of −10 dB, becoming in many cases the predominant interference mechanism. A 10 dB reduction of the feeder-link second adjacent channel interference was assumed due to satellite channel filtering in order to avoid this predominance.

Further problems which can result are significant transmission of strong second adjacent channel signals through the satellite transponder and also intermodulation with the wanted signal in the transponder non-linear amplifier. These result in further interference components being radiated within and outside the nominal channel bandwidth on the down link. In the Regions 1 and 3 down-link Plan, neighbouring or overlapping coverage areas occur with channels at frequency spacings of two channels, having the same sense of polarization at the same orbit position. Thus there is some possibility of creating additional down-link interference on wanted channel *n* due to:

- the channel *n* feeder-link signal passing through co-located transponders operating on channel *n* ± 2;
- intermodulation in the same transponders on channels n±2 resulting from signals on channels n±4.

Hence, adequate rejection of second adjacent channel signals must be provided by filtering in a satellite transponder to minimize this possible interference mechanism.

A study in the United Kingdom concluded that the need to take into account second adjacent channel interference should be avoidable in feeder-link planning in Regions 1 and 3, assuming direct frequency translation, provided that a second adjacent channel rejection of at least 40 dB through the satellite transponder can be provided [Shelswell, 1984]. The second study carried out in Japan showed that, assuming severe rain fading (about 18 dB) on the second adjacent channel, the required second adjacent channel rejection of the input and output channel filter in combination is approximately 50 dB.

Rejection by 55 dB of signals in the second adjacent channel can be obtained in practice from the combined effect of transponder input and output filters [CCIR 1986-90b]. Therefore, it is confirmed that it would not be necessary to take second adjacent channel interference into account when evaluating the feeder-link Plan for Regions 1 and 3.

For planning in Regions 1 and 3, the second adjacent-channel interference was not taken into account.

4.4 Calculation of the equivalent protection margin for Regions 1 and 3*

The feeder-link equivalent protection margin (M_u) is given by the formula:

$$M_u = -10 \log \left(10^{-M_1/10} + 10^{-M_2/10} + 10^{-M_3/10} \right) \text{(dB)}$$

where M_1 is the value in dB of the protection margin for the same channel, i.e.:

$$M_1 = \left[\frac{\text{wanted power}}{\text{sum of the co-channel interfering powers}} \right] \text{(dB)} - \text{co-channel protection ratio (dB)}$$

M_2 and M_3 are the value in dB of the protection margin for the upper and lower adjacent channels respectively, i.e.:

$$M_2 = \left[\frac{\text{wanted power}}{\text{sum of the upper adjacent channel interfering powers}} \right] \text{(dB)} - \text{adjacent channel protection ratio (dB)}$$

$$M_3 = \left[\frac{\text{wanted power}}{\text{sum of the lower adjacent channel interfering powers}} \right] \text{(dB)} - \text{adjacent channel protection ratio (dB)}$$

All powers are evaluated at the receiver input.

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* The definition of the equivalent protection margin for Regions 1 and 3 is included in § 4.11 of Recommendation 566.

4.5 Calculation of the overall equivalent* protection margin for Regions 1 and 3**

The overall equivalent protection margin M is given in dB by the expression [Brajan, 1986]:

$$M = -10 \log \left[10^{-(M_u + R_{cu})/10} + 10^{-(M_d + R_{cd})/10}\right] - R_{co}$$

where M_u = equivalent protection margin for the feeder link (as defined in Section 4.4)

M_d = equivalent protection margin for the down link

R_{cu} = co-channel feeder-link protection ratio

R_{cd} = co-channel down-link protection ratio

R_{co} = co-channel overall protection ratio.

The values of the protection ratios used for planning are as follows:

R_{cu} = 40 dB
R_{cd} = 31 dB
R_{co} = 30 dB.

4.6 *Interference between co-located satellites*

The most critical cases of feeder-link interference are for cross-polar channels transmitted to co-located satellites.

For the case where co-located satellites use a common cross-polarized channel, a protection ratio of 40 dB is needed. Discrimination of more than about 30 dB from the satellite receiving antenna pattern requires geographical separation of feeder-link service areas. The discrimination is the difference in co-polar gain towards points within the wanted service area and the cross-polar gain towards the closest point in the interfering service area. Satellite antenna patterns are typically given as functions of φ/φ_0 where φ is the exocentric angle between the on-axis direction and the direction of interest, and φ_0 is the 3 dB beamwidth of the satellite antenna. The discrimination between wanted and interfering signals is then the difference between the gain towards the wanted feeder-link station and the gain at angle φ. If the maximum discrimination is taken to be the opposite of the on-axis gain, 40 dB discrimination at the edge of service area would require an on-axis gain of 43 dB and values of φ/φ_0 greater than 2. Satellite antenna gains of 43 dB are not consistent with country-wide feeder-link service areas for many countries. Provisions for inhomogeneities in received signals due to rain attenuation and unequal transmit power levels would require even higher antenna gains. An on-axis gain of 49 dB (0.6° beamwidth) would provide, at best, a 6 dB margin for rain attenuation.

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* The adjective 'equivalent' indicates that the protection margins for all interference sources from the adjacent channels as well as co-channel interference sources have been included.

** These definitions are included in Recommendation 566.

Consider also the case where co-located satellites operating on cross-polarized adjacent channels have common feeder-link service areas. Assume that the discrimination capabilities are 25 dB for the satellite receiving antenna and 30 dB for the earth-station transmitting antenna. Since the two interference components may be in phase, voltage addition must be used to determine the interference level. In clear skies, the feeder-link C/I for an adjacent channel would be 21.1 dB. When the wanted feeder-link path is subjected to 10 dB rain attenuation, the feeder-link C/I drops to 11.1 dB. The protection ratio of 24 dB implied by the WARC-BS-77 cannot be achieved for this example, even under clear-sky conditions.

One possible solution to the problem of adjacent channel interference is to provide a slight separation between co-located satellites. A study performed in Canada showed that an improvement in isolation can be obtained in the case of two satellites transmitting cross-polarized adjacent channels by separating these satellites by a fraction of a degree such that they are seen as two distinct orbital locations by the feeder-link transmitting antennas but as co-located by the smaller receiving antennas. This removes almost completely the susceptibility of overall link adjacent channel C/I to rain fades on the feeder links at the cost of a small gain loss at the receiving terminal.

Figure 4 shows the results of the parametric study giving the overall adjacent channel C/I as a function of orbital separation and for different transmitting antenna sizes. The technical parameters adopted at the RARC SAT-83 including the transmit and receive antenna mispointings were used in this analysis. The figure also gives the variation in receiving antenna gain as a function of the orbital separation. It should be noted that 1 dB receiving gain loss due to mispointing is already taken into account in the earth-station G/T calculation.

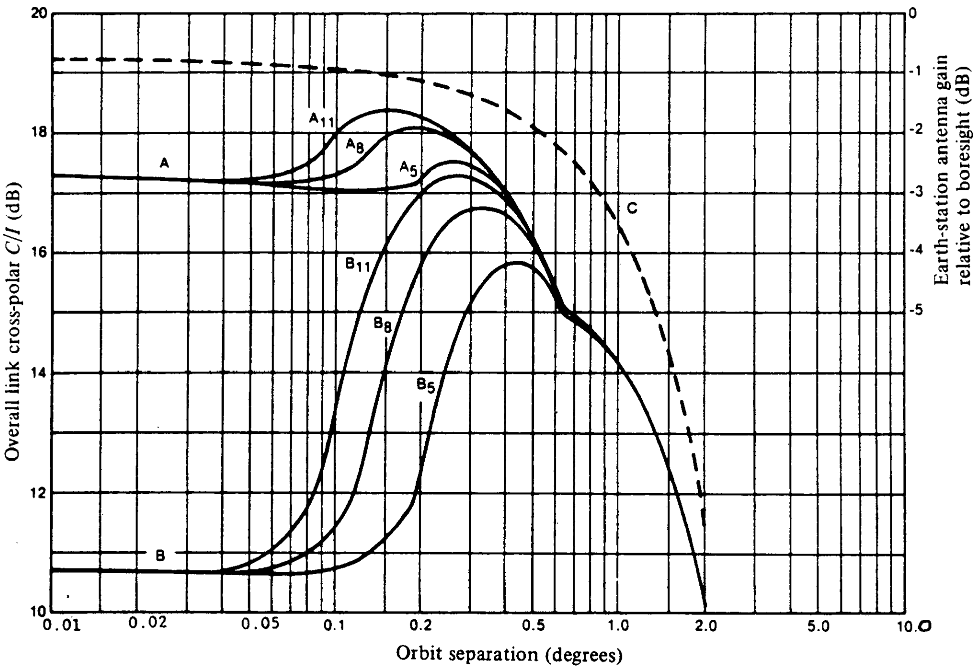

FIGURE 4 – *Cross-polar C/I improvement through orbital separation*

Curves A : clear-air conditions on feeder links and down link

B : 10 dB rainfall attenuation on the wanted feeder link

C : degradation of the earth-station receive co-polar gain

A_5 : overall link cross-polar C/I for 5 m antennas at the feeder-link sites (clear-air situation)

A_8 : overall link cross-polar C/I for 8 m antennas at the feeder-link sites (clear-air situation)

A_{11} : overall link cross-polar C/I for 11 m antennas at the feeder-link sites (clear-air situation)

B_5 : overall link cross-polar C/I for 5 m antennas at the feeder-link sites (10 dB fade situation)

B_8 : overall link cross-polar C/I for 8 m antennas at the feeder-link sites (10 dB fade situation)

B_{11} : overall link cross-polar C/I for 11 m antennas at the feeder-link sites (10 dB fade situation)

The optimum orbital separation is the point of best polarization discrimination for faded condition on the feeder link. This represents the best trade-off between feeder-link polarization discrimination and down-link loss in gain. This optimum is found to be 0.4° for 5 m feeder-link transmitting antennas. This separation was used in the development of the plan for Region 2 at the RARC SAT-83. The use of larger transmitting antennas will shift this optimum to smaller orbital separation (e.g., 0.3° for 8 m antennas and 0.27° for 11 m antennas).

The WARC ORB(88) Conference decided that administrations could place the satellites of a same "group" of satellites (i.e. sharing the same nominal position in the Plan) at any position no further than 0.2° away from the nominal position, provided that the agreement of the other administrations on that orbital position is obtained. The advantage of this arrangement is that it permits additional discrimination between feeder links (large transmitting antennas) whilst for the purposes of reception of the down link (small antennas) these satellites can still be considered as being at the same position.

4.7 *Effect of AM/PM conversion*

Section 3.3 above discusses the degradation in effective feeder-link C/N caused by AM/PM conversion in the satellite transponder. A similar effect may be expected to occur with effective feeder-link C/I ratios, although there is presently insufficient experimental evidence to confirm this. Indeed, tests in the United Kingdom indicate that with low AM/PM conversion (< 2°/dB), the effect of mutual interference on the feeder link is very similar to its effect on the down link [Shelswell, 1984]. Further study is required with higher values of AM/PM conversion currently found with the high-power travelling-wave tube amplifiers that are required for satellite broadcasting.

The decrease in overall link C/I ratios will depend upon the relative C/I ratios in the feeder link and down link in a similar way to that in which link imbalance affects the overall C/N ratio as discussed in § 3.3.

4.8 *Techniques for alleviating mutual interference between feeder links*

To alleviate mutual interference between feeder links, the following methods can be adopted (see the Report of WARC ORB-85):

- Use of a common set of technical parameters for all feeder links in planning is desirable but preliminary studies by a number of administrations have indicated that there may be a difficulty in obtaining the required carrier-to-interference ratios on a small number of feeder links, particularly when certain administrations have special requirements to be met.

  In order to overcome this difficulty, a degree of flexibility in the values of planning parameters used is proposed. Employment of one or more of the following techniques may be used, where necessary, in the planning process to attain the target values for interference protection.

- Adjustments of the maximum level of e.i.r.p. of potential interfering feeder links or feeder links subject to excessive interference, provided that adequate carrier-to-noise and carrier-to-interference ratios on the adjusted feeder links are maintained.

- Where independent planning of orbit positions is adversely affected, the off-axis co- and cross-polar side-lobe reference patterns of the earth-station transmitting antenna may be limited to $29 - 25 \log \varphi$ (dBi), for values of off-axis angle, φ, in the regions of the adjacent and next-but-one adjacent orbital positions in the plane of the geostationary-satellite orbit.

- Where insufficient cross-polar isolation is achieved, the off-axis cross-polar side-lobe reference pattern of the earth-station transmitting antenna may be limited to $24 - 25 \log \varphi$ (dBi) for $0.76° \leq \varphi \leq 22.9°$ and -10 (dBi) for $\varphi > 22.9°$.

- Adjustment of the feeder-link channel assignments, retaining the same translation frequency for all assignments associated with a given down-link beam.

- Modifying the satellite receiving antenna beam pattern shape, size, and/or side-lobe response (for example, a multiple beam or shaped beam antenna).

— Off-setting the beam-pointing direction of the satellite receiving antenna subject to maintaining the target carrier-to-noise ratio.

— Improving the beam-pointing accuracy of the satellite receiving antenna to 0.1°.

— Setting an upper limit to the rain attenuation margin included in the feeder-link power budget.

— Separating satellite orbital positions by ± 0.2° from the nominal position and specifying the off-axis e.i.r.p. of the relevant earth station in the range 0° to 1° off-axis beam angles.

For such cases, where e.i.r.p. (dBW) is the earth station on-axis e.i.r.p., the off-axis e.i.r.p. of the earth-station transmitting antenna for angles $0° \leqslant \varphi < 1°$ should not be greater than:

$e.i.r.p.$ (dBW) for $0° \leqslant \varphi \leqslant 0.1°$

$e.i.r.p. - 21 - 20 \log \varphi$ (dBW) for $0.1° < \varphi \leqslant 0.32°$

$e.i.r.p. - 5.7 - 53.2\, \varphi^2$ (dBW) for $0.32° < \varphi \leqslant 0.44°$

$e.i.r.p. - 25 - 25 \log \varphi$ (dBW) for $0.44° < \varphi < 1°$

5. Feeder-link earth station characteristics

5.1 *E.i.r.p.*

Once the frequency band and satellite G/T are specified, the earth station e.i.r.p. required to meet the C/N condition is largely determined by the statistics of precipitation-induced attenuation at the earth station sites. If L designates the net path loss in dB that is not exceeded during a certain percentage of the worst month, for example, 99%, then the required earth station e.i.r.p. per channel is given by the equation:

$$e.i.r.p. = P_E + G_E = C/N + 10 \log (kB) - G/T + L \qquad \text{dBW} \qquad (4)$$

where:

P_E: earth-station transmitter power per channel (dBW),

G_E: on-axis gain of earth-station antenna (dBi),

C/N: carrier-to-noise ratio at the input to the satellite receiver exceeded for, e.g. 99%, of the worst month (dB),

k: Boltzmann's constant (1.38×10^{-23} J/K),

B: IF bandwidth of satellite receiver (Hz),

G/T: figure of merit of satellite (including receiver, antenna and feed) (dB(K^{-1})).

The considerations set forth in § 3.3 suggest that a satellite input C/N ratio of the order of 26 dB should be chosen. To illustrate the use of this equation, take $C/N = 26$ dB, $B = 27$ MHz (as specified in the Plan for Regions 1 and 3), $G/T = 5$ dB(K^{-1}) (corresponding to $T = 2000$ K and $G = 38$ dB at the edge of a 1.5° beam) and $L = 212$ dB (209 dB free-space loss at 18 GHz plus 3 dB rain attenuation corresponding to 1% of the worst national average of projected worst month statistics for Europe (see Report 565)). The result of the calculation for the earth-station e.i.r.p. in this case is 78.7 dBW. This is well within the capability of e.i.r.p. from an 18 GHz earth station having a transmitter power of about 200 W and an antenna diameter of about 5 m with an efficiency of 55%.

In practice, when considerations other than C/N are taken into account, the e.i.r.p. values required for feeder links will be in the range of 78-87 dBW depending on the characteristics of each system. As an example, for Region 2 planning a nominal e.i.r.p. of 87 dBW has been used.

Another practical example, based on the use of several feeder-link earth stations with a satellite having a narrow-beam receiving antenna to mitigate the problems of mutual feeder-link interference, leads to a required e.i.r.p. of 81.5 dBW. For that example the following parameter values have been chosen: $C/N = 26$ dB, $B = 27$ MHz (see Regions 1 and 3 Plan), $G/T = 8.5$ dB(K^{-1}) (corresponding to $T = 2500$ K, $G = 46.5$ dB at the boundary of a 0.6° beam, a margin of 4 dB for a receiving antenna pointing offset to account for feeder links located near the edge of coverage area) and $L = 218.3$ dB (209.3 dB of free-space loss at 18 GHz, plus 9 dB as an example of rain attenuation). The minimum e.i.r.p. required is then 81.5 dBW. In order to take into account station margin (tracking, measurement, etc.), an additional 3 dB may be added to reach the maximum necessary e.i.r.p. of 84.5 dBW.

Antennas and transmitters are readily available which can satisfy the e.i.r.p. requirement, taking into account feed and multiplexer losses. Antennas (both Cassegrain and centre fed) are available with 8 m and greater diameters and 18 GHz transmitter tubes with an output power of 1 kW are currently being developed.

5.2 *Transmitting antenna reference pattern*

A co-polar reference radiation pattern for transmitting earth-station antennas in the FSS is proposed in Recommendation 465 for antennas with $D/\lambda \geqslant 100$:

$$\begin{aligned} G &= 32 - 25 \log \varphi \quad \text{dBi} \qquad 1^\circ < \varphi \leqslant 48^\circ \\ &= -10 \quad \text{dBi} \qquad \varphi > 48^\circ \end{aligned} \tag{5}$$

Report 391 discusses this radiation pattern and gives supportive data. Report 390 discusses the factors influencing the side-lobe levels. Report 453-3 (1982), however, suggests a more stringent pattern to increase the spectrum-orbit resource utilization:

$$G = 28 - 25 \log \varphi \quad \text{dBi} \tag{6}$$

to a minimum of -20 dBi.

Based on the opinions of antenna manufacturers in France, and on tests conducted in Canada on recent high-performance antennas (see Annex I) it may be possible that antennas can be manufactured that will have no more than 10% of their side-lobe peaks above this envelope.

Among the factors indicating that these levels are achievable in practical antennas is that the design of feeds (including any sub-reflectors) can be optimized for only the transmit frequency bandwidth employed (500 or 800 MHz, depending on the Region).

The XVIth Plenary Assembly of the CCIR adopted Recommendation 580-1, which states that new earth-station antennas having a D/λ exceeding 150, installed after 1988 and operating with a geostationary-satellite should have a design objective such that the gain of 90% of the side-lobe peaks does not exceed:

$$G = 29 - 25 \log \varphi \quad \text{dBi} \qquad 1^\circ \leqslant \varphi \leqslant 20^\circ \tag{7}$$

Report 391 also suggests radiation patterns for small antennas ($D/\lambda < 100$), but this is equivalent to antennas smaller than 1.7 m at 17 GHz and it is unlikely that such small antennas will be used to feed broadcasting satellites.

It would also be possible to optimize antenna side-lobe performance to correspond to specific satellite separations for a plan using a fixed orbital separation. In this case, it might be desirable to use one reference pattern for planning of the broadcasting-satellite service and a separate reference pattern for coordination with other services.

Appendices 28 and 29 to the Radio Regulations extend co-polar radiation patterns to angles smaller than 1°, assuming a Gaussian main lobe and a plateau at the first side-lobe level.

5.2.1 *Reference patterns in Region 2*

The new radiation patterns described below and shown in Fig. 5 were adopted by the RARC SAT-83 for planning the feeder links to the BSS. The background information is given in Annex I to this Report.

5.2.1.1 *Co-polar component*

The co-polar component of the feeder-link antenna is based on a side-lobe envelope of $29 - 25 \log \varphi$ down to -10 dB relative to the isotropic source for the back-lobe region as indicated in Fig. 5. The main lobe of the antenna is constrained by the segment $36 - 20 \log \varphi$ to which the Gaussian main lobes of antennas of any size, assuming an antenna efficiency of 65%, are tangent. This segment extends to an angle of 0.32° beyond which a portion of the Gaussian main lobe of the 2.5 m antenna (the smallest antenna size allowed in the Plan) joins it to the side-lobe envelope $29 - 25 \log \varphi$. This is to allow for the broadening of the main lobe in the case of small antennas.

5.2.1.2 *Cross-polar component*

The cross-polar component of the feeder-link antenna is based on a plateau near on-axis with a discrimination of 30 dB relative to co-polar on-axis gain. For large off-axis angles, the cross-polar side lobes have to meet the sloped segment ($9 - 20 \log \varphi$) down to -10 dB relative to the isotropic source. The slope of this segment is such that the junction with the near on-axis plateau will always be where the worst cross-polar side lobe occurs, which happens to be at the -3 dB point on the co-polar component.

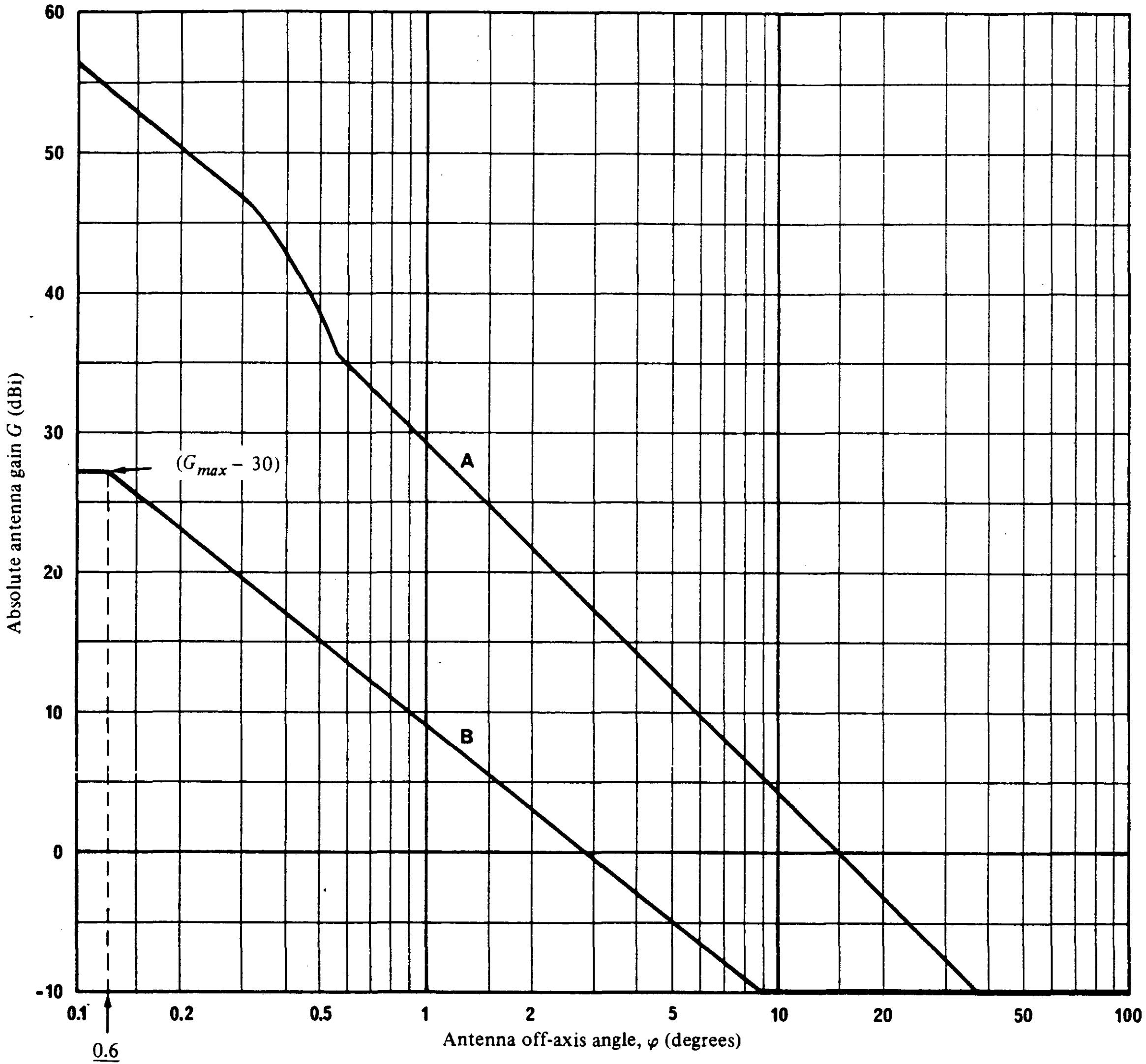

FIGURE 5 – *Reference patterns for co-polar and cross-polar components for transmitting antennas for Region 2*

Curves A: co-polar component
(dBi relative to isotropic source)

$36 - 20 \log \varphi$	for	$0.1° \leq \varphi < 0.32°$
$51.3 - 53.2\,\varphi^2$	for	$0.32° \leq \varphi < 0.54°$
$29 - 25 \log \varphi$	for	$0.54 \leq \varphi < 36°$
-10	for	$\varphi \geq 36°$

B: cross-polar component
(dBi relative to isotropic source)

$G_{max} - 30$	for	$\varphi < \left(\frac{0.6}{D}\right)^{\circ}$
$9 - 20 \log \varphi$	for	$\left(\frac{0.6}{D}\right)^{\circ} \leq \varphi < 8.7°$
-10	for	$\varphi \geq 8.7°$

where:

φ:	off-axis angle referred to the main-lobe axis;
G_{max} :	on-axis co-polar gain of the antenna;
D:	diameter of the antenna (m) ($D \geq 2.5$)

5.2.1.3 *Method of analysis for meeting the reference patterns*

The evaluation of the measured antenna patterns as to whether they meet the reference patterns or not is made as follows:

- for the co-polar component, the reference pattern must not be exceeded in the angular range between 0.1° and 0.54°;
- for the cross-polar component, the reference pattern must not be exceeded in the angular range between 0° and (0.6/*D*)°; and
- at larger off-axis angles, the reference pattern can be exceeded by no more than 10% of the side lobes contained in each reference angular window. These windows are 0.54° to 1°, 1° to 2°, 2° to 4°, 4° to 7°, 7° to 10°, 10° to 20°, 20° to 40°, 40° to 70°, 70° to 100° and 100° to 180°. The first reference angular window for evaluating the cross-polar component should be (0.6/*D*)° to 1.0°.

5.2.2 *Reference patterns in Regions 1 and 3*

For planning feeder links in Regions 1 and 3 the WARC ORB-88 adopted off-axis e.i.r.p. values which should not be exceeded. These values were based on the use of earth-station transmitting antennas having a nominal gain of 57 dBi and having the characteristics described below.

5.2.2.1 *Antenna diameter*

For a given value of on-axis e.i.r.p. and a given relative antenna pattern, the off-axis e.i.r.p. depends on the diameter of the antenna. The larger the diameter of the antenna, the smaller is the off-axis e.i.r.p. which is a potential source of interference between adjacent orbital positions.

Hence, for planning of feeder links it is necessary to define a reference antenna diameter. For the band 17.3-18.1 GHz the value adopted is 5 m, and 6 m for the band 14.5 to 14.8 GHz.

Smaller antennas of, for example, 2.5 m diameter, can also be used provided that there is no degradation of the interference situation. In practice, this means that the power might need to be reduced or the antenna pattern improved so that there is no increase in the off-axis e.i.r.p., and hence no unacceptable interference to the adjacent orbital position or to other services.

5.2.2.2 *On-axis gain*

The on-axis gain for the 5 m antenna at 17.3-18.1 GHz and for the 6 m antenna at 14.5 to 14.8 GHz is taken as 57 dBi.

5.2.2.3 ***Off-axis e.i.r.p. of transmitting antennas***

The co-polar and cross-polar off-axis e.i.r.p. for planning in Regions 1 and 3 are given in Figure 6.

5.2.2.4 *Cross-polar off-axis gain*

Studies have indicated that, for planning purposes, there is no necessity to maintain high cross-polar rejection at angles appreciably off-axis. Thus cross-polar characteristics identical to the co-polar may be used at angles corresponding to the orbital separations used in Regions 1 and 3.

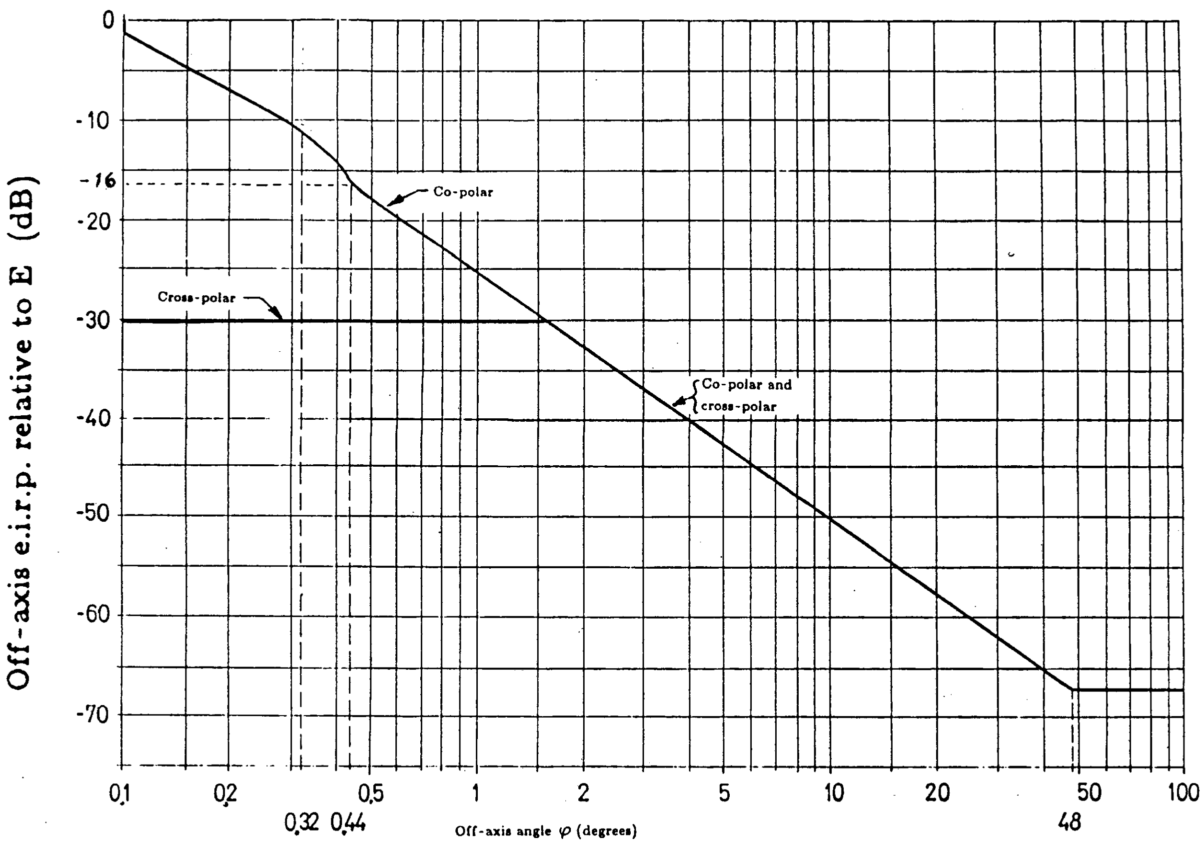

FIGURE 6 - *Earth station e.i.r.p. at angles off the antenna axis*

Co-polar component (dBW):

E (dBW) for $0° < \theta \leq 0.1°$
E - 21 - 20 log θ (dBW) for $0.1° < \theta \leq 0.32°$
E - 5.7 - 53.2 θ^2 (dBW) for $0.32° < \theta \leq 0.44°$
E - 25 - 25 log θ (dBW) for $0.44° < \theta \leq 48°$
E - 67 (dBW) for $\theta > 48°$

Cross-polar component (dBW):

E - 30 (dBW) for $0° \leq \theta \leq 1.6°$
E - 25 - 25 log θ (dBW) for $1.6° < \theta \leq 48°$
E - 67 (dBW) for $\theta > 48°$

where:

E (dBW) is the earth station e.i.r.p. on the antenna axis.

and

θ = off-axis angle referred to the main lobe axis (degrees).

5.3 *Use of small transmitting antennas*

The minimum diameter earth-station antenna considered by the RARC SAT-83 using the feeder-link transmitting pattern described in § 5.2.1 is 2.5 m. The main beam broadening of a 2.5 m antenna ($D/\lambda = 150$) has been incorporated into the co-polar reference pattern. Such transportable terminals would not create more interference than that calculated in a plan provided that their side-lobe radiation patterns do not exceed the side-lobe envelopes proposed for planning purposes and provided that a maximum limit on transmitter power is adopted for planning.

For Regions 1 and 3, the use of an antenna with a diameter smaller than 5 m can be taken into account provided it is compatible with the interference conditions in the feeder-link Plan based on a diameter of at least 5 m. A preliminary study carried out in Japan showed that under certain circumstances in Region 3, there would be no difference in the C/I values for co-located satellites regardless of the use of transmitting antennas having a diameter of, for example, 2.5 m or even 1 m when the systems are homogeneous in e.i.r.p. Little interference would occur to adjacent satellites, even when using feeder-link transmitting antennas which have a diameter of 2.5 m and the characteristics of Recommendation 465, under the same e.i.r.p. conditions, if a 17 GHz feeder-link Plan is developed by a direct translation of the WARC-BS-77 down-link Plan. WARC-ORB(88) adopted a minimum antenna diameter of 2.5 m and compliance with the off-axis characteristics given in Figure 6 appropriate to the nominal on-axis antenna gain of 57 dBi.

The C/N_u and C/I_u achievable with these transportable earth terminals may not meet the values planned for 99% of the worst month using a larger antenna but would in most cases be adequate under clear-sky conditions as indicated in Table I for C/N_u. The C/N_u of the transportable terminals depends primarily on the transmitted power and on the satellite G/T.

The antenna systems of such transportable terminals will need to be as simple as possible and should be of practical dimensions to be carried on roads. A tracking system should not be required in all cases. Present practice in the fixed-satellite service seems to indicate that 4.5 m folding antennas and 2.5 m non-folding antennas would meet the road clearance standards in most of the cases. For a satellite station-keeping allowance of ± 0.1°, the use of antennas larger than 3 m would result in a variation of PFD at the satellite of more than 3 dB in the absence of automatic tracking.

However, when one considers the very slow drift rate of the satellite and that use of such small transportable antennas will usually be temporary, the assumption of 0.1° drift instead of 0.28° as the worst case seems reasonable. Thus, assuming a 3 dB variation in PFD at the satellite, only antennas larger than 5 m would require automatic tracking.

5.4 *Power control*

Power control of feeder links is the rapid, automatic adjustment of earth-station transmitter power to compensate for rain-induced attenuation in the path of the desired signal to a satellite.

5.4.1 *Application of power control*

In the presence of feeder-link power control (PC), the input level of the signal at the satellite transponder is maintained approximately constant and rain attenuation along the feeder-link path is effectively compensated.

As a consequence, during rain at the feeder-link station only, the use of feeder-link power control maintains a constant value of C/N_T as illustrated in Fig. 7.

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 [CCIR, 1978-82e; 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.

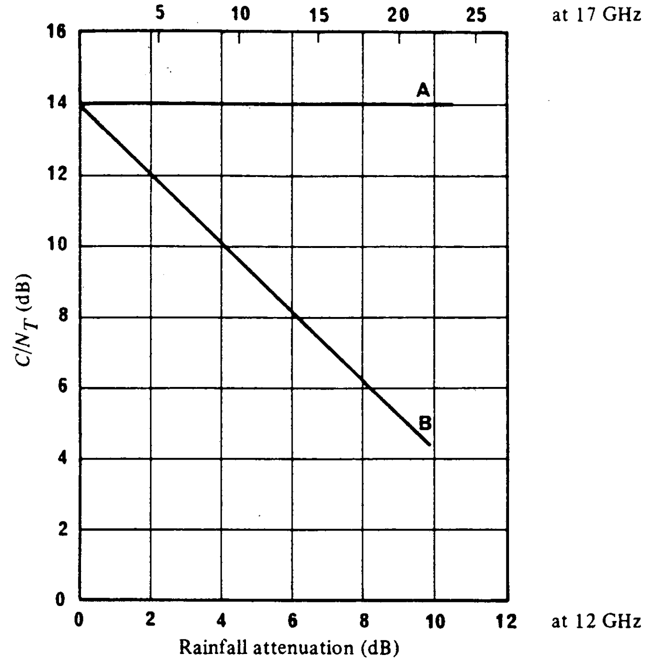

FIGURE 7 – *The effect of rainfall attenuation on C/N_T in the presence of feeder-link power control (PC)*

Clear-sky C/N_u = 24 dB

Clear-sky C/N_d = 14.5 dB

Curves A: rain at feeder-link station only

B: correlated rain at feeder-link station and down-link station

5.4.2 *Conditions for use of power control without increased interference*

Use of power control to increase the availability of feeder links beyond the values used for planning is analyzed in this section.

In [CCIR, 1982-1986c; OHMI, 1985] the conditions are determined that allow use of power control on an interfering feeder link without degradation of the C/I of an interfered-with link below the value obtained when the interfering feeder link is in clear sky.

In studying feeder-link interference problems, the geographical locations of interfering earth stations and wanted feeder-link beam areas are important factors affecting the feeder-link carrier-to-interference ratio. These factors affect the cross-polarization discrimination (XPI_{sat}) of the wanted-satellite antenna because XPI_{sat} is a function of the ratio of the off-axis angle (φ) to the half-power beam-width (φ_0).

For the satellite-receiving antenna reference pattern shown in Fig. 16, the XPI_{sat} can be graphically expressed as in Fig. 8.

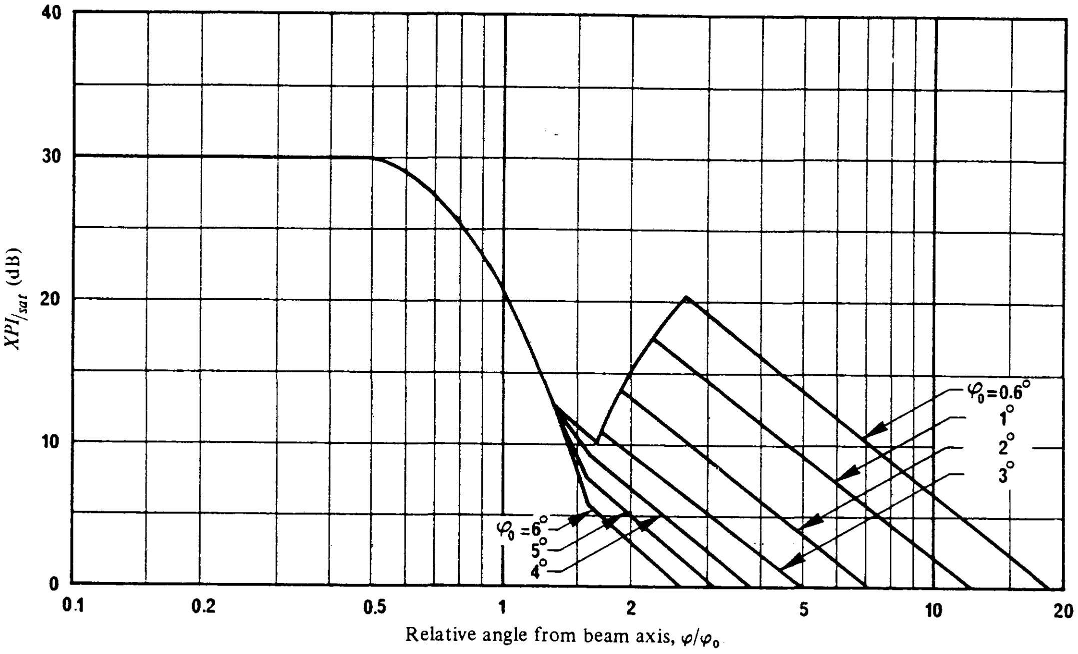

FIGURE 8 – *Cross-polarization discrimination (XPI_{sat}) of satellite-receiving antenna (reference patterns are assumed as shown in Fig. 16)*

(φ_0 : half-power beamwidth)

$$XPI_{sat}\ (\text{dB}) = G_{rcwi}\ (\text{dB}) - G_{rxwi}\ (\text{dB})$$

In order to analyze the effect of the XPI_{sat} on C/I_u, the equation of C/I_u which includes the parameter XPI_{sat} explicitly, is given in equation (8).

$$\frac{C}{I_u} = \frac{P_w}{P_i} \cdot \frac{L_i}{L_w} \cdot \frac{R_i}{R_w} \cdot \frac{G_{rcww}}{G_{rcwi}} \cdot \frac{1}{A + \dfrac{1}{XPI_{sat}} + \dfrac{1}{XPI_{es}}} \tag{8}$$

where:

P_w : transmitter power at the wanted earth station;

P_i : transmitter power at the interfering earth station;

L_w : spreading ("free space") loss on the wanted path;

L_i : spreading ("free space") loss on the interfering path;

R_w : rain attenuation on the wanted path;

R_i : rain attenuation on the interfering path;

G_{rcww} : co-polar gain of the wanted-satellite receiving antenna in the direction of the wanted earth station;

G_{rcwi} : co-polar gain of the wanted-satellite receiving antenna in the direction of the interfering earth station;

A : coefficient of depolarization due to rain as expressed in the following equation:

$A = 10^{-(XPD/10)}$, where XPD is the rain depolarization given in § 3.4.2, in dB, as a function of rain attenuation and elevation angle;

XPI_{sat} : ratio of co-polar gain (G_{rcwi}) to cross-polar gain (G_{rxwi}) of the wanted-satellite receiving antenna in the direction of the interfering earth station as expressed in the following equation:

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

XPI_{es} : ratio of co-polar (G_{tci}) to cross-polar (G_{txi}) of the interfering earth-station transmitting antenna in the direction of the wanted-satellite as expressed in the following equation:

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

Thus, XPI_{sat} and XPI_{es} indicate the cross-polarization discrimination capability of the satellite antenna and the earth-station transmitting antenna, respectively.

The change in the C/I_u, on an interfered-with link, ΔM, can be expressed as follows when power control is used on an interfering link:

$$\Delta M = \frac{C/I_{u,\,rain}}{C/I_{u,\,clear}} = \frac{R_i}{\Delta P_i} \cdot \frac{1}{1 + \cfrac{A}{\cfrac{1}{XPI_{sat}} + \cfrac{1}{XPI_{es}}}} \tag{9}$$

where:

$C/I_{u,\,rain}$: C/I_u when rain occurs at the interfering site with resultant rainfall attenuation of R_i;

$C/I_{u,\,clear}$: C/I_u when the interfering site lies in clear weather ($C/I_{u,\,clear}$ is regarded as a reference C/I_u);

ΔP_i : power increase of earth transmitter by power control.

The limits on increased earth-station transmitter power which keep ΔM (dB) non-negative, i.e., not degrade the C/I on the interfered-with path from the value of C/I when the interfering site is in clear weather, are shown as a function of rain attenuation in Fig. 9, Curve (A) for the case where XPI_{sat} = 20 dB and XPI_{es} = 30 dB. Within the hatched area the transmitter power can be increased in any desired manner. An example of one possible algorithm for raising transmitter power as rain attenuation increases is shown in Curve (B) of Fig. 9.

Power control as shown in Curve (B) of Fig. 9 results in a positive ΔM (dB) as illustrated in Curve (B) of Fig. 10, i.e., the C/I_u on the interfered-with link is higher in rain than in clear skies by the amount shown. Curve (A) of Fig. 10 plots ΔM for the case where power control is not used and Curve (C) plots ΔM for power control as shown in Curve (A) of Fig. 9.

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

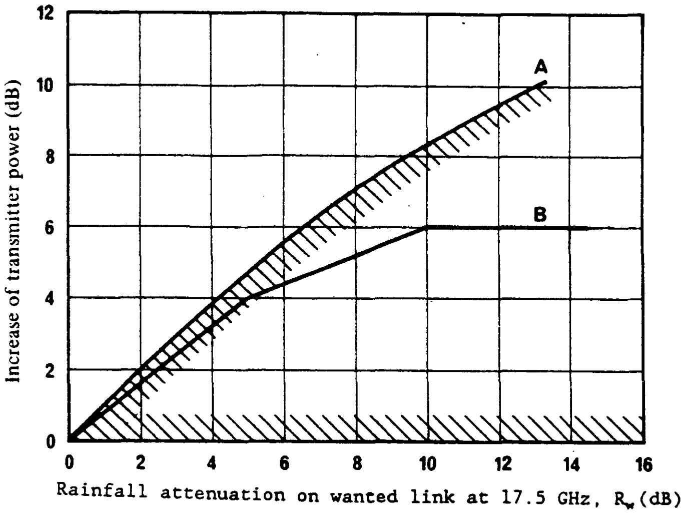

FIGURE 9 – *The possible increase of transmitter power for power control*

Curves A: upper limit for power control
B: an example of power control as illustrated in Table IV

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

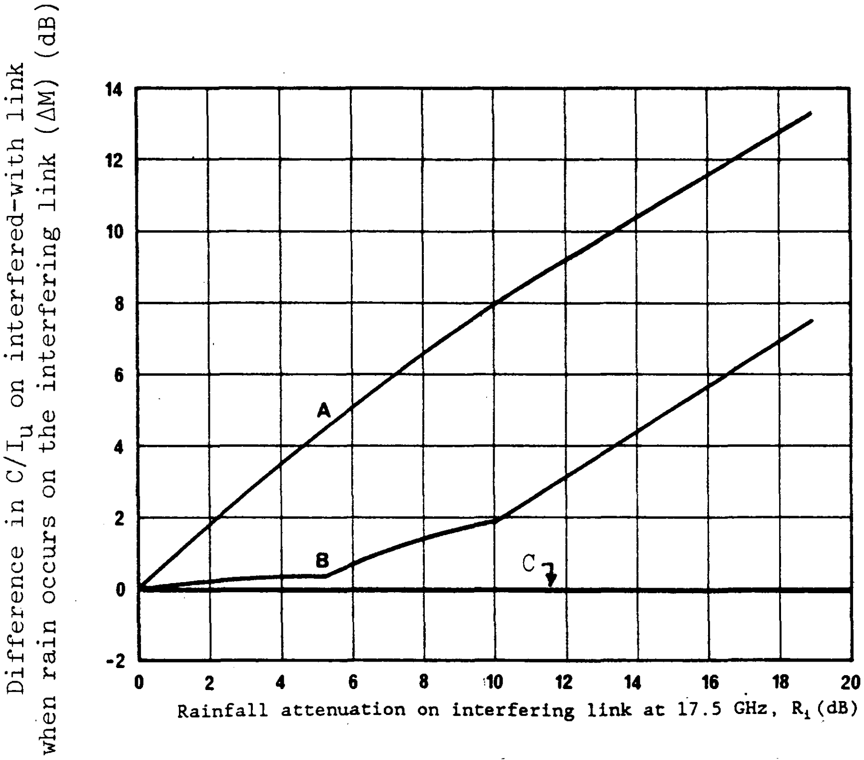

FIGURE 10 – *An example of effective power control*

Curves A: without power control
B: with power control, corresponding to curve B in Fig. 9
C: Upper limit for power control without degradation of C/I_u on an interfered-with link, corresponding to Curve A of Fig. 9

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

TABLE IV – *Possible increase of earth-station transmitter power for power control for various values of XPI_{sat} and satellite elevation angle*

XPI_{sat} (dB)	Satellite elevation angle (degrees)	Increase of earth-station transmitter power (dB)	
		For rainfall attenuation 0 dB to 5 dB	For rainfall attenuation 5 dB to 10 dB and more
10 to 15	0 to 10	0	0
	10 to 30	0 to 4	4 to 7
	30 to 50	0 to 4	4 to 8
	50 to 60	0 to 5	5 to 9
	60 to 90	0 to 5	5 to 10
15 to 20	0 to 10	0	0
	10 to 30	0 to 2	2 to 4
	30 to 40	0 to 3	3 to 4
	40 to 50	0 to 3	3 to 6
	50 to 60	0 to 4	4 to 8
	60 to 90	0 to 5	5 to 9
20 to 25	0 to 30	0	0
	30 to 40	0 to 2	2
	40 to 50	0 to 3	3 to 4
	50 to 60	0 to 4	4 to 6
	60 to 90	0 to 5	5 to 8
25 to 30	0 to 40	0	0
	40 to 50	0 to 2	2
	50 to 60	0 to 3	3
	60 to 90	0 to 5	5

5.4.3 Use of power control with potential for increased interference

Some applications of power control can worsen the interference situation. Studies have shown [CCIR, 1978-82f], that the difference between interference levels in the case where power control is used at all stations to maintain C/N at the minimum required value, and where it is n ot 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:

$$I_{pc} - I_{npc} = M_w - M_i + (CPA)_{i\ inst.} - (CPA)_{w\ inst.} \qquad (10)$$

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 depolarization of the interfering path.

For most of the interference situations and for most of the time, the effects of interference on C/I_u will be the same with and without power control if the climatic conditions are statistically similar on the wanted and unwanted paths. There is a distinct difference, however, depending on the use or non-use of power control, whether a feeder link is affected by interference during rain on its own path or during rain on the path of the interfering feeder link.

For co-polarized, co-channel interference, which will only be important for large orbital separation and/or large feeder-link service area separation, power control would appear to offer certain potential advantages. It would permit a significant reduction in transmitting power for large percentages of time, potentially resulting in long-term savings of earth-station prime power and improved transmitter reliability. For the cases examined [CCIR, 1982-86d], use of power control increased the percentages of time that design levels of C/I could be maintained.

In the case of co-located satellites having common or adjacent feeder-link service areas and operating on adjacent cross-polarized channels, de-polarization must be taken into account in analyzing the effects of power control on C/I.

The effect of power control in the cross-polar C/I is calculated using two identical earth-station transmitters both located near the −3 dB edge of the feeder-link coverage area and directed towards co-located satellites. Cross-polar discrimination capabilities of 27 dB and 30 dB for circularly polarized satellite receiving antenna and earth-station transmitting antenna, respectively, are assumed. This gives a single entry cross-polar C/I_u of 21.2 dB under clear-sky conditions when voltage addition is assumed. An elevation angle of 40° is assumed and the cross-polar C/I_u is calculated as a function of rainfall attenuation on the feeder link for three scenarios:

(a) it rains at the wanted site only;

(b) it rains at the wanted and interfering sites simultaneously; and

(c) it rains at the interfering site only.

Use of power control at both sites is assumed.

The results are given in Figs. 11, 12 and 13, respectively for scenarios (a), (b) and (c). Although the RARC SAT-83 adopted voltage addition for C/I calculations, these figures have been drawn on the basis of power addition. The figures indicate that the use of up-link power control increases the C/I_u when it rains at the wanted site but decreases the C/I_u when it rains at the interfering site. The use of up-link power control has no effect on cross-polar C/I_u when it rains simultaneously at both the wanted and interfering sites.

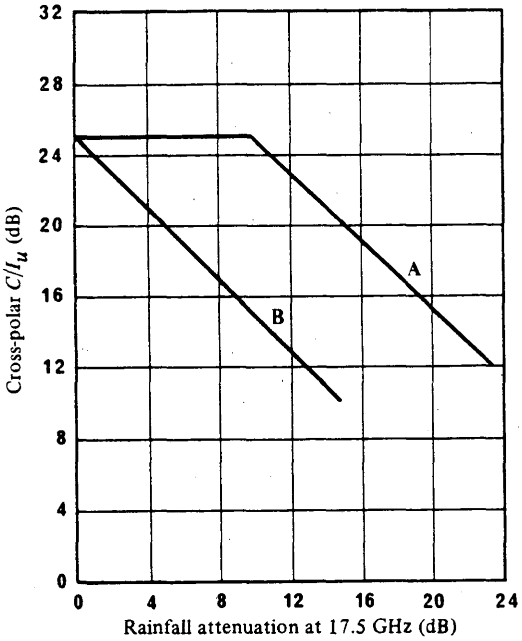

FIGURE 11 – *The effect of automatic gain control (AGC), or 10 dB of power control (PC), on the cross-polar* C/I_u *between circularly polarized feeder links at 17.5 GHz when it rains at the wanted site only (scenario (a))*

XPI_{sat} = 27 dB
XPI_{es} = 30 dB

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

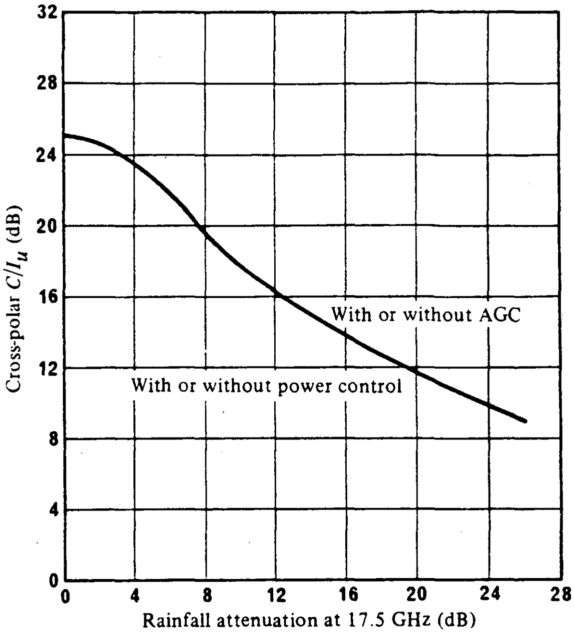

FIGURE 12 – *The effect of automatic gain control or power control on the cross-polar* C/I_u *between circularly polarized feeder links at 17.5 GHz when it rains simultaneously at the wanted and the interfering transmitter sites (scenario (b))*

XPI_{sat} = 27 dB
XPI_{es} = 30 dB

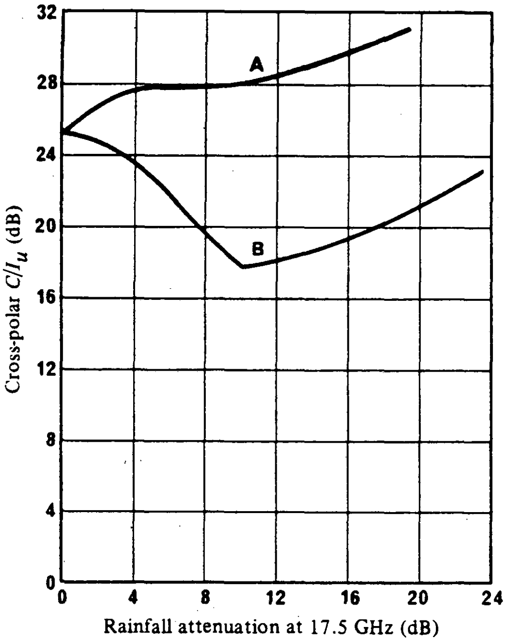

FIGURE 13 – *The effect of power control (PC) on the cross-polar* C/I_u *between circularly polarized feeder links at 17.5 GHz when it rains at the interfering site only (scenario (c))*

XPI_{sat} = 27 dB
XPI_{es} = 30 dB

Curves A: Without power control
B: With 10 dB power control

5.4.4 WARC-ORB(88) method for the calculation of power control in Regions 1 and 3

5.4.4.1 Conditions to be observed

In the Regions 1 and 3 Plan, power control is permitted according to the characteristics given in Figure 14 provided that the amount of interference generated to any other feeder link in the Plan does not degrade its overall free space C/I by more than 0.5 dB and that the power increase does not exceed the rainfall attenuation exceeded for 1% of the worst month or 10 dB.

5.4.4.2 Calculation method

a) Compile a list of all assignments of other administrations (A, B, C, ..) in the same orbital position and the two adjacent positions (i.e. in total, three orbital positions) liable to suffer interference from the assignment studied.

b) Calculate the feeder link equivalent protection margin of assignment A in free space conditions, taking account of all interference sources affecting A in the visible arc at the worst test points, namely:

   - for assignment A: the point corresponding to the minimum C/N ratio

   - for each interference source affecting A: the point corresponding to the maximum interference power affecting A.

c) Calculate for the assignment studied the rain attenuation for 0.1% of the worst month and the corresponding rain depolarization value at all test points (see Sections 3.4.1 and 3.4.2, respectively).

d) Recalculate the feeder link equivalent protection margin of assignment A taking into account the rain effects at the assignment studied at the worst test points, namely:

   - for assignment A: the test point used in b) above

   - for the assignment studied: the worst test point corresponding to the maximum interference power affecting A.*

   At this stage, the e.i.r.p. of the assignment studied is of the nominal value.

e) Increase the e.i.r.p. of the assignment studied by 0.1 dB and recalculate the equivalent up-link margin of A as in d) above.

f) Repeat the operation of e) above until the equivalent up-link margin of assignment A is impaired by more than 0.5 dB in relation to the value found under b) above, or until the e.i.r.p. increase exceeds 10 dB or the rain attenuation calculated the assignment studied at the worst test point (see step c)). Adopt the e.i.r.p. increase in the preceding iteration step.

g) Repeat the operations in steps b) to f) above (inclusive), considering the assignments B, C,...

h) Adopt the smallest of the increases in e.i.r.p. found under f) above for the various assignments A, B, C...

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* This test point may in general not be the same as that calculated under b).

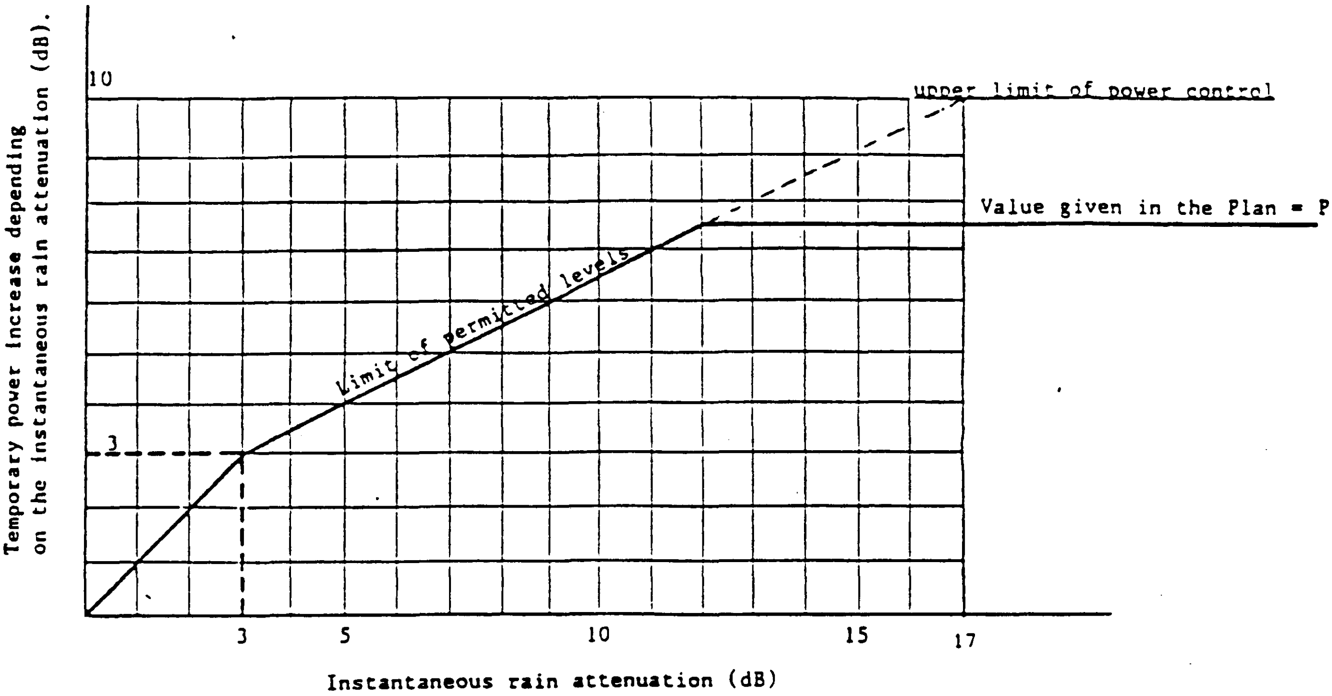

FIGURE 14

Characteristic for up-link power control

Note:

P: The value of permitted increase given in the feeder-link Plan for Regions 1 and 3 countries, which varies for each assignment. The upper limit of this value is 10 dB.

5.4.5 *Conclusions*

One application of power control would be to increase the feeder link availability above that used for planning. In this application, the increase in power would be limited to that amount which, assuming perfect implementation, would result in no increase in interference to other feeder links.

Another use of power control would be to minimize the transmitted power required except for small percentages of time. Power control, rather than a fixed margin, would be used to compensate for rain attenuation. Interference to other feeder links could increase above the clear sky value.

Use of power control in the latter application to maintain a desired C/N and C/I in the presence of rainfall attenuation clearly has benefits and disadvantages in the case of co-located cross-polarized satellites. On the one hand, C/I is improved when rain occurs on the desired path while on the other hand C/I is degraded when rain occurs on the intefering path. The decrease in C/I due to rain on the wanted path is equal to the rainfall attenuation in the absence of power control. Figures 11 to 13 show that the decrease in C/I due to rain on the interfering path is less than the rainfall attenuation when power control is used. Studies in [CCIR, 1982-86d] verify this result and calculate the difference in degradation of C/I as 4.3 dB in the presence of a 10 dB rain fade, depolarization corresponding to a 10 dB rain fade, and a feeder-link elevation angle of 30°.

The above result offers the possibility that power control might alleviate the adjacent, cross-polarized channel interference problem, associated with co-located satellites. When combined with depolarization control (§ 5.5), power control could further minimize the variation of C/I in the presence of rain.

There are possible disadvantages of the use of power control to minimize degradation of C/I due to atmospheric effects. All feeder-link stations must use power control for the benifits to be realized. Furthermore, control of the interference environment passes from the feeder link on the victim path to the feeder link on the interfering path.

Optimal use of uplink power control requires accurate measurement of the rain attenuation. This is essential to maintain the optimum power flux density at the satellite, thus ensuring optimum operation at the required input. Four methods are possible, each having some inherent difficulties. When uplink power control is to be applied, the method most suited to the particular system requirements should be adopted.

Methods of implementing uplink rain compensation are described in Annex III.

5.5 *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 [CCIR, 1978-82g; Fromm and McEwan, 1981; Bradford University, 1981], during both clear-sky and rain (or ice) conditions. This technique could be realized with little additional hardware in the transmitting station.

Depolarization compensation would appear to be of value for feeder links to broadcasting satellites only if power control were employed and then only for co-located satellites. In the event that power control is not used, an increase in interference would only occur for ice depolarization in the absence of rain attenuation on the interfering path. The increase in interference would have to occur at the same time the desired signal is faded to its value at 1% of the worst month for an unsatisfactory C/I to result. The joint probability for the occurrence of both events is smaller than 1% of the worst month.

Only the combined application of feeder-link power control and compensation for depolarization would provide major improvements in C/I for interference-critical feeder links. Studies have shown that such techniques can be introduced at any time with the provision of a suitable earth transmitting station only. There are no implications for the satellite design [CCIR, 1978-82g, Fromm and McEwan, 1981; Bradford University, 1981]. Obviously, earth-station e.i.r.p. levels then need to be raised during adverse propagation conditions above the maximum level used during clear-sky conditions. Another study has demonstrated the compatibility of such a technique with a feeder-link plan which is based on the principle of maximum e.i.r.p. levels for feeder-link transmitting earth stations [CCIR, 1982-86e].

5.6 *Diversity operation of feeder links*

The technique of site diversity to achieve greater availability of satellite links is well documented. Report 564 indicates that the probability of attenuation being exceeded simultaneously at two sites is less than the probability of the same attenuation being exceeded at one of the sites by a factor which decreases with increasing distance between the sites and with increasing attenuation. The relative joint probability is defined as the ratio of the former probability to the latter probability and is plotted in Fig. 15 for attenuations up to 10 dB and site separation up to 25 km on the basis of a log-normal distribution of rain cells [Strickland, 1974]. It is noted that for any given distance between diversity sites, the relative joint probability decreases rapidly with attenuation and remains almost constant for attenuation greater than about 10 dB. This joint probability data is used to illustrate the effect of site diversity on C/N_u and cross-polar C/I_u.

The availability of high values of C/N_u and C/I_u during rain is mainly governed by rain attenuation in the case where it rains at the wanted feeder-link site only. This rain scenario is considered the worst case since both the C/N_u and C/I_u decrease on a dB-per-dB basis during rain. Figure 15 indicates that under these worst-case conditions, the use of site diversity with diversity stations separated by a least 10 km would provide at least a factor of 10 improvement in the availability of high values of C/N_u and C/I_u for attenuation values greater than about 5 dB. In other words, the C/N_u and/or the C/I_u ratios exceeded for 99% of the worst month without site diversity (assuming an attenuation of at least 5 dB) could be made to correspond to an availability exceeded for 99.9% of the worst month by using site diversity with diversity stations separated by at least 10 km. A further improvement in availability by an additional factor of 10 is possible with diversity stations separated by at least 20 km. Clearly, the use of site diversity is most advantageous where the combination of rain rate and elevation angle gives high values of signal attenuation because the relative joint probability decreases to a minimum with increasing attenuation for any given separation distance between diversity stations.

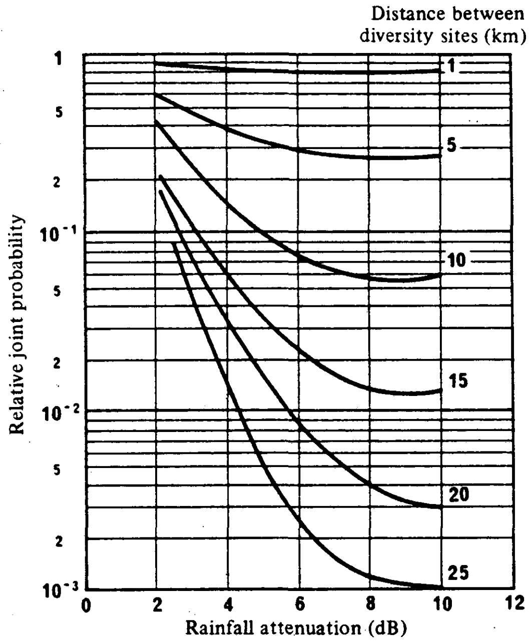

FIGURE 15 – *Relative joint probability of site diversity as a function of rainfall attenuation and distance between diversity sites*

The use of site diversity can only increase the availability of high values of C/N_u and C/I_u relative to the values calculated in a plan which is based on a single feeder-link station. Therefore, the Region 2 Plan permits the use of site diversity in the implementation of feeder links.

Even though the use of site diversity can effectively compensate for the effects of rain and depolarization, the cost and complexity of diversity stations may be significant. The use of diversity for transportable stations is particularly problematic from the standpoint of cost and operational complexity.

6. Satellite receiving antenna characteristics

The characteristics of the satellite receiving antenna are, to a large extent, governed by the type of service envisaged in the BSS. The receiving antenna may be implemented in a number of different ways depending on its system use. They include: separate fixed aperture, separate pointable aperture, common aperture separate feeds and common aperture shared feeds.

Design considerations of satellite antennas are given in Report 558 and, for the aspect of polarization, greater details are given in Report 555.

Report 558 discusses beam shaping methods and Report 810 discusses advances in antenna technology to enable reduction of radiation levels outside the desired service area.

6.1 *Use of the same antenna for feeder link and down link*

From the standpoint of spacecraft cost, complexity and weight, a common transmit/receive antenna would be advantageous. In this case, the cross-polar gain, beamwidth, pointing accuracy and the radiation pattern would be tied to the down-link antenna characteristics. In the case where feeder-link and down-link service areas do not overlap, the WARC-BS-77 reference patterns in Report 810 are applicable for non-shaped beams with circular or elliptical cross section except for degraded cross-polar performance. For shaped beams, the possible new pattern would apply.

When shaped beams are used for overlapping feeder-link and down-link service areas, the feeder link receiver feeds coincide geometrically with the down-link feed clusters and the feeds must be shared. There is a paucity of data for antenna performance across a wide frequency range such as between 12 and 18 GHz. The main problems will be cross-polar performance and side-lobe control. Feeder-link performance is critically dependent on a high value for cross-polarization discrimination. Care will be required in the design of the satellite antenna to avoid a degradation of 3 to 5 dB in cross-polar performance.

In accordance with Reports 558 and 810, consideration should be given to the fact that a particular antenna configuration can be more readily optimized when only one frequency band is involved. When the feeder links and down links are serviced by a common antenna and the frequency bands have a ratio of 1.5 : 1, the resulting minimum gain is about 0.5 dB lower than the optimum value achievable within the service area if separate antennas are used.

6.2 *Use of separate antennas for feeder link and down link*

Separate receiving antennas would offer greater flexibility in terms of independence of the feeder-link frequency, polarization and service area.

A separate, fixed aperture feeder-link antenna is the exact parallel of the down-link antenna, and hence its performance should be identical and the same patterns would apply if the same design care is exercised.

It may be desirable that considerable numbers of small fixed or transportable feeder-link stations operate from a feeder-link service area that is smaller, equal to or even larger than the down-link service area. A separate, pointable satellite receiving antenna would be useful in this case. As an example, for design simplicity, the antenna could be small, say 1.5 m in diameter, and mechanically steerable. However, side-lobe and cross-polar performance could be degraded because of interference caused by the feeds and supporting strut, if a prime focus feed is used. Because of required feeder-link isolation, it is important to use off-set feeds to avoid degradation of side lobes and cross-polarization discrimination to around 25 dB.

6.3 *Antenna size and beamwidth*

The beamwidth of the satellite receiving antenna is determined primarily by the locations of the feeder-link earth stations. At one extreme, there may be only a single fixed earth station, located most often near the centre of the service area but, in some cases, outside the service area. At the other extreme, there may be considerable numbers of small fixed or transportable feeder-link stations operating from any point within the broadcasting-satellite service area or, even in some cases, outside the down-link service area.

Where there is only a single earth station or when earth station locations are confined to a small geographical region, a general study carried out in France for Region 1 [CCIR, 1978-82h] has shown it would be highly advantageous from an interference point of view to use narrow beam satellite antennas, as for example 0.6° beam. Use of such antennas would also tend to reduce earth-station e.i.r.p. by increasing the satellite figure-of-merit G/T. Narrow beam steerable antennas can also be advantageous in improving interference and increasing the satellite G/T.

When there are a number of feeder-link earth stations providing simultaneous feeds from locations throughout, or even outside the down-link service area, as may be the case in multibeam satellite systems for the broadcasting of national programmes from locations inside a country, two cases may be identified:

- if access is to be provided from only one or few known locations, a small service area served by a small spot beam satellite receiver antenna can be planned;
- if the locations of the national transmitters are not known prior to the plan or if access from anywhere within the country is desired, e.g., for transportable terminals, a country-wide feeder-link service area needs to be planned.

The range of interest of the satellite receiving antenna gain at the −3 dB edge of coverage area varies from about 28 dBi for a large country-wide feeder-link beam of 3° × 8° to 45 dBi for a small spot beam of 0.6° diameter.

6.4 *Antenna pointing accuracy*

Under the Final Acts of the WARC-BS-77, the pointing accuracy of the satellite transmitting antenna must be within 0.1°. Pointing accuracy is also important for receiving antennas, particularly those with narrow beams.

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 French study [CCIR, 1978-82h]. This study shows that, at least for the WARC-BS-77 Plan, assuming that the position of each feeder-link earth station is at the centre of the corresponding beam in the WARC-BS-77 Plan, an increase in the receiving antenna pointing error from 0.1° to 0.2° does not appreciably worsen the interference situation.

Should only one antenna be used for transmission and reception, the pointing accuracy of 0.1° for the receiving antenna is governed by the Radio Regulations. Where two separate reflectors are used for transmission and reception, one solution is to attach the reflector to the body of the satellite in a manner such that the transmitting antenna can be steered using an automatic pointing mechanism operating by detection of a land radio-frequency beacon. With this precise antenna pointing system, a transmit reflector can be stabilized to within 0.1°.

The pointing accuracy of 0.2° mentioned above can be achieved by using signals from the control system for the transmitting antenna described above [CCIR, 1978-82i].

As the pointing error tolerances are increased, however, antennas with smaller diameters (i.e. larger beam size) become necessary in order to assure service area coverage and this has a deleterious effect on frequency re-use.

Report 558 discusses the effect of pointing accuracy upon variation of gain within a given service area.

It is believed that pointing accuracies of ± 0.1° in direction and ± 1° in rotation about the beam axis are readily achievable and may be used for planning purposes. These tolerances would be consistent with the tolerances suggested for the satellite transmitting antenna on the down link.

6.5 *Antenna reference pattern*

If both the transmitting and receiving satellite antennas are based on the same technology, it is desirable that both antennas should have the same reference patterns. With regard to purity of polarization and the side lobes, however, a greater tolerance can be allowed for the receiving antenna. This was shown by several studies carried out by ESA and EBU [CCIR, 1978-82j], by France [CCIR, 1978-82i] and by Japan [CCIR, 1978-82k], which considered interference in a feeder-link plan directly translated from the WARC-BS-77 Plan, assuming the following receiving antenna characteristics:

- the same antenna patterns as established by the WARC-BS-77, both for the co-polar and cross-polar components;
- higher first side-lobe of the co-polar component;
- higher cross-polar component near the beam axis.

These studies show that in the WARC-BS-77 Plan there may not be significant increase in interference resulting from relaxation of the cross-polar component near the beam axis to −33 dB or even −30 dB below on-axis antenna gain. This conclusion is not applicable to Region 2.

As for the co-polar component, a relaxation of up to 10 dB in the region of the first side-lobe may not significantly increase the interference between feeder links in Region 1 and in most feeder links in Region 3, except that at certain orbital positions in Region 3, the worst value of adjacent channel carrier-to-interference ratios may be degraded by 4.2 dB. Even this degradation may not be significant.

In the case of co-located satellites serving common or adjacent service areas on adjacent cross-polarized channels, the purity of polarization may be critical to achieving necessary C/I ratios.

When a fast roll-off or shaped beam antenna has been used for transmitting in order to promote frequency re-use, a fast roll-off or shaped beam antenna may also be needed for receiving. The side-lobe roll-off of the receiving antenna must be rapid to avoid impacting on service area separations needed for frequency re-use.

In the case of the Region 2 planning, done at the RARC SAT-83, the same antenna reference patterns were used for the receiving and the transmitting satellite antennas. These co-polar and cross-polar patterns are described in Report 810.

For Regions 1 and 3, the WARC ORB-88 adopted the characteristics detailed in the following:

6.5.1 *Satellite receiving antenna*

If a common transmitting/receiving antenna is used, the cross-polar gain, beamwidth, pointing accuracy and radiation pattern would be dependent upon the down-link antenna characteristics.

Where separate antennas are used for transmitting and receiving, the parameters of the receiving antenna are given in the following sub-sections. Separate receiving antennas offer greater flexibility in terms of independence of the feeder-link frequency, polarization and service area.

6.5.2 *Cross-section of receiving antenna beam*

Initial planning is to be based on beams of elliptical or circular cross-section. If the cross-section of the receiving antenna beam is elliptical, the effective beamwidth φ_0 is a function of the angle of rotation between the plane containing the satellite and the major axis of the beam cross-section and the plane in which the beamwidth is required.

The relationship between the maximum gain of an antenna and the half-power beamwidth can be derived from the espression:

$$G_m = 27843/ab$$

or:

$$G_m(\text{dB}) = 44.44 - \log a - \log b$$

where:

a and b are the angles (in degrees) subtended at the satellite by the major and minor axes of the elliptical cross-section of the beam.

A minimum value of 0.6° for the half-power beamwidth is adopted for planning, except where an administration requests a lower value for its own beams.

6.5.3 *Co-polar reference pattern*

The co-polar reference pattern is given by the formula:

Co-polar relative gain (dB) (see Fig. 16, curve A)

$$G = -12(\varphi/\varphi_0)^2 \qquad \text{for } 0 \leqslant \varphi/\varphi_0 \leqslant 1.30$$

$$G = -17.5 - 25\log(\varphi/\varphi_0) \qquad \text{for } \varphi/\varphi_0 > 1.30$$

After intersection with Curve C: as curve C (curve C equals minus the on-axis gain).

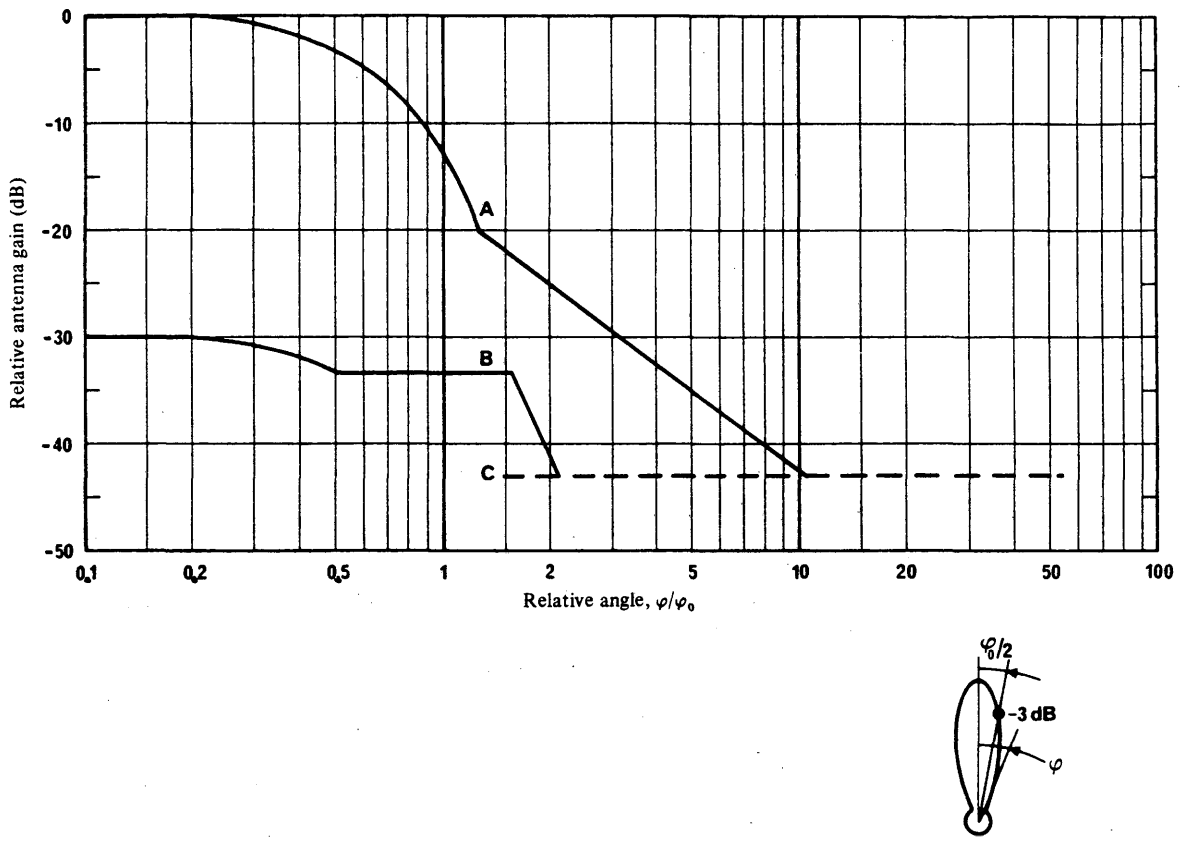

FIGURE 16 – *Satellite receiving antenna reference pattern for Regions 1 and 3 adopted by the WARC ORB-88*

Curves A: co-polar component (see § 6.5.3)
B: cross-polar component (see § 6.5.4)
C: minus the on-axis gain (curve C in this figure illustrates the particular case of an antenna with an on-axis gain of 43 dBi)

Note. – This receiving antenna reference pattern differs from that of the WARC-BS-77 transmitting antenna pattern.

6.5.4 *Cross-polar reference pattern*

The cross-polar reference pattern is given by the formula:

Cross-polar relative gain (dB) (see Fig. 16, curve B)

$$G = -30 - 12(\varphi/\varphi_0)^2 \qquad \text{for } 0 \leqslant \varphi/\varphi_0 \leqslant 0.5$$

$$G = -33 \qquad \text{for } 0.5 < \varphi/\varphi_0 \leqslant 1.67$$

$$G = -\left[40 + 40 \log \left|\varphi/\varphi_0 - 1\right|\right] \qquad \text{for } \varphi/\varphi_0 > 1.67$$

After intersection with curve C: as curve C (curve C equals minus the on-axis gain).

6.5.5 *Use of fast roll-off antennas*

In order to reduce co-polar interference, the pattern shown in Figure 17 has been used for some assignments. This pattern is derived from an antenna producing an elliptical beam with fast roll-off in the main lobe. Three curves for different values of φ_o are shown as examples.

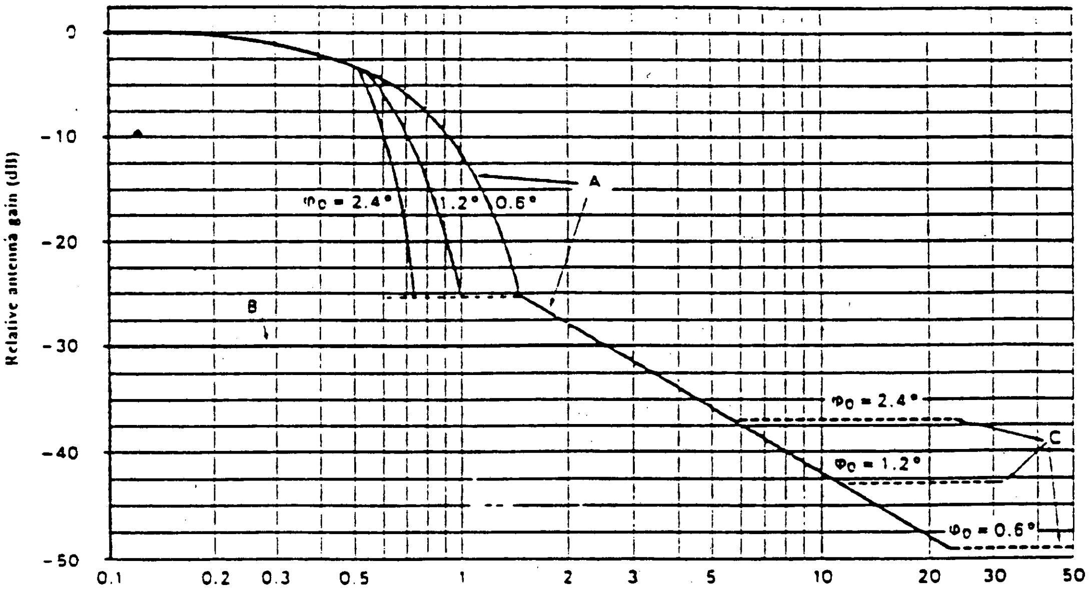

FIGURE 17

<u>Reference patterns for co-polar and cross-polar components for satellite receiving antennas with fast roll-off in the main beam for Regions 1 and 3</u>

Curve A: Co-polar component (dB relative to main beam gain)

$-12\ (\varphi/\varphi_o)^2$ for $0 \leq \varphi/\varphi_o \leq 0.5$

$-33.33\ \varphi_o^2\ (\varphi/\varphi_o - x)^2$ for $0.5 < \varphi/\varphi_o \leq 0.87/\varphi_o + x$

-25.23 for $0.87/\varphi_o + x < \varphi/\varphi_o \leq 1.413$

$-(22 + 20 \log (\varphi/\varphi_o))$ for $\varphi/\varphi_o > 1.413$

after intersection with curve C: as curve C

Curve B: Cross-polar component (dB relative to main beam gain)

-30 for $0 \leq \varphi/\varphi_o < 2.51$

after intersection with curve A: as curve A

Curve C: Minus the on-axis gain (Curves A and C represent examples for three antennas having different values of φ_o as labelled in Figure 17 . The on-axis gains of these antennas are 37, 43 and 49 dBi, respectively).

where φ = off-axis angle (degrees)

φ_o = dimension of the minimum ellipse fitted around the feeder-link service area in the direction of interest (degrees)

$$x = 0.5 \left[1 - \frac{0.6}{\varphi_o} \right]$$

7. Automatic gain control (AGC)

AGC on board spacecraft minimizes the effect of rain fades at the feeder-link station on the down-link C/N ratio by keeping the TWTA at saturation. The AGC operates on individual channels and increases the transponder gain of the wanted signal and of any portion of an interfering signal which falls within the filter bandwidth of the wanted channel. Therefore, during rain at the feeder-link station(s) the use of AGC permits the operation of the transponder close to saturation but the ratio of the wanted carrier to the portion of the interfering adjacent cross-polarized carrier which falls into the filter bandwidth of the wanted channel remains constant. Therefore, the use of AGC has no effect on the cross-polar C/I_u of the two feeder links under consideration.

However, the satellite using AGC radiates on the down link a constant level of the wanted signal which is attenuated on the feeder link, but re-radiates on the down link a higher level of the interfering cross-polar signal on the adjacent channel, which is not attenuated when there is no rain on the interfering feeder link. This situation may cause an increase in down-link interference to other systems receiving this re-radiation as co-channel interference. This problem could be significant only for co-located satellites serving common or adjacent service areas.

A limit on the range of AGC, in co-located satellites with cross-polarized channels, to less than 10 to 15 dB may be needed to guard against this problem of re-radiation on the down link. This problem can be reduced if satellites with cross-polarized channels serving the same service area or adjacent service areas are separated by at least 0.3° on the geostationary orbit. Non-co-located satellites with cross-polarized channels need not be subject to this limit of AGC range. A 10 dB limit on AGC range could be insufficient to maintain a constant TWTA output in some rain climates for certain elevation angles. The use of some other mechanism (power control, site diversity) might be required in these circumstances to maintain a constant signal level on the down link.

The Region 2 feeder-link Plan is based on a limit of 15 dB on the dynamic range of AGC on board some cross-polarized spacecraft to guard against this problem of re-radiation on the down link.

8. 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 satellite antennas and transponder systems.

There are two factors to be determined:

- the type of polarization (i.e., circular or linear);
- the sense of polarization (i.e., same or opposite to that of the down link).

The choice of feeder-link polarization will have to take into account the down-link polarization. The same *type* of polarization for both feeder and down link will normally benefit the satellite antenna design, permitting a less complex and lighter construction.

If the same type of polarization is used for both links, then the relative merits of the sense of polarization depend on the design of the satellite antenna. The use of the same sense of polarization is beneficial to the design of satellite antennas with specially shaped beams, using a multiple feed into a single reflector, and has been adopted in the Region 2 Plan. However, it relies totally on frequency selectivity to provide isolation between the transponder input and output. On the other hand, use of the opposite sense of polarization permits the use of a simple single feed into a common reflector for circular or elliptical beam shapes, and is being assumed in certain proposals for feeder-link plans for Regions 1 and 3. For circular polarization the feed is connected through a polarizer to an orthogonal mode coupler to separate transmitting and receiving paths, giving additional isolation of typically 30 dB, thus easing filtering requirements in the transponder. The latter approach has generally been taken in planning studies conducted in Region 1.

Regarding the effect on sharing with other services, it will be the relatively wide angle side-lobes of co-polar and cross-polar radiation patterns of the earth-station antenna which are important. These will be at about the same level regardless of the type of polarization. Hence, the choice of polarization will make little difference in the interference into terrestrial services and the fixed-satellite service in the space-to-Earth direction.

When satellites are separated by more than about 10°, the type and/or sense of polarization need not be specified for planning purposes.

Feeder-link interference is most critical between co-located or neighbouring satellites serving the same or adjacent coverage areas, thus making the value of the cross-polar discrimination a key parameter value for feeder-link planning. Linearly polarized antennas have better cross-polar discrimination than circularly polarized antennas. Table V gives typical *XPD* values.

TABLE V – *Cross-polar discrimination characteristics, XPD (dB) of feeder-link antennas*

Type of polarization	Antenna	
	Earth-station transmit	Satellite receive
Linear	35	33
Circular	30	27

The CCIR rain model (see Report 564) predicts a very small differential in attenuation between vertical and horizontal polarization for small values of attenuation and increasing to about 1.5 dB differential at 15 dB attenuation. The model also predicts that the attenuation of circularly polarized waves is the median between the attenuation of the vertical and horizontal polarization and that the cross-polar depolarization of true vertical and true horizontal polarization can be up to 15 dB better than that of circular polarization (see Report 814).

8.1 *Rain at one site*

The effect of misalignment β_T on the cross-polar *C/I* of feeder links is illustrated in Fig. 18 for the case when it rains at the wanted site only. The cross-polar channels are used by the same satellite or another co-located satellite serving an adjacent coverage area. If the coverage areas overlap significantly, the cross-polar channels could suffer up to 3 dB more interference than indicated in Fig. 18. The figure shows that under clear-sky conditions and under rain conditions, circular polarization offers better *C/I* for any misalignment greater than about 3°. This is illustrated for values of attenuation up to 15 dB. The effect of tilt angle on linear polarization *C/I* degradation during rain is small as indicated by the similar performance of the vertical and horizontal polarization. This is because the interfering signal is not attenuated or depolarized.

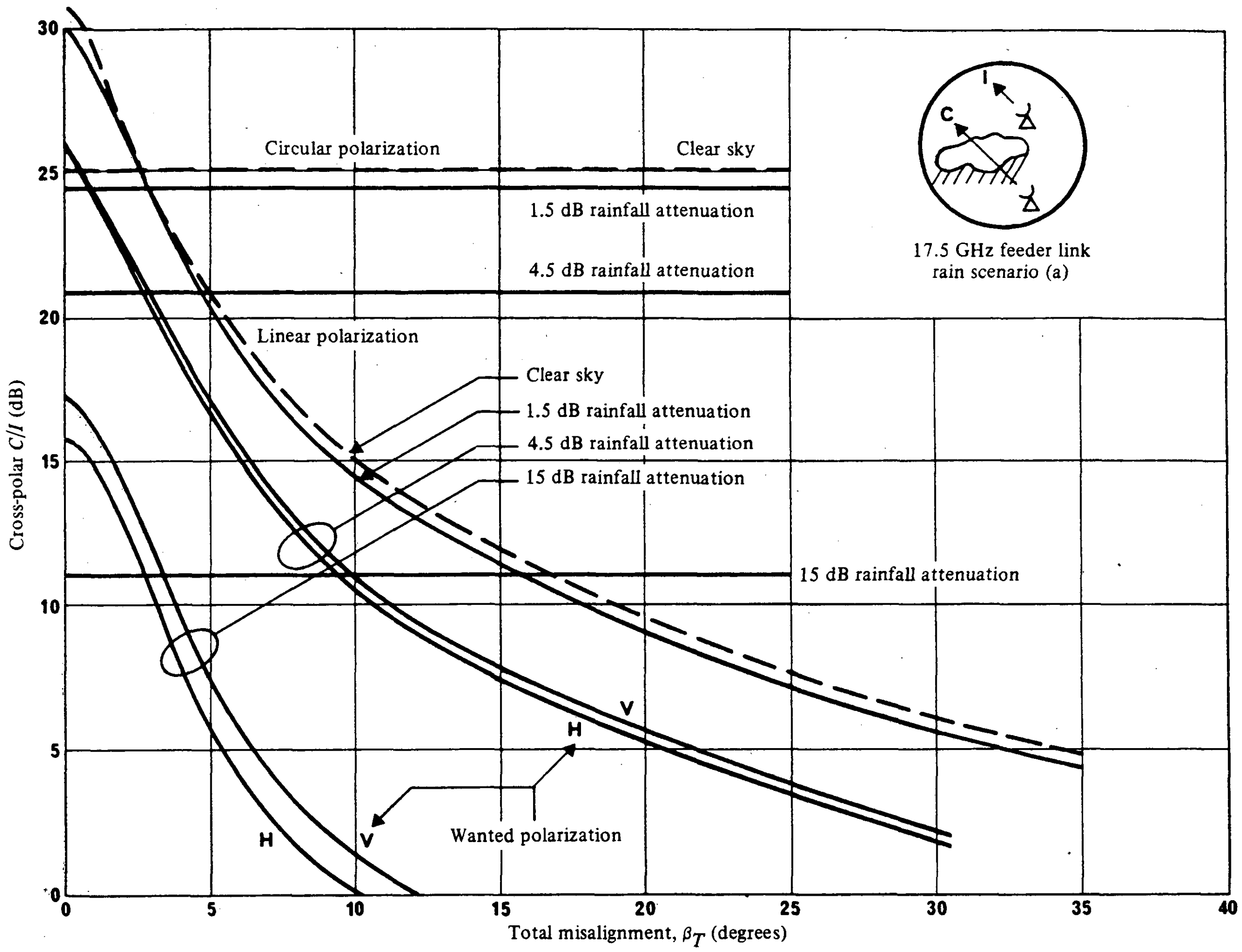

FIGURE 18 – *Cross-polar C/I of feeder links in the presence of rain at the wanted site only*

— — — clear sky

——— attenuated

8.2 *Rain at both sites*

When it rains at both the wanted and the interfering transmitter sites, the combined effects of rain and misalignment on *C/I* are complicated by the contribution of the depolarization of the interfering signal. This rain scenario is applicable to two nearby feeder-link earth stations transmitting cross-polarized channels to the same satellite or to co-located satellites. The effect of misalignment and tilt angles on linear polarization is illustrated in Fig. 19 for a 4.5 dB attenuation and in Fig. 20 for a 15 dB attenuation (see also Annex I to Report 814).

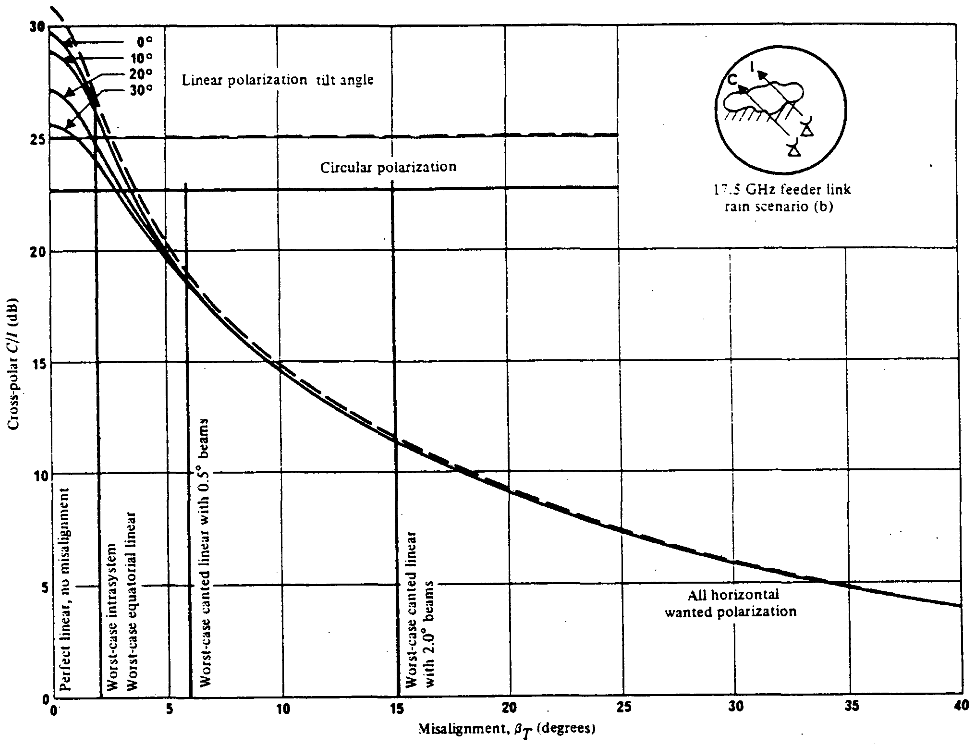

FIGURE 19 – *Cross-polar C/I of feeder links in the presence of 4.5 dB of rainfall attenuation at the wanted and interfering nearby sites*

— — — clear sky
——— 4.5 dB of rainfall attenuation

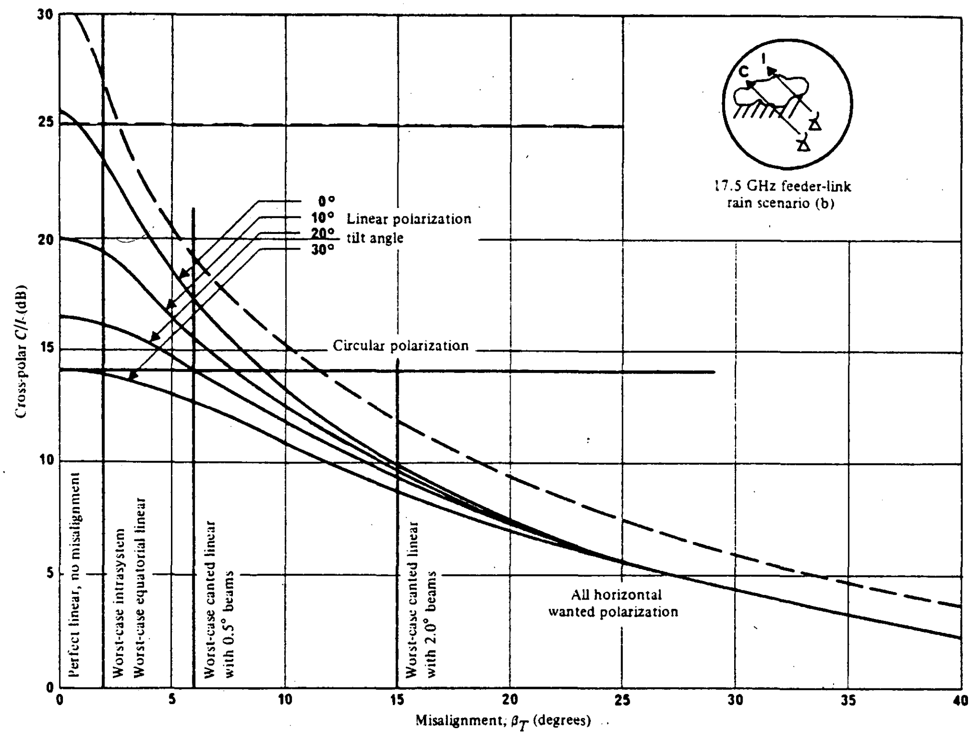

FIGURE 20 – *Cross-polar C/I of feeder links in the presence of 15 dB of rainfall attenuation at the wanted and interfering nearby sites*

— — — clear sky
——— 15 dB of rainfall attenuation

8.3 *Misalignment*

Circular polarization (CP) cross-polar discrimination (*XPD*) is independent of both the rotational alignment of the transmitting and receiving antenna polarizers and the orientation of the local horizontal and vertical vectors. Linear polarization (LP) is capable of better *XPD* than is CP, but only if the rotational alignment of the LP transmitting and receiving antennas is maintained within 2° and the transmitting antenna polarization tilt angle is less than 20°.

For feeder-link service areas up to several hundred kilometres in diameter and satellite elevation angles less than 60° (late eclipse slots and/or non-equatorial service areas), the variation of the tilt angle across each such service area is no more than approximately 20°. For such service areas, the local vertical (or horizontal) LP vector could be defined at the area's centre, or could be off-set somewhat towards a sub-area of heavier precipitation. The rotational alignment of each feeder-link transmitting antenna polarization within the service area could be adjusted, according to the equation in Annex I to Report 814 so that co-linearity with the BSS receiving antenna is achieved. This alignment could be maintained to ± 0.5° on the ground. The satellite antenna rotation tolerance is ± 1.0°. This tolerance could be reduced further, if necessary, by polarization tracking techniques on the satellite.

For larger service areas (for example the contiguous United States), within which the tilt angle varies by many tens of degrees, the 20° tilt angle could be exceeded. The concept of "progressive" linear polarization [Ohm, 1981] provides the theoretical basis for a BSS feeder-link satellite receiving antenna which is not subject to this tilt angle limitation; but until a satellite antenna based on this concept has been successfully demonstrated, this concept should not be used for BSS planning. The same system advantage could be obtained mechanically by using a steerable satellite receiving antenna of very narrow beamwidth (for example 0.5°) which when pointed towards any location visible from the satellite has its polarization vector rotated to be co-linear with local horizontal (or vertical) feeder-link transmitting antennas.

Either the progressive LP method or the polarization method of Annex I to Report 814 would provide adequate *XPD* within a service area served by its satellite cluster. For contiguous or overlapping service areas, only the progressive LP satellite antenna (either mechanical or electrical) would permit a feeder-link transmitter antenna located at the common service area border to be properly aligned as seen from both satellite clusters. However, as discussed in § 4.1, for 5 m feeder-link transmitter antennas, adequate isolation (cross- or co-polar) already exists between satellite clusters at least 10° apart.

9. General planning considerations

Planning of the feeder links can be done simultaneously with planning of the down links or it can take place separately at a later time. Simultaneous planning is discussed in Report 633. This section discusses some features of feeder-link planning that must be considered in either case.

9.1 *Feeder-link frequency*

In general, for a given size of antenna, the higher the frequency the more directional is the satellite receiving antenna and the more the interference decreases. However, propagation effects including depolarization will be more severe the higher the frequencies. According to studies carried out in Japan [CCIR, 1978-82l], in practice, as far as the worst carrier-to-interference ratios are concerned, there is little difference between the two feeder-link systems using the frequency bands 14 GHz and 17 GHz.

9.2 *Antenna location and size*

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.

The broadcasting-satellite systems of small countries may have a single feeder- and down-link beam. Access to the satellite system may be derived from one or a few locations or from anywhere within the country. If the locations are known in advance of the plan, feeder-link service areas smaller than the down-link service area may be planned and the satellite may be equipped with a spot beam receiving antenna. If the locations of the earth stations are not known in advance of the plan, or if access from anywhere within the down-link service area using small transportable terminals is desirable, a country-wide feeder-link service area needs to be planned.

Geographical considerations (e.g., time zones) in a country and/or cultural diversity of its population may dictate the requirement of multiple down-link beams. In this case, the feeder-link antenna for each beam may be either located inside each respective down-link service area, located at specific locations inside the country, or located anywhere inside the country. If it is desired to locate the earth station only inside each respective down-link service area, coincidental feeder-link and down-link service areas may be planned. However, programmes originating from outside the down-link service area for broadcasting inside the down-link service area may need to be distributed via terrestrial systems or via fixed satellites.

If it is desired to locate the earth station anywhere inside a country served by several beams, direct access to the broadcasting satellite may be achieved with the planning of a country-wide feeder-link service area. Programmes originating from outside the down-link service area would directly access the broadcasting satellite using the planned feeder-link frequency bands.

Planning of feeder links based on one size of earth station and a maximum transmitting power value would result in greater homogeneity between feeder links. For a given antenna size and a given co-channel protection ratio, there is an orbital separation beyond which the interference from unwanted feeder-link stations becomes negligible and need not be considered in the planning of feeder links. As an example, for a 5 m antenna diameter and a side-lobe envelope meeting the $29 - 25 \log \varphi$ (dBi) reference pattern, the satellites have to be separated by at least 7.5° to attain an isolation of 40 dB in the presence of 10 dB differential rain attenuation to permit frequency re-use. In this example, co-polar transmissions are assumed, no satellite receiving antenna discrimination is considered, and the feeder-link stations are located in the same service area.

In the case where the two co-channel transmissions are cross-polar, a smaller orbital separation is required since part of the 40 dB isolation is provided by the polarization discrimination of the transmitting earth-station antenna and the satellite receiving antenna. Similarly, if the feeder-link service areas are not adjacent, the satellite receiving antenna can provide for a portion of the 40 dB protection ratio because of the angular separation. The required orbital separation can consequently be reduced to the point where the satellites are almost co-located.

In the case of interference from the adjacent channel, the required orbital separation is further reduced compared to the respective cases mentioned above since there is typically 16 dB less isolation required in this case. A particular case is dealt with in § 9.4 where it is found that the required orbital separation for cross-polar adjacent channels transmitted from the same service area under a 10 dB rain fade differential is only a fraction of a degree. This concept was extensively used in the planning of the feeder links in Region 2.

Because of the relatively larger size of the earth-station transmitting antenna, the required isolation will, in normal conditions, be reached on the feeder links for smaller orbital and/or service area separation than that required for the down links except when the feeder-link service area is larger or outside the corresponding down-link service area.

In the feeder-link Plans for Regions 1 and 3 and for Region 2, a nominal 5 m antenna diameter was found to be attractive and was used for planning. In addition to completely decoupling feeder links for satellites separated by about 10°, 5 m was found to be within the range of sizes that can be considered for transportable applications. Further, the required transmitted power for a viable feeder link was found to be readily achievable. Smaller antennas to a minimum of 2.5 m diameter were allowed in the Plans and were considered in the development of the antenna reference pattern (see § 5.2) such that their use will not increase the level of interference to other feeder links as calculated in the Plans. In satellites separated by more than 0.55°, no additional interference can result from use of 2.5 m antennas. It is understood, however, that with the use of these smaller antennas, lower C/N and C/I values will be realized than with the antenna size used as the basis for planning.

9.3 *Transmitted power*

In order to avoid excessive interference into adjacent satellites and into terrestrial services and because of the fact that off-axis feeder-link antenna side-lobe envelopes are defined in terms of absolute gain relative to an isotropic source and in order to simplify feeder-link planning, a maximum allowable power into the antenna of a broadcasting-satellite feeder link is found to be the most appropriate way of specifying the interference characteristics of the feeder-link transmitting station along with the antenna reference pattern. This maximum power limit would apply for all conditions and all antenna sizes.

Another benefit of setting a limit on the feeder-link transmitted power is that, if the planning is done with a nominal antenna size, the principle of homogeneous PFD at the orbit applies, giving the best utilization of the spectrum orbit resource. It should be noted however, that inhomogeneity of e.i.r.p. is dependent only on the difference in transmitted power, not on antenna gain, when satellites are separated by more than a fraction of a degree.

9.4 *Co-located satellites*

The most critical cases of feeder-link interference occur when satellites are co-located. As discussed in § 4.6, two situations are found in practice:

- the co-located satellites use the same channel but are cross-polarized to each other and their service areas are separated; and
- the co-located satellites have common or adjacent service areas and operate on cross-polarized adjacent channels.

Several methods for coping with low *C/I* ratios are available but all have an associated penalty. Site diversity combined with uniform feeder-link e.i.r.p. could be used at high cost and operational inflexibility. Degraded interference performance could be accepted for the small percentages of time associated with high precipitation losses. Power control combined with depolarization compensation is a potential solution but these techniques have not yet reached an adequate level of development.

When the channels are adjacent, there are several additional methods which might be used. Channel spacing could be increased at the cost of fewer total TV channels. Bandwidths of each channel could be reduced but with adverse impact on applications, such as high definition TV, requiring wide bandwidths.

Another solution to reduce interference would be to separate co-located satellites by a small orbital arc. This approach was adopted to develop the Region 2 feeder-link Plan and is described below.

Other factors that need to be considered when satellites are co-located are the probability of collision and potential interference on the spacecraft service function links.

9.4.1 *Satellite clusters and reduction of interference*

A satellite cluster as defined by the RARC SAT-83 in the Region 2 Plan is formed by satellites at two orbital positions which are separated by 0.4° in the Plan and which are assigned cross-polarized adjacent channels at each of the two orbital positions. Because of the other methods available to combat feeder-link interference between cross-polarized first adjacent channels, it was felt that significant flexibility in the orbital positioning of satellites was needed at the time of implementation. In the Region 2 Plan, satellites sharing the same cluster can be located at any position within the 0.4°-wide cluster with the agreement of the other administrations sharing the same cluster of satellites. Under these conditions, the optimum orbital separation between satellites can be chosen at the time of implementation and depends on:

- rain climatic zone,
- elevation angle,
- earth-station antenna diameter, and
- site diversity.

The RARC SAT-83 adopted a minimum separation of 0.9° between the centres of satellite clusters in the Plan.

9.4.2 *Collision probability*

Still another advantage to separating "co-located" satellites derives from a reduction in the probability of collision. Using the method of caculation given in [Hechler and Van der Ha, 1980], the probability of collision increases from 9×10^{-7} per year to 5×10^{-5} per year as the number of satellites, each with 100 m^2 cross-section and sharing the same 0.1° arc, increases from 2 to 12. While there would still be a 99% probability of no collision in about 200 years, the probability of any collision on the geostationary orbit would increase significantly if satellites were exactly co-located at many positions on the orbit. Once a collision occurs, secondary debris significantly increases the probability of additional collisions. It may, therefore, be preferable to minimize the risk of collision by slightly separating "co-located" satellites.

9.4.3 *Interference on spacecraft service function links*

A small orbital separation between satellites may also be used to maintain interference levels into satellite TTC channels at an acceptably low level.

The frequency separation between the limit of the television channel at the band edge and the nearest TTC channel will be of the order of 2 MHz and the television channel satellite emission roll-off is assumed to be 2 dB per MHz with typical filtering.

Isolation between the television channel at the band edge and TTC channels due to the television channel filter can be as low as 4 dB and as great as about 23 dB in the case of 12 MHz wide guard bands. Transmission of TTC channels in opposite polarization to the television channel at the band edge would increase the isolation to the 25-44 dB range under clear-sky conditions and to the 15-34 dB range in the presence of 10 dB rain attenuation on the wanted path. Nominal separation of "co-located" satellites would increase the isolation and provide flexibility in the choice of polarization for TTC channels.

9.4.4 *Method to resolve incompatibilities in the feeder link Plans*

After planning of feeder links, some cases of incompatibility may remain. The concerned administrations, after coordination, could use the following means to settle these situations. The interfering station could transmit at a lower power than the nominal value under clear sky conditions while keeping sufficient quality and an acceptable interference level. In the presence of rain attenuation, the interfering station would be allowed to increase its e.i.r.p., which could decrease the *C/I* ratio on the link subject to interference, but not below the limit given in the plan.

9.5 *Frequency translation*

For Region 2, the feeder-link Plan has been based on the use of a single frequency translation between the 17 GHz feeder-link channels and the 12 GHz down-link channels.

WARC-ORB(88) generally accepted for Regions 1 and 3 (in the 17.3 to 18.1 GHz band) the principle of a single translation frequency (5.6 GHz) except for the cases where it was necessary to resolve incompatibilities in the Plan.

As the maximum available bandwidth for the feeder-link band 14.5-14.8 GHz is only 300 MHz as against 800 and 500 MHz in the down-link Plan for Regions 1 and 3, respecitvely, several translation frequencies where selected allow any channel in the Plan to be used. Consequently, a particular feeder-link channel was assigned to several BSS Plan channels simultaneously.

For the feeder-link band 14.5-14.8 GHz, 14 channels and 2 appropriate guard bands should be assumed.

Selection of translation frequencies for this purpose and for this band is a complex task due to two domains within the possible range of translation frequencies which would create spurious mixing products within certain channels. Therefore, it is necessary to optimize the translation frequencies. Ratios of translation frequency to any frequency within the necessary bandwidth of a feeder-link channel to be avoided are 1/6 and 2/11.

The following parameters shall be used for planning feeder links in the frequency band 14.5-14.8 GHz:

Necessary bandwidth of a channel:	27 MHz
Channel separation:	19.18 MHz
Number of channels:	14
Centre frequency of the lowest channel (1):	14 525.30 MHz
Centre frequency of the highest channel (14):	14 774.64 MHz
Lower guard band:	11.80 MHz
Upper guard band:	11.86 MHz

Translation frequencies:

a) for BSS channels 1 to 14	2 797.82 MHz
b) for BSS channels 15 to 28	2 529.30 MHz
c) for BSS channels 29 to 40	2 260.78 MHz

Table VI indicates the correspondence between the channel numbers, the frequencies assigned to the feeder links and the frequencies assigned in the WARC-BS-77 Regions 1 and 3 Plan, for the three translation frequencies.

TABLE VI – *Table showing correspondence between channel numbers and assigned frequencies for the feeder links in the frequency band 14.5-14.8 GHz and the relationship to the BSS Regions 1 and 3 Plan assignments*

Feeder-link assignments		Translation frequencies (MHz)					
		2 797.82		2 529.30		2 260.78	
		BSS Regions 1 and 3 Plan assignments					
Channel No.	Frequency (MHz)	Channel No.	Frequency (MHz)	Channel No.	Frequency (MHz)	Channel No.	Frequency (MHz)
1	14 525.30	1	11 727.48	15	11 996.00	29	12 264.52
2	14 544.48	2	11 746.66	16	12 015.18	30	12 283.70
3	14 563.66	3	11 765.84	17	12 034.36	31	12 302.88
4	14 582.84	4	11 785.02	18	12 053.54	32	12 322.06
5	14 602.02	5	11 804.20	19	12 072.72	33	12 341.24
6	14 621.20	6	11 823.38	20	12 091.90	34	12 360.42
7	14 640.38	7	11 842.56	21	12 111.08	35	12 379.60
8	14 659.56	8	11 861.74	22	12 130.26	36	12 398.78
9	14 678.74	9	11 880.92	23	12 149.44	37	12 417.96
10	14 697.92	10	11 900.10	24	12 168.62	38	12 437.14
11	14 717.10	11	11 919.28	25	12 187.80	39	12 456.32
12	14 736.28	12	11 938.46	26	12 206.98	40	12 475.50
13	14 755.46	13	11 957.64	27	12 226.16	–	–
14	14 774.64	14	11 976.82	28	12 245.34	–	–

9.6 *Total needed bandwidth for feeder links*

Values derived from studies for the feeder-link/down-link bandwidth ratio vary from 1:1 to 1.5:1 depending on the assumed feeder-link characteristics [CCIR, 1978-82m]. Values below 1:1 are not reasonable, mainly because they imply signal processing repeaters in the satellite, making it more complex, costly and more prone to failure.

9.7 *Independence between orbital locations in the Regions 1 and 3 Plan*

Studies in France [CCIR, 1978-82n, o] showed that, for the 6° spacing of Regions 1 and 3 it is possible to plan independently for each orbital position with alternate polarization from one orbital position to the next, and from one channel to the next under the following hypotheses:

- diameter of earth station antennas: at least 3 m;
- antenna pattern and beamwidth for receiving and transmitting satellite antenna the same as in the WARC-BS-77 Plan;
- protection ratios: co-channel 40 dB, adjacent channel 24 dB;
- translation of the WARC-BS-77 Plan;
- essentially the same power flux-density at the satellites;
- polarization discrimination of 30 dB in the side lobes;
- the various earth stations are each situated in the centre of the corresponding down-link beam;
- rain-induced depolarization is taken as −20 dB.

Further study is required with respect to other planning hypotheses for Regions 1 and 3.

9.8 *Service area considerations, impact on frequency re-use*

As indicated above there are several reasons why it may be advantageous to consider a feeder-link service area that may be different from the corresponding down-link service area(s). From an interference point of view there are advantages to narrow feeder-link beams located near the respective centres of the corresponding down links [CCIR, 1978-82h]. Such a scenario might, however, constrain operational flexibility. In some situations operational requirements may dictate simultaneous access to several satellites at various locations or to several down-link beams from the same orbital location. Feeder-link transmissions could emanate from a single location which may or may not be in one of the down-link areas, or from anywhere within a number of down-link areas [Bouchard, 1982]. This would apply for example to a large country or to a grouping of administrations which of necessity must be fed by multiple down-link beams. In these latter situations the ability to re-use a frequency allotment need not be constrained by the feeder-link plan if technical criteria are developed to guard against feeder-link interference.

Frequency re-use capability can be expressed in terms of the required orbital separation between the satellites of the interfering systems as a function of the separation between the respective service areas for the four combinations of co- and adjacent channel and co- and cross-polarity. In the case of large countries which are served by several adjacent down-link beams and where there are requirements for country-wide access to each of these beams, frequency re-use may be constrained when the dimension of the feeder-link service area is significantly greater than the dimension of any of the down-link beams under certain combinations of:

- orbital separation,
- feeder-link earth station antenna diameter,
- inhomogeneities between feeder links, and
- feeder-link protection ratio [CCIR, 1978-82p].

However, appropriate values of these parameters can always be chosen to ensure that the frequency re-use capability of the feeder links is at least equal to or greater than that of the down link.

An integrated planning approach for the feeder links and the down links is therefore necessary to support the planning of a feeder-link service area different from the down-link service area. The simultaneous planning of both feeder links and the down-links at the RARC SAT-83 make this approach possible. A study was performed in Canada assuming the following technical parameters:

- side-lobe reference pattern of the feeder-link transmitting antenna: $32 - 25 \log \varphi$, dB;
- radiation pattern of the satellite receiving antennas: the same as that given in the Final Acts of WARC-BS-77 for the satellite transmitting antenna;
- feeder-link protection ratios: in the range of 35 to 45 dB;
- down-link protection ratio: 35 dB single entry;
- channel bandwidth: 18 MHz;
- channel spacing: in the range of 13 to 17 MHz.

Assuming a transmitting antenna diameter of 8 m for feeder links having inter-system inhomogeneities of 8 dB, co-channel protection ratio of 40 dB and adjacent channel protection ratio of 20 dB, the study has shown that the planning of country-wide feeder-link service areas is possible provided that the multi-beam satellites of large countries and the satellites of their neighbouring countries are:

- spaced more than 6° apart when co-channel co-polar allotments are intended for feeder links from anywhere within the countries;
- spaced more than 1° apart when adjacent channel co-polar or co-channel cross-polar allotments are intended for feeder links from anywhere within the countries.

These conclusions apply for both country-wide satellite receiving antennas and steerable spot beam satellite receiving antennas.

10. Sharing in the feeder-link bands

10.1 *General*

As a result of allocation actions taken by the WARC-79, the use of the frequency bands shown in § 2 of this Report 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.

The band 17.3-18.1 GHz is one of the bands chosen by the WARC ORB-85 for planning feeder links in Regions 1 and 3. The lower part of that band, 17.3-17.8 GHz, has been planned for feeder links in Region 2 (RARC SAT-83). This section provides information regarding the several sharing situations that will exist in the 17.7-18.1 GHz portion of this band. Sharing situations with the attendant possibility of interference will involve feeder links to broadcasting satellites, the fixed service and the fixed-satellite service in all Regions [CCIR, 1982-86f].

Some cases of sharing are under consideration in Study Groups 4 and 9.

10.2 *Sharing situations in the band 17.7-18.1 GHz*

The sharing situations that will exist in the band segment 17.7-18.1 GHz are shown in Fig. 21. Since the allocations to the three services are world-wide, interference is possible between BSS feeder links and the fixed and fixed-satellite services in all Regions. The severity of interference and interference reduction techniques for each of the cases indicated in Fig. 21 will be outlined in the sections that follow.

10.2.1 *Interference from FSS space-station transmitters to BSS space-station receivers*

Interference from FSS space-station transmitters can reach BSS space-station receivers in two ways (cases 1A and 1B, Fig. 21). One way is from the side lobes of the FSS space station transmitting antenna into the side lobes of the receiving antenna of a nearby BSS space station. The second way is from the main beam of an FSS space-station transmitting antenna into the main beam of the receiving antenna of a nearly antipodal BSS space station.

10.2.1.1 *Nearly co-located FSS and BSS space stations (case 1A)*

Interference from an FSS space station to a nearby BSS space station will be negligible unless the satellites are extremely close to each other due to the fact that the interference is transmitted and received in the far side lobes of both antennas. Small satellite separations of the order of 0.1°, i.e., separations of about 74 km, provide sufficient signal attenuation (space loss) to reduce interference to negligible levels.

10.2.1.2 *Nearly antipodal FSS and BSS space stations (case 1B)*

If an FSS and BSS space station are nearly antipodal, interference could occur in rare cases. Typically, the existence of planned BSS satellites should have a negligible constraint on the location of FSS satellites. However, some care may be required when the inter-satellite separation is in the range of 160° to 162.5°.

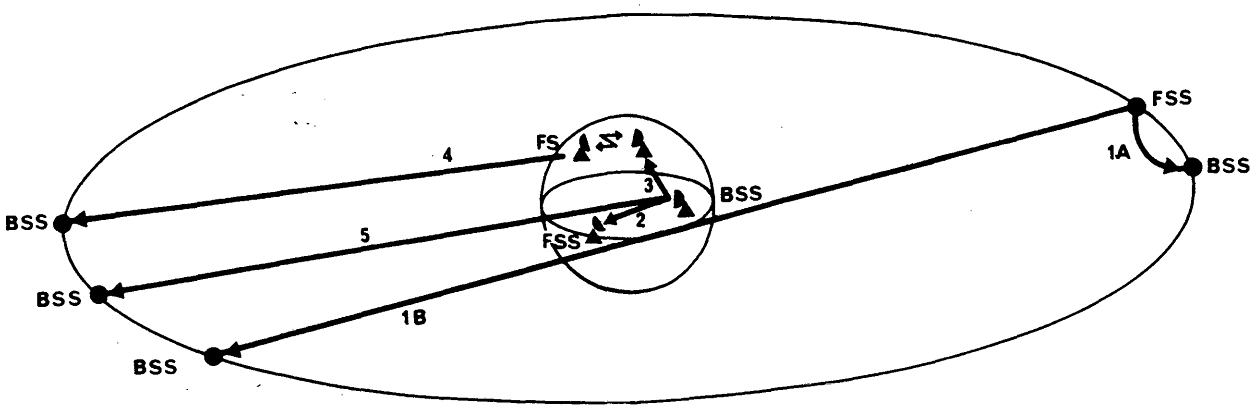

FIGURE 21

Case	*From*	*To*	*Comments*
1A	FSS (S-E)	BSS, nearby satellite	Small satellite separations will reduce interference to acceptable levels
1B	FSS (S-E)	BSS, antipodal satellite	Rare situation; Appendix 29 (increase of ΔT of 10% in Region 2)
2	BSS feeder link	FSS, receiving earth station	Appendix 28 type coordination procedure should apply
3	BSS feeder link	FS, receiver	Appendix 28 type coordination procedure should apply
4	FS transmitter	BSS, satellite receiver	Rare situation, but see Recommendation No. 4 (RARC SAT-83)
5	BSS feeder link in one Region	BSS, satellite receiver in another Region	Appendix 29 type coordination (increase of ΔT of 10% in Region 2)

10.2.1.3 *Cases 1A and 1B in Region 2*

The RARC SAT-83 (Part II, Annex 4, Section 1 of the Final Acts) applied Appendix 29 to this situation, but changed the criterion that triggers coordination to a 10% increase in ΔT. In the case of nearly antipodal satellites, Appendix 29 coordination is required only when the PFD at the limb of the Earth exceeds -123 dB(W/(m^2 · 24 MHz)), and geocentric satellite separation is more than 150°.

10.2.2 *Interference from a BSS feeder-link transmitter to an FSS receiving earth station* .

Interference can be caused from a BSS feeder-link transmitter (the Earth-to-space direction of transmission) to the receiver of an FSS earth station (employing the same frequency band segment in the space-to-Earth direction of transmission) (case 2, Fig. 21). The extent of potential interference can be determined employing an adaptation of the interference calculation procedures described in Reports 557, 382, 388 and 448. Separating the two stations or siting them so that there is sufficient shielding due to terrain or artificial barriers can reduce the likelihood and level of interference to permissible values.

The RARC SAT-83 applied Appendix 28 coordination to this situation (Final Acts, Part II, Annex 4, Section 3), modified to take account of earth-station characteristics and propagation conditions in this band segment.

10.2.3 *Interference from a BSS feeder-link transmitter to a fixed-service receiver*

Interference can be caused by BSS feeder-link transmissions into the receiver of a fixed-service terrestrial station (case 3, Fig. 21).

Determination of the coordination area around the feeder-link transmitting earth station and fixed-service receivers, where these contours are in different countries, should be based on Appendix 28 to the Radio Regulations. Report 382 provides a related, although not identical, procedure reflecting the most recent, albeit in some instances at present, provisional propagation data of Reports 724, 563 and 569. More detailed interference calculation methods of Reports 448 and 388, mentioned above, can also be used in this interference situation to estimate the level of interference expected. Adequate physical separation of the stations, or the use of natural or artificial shielding can reduce interference to permissible levels as in the previous interference situation. Part II, Annex 1, Section 3 of the RARC SAT-83 Final Acts reaffirms Appendix 28 to the Radio Regulations as the way to determine if a terrestrial station could be affected.

10.2.4 *Interference from a fixed-service transmitter to a BSS space-station receiver*

Interference can be caused in certain rare cases by transmissions from a terrestrial station in the fixed service into the receiver of a BSS space station (case 4, Fig. 21). As in the interference situation described in §10.2.1.2, the BSS space-station receiving antenna must have significant gain in the direction of the limb of the Earth. There may be many terrestrial stations in the 17.7-18.1 GHz band segment eventually, and their antennas are typically pointed within a degree or so of the horizon. More potential interference situations may exist, therefore, than for the antipodal satellite case described in § 10.2.1.2. However, interference can be caused only if the fixed-service station employs the maximum permissible e.i.r.p. of 55 dBW towards the geostationary orbit and uses transmission bandwidths not significantly greater than those used by the BSS feeder link. Given the typical channelization plans for the fixed service in this band, and the e.i.r.p.s now in use, it is considered that this interference situation will be rare. However, the RARC SAT-83 adopted Recommendation No. 4 which asks the CCIR to continue its study of this situation on an urgent basis in time for consideration by the WARC ORB-85.

10.2.5 *Interference from BSS feeder-link stations in one Region to BSS satellite receivers in another Region*

Interference can be caused to broadcasting-satellite space-station receivers of one Region from feeder-link transmissions of another Region (case 5, Fig. 21). Interference within a Region is limited or prevented by the development of the respective regional plans, and by the modification procedures incorporated in each. Part II, Annex 4, Section 2 of the RARC SAT-83 Final Acts applied Appendix 29 to limit interference from Regions 1 and 3 feeder links (to be planned at the WARC ORB) to Region 2 BSS satellite receivers using an increase in ΔT of 10% as a coordination trigger.

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[1978-82]: **a.** 10-11S/43 (Canada); **b.** 10-11S/159 (EBU); **c.** 10-11S/175 (Canada); **d.** 10-11S/151 (France); **e.** 10-11S/118 (Japan); **f.** 10-11S/158 (EBU); **g.** IWP 10-11/1-25; **h.** 10-11S/127 (France); **i.** 10-11S/152 (France); **j.** 10-11S/9 (EBU); **k.** 10-11S/129 (Japan); **l.** 10-11S/21 (Japan); **m.** 10-11S/120 (IWP 10-11/1); **n.** 10-11S/67 (France); **o.** 10-11S/128 (France); **p.** 10-11S/148 (Canada).

[1982-86]: **a.** 10-11S/12 (France); **b.** 10-11S/24 (USA); **c.** 10-11S/134 (Japan); **d.** 10-11S/27 (USA); **e.** 10-11S/36 (ESA); **f.** 10-11S/25 (USA).

[1986-90]: **a.** 10-11S/105 (Japan), **b.** 10-11S/22 (Japan)

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ANNEX I

FEEDER-LINK TRANSMITTING ANTENNA SIDE-LOBE CHARACTERISTICS

RESULTS OF MEASUREMENTS

This Annex gives the results of some measurements on antennas of a type suitable for the feeder-link transmission to broadcasting satellites.

An 8 m Gregorian type antenna built in 1979 was measured in Canada. The measurement data are shown in Fig. 22. This linearly polarized antenna was optimized for high performance for transmit/receive operation at 14/12 GHz. The efficiency was found to be 78%. The results are given for three frequencies in each band (edges and centre of the band) and two azimuthal profiles (E and H planes). This antenna which is understood to be representative of the new generation of antennas meets the 29 – 25 log φ side-lobe envelope. It is likely that the feeder-link antennas which will need to be optimized for only one frequency band will also meet this envelope at 17 GHz.

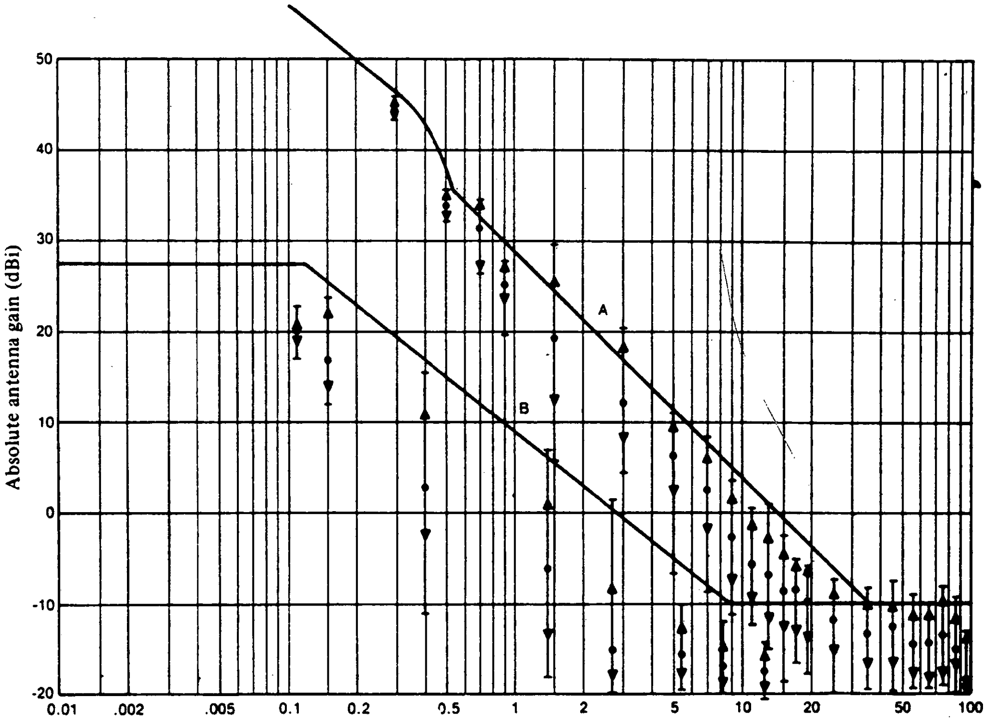

FIGURE 22 – *Measured co-polar and cross-polar patterns of an 8 m Gregorian antenna at 14/12 GHz*

Curves A: co-polar component
B: cross-polar component

⊤ : Upper limit
▲ : Upper 10% point
● : Median point
▼ : Lower 10% point
⊥ : Lower limit

ANNEX II

OPERATIONAL AND TECHNICAL CHARACTERISTICS OF FEEDER LINKS

1. Introduction

The feeder link Plan and the associated provisions for the 12 GHz BSS were established for Regions 1 and 3 at WARC-ORB(2) in 1988. When further studying the technical characteristics of the feeder links for optimal operation, additional information, based on actual operating conditions is required, particularly in overcoming the problems of heavy rain attenuation, and in increasing the effectiveness of transportable earth stations.

2. Feeder link operation in rainy conditions

The feeder link for the Japanese broadcasting satellite (BS-2), in use since 1984, operates in the band 14.0 - 14.5 GHz. Almost all of the TV programmes are transmitted from the main earth station, but transportable and secondary earth stations are occasionally used for various other purposes.

Table VII shows the technical characteristics, purposes and uses of the NHK earth stations in the BS-2 satellite broadcasting system.

The main earth station uses an 8 m antenna with a nominal e.i.r.p. of 80 dBW under clear sky conditions to obtain a feeder link C/N of about 30 dB. When rain attenuation on the feeder link is within the range of 3 dB to 6 dB, the e.i.r.p. is increased by 3 dB (Step 1), and when it exceeds 6 dB, the e.i.r.p. is increased by 6 dB (Step 2).

The main earth station makes it a practice to be ready at all times to switch to back-up operation, making effective use of meteorological data and other information from a wide variety of sources,such as near and long range radars, lightning detectors, local rainfall data and weather information, also data from direct observation of the sky.

At present, the secondary earth stations are located several hundred kilometres away from the main earth station. However, in order to ensure secure back-up operation, another earth station for site-diversity use is scheduled to be built about 50 km away from the main earth station, which will be linked by a terrestrial link suitable for carrying television programme transmissions.

Figure 23 shows an example of comparatively small rainfall attenuation, which can be compensated for by the Step 1 and Step 2 operations.

Figure 25 gives an example in which a thick thundercloud, of sufficient size to darken the area even at mid-day, approaches the area around the main earth station and produces a downpour with a measured value of more than 50 mm/hr. In this case the attenuation reaches 20-30 dB.

3. Systems of transportable earth stations

For the BS-2 satellite broadcasting system, there is a growing need to use small earth stations, each with a small antenna and low power consumption for the sake of economy and ease of operation.

As for the antenna, technological progress has enabled development of lower side-lobe antennas. Transportable earth stations with a 2.5 m antenna and 74-77 dBW of e.i.r.p. are being used effectively for transmission of various kinds of television programmes. The transportable earth stations do not use power control.

As for the future use of transportable earth stations, it is expected that as the broadcasting satellite service comes into wider use, transportable earth stations will increase in number for the versatility of television programme productions.

TABLE VII - *Technical characteristics and purposes of use of feeder link earth stations in the BS-2 satellite broadcasting system*

	Main earth station	Sub-earth station	Transportable earth stations	
			Type B	Type C
Antenna diameter (m)	8	8	2.5	2.5
E.i.r.p.[1] (dBW)	86	84 or 81	77	74
Location	Tokyo	Osaka, Fukuoka[2] and Sapporo[3]	Tokyo	Main cities
Examples of transmission objective[4]	A, F	B, D	C, F, E	B, C, E

Notes

[1] The e.i.r.p of a transportable earth station do not exceed the respective e.i.r.p.s of a reference earth station(5 m dia.,1 kW) at antenna-off-axis angles of 6, 12 and 18 degrees.

[2] A major city; 1000 km west of Tokyo.

[3] A major city, 1000 km north of Tokyo.

[4] Notation in this row is as follows;

A : Transmission of regular programs(2 channels, all day)
B : Transmission of regular programs originating from NHK's main local stations
C : Transmission from the sites of special events
D : Back-up operation.
E : Emergency news reporting
F : Experimental transmission of Hi-Vision (MUSE), and other signals.

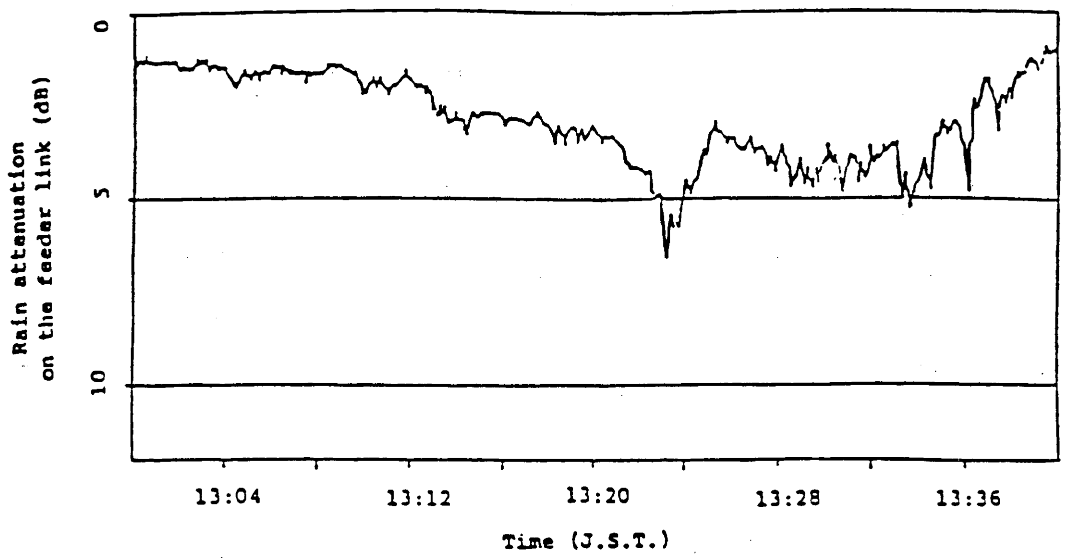

FIGURE 23 - *Moderate rain attenuation on the feeder link to the BS-2 satellite*

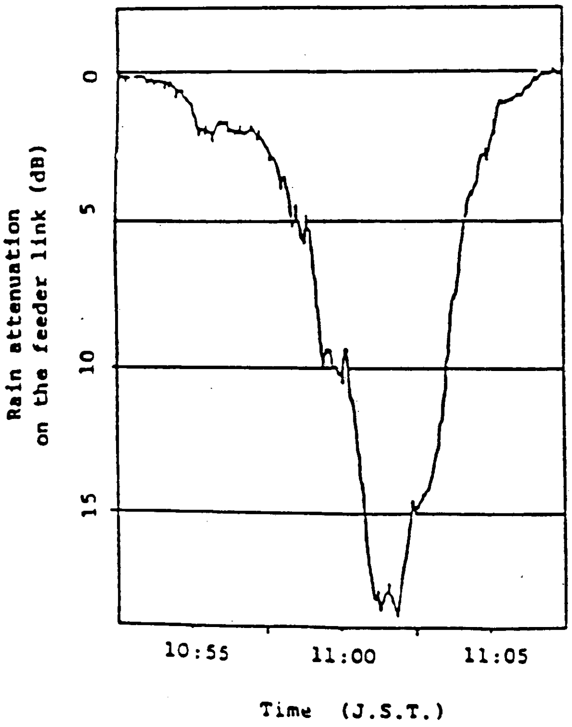

FIGURE 24

Heavy rain attenuation on the the feeder link to the BS-2 satellite

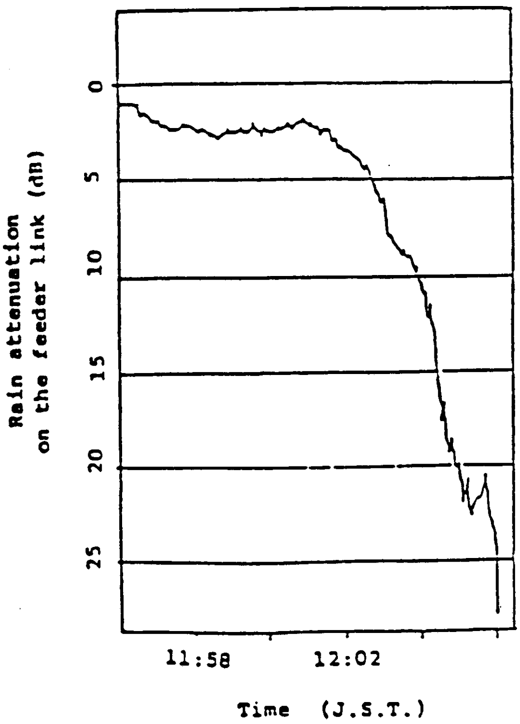

FIGURE 25

Extremely heavy rain attenuation attenuation on the feeder link to the BS-2 satellite

ANNEX III

METHODS OF CONTROLLING UPLINK RAIN COMPENSATION

1. **Monitoring of satellite beacon**

Power control may be adjusted in accordance with measured attenuation of a satellite beacon signal. These signals are normally of lower power in order to conserve satellite primary power. A tracking narrow band receiver with a reasonable fade margin is used for beacon reception.

Typical beacon transmitters vary in output due to temperature change. Normally, stability is maintained within a ±1 dB range. However, this variation can add further to the errors inherent in beacon level measurement.

2. **In-satellite processing**

Measurements of the power level received at the satellite or, where used, the AGC control voltage could be encoded and transmitted back to the originating earth station via a low rate data circuit. This would be received on a narrow band tracking receiver.

Two potential problems are inherent in this method:

- the reliability of the measurement equipment in the space segment needs to be of a very high order, and individual measurements would be necessary for each of the feeder links received. This adds complexity and weight to the space segment which should be avoided if possible;

- account would need to be taken of uplink losses due to mispointing rather than rain attenuation.

3. **Measurement of downlink power**

This method is potentially very simple but suffers from several problems:

- the downlink beam is not necessarily receivable at the uplink point;

- because of the non-linear characteristics of a transponder near saturation a small error in measurement could give rise to a large error in uplink power with consequent interference problems;

- the use of AGC in the satellite would be inhibited.

4. **Radiometer**

A simple relationship is assumed to exist between attenuation on a path through the medium and the thermal noise generated along the path.

There are shortcomings in the accuracy of the radiometer caused by:

- antenna feed losses and antenna feed pattern not being ideal;

- thermodynamic equilibrium does not exist everywhere so the medium is not a pure absorber, hence the physical temperature of the atmosphere is not constant.

When the sky noise is subsequently integrated over the antenna pattern, errors of up to 1 dB can occur.

REPORT 812-3

COMPUTER PROGRAMS FOR PLANNING BROADCASTING-SATELLITE SERVICES IN THE 12 GHz BAND

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

(1978-1982-1986-1990)

1. Introduction

During the preparatory work for planning BSS in Regions 1 and 3 (WARC 77) and in Region 2 (RARC SAT 83), a certain number of synthesis computer programs were established to help planning. Although these programs are now obsolete in some aspects (software, computer used, etc.), a summary of the method used is useful.

Analysis programs have been established by the IFRB to assess the results of the plans during both conferences. Those analysis programs have to be used now when comparing results of the various synthesis programs.

2. Summary of synthesis programs

Synthesis programs are available to determine optimum beam size for arbitrary borders, optimum equivalent isotropically radiated power (e.i.r.p.), corresponding optimum receiver figure-of-merit G/T, optimum orbit positions for a set of non-homogeneous broadcasting satellites, and to plan compatible orbit locations, channel frequency, and polarization assignments, according to a variety of performance criteria and user requirements.

The following paragraphs provide a general description of the topics treated in the various programs. A list of the programs is given in the annex.

2.1 *System configuration synthesis and cost evaluation*

2.1.1 *Purpose of the programs*

The purpose of these programs is to determine a minimum cost satellite communication system subject to a variety of performance constraints and demands for service (both in terms of number of channels and station locations). The object is to determine the combination of key parameters, i.e., spacecraft e.i.r.p., earth-station antenna diameter, receiver noise temperature, and earth-station transmitter power, which minimizes a cost criterion, such as capital cost, or present worth. All the programs perform an exhaustive search, thereby guaranteeing that a global minimum is found. Two programs are aimed specifically at broadcasting satellites, while the third program treats telephony service and video together to find an overall system optimum.

A fourth program examines the cost impact of employing various spectrum saving techniques for both broadcasting and fixed service satellite systems, and provides a tool for maximizing the use of the orbit-spectrum. This program does not make orbital, frequency, or polarization assignments. More complete descriptions of the various programs are given in the reports submitted to the CCIR as listed in the Annex.

2.1.2 *Satellite position optimization*

A non-linear programming technique was developed for the optimization of the orbital positions of a set of non-homogeneous broadcasting satellites with given characteristics. The optimization criterion is the minimization of the total arc occupied by all satellites. All transmissions are assumed to be co-channel and co-polar. The constraints to the optimization is the total carrier-to-interference ratio at each receiver due to the transmissions from all the other satellites. The order of satellites is not changed during the optimization procedure. Details of the technique used may be found in [CCIR, 1978-82a].

Another optimization process using a computer program developed in Japan has been reported by the CCIR Secretariat [CCIR, 1978-82b]. Although this computer program was developed for application to the fixed-satellite service, it is felt that it may be of interest for the planning of the broadcasting-satellite service.

Relevant optimization procedures are also discussed in Report 453, § 8.2.2.

2.1.3 *Antenna beam optimization*

The WARC-BS-77 adopted elliptical (or circular) satellite-antenna beams for planning purposes. The ellipse was to be chosen to enclose a polygon whose corners were to be supplied by each administration to define its service area. To minimize the power at the satellite as well as the interference outside the service area, the ellipse should have the minimum area consistent with the desired coverage. Three computer programs are described below to determine the characteristics (boresight, dimensions, and orientation) of this ellipse.

2.1.3.1 *Program developed in Canada*

A computer program was developed in Canada [CCIR, 1978-82c, d; Chouinard, 1981a, b] in which spherical trigonometry is extensively used to simplify the optimization of circular and elliptical beams to a two-dimensional numerical convergence process. This convergence process is fully automated and the program is of an interactive type allowing the user to modify system parameters and control the program execution. Allowable pointing and rotation errors of the transmitting antenna as well as rain attenuation are taken into account in the calculation of the minimum elliptical beam parameters and required e.i.r.p. The transmit power is also given as an indication of the system practicability.

2.1.3.2 *Search program developed in the United States of America*

In this program [CCIR, 1978-82e; Akima, 1981], a series of searches is performed for sufficiently wide ranges of longitude and latitude of the boresight, orientations of the ellipse, axial ratios, and lengths of the major axis of the ellipse to determine the parameters of the minimum ellipse. Both the pointing tolerances and the orientation angle tolerance are taken into consideration during the search procedure. Computer time and cost depend on the step sizes of the parameters used during the searches. With a step size of 0.1° each for the latitude and longitude of the aim point, 1° for the orientation angle of the ellipse, 0.2 for the axial ratio, and 0.1° (as measured in satellite coordinates) for the major axis, the computing time for an average ellipse is about two seconds and the corresponding cost about $0.70 (US) when the program is run on a CDC CYBER 170/750 computer.

2.1.3.3 *Program developed in the United States of America using non-linear programming techniques*

In most complex optimization problems, solutions cannot practically be obtained by direct differentiation. Computer programs then use a method of successive approximations. The program is formulated in terms of an objective function whose value is to be minimized and one or more constraint equations. If either the objective function or any of the constraint equations are not linear, this technique is called a non-linear programming technique.

In this program [CCIR, 1978-82e], the constraint equations state that all of the given points must lie on or inside the ellipse. The equations are non-linear and have five parameters, related to the coordinates of the centre, its dimensions (major and minor axes), and its orientation with respect to a given reference line. Thus, the computer must make a search in five-dimensional space. This program uses a method described by Nelder and Mead called a polyhedron search.

Antenna pointing tolerances are incorporated into the constraint equations by requiring the constraint points to lie inside the ellipse by at least the directional tolerance, and by requiring that they remain within this tolerance when the ellipse is rotated one way or the other by the rotational tolerance.

Additionally, the program computes the power necessary to produce a given e.i.r.p. from the satellite, taking into consideration the rain zone of the service area, the atmospheric attenuation model used, and the minimum elevation angle at any of polygon points.

2.1.3.4 *Further optimization*

The above processes describe optimization of e.i.r.p. contours. In some instances the resulting power flux-density over the service area exhibits a large spread due to varying climatic conditions within the area.

A further stage of optimization [CCIR, 1978-82d] reduces the spread of power flux-density by iteratively reducing the constant gain contour in such a way that the minimum required signal power is met or exceeded at each vertex of the polygon defining the required service area for the given climatic conditions. This process further reduces the required satellite power and also the potential for interference.

2.2 *Assignment of orbit, spectrum, and polarization for multiple users of broadcasting satellites*

The following programs provide alternative computerized methods for generating frequency, orbit and polarization assignments for broadcasting satellites. In general these computer programs devise plans to transmit one television programme per service area, but may also be used for certain non-regular channel assignment scenarios.

In the computer programs developed by Télédiffusion de France (TDF), the program is divided into three parts which separately and successively assign channels, position on the orbit, and polarizations. In the case of the channels, co-polar and cross-polar matrices of the emission discrimination are considered and assignments are chosen to avoid the same or adjacent channels being used by service areas which are potentially the most subject to mutual interference, that is, service areas corresponding to the smallest terms in the matrix. The aim of the assignments is, therefore, to eliminate those cases having the highest potential for interference. The orbital positions and the polarizations are then determined so as to give the maximum possible value of protection margin to the service area which is the most subject to interference. From this aspect, the method does in fact optimize the plan.

In the computer programs developed by the RAI, the initial step is to assign positions on the orbit according to the particular requests of the various services areas. As these positions are specified from the start, it is not necessary to calculate several beams for each service area nor to calculate the emission discrimination matrices, and it is possible to proceed directly to the calculation of the interference matrix. The assignment algorithm is based on the examination of a compatibility matrix, which shows whether two service areas can, or cannot use the same channel or the adjacent channel and the same polarization. Using operational-research methods, polarizations and then channels are assigned in such a way as to minimize the total number of channels required in the planning, subject to the condition that no service area has a negative protection margin. The initial assignments of positions can then be modified and the cycle of calculations repeated, in order to improve the results.

More recently [Carmassi and Tomati, 1983], the RAI's computer program has been improved by the extensive use of graph theory. The initial step is still the assignment of orbital positions to the various service areas. Then polarization, channels and minimum spacing between carriers (if needed to be determined) are computed with an optimized procedure (none of the possible solutions is omitted) according to the desired channel allocation framing for the RF bandwidth available.

Three additional methods of assignment of orbit, frequency and polarization for multiple users of broadcasting satellites have recently been developed and implemented on the computer in Canada in preparation for the RARC SAT-83. All methods can accommodate administrative operational constraints, e.g. multibeam satellites, specified orbital positions, channels and polarizations, etc.

The first method, BSS CAPS [Christensen, 1981; Leonard, 1981] features:

- the rapid evaluation of a single-valued objective function which is a measure of the severity of the total interference of the BSS plan being synthesized; and
- a menu of computer programs which enables the planner to successively make changes both manually and automatically in the assignments of channels and/or polarizations and manually in the assignment of satellite longitudes.

By iteratively applying the various manual and automatic computer program options, the interference, as indicated by the objective function, is minimized. Since it was difficult to predict the exact planning methodology and constraints which will be favoured at RARC SAT-83, BSS CAPS was designed to provide a maximum of planning flexibility.

The second method, the minimum impact method [Nedzela and Sidney, 1981], starts from the minimum orbital separation matrices and produces a plan by simulataneously assigning a channel, an orbital position and a polarization to each service area in such a way that the number of possible assignments remaining for the next service area is maximized. To a first approximation this program gives an indication of the maximum orbit/spectrum capacity under the assumed constraints and provides a good starting point for further refinement by one of the other routines.

The third method [Chouinard and Vachon, 1981] using the "branch and bound" technique begins with an initial assignment of orbital positions from which the compatibility matrices are generated in a manner similar to the above RAI method. All possible simultaneous assignments of channels and polarizations are then generated. From these, the plan is extracted that meets:

- the single entry protection ratio;
- the aggregate protection ratio, and
- the minimum carrier spacing.

The exponential nature of this exhaustive assignment process required special techniques to limit the computing time. The program indicates those service areas that constrain the plan in order that the appropriate orbital positions may be modified.

The above three programs are designed to be used in a complementary fashion to provide maximum flexibility and insight.

3. Interference analysis programs

To prepare the planning conferences, some administrations provided to the IFRB various interference analysis programs (see list in the annex).

For the conferences, the IFRB has derived from those programs its own software which has been used during the planning process.

This software is also now used by the IFRB during coordination procedures for modifications of the plans.

Note - The CCIR invites the IFRB to provide a brief summary of the main features of those programs to be incorporated in this paragraph during the 1990-94 study period.

4. Additional considerations

4.1 *Shaped-beam considerations*

The programs discussed in this Report include only one that deals, as part of an analysis program, with shaped beams, whereas such beams may be desirable for efficient spectrum – orbit utilization and efficient utilization of space station power. The use of shaped beams is being studied by some administrations, and *additional* computer programs to incorporate such beams in the *analysis* process are being developed. The analysis program used during the RARC SAT-83 did not include such a capability but did include the capability of using a "rapid roll-off" pattern as an option to the standard reference pattern for the space station transmitting antenna (see Final Acts, WARC ORB-85). Computer programs of this type may be necessary for planning the broadcasting-satellite service in the future in order to handle such beam specifications as some administrations may submit. Further study of the desirability and feasibility of incorporating shaped beams in planning programs is required.

4.2 *Computer tools for simultaneous planning of the broadcasting-satellite service and feeder links*

When the planning of the broadcasting-satellite service (BSS) and the associated feeder links (AFL) proceeds independently, two separate computer programs will be required to test and evaluate the separate BSS and AFL plans. These programs will be similar, but they will also have distinct features, particularly with respect to the input parameters. When the BSS and the AFL are planned simultaneously and together, the computer tools required comprise more than a combination of the two separate programs. The following features are desirable in a combined BSS and AFL computer analysis program to test and evaluate complete BSS and AFL plans, particularly those that take advantage of the added flexibilities made possible by simultaneous planning:

- maximum flexibility to handle unforeseen conditions and changes in parameter values or models;
- the capability of determining the feeder-link locations giving rise to the worst feeder link C/I;
- the capability of analyzing feeder-link plans separately, BSS plans separately, or both together;
- the capability to allow independent specification of feeder link and BSS frequencies and service areas and to allow any connections between the two;
- the capability to specify feeder-link power in terms of either e.i.r.p. or C/N at the satellite, including the proper rain margins;
- the capability to accommodate possible non-standard systems.

ANNEX I

LIST OF DOCUMENTS AND REFERENCES

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SECTION 10/11E: SHARING

REPORT 631-4*

FREQUENCY SHARING BETWEEN THE BROADCASTING-SATELLITE SERVICE (SOUND AND TELEVISION) AND TERRESTRIAL SERVICES

(Question 1/10 and 11, Study Programmes 1A, 1C, 1D and 1E/10 and 11)

(1974-1978-1982-1986-1990)

1. Introduction

Under the Radio Regulations, as revised by the World Administrative Radio Conference, Geneva, 1979, the broadcasting-satellite service has allocations, or is permitted to operate, under certain conditions in the following bands, all shared with other services:

- 620 to 790 MHz, which is mainly used by the fixed, mobile, and terrestrial broadcasting services;
- 2500 to 2690 MHz to be shared with the fixed, mobile, broadcasting and fixed-satellite services;
- 11.7 to 12.5 GHz in Region 1 to be shared with the fixed and broadcasting services on a primary basis (and with the mobile service on a secondary basis);
- 11.7 to 12.2 GHz in Region 3 where it is to be shared with the fixed, mobile and broadcasting services;
- 12.2 to 12.70 GHz in Region 2, shared with the fixed, mobile and broadcasting services;
- 12.5 to 12.75 GHz in Region 3 shared with the fixed, mobile and fixed-satellite services;
- 22.5 to 23 GHz in Regions 2 and 3, where it is to be shared with the fixed and mobile services (and, in the upper 0.45 GHz of that band, with the inter-satellite service);
- 40.5 to 42.5 GHz to be shared with the broadcasting service on a permitted basis; and
- 84 to 86 GHz to be shared with the fixed, mobile, and broadcasting services, except that these services cannot cause harmful interference to broadcasting-satellite earth stations operating in accordance with a plan yet to be adopted by a subsequent Administrative Radio Conference.

2. Elements to be considered in frequency sharing

In establishing the bases for frequency sharing between the broadcasting-satellite, terrestrial and inter-satellite 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 service are listed in Report 634. Also, the technical characteristics of the sharing systems, such as e.i.r.p., antenna aperture, sidelobe levels, receiver sensitivity and the kind of modulation used; and geographical considerations (such as the line of direction from the interfered-with to the interfering position and the establishment of "exclusion areas" and the service areas) are factors to be taken into account. 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.

Before taking a step that would restrict or prevent the operation of a service having a primary allocation in a band, and which are involved in one or more of the interference situations discussed in this report, every effort should be made to increase the feasibility of sharing between the services.

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* This Report should be brought to the attention of Study Groups 8 and 9.

Among the measures that could increase the feasibility of sharing are the following:

- use of performance objectives and availability criteria commensurate with the needs of the service to be provided;
- selection of characteristics of the model system to be protected that would result in minimum sensitivity to interference, consistent with practical system designs (e.g. adequate transmitter power and antenna gains, reasonable path lengths, "rugged" modulation methods, etc.) (Note that in most cases, decreasing sensitivity to interference also improves system performance.);
- restricting the operation of highly sensitive systems to band segments not also allocated to a service having a relatively high potential to cause interference.

Among the steps that could restrict, or prevent the operation of, a service having a primary allocation are CCIR Recommendations or Radio Regulations establishing interference threshold (trigger) levels, or power flux density limits.

2.1 *Sound broadcasting*

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

The WARC-79 has recommended that the band 500 to 2000 MHz be analyzed to establish optimum locations for satellite sound broadcasting. Further study is required to determine whether there is any specific region of this band which is particularly desirable. Further study is also required to determine if sharing is feasible and, if so, under what conditions. Report 941 (Study Group 9) concludes that in the case of the protection of terrestrial radio-relay systems against a possible FM satellite sound-broadcasting system operating in the band 1427 to 1530 MHz, some form of energy dispersal would be required on the satellite emission. Digital modulation provides energy dispersal inherently. The application of artificial energy dispersal to FM satellite sound-broadcasting transmissions requires further study. The study in Report 941 assumed powers of the order indicated in Report 955 and that protection required limitation of the flux to the values applicable in the 2500 to 2690 MHz band (see § 4.1). Even with 14 dB energy dispersal (i.e. a power flux-density in a 4 kHz band 14 dB below the total PFD) protection of the fixed service appeared possible only under certain conditions, including a wide geographical separation between the broadcasting-satellite service area and the radio-relay systems concerned.

2.2 *Television broadcasting*

2.2.1 *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) insures 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:

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

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 145.8 dB.

2.2.2 *Power flux-density requirements*

Report 215 discusses examples of the required power flux-densities for the broadcasting-satellite service in some detail, and Table XIVa and b of that Report contains numerical values of such power flux-densities. Report 811 indicates power flux-densities relevant to planning this service in the 12 GHz band.

Corresponding values for terrestrial amplitude-modulation television broadcasting services are indicated in Report 961.

2.2.3 *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.

2.2.4 *Protection ratios*

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

2.2.5 *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 wide radio frequency band to meet power flux-density limitations. Careful consideration, however, should be given to technical and economic impacts of the application of such techniques on the systems.

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

2.2.6 *Calculation of power flux-density produced by a geostationary satellite*

Several methods may be used to calculate the power flux-density at a given point on earth as produced by a broadcasting satellite (see, for example, Report 215).

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

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

3.1 *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 § 3.1.1. 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 § 3.1.2.

3.1.1 *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:

$$F_s = \left\{ \begin{array}{l} -129 \\ -129 + 0.4\,(\delta - 20) \\ -113 \end{array} \right\} \text{dB(W/m}^2) \quad \begin{array}{l} \text{for } 0° < \delta \leqslant 20° \\ \text{for } 20° < \delta \leqslant 60° \\ \text{for } 60° < \delta \leqslant 90° \end{array}$$

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

In Recommendation No. 705 of the WARC-79, 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. These assumptions are summarized in Table I; they will be discussed in some detail in order to illuminate the problems involved in reaching agreement on a satisfactory limit on the power flux-density.

3.1.1.1 *Minimum terrestrial power flux-density to be protected*

Recommendation 417 gives the values 67 and 70 dB(μV/m) for the field-strengths in Band V (610 to 960 MHz) corresponding to F_{tqp} and F_{tqm} in equations (1) and (2), respectively. The Recommendation also notes that "in a practical plan, because of interference from other television transmissions, the field-strengths that can be protected will generally be higher". Nevertheless, some administrations studying the question were agreed that advances in receiver technology and practical experience with terrestrial television reception suggested that consideration should be given to protecting lower values of field strength.

The EBU has suggested that in the service areas where a minimum median protected field of 70 dB(μV/m) at 50% of the locations is taken as a basis, there is often a considerable number of home receivers and relay stations providing satisfactory pictures with a lower field. It can be considered that points where the field is about 65 dB(μV/m) provide a satisfactory coverage. In many cases it is the only way of providing a service, because no other frequency is available. It is therefore necessary to protect a field of 65 dB(μV/m) against the total interference. Nevertheless, if this value is increased to 68 dB(μV/m) and if power-law addition is assumed, the field to be protected against interference caused only by satellites should be taken as equal to 65 dB(μV/m). The minimum power flux-density to be protected for the terrestrial system is then -81 dB(W/m^2).

Table I shows examples of calculations of the limiting values of power flux-density from a broadcasting satellite required to protect the terrestrial broadcasting service. The example from the USSR gives the values of power flux-density, taking into account the following:

- frequency band occupied by the interfering signal;
- bandwidth of the amplitude-modulation, vestigial-sideband receiver;
- level of random noise at the output of the amplitude-modulation, vestigial-sideband receiver.

3.1.1.2 *Protection ratio*

The values of protection ratio given in Table I were measured under different conditions. More detailed results are given in Report 634, which also discusses the various measuring conditions and system parameters which affect the assessment of protection ratio. In that Report, it is suggested that, where possible, the protection ratio should be defined for a specified combination of conditions and parameters. Corrections which may be applied for different conditions and parameters are also given in Report 634. The value of protection ratio proposed by the EBU (see Table I) is based on the reference conditions.

3.1.1.3 *Directivity discrimination*

None of the examples takes explicit account of the directivity of the receiving antenna; instead they consider the worst case in which the interfering satellite signal arrives from a direction close to the receiving antenna axis. However, all administrations appear to accept the idealized antenna pattern for Band V given in Recommendation 419, although the USA Administration notes that in practice, more directive antennas are likely to be used at the service area boundaries in question. In any case, using the pattern of Recommendation 419 would lead to an escalation of satellite power flux-density with angle of arrival similar to that given in the provisional limit of Recommendation No. 705 of the WARC-79.

3.1.1.4 *Polarization discrimination*

If circular polarization is used for the broadcasting satellite transmission, a discrimination of up to 3 dB may be expected from the linearly polarized terrestrial receiving antenna. Report 339 (New Delhi, 1970) contained data for the discrimination that will be achieved in the usual case where the satellite transmitting antenna and the terrestrial receiving antenna are not to be aligned with each other.

3.1.1.5 *Margin for ground reflections*

There is no direct experimental evidence regarding this quantity, but the United Kingdom Administration reports that extrapolation to Band V of experimentally verified theoretical predictions of reflection from irregular terrain at 230 MHz suggest that 3 dB is a reasonable value. The Administration of France and the EBU agree with this assumption and cite extreme cases of near unity reflection of terrestrial signals from the sea which could enhance the interfering signal by 6 dB.

TABLE I – *Examples of the calculation of the limiting values of power flux-density from a broadcasting satellite required to protect the terrestrial broadcasting service in the band 620 to 790 MHz*

1. *Data relating to the wanted signal*				
Source documents		(1978-82) 10-11S/11 (EBU)	(1970-74) 11/64 (USA)	(1978-82) 10-11S/53 (USSR)
1.1 Television standard and system		I/PAL, L/SECAM, G/PAL	M/NTSC	K/SECAM
1.2 Assessment scale		Quality 5-point (5: excellent)	Impairment 6-point (1: imperceptible)	Impairment 5-point (5: imperceptible)
1.3 Grade of picture quality		4.5	3	4.5
1.4 Picture signal-to-unweighted noise ratio (dB)		$\geqslant$41.5	27	Not less than 40
1.5 Minimum field strength to be protected against interference caused by satellite (dB(μV/m))		65	56(1)	70
1.6 Minimum power flux-density, terrestrial, to be protected, F_{tqp} (dB(W/m^2))		−81	−90	−76
2. *Data relating to the protection ratio*				
Source documents		(1978-82) 10-11S/11 (EBU)	(1970-74) 11/49 (USA)	(1978-82) 10-11S/53 11/116 (USSR)
2.1 Picture content of wanted signal		Slides	Slides and off-the-air programmes	Slides
2.2 Characteristics of unwanted signal	Picture content	Colour-bars	Colours-bars and off-the-air programmes	Colour-bars
	Frequency deviation peak-to-peak (MHz)	12	18	22
	Pre-emphasis	Yes	No	Yes
	Dispersal	No	No	No
2.3 Protection ratio R_q (dB)		54(2)	35	47(3)
3. Directivity discrimination, D_d (dB) (4)		–	–	–
4. Polarization discrimination, D_p (dB)		2	–	2
5. Reflection margin, M_r (dB)		3	–	3
6. Multiple interference entry margin, M_i (dB)		–	–	–
7. Resultant limit on power flux-density, F_s (dB(W/m^2))		−136	−125	−124

(1) The assumed fading margins are those associated with an e.i.r.p. of 2 MW from an antenna at a height of 300 m in the terrestrial broadcasting service. Median field strengths of 60 dB(μV/m) and 65 dB(μV/m) would yield the same picture quality as above, for 90% and 99% of the time, respectively.

(2) For L/SECAM the protection ratio is 50.5 dB.

(3) Protection ratios for various peak-to-peak deviations are shown in Fig. 8 of Report 634.

(4) No directivity discrimination can be assumed, since only angles of elevation less than 20° are considered.

3.1.1.6 *Multiple interference margin, M_i*

In the service area of a terrestrial transmitter, a satellite can cause interference only when the receiving antennas point in a direction not very different from that of the satellite. It is therefore unnecessary to allow for interference from several satellites, if it can be assumed that there will never be more than one satellite emission at the same time on the same channel and in about the same direction.

3.1.1.7 *Summary and conclusions*

From information provided by the EBU, the numerical value has been calculated for the limit which should be imposed on the power flux-density to protect terrestrial broadcasting in the band 620 to 790 MHz, against the emissions from future satellites, using frequency-modulation television. The result is given for systems I/PAL, L/SECAM and G/PAL. For these three systems, the figure is -136 dB(W/m^2), for the reference conditions. This is 7 dB lower than the provisional value recommended by the WARC-79.

The service area boundaries were defined in terms of very nearly the same minimum values of terrestrial field strength to be protected as recommended by the CCIR, and possible fading of the terrestrial signal at the service area boundaries was neglected.

The example presented by the Administration of the USA afforded protection to a much lower terrestrial field strength, taking into account both an assumed better receiving installation, significant terrestrial signal fading, and a lower picture quality. In the USA, a lower protection ratio is used which corresponds to the lower assumed picture quality and is based on a wider frequency deviation for the interfering frequency-modulation satellite signal, as well as picture contents more typical of off-the-air programming. The satellite power flux-density limit in the example presented by the USA Administration was -125 dB(W/m^2), i.e. 4 dB higher than the provisional value recommended by the WARC-79.

Under the conditions presented by the Administration of the USSR in Table I, footnote (2), the limit for the power flux-density was -124 dB(W/m^2), i.e. 5 dB higher than the provisional value recommended by the WARC-79.

Having studied all the values incorporated in equation (1) as well as the results of protection ratio measurements in television for maximum permissible power flux-density at the surface of the Earth from broadcasting satellites operating in the band 620 to 790 MHz, the USSR Administration proposed the following values:

$$F_s = \left\{ \begin{array}{l} -77 - R_{oq} + \gamma \\ -77 - R_{oq} + \gamma + 0.4(\delta - 20) \\ -61 - R_{oq} + \gamma \end{array} \right\} \text{dB(W/m}^2\text{)} \quad \begin{array}{l} \text{for } 0° < \delta \leq 20° \\ \text{for } 20° < \delta \leq 60° \\ \text{for } 60° < \delta \leq 90° \end{array}$$

where $\gamma = 0.45\,(D_v - D_{ov}) + M_d D_{dv}$, the correction coefficient depending on the energy distribution of FM interference, taking account of its perception by the viewer.

R_{oq} is the protection ratio for the value of the frequency deviation D_{ov} taken as reference (determined from the corresponding curve in Fig. 8 of Report 634);

D_{dv} is the peak-to-peak amplitude of the frequency deviation due to the dispersal signal in MHz; and,

M_d is the coefficient determined from Fig. 9, Report 634.

In evaluating F_s it was assumed that,

$$F_{tqp} = -76 \text{ dB(W/m}^2\text{)}, \qquad D_d = 0, \qquad D_p = 2 \text{ dB}, \qquad M_r = 3 \quad \text{and} \quad M_i = 0$$

Until greater agreement is reached concerning the values to be assumed for the relevant parameters, it is premature for the CCIR to recommend a single value for the satellite power flux-density limit necessary to protect terrestrial broadcasting. Indeed the possibility cannot be dismissed that it may be necessary to adopt different power flux-density limits for combinations of wanted and unwanted signals having different signal standards.

3.1.2 *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. 1 and 2 for the following characteristics:

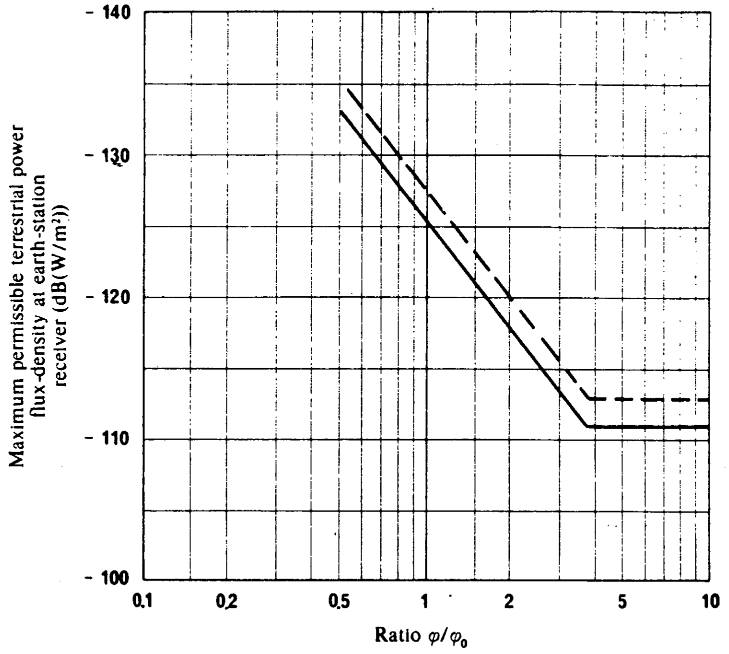


FIGURE 1 — *Example of maximum permissible power flux-density from a terrestrial transmitter to protect an earth-station receiver*

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

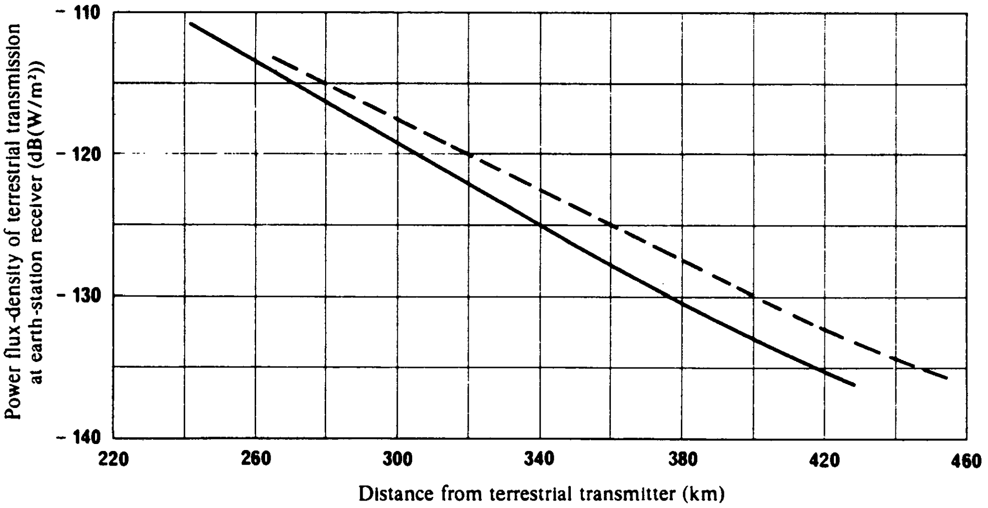


FIGURE 2 — *Example of separation distance to protect earth-station receivers from terrestrial transmitters*

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

3.1.2.1 *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).

3.1.2.2 *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 (edge of beam area): 36 dB (525 lines), 45 dB (625 lines);
- satellite power flux-density at edge of beam area:
  -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.

3.2 *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 I.

4. Sharing in the band 2500 to 2690 MHz

4.1 *Sharing with the fixed service*

(*Note.* – Proposed fixed-satellite systems used for television distribution are also subject to these considerations to the extent that they are technically similar to broadcasting-satellite systems.)

The band 2500 to 2690 MHz is shared by the fixed, mobile, fixed-satellite and broadcasting-satellite services, all of which have primary allocations in the band. Other services have secondary allocations in the upper portion of the band, 2655 to 2690 MHz. Both the broadcasting-satellite and the fixed-satellite services are subject to the same limit on power flux-density (as given in Nos. 2561 to 2564 of the Radio Regulations). Therefore, the considerations and conclusions of this section apply to both these services.

The terrestrial systems in the fixed service which are considered for frequency-sharing with broadcasting or fixed satellites include line-of-sight and trans-horizon radio-relay systems and a certain type of television distribution system. Conditions of sharing between the television broadcasting-satellite service and other terrestrial services are not presented due to the lack of sufficient data.

The type of broadcasting-satellite system chosen for examination is one designed for community reception. An example of the parameters of such a system is given in Table II.

TABLE II – *Example of the characteristics of a satellite television system for community reception (operating in the vicinity of 2600 MHz)*

(System M, USA and Canada)
Circularly-polarized emission
Frequency modulation
Equivalent rectangular bandwidth: 20 MHz
Earth-station receiving antenna gain (2.5 m paraboloid): 34 dB(1)
Earth-station receiving antenna discrimination: $10.5 + 25 \log (\varphi/\varphi_0)$ where: φ : angle off the main beam axis, φ_0: angle between the half-power points, 3.1°
Minimum side lobe gain: 0 dB
Satellite field-strength to be protected at beam edge: 28 dB(μV/m)
Luminance signal-to-unweighted r.m.s. noise: 36 dB
Required protection ratio from ITFS(2): 30 dB(3)

(1) A 2.5 m diameter antenna has been used in this example because it is considered to result in overall minimum system cost for many Region 2 applications, as found in a study performed in the United States [Kelley *et al.*, 1976].

(2) ITFS means "Instructional Television Fixed Service".

(3) Taken from Report 634.

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

Although this case could not be studied in detail owing to lack of relevant information, it should be noted that the establishment of circuits comprising a large number of relay stations often implies the repetitive use of frequencies according to a plan occupying a continuous section of the allocated band which cannot be departed from without difficulty (see Recommendations 283 and 382).

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.

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

Frequency-sharing between broadcasting-satellite systems and trans-horizon radio-relay systems in the vicinity of 2600 MHz is technically feasible only to the extent that each system can accept certain technical and operational limitations required to protect it against interference from the other. (See also § 8.4.3 of the Report of the Special Joint Meeting, Geneva, 1971.)

4.1.2.1 *Protection of trans-horizon systems*

Protection of trans-horizon systems from harmful interference from the broadcasting-satellite service is currently provided by a combination of power flux-density limits on the satellites (Nos. 2561 to 2564 of the Radio Regulations), by a statement urging that trans-horizon system antennas not be directed toward the geostationary-satellite orbit (No. 764 of the Radio Regulations) and by inference, not within 2° of it (No. 2502 of the Radio Regulations).

Methods for determining the azimuths and elevation angles to be avoided by trans-horizon system antennas are given in Report 393.

4.1.2.2 *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. Therefore, the establishment of a satellite broadcasting coverage area would prevent the introduction of new trans-horizon systems in that area and also, nearby, if the entire area were to be protected from interference.

4.1.3 *Sharing with a certain type of fixed terrestrial television distribution*

An example of the characteristics of the type of terrestrial television distribution system in question is given in Table III. 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. 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.

4.1.3.1 *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.

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 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 Table II (i.e. -115 dB(W/m^2) beam centre).

TABLE III – *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

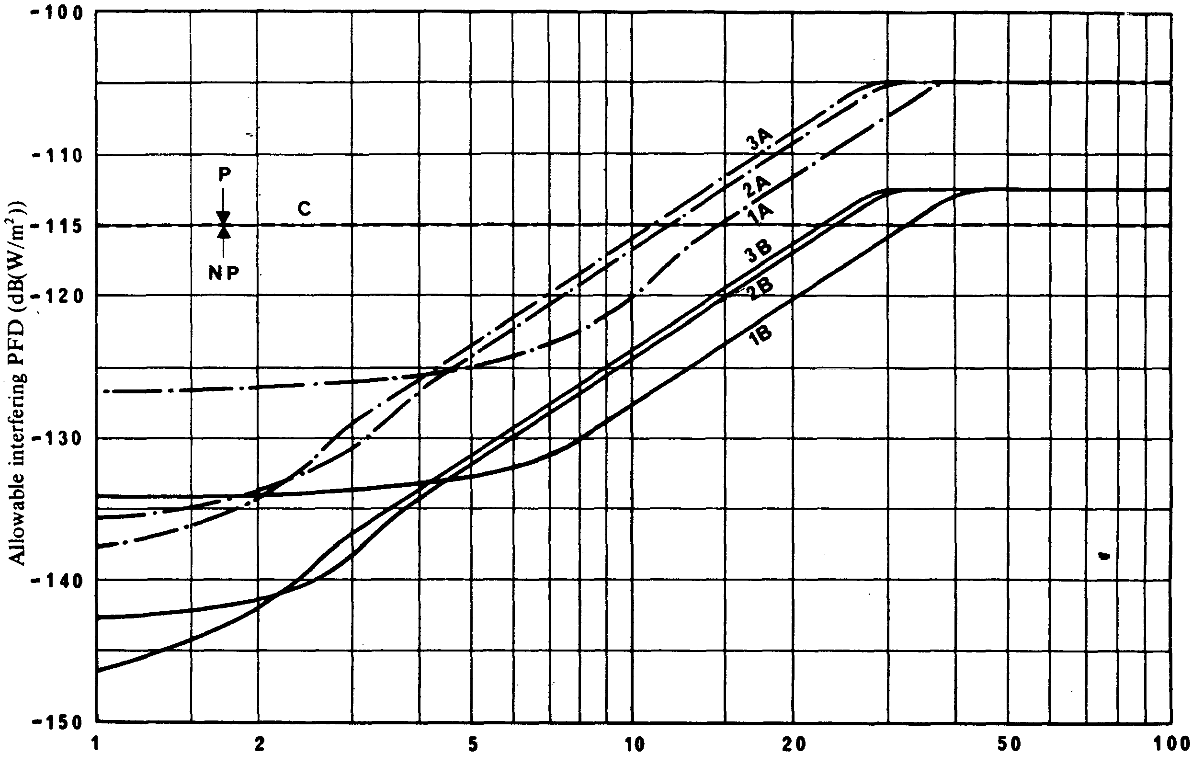


FIGURE 3 – *Allowable interfering broadcasting satellite power flux-density as a function of offset angle (for protection of the ITFS system)*

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/m²))
P : protected
NP: not protected

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, a broadcasting-satellite system would not cause interference to a 43 dB S/N ITFS system having the characteristics shown in Table III 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).

ITFS systems having higher S/N objectives, say 45 or 49 dB, would be protected against interference with even smaller offset angles. Similarly, lower protection ratios, which might be acceptable for interfering BSS signals of higher peak-to-peak deviation (as discussed in Report 634, § 1.6) would also result in smaller offset angles to achieve the desired level of protection.

4.1.3.2 *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. 4. This protection is achievable at a minimum angle of elevation for the satellite of 31°.

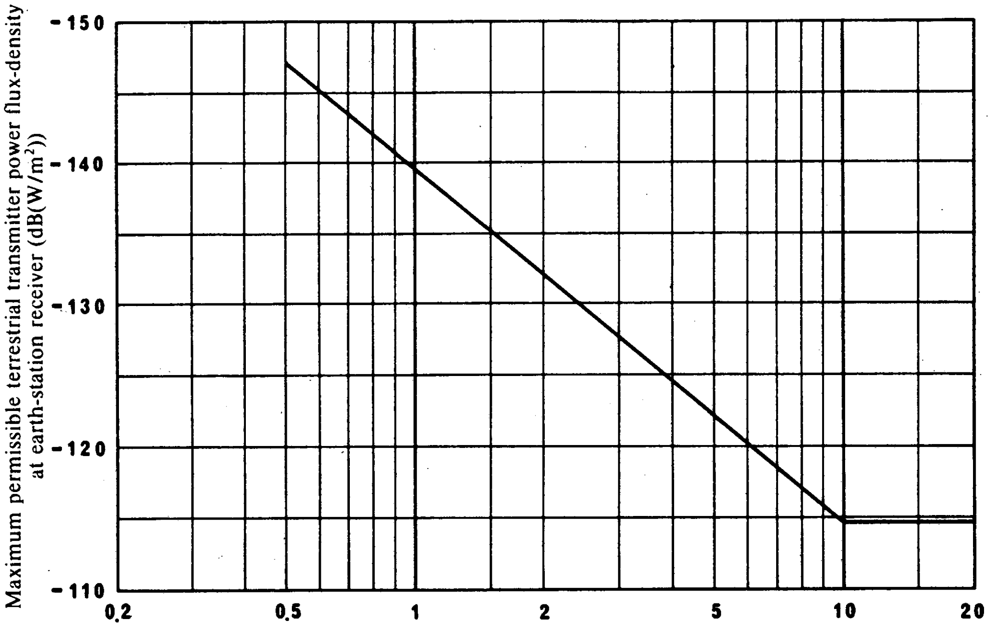


FIGURE 4 – *Example of maximum permissible power flux-density from terrestrial station transmitters to protect BSS earth-station receivers* (ITFS at 2.6 GHz)

φ : direction of satellite relative to axis of main beam of terrestrial receiving antenna
φ$_0$: 3 dB beamwidth of terrestrial receiving antenna

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. 5. These values assume no site shielding, and were calculated from the following formula:

$$E_t(d, r) = \text{e.i.r.p.}_t - 10 \log (4\pi d^2) - L_t(d, r) + 145.8 \qquad (4)$$

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 was 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. 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.

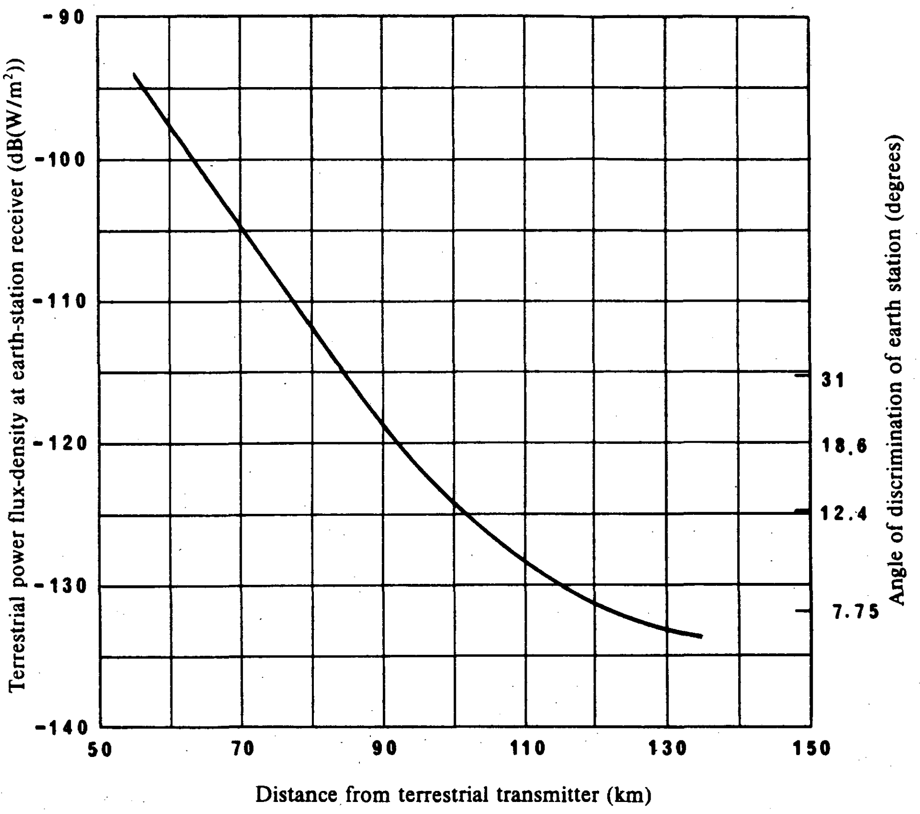


FIGURE 5 – *Example of separation distance to protect earth-station receivers from terrestrial transmitters*
(ITFS at 2.6 GHz)
E.i.r.p.: 20 dBW

Although the actual separation distances and discrimination angles were not, in several cases, sufficient to ensure interference-free reception based on the criteria of this Report, 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 this Report, they do suggest that the methods herein are conservative, and that there may be more interference-free locations and areas than indicated by the curves in this Report.

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.

4.2 *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 lead 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.

4.3 *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.

5. Sharing in band 11.7 to 12.75 GHz

This section presents the conditions for frequency-sharing in the 12 GHz band between the broadcasting-satellite and terrestrial services. Sharing between the broadcasting-satellite service and the fixed-satellite service in the band 11.7 to 12.2 GHz (applicable to Region 2) is considered in Reports 561 and 809.

Rainfall attenuation in some climates may require large propagation margins if high service reliability is desired. The effect of this margin should be taken into account when considering sharing problems.

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

5.1.1 *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 bandwidth values. 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 on the order of 10 dB exist [CCIR, 1974-78a, b and c].

The WARC-BS-77 adopted the use of energy dispersal for the broadcasting-satellite service specifying the value of 600 kHz. The WARC ORB-85 in incorporating the RARC SAT-83 broadcasting-satellite service Plan for Region 2 into the Radio Regulations, required the use of energy dispersal such that the spectral power flux-density, measured in a 4 kHz bandwidth, be reduced by 22 dB in relation to that in the centre bandwidth. This reduction corresponds to a peak-to-peak deviation of approximately 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 IV from the total power flux-density in the 27 MHz bandwidth.

TABLE IV — *Energy dispersal advantage relative to a 4 kHz band*

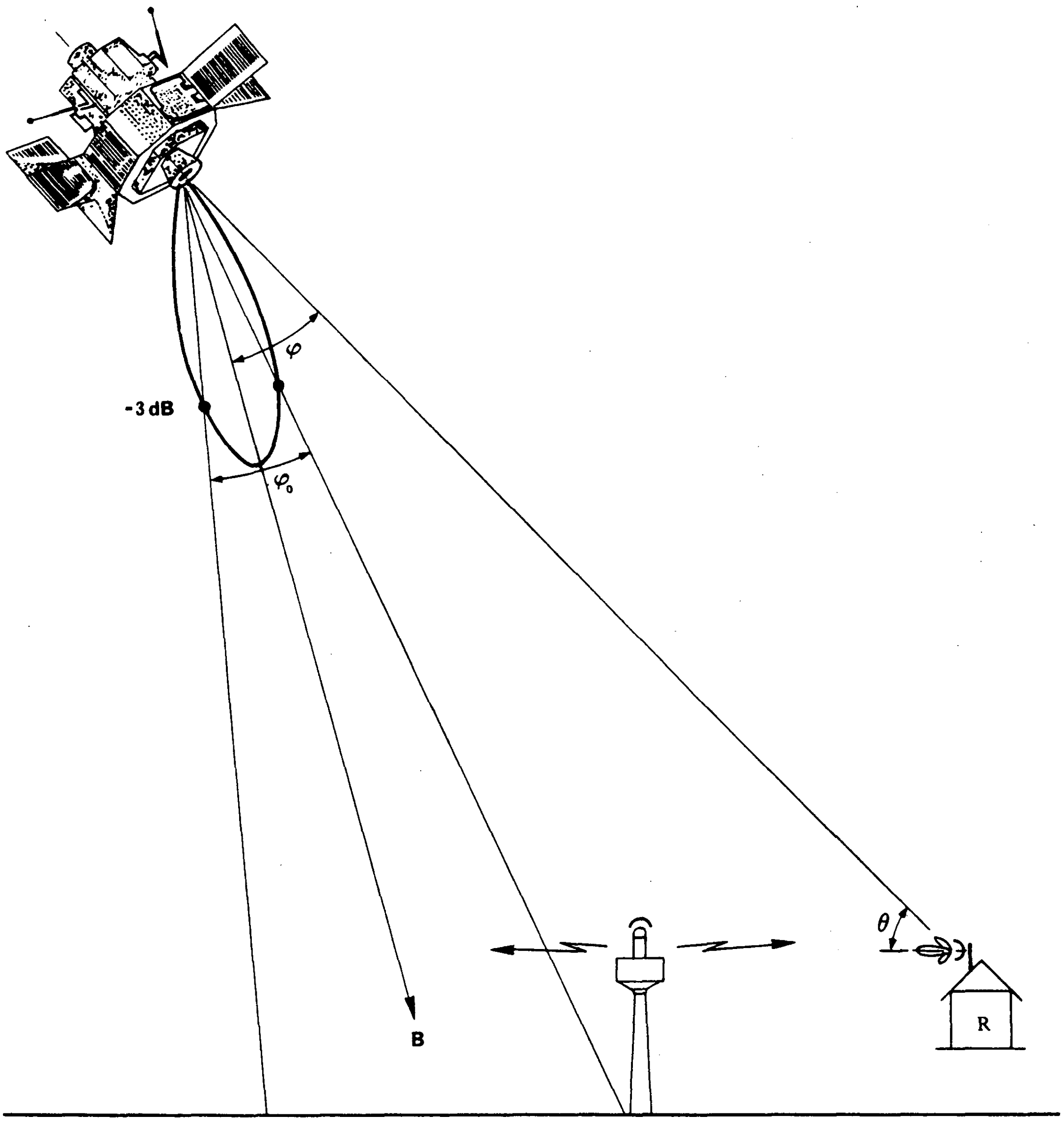
Condition of dispersal	Energy dispersal (dB)
Natural	10
600 kHz (WARC-BS)	22
1 MHz	25
2 MHz	27
4 MHz	30

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 they 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.

Both the WARC-BS-77 and RARC SAT-83 adopted circular polarization for the broadcasting-satellite service. Terrestrial systems employing linear polarization should not rely on more than 3 dB of polarization discrimination.

5.1.2 *Interference to terrestrial broadcasting from the BSS*

Interference to terrestrial broadcasting from broadcasting satellites is treated in this section as depicted in Fig. 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-axis angle, φ) and that of the terrestrial receiver antenna discrimination (which can be expressed as a function of the angle of arrival, θ).



Service area of broadcasting satellite

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

φ : off-axis angle of satellite antenna

B : beam centre

θ : angle of arrival

R : terrestrial receiver

To illustrate the concepts of this sharing model, the beam centre indicated in Fig. 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. 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 V), 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. 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.

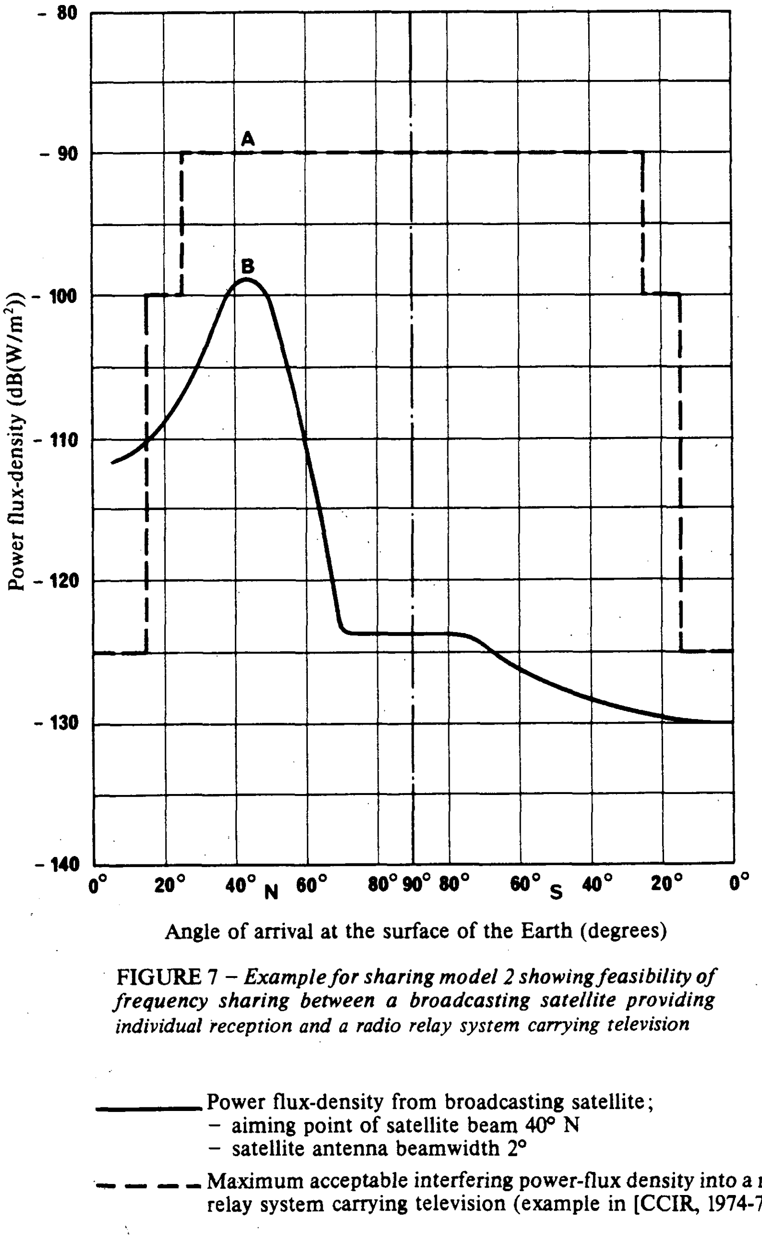


FIGURE 7 – *Example for sharing model 2 showing feasibility of frequency sharing between a broadcasting satellite providing individual reception and a radio relay system carrying television*

———— Power flux-density from broadcasting satellite;
– aiming point of satellite beam 40° N
– satellite antenna beamwidth 2°

— — — — Maximum acceptable interfering power-flux density into a radio relay system carrying television (example in [CCIR, 1974-78e]).

—·—·— Equator

Curves A: terrestrial system
B: satellite

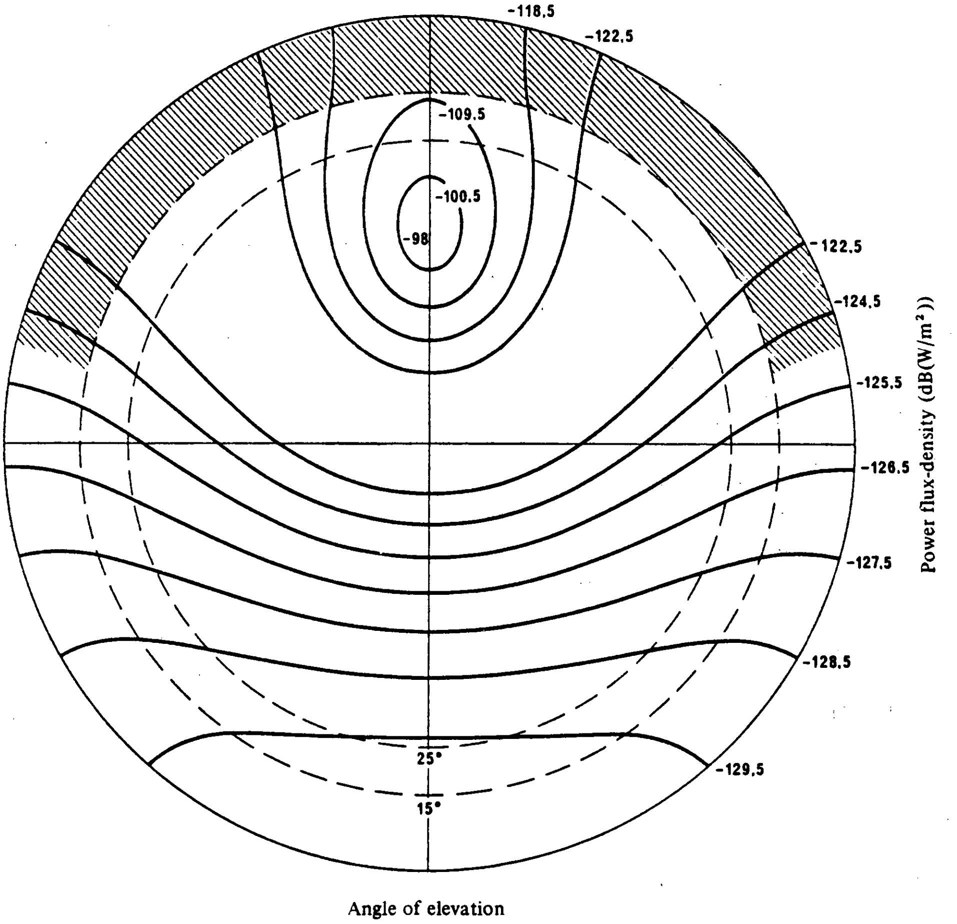


FIGURE 8 – *Power flux-density from a broadcasting satellite with a 2° beam aiming at a latitude of 40° N*

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, limits from [CCIR, 1974-78 f].

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

(From [CCIR, 1974-78a])

Wanted system	Percentage of time	Maximum interfering power flux-density (dB(W/m^2)) 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	$35-25 \log \varphi$
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 $0.707 \varphi_0 < \varphi \leqslant 1.26 \varphi_0$ $-(8.5+25 \log_{10} (\varphi / \varphi_0))$ 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).

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 [CCIR, 1974-78d].

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 Report 810, Fig. 2. Values for the antenna gain according to this reference curve are shown in Table VI.

It appears from Table VI 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 VI – *Gain and angular discrimination for receiving antennas in the terrestrial broadcasting system*

Off-axis 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. 6).

The relative gain of the broadcasting-satellite transmitter antenna is assumed to comply with Report 810, Fig. 1, curve A. The required value of φ/φ_0 (Fig. 6) to obtain sufficient additional angular discrimination has been calculated and is shown in Table VII.

TABLE VII – *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 VII.

Other examples are given in [CCIR, 1974-78g, h, i, j and k].

As a result of experiments with NTSC 525-line television signals in Japan [CCIR, 1978-82a] 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).

5.1.3 *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 · 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 · 4 kHz)) independent of an angle of arrival.

The following approximation is used in the calculations:

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

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 · 4 kHz));

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

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

---

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

$G(\theta)$: 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.

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.

5.1.3.1 *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.

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 VIII. 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.

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

θ (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

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. The WARC ORB-85, in incorporating the RARC SAT-83 Plan for Region 2, required the use of energy dispersal as discussed in § 5.1.1. Thus, we will assume as a worst case that the entire power of the BSS signal is contained in a 600 kHz bandwidth.

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 VIII, 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 IX and X show the increases in the baseband noise power caused by the interfering BSS signal, calculated with Table VIII. 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 $\theta = 10°$ and $D = 0.6$ m considered in Table X 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°.

TABLE IX – *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 VIII have been used.
θ denotes the off-axis angle, and D denotes the diameter of the FS receiving antenna.)

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

θ (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

5.1.3.2 *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.

Insofar 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 IX and X. If the system margin is greater than this ratio, the interference is considered tolerable.

5.1.3.3 *Interference to radio-relay systems carrying AM-VSB TV*

The conditions for protection of TV radio-relay using AM-VSB against interference from broadcasting satellites are given in Report 789. The maximum allowable interfering power flux-density should not exceed:

$$-134 \text{ dB}(\text{W}/(\text{m}^2 \cdot 5 \text{ MHz})) \qquad \text{for angle of arrival } \theta = 0° \tag{8}$$

$$-134 + 10.5 + 25 \log (\theta/\theta_0) \qquad \text{for } \theta > \theta_0/2 \text{ for receiver antenna gains of 40.5 dBi} \tag{9}$$

The CPM for the RARC SAT-83 proposed that within the main beam of the radio-relay antenna a PFD of:

$$-134 + 12\, (\theta/\theta_0)^2 \; (\text{dB}(\text{W}/(\text{m}^2 \cdot 5 \text{ MHz}))) \qquad \text{for } 0 \leqslant \theta \leqslant \theta_0/2 \tag{10}$$

(where θ_0 is the half-power beamwidth of the receiving antenna), would be appropriate to protect radio-relay systems with the specific characteristics assumed in Report 789 and using AM-VSB.

At present, there is no standard method for determining the PFD in a band as wide as 5 MHz, the reference bandwidth of concern to the terrestrial broadcasting service (using AM-VSB) and TV radio-relay using AM-VSB. A worst-case assumption would include the entire BSS satellite power in a 5 MHz band. Power extrapolation methods are commonly used to derive this measurement. However, some standard methods should be developed and adopted.

It is expected that the wide geographical separation between the Region 2 and the Regions 1 and 3 service areas will in most situations create favourable coexistence of the FS and BSS services.

As an example, the PFD values in a 4 kHz bandwidth produced in Region 1 territory of Senegal from a satellite positioned to serve the most easterly parts of Region 2 (i.e 65° W to 95° W serving Brazil) are found to be in compliance with the limits of Annex 5 of Appendix 30 of the Radio Regulations, 1982, by more than 16 dB. Similarly, for satellites restricted to orbital positions east of 85° W, protection of the AM-VSB broadcasting service in Senegal is also provided. Between 85° W and 95° W, the use of shaped beams and the higher attenuation which can be expected for lower angles of arrival could also lead to compliance. It is noted that BSS satellite positions west of 86° W covering the north-east part of Brazil would probably be avoided since the low elevation angle of receiving earth stations would lead to large values of rainfall attenuation.

However, the most westerly positioned Region 2 BSS satellites would be more likely to cause interference to the fixed-service systems in the eastern part of Region 1.

For example, Fig. 9 shows the PFD values which would be produced in the most eastern part of Region 1, i.e. on USSR territory by a Region 2 BSS satellite positioned at 175° W to serve Alaska with a 3° × 1° elliptical beam antenna on the satellite using the WARC-BS-77 satellite transmitting reference pattern.

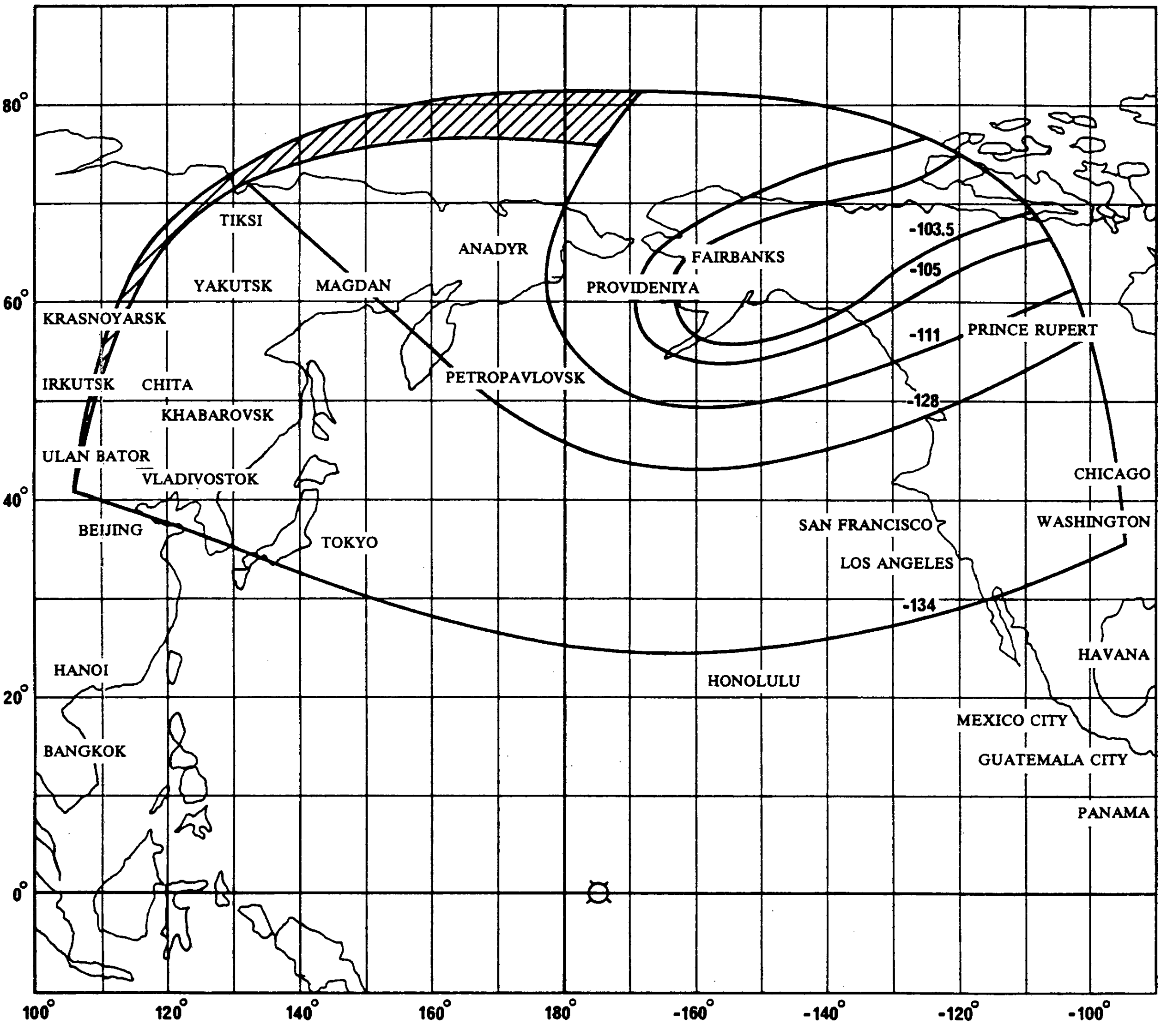


FIGURE 9 – *PFD contours of a Region 2 BSS satellite positioned at 175° W (3° × 1° elliptical beam antenna)*

There is an area (shaded in Fig. 9) where the PFD limits given in equations (8), (9) and (10) for radio-relay links carrying AM-VSB signals would be exceeded.

The conclusions of the CPM for the RARC SAT-83 on the possibilities of improving sharing and their impact are summarized in Table XI.

TABLE XI – *Possibilities for improving inter-regional sharing and their impact*

	Possibilities for improving sharing	Impact
1	Reduce BSS satellite e.i.r.p.	Larger ground receiver antenna required; individual reception may not be possible
2	Reduce coverage by use of small area beams	Entire population of desired service areas may not be served
3	Use individual reception only in highly populated areas well away from regional interface	Would require community reception in other parts of the desired service area
4	Beam shaping of satellite transmitting antenna	More uniform PFD in service area and less outside
5	Relocate satellite position	This may increase antenna discrimination at FS receivers in potential interference areas
6	Assign only certain frequency segments to BSS on one side of the regional interface and assign (or reassign) other frequencies to FS systems on the other side of the interface	Requires ITU or bilateral coordination but eliminates all interference considerations
7	Use satellite polarization orthogonal to FS receive antenna	With the use of circular polarization for the BSS and linear polarization for the FS, up to 3 dB of discrimination can be expected
8	Better fixed-service receive antenna pattern	Reduced coupling to BSS transmissions
9	Avoidance of orbit by FS receiving antenna	As much as 40 dB of discrimination can be obtained
10	Energy dispersal	Effective in spreading interference over the reference bandwidth of the interfered-with signal. For a reference bandwidth of 4 kHz, 22 dB of dispersal can be obtained with 600 kHz of spreading (1)

(1) This is not effective in protecting a 5 MHz AM-VSB signal.

Gaseous absorption can be a significant factor in reducing interference on satellite terrestrial paths where frequencies above 10 GHz are used and the signal arrives at the Earth with low elevation angles.

It can be concluded that sharing between the BSS and FS is generally feasible. There are some cases in which difficulties might arise. For these cases, technical solutions (beam shaping, antenna polarization discrimination, improvement in terrestrial antenna design, reduced satellite e.i.r.p., fixed-service pointing restrictions, frequency planning, reduced service areas) are possible, but bilateral or multilateral discussions among the administrations concerned may be necessary.

5.1.3.4 *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.

5.2 *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 XII.

TABLE XII – *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

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. 8 can be drawn. An example for a 625-line system is given in Fig. 10 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. 10 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 Report 810, Fig. 2).

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. 10, then the separating distance required between an outside broadcasting link and the earth-station receiver may be determined from Fig. 11.

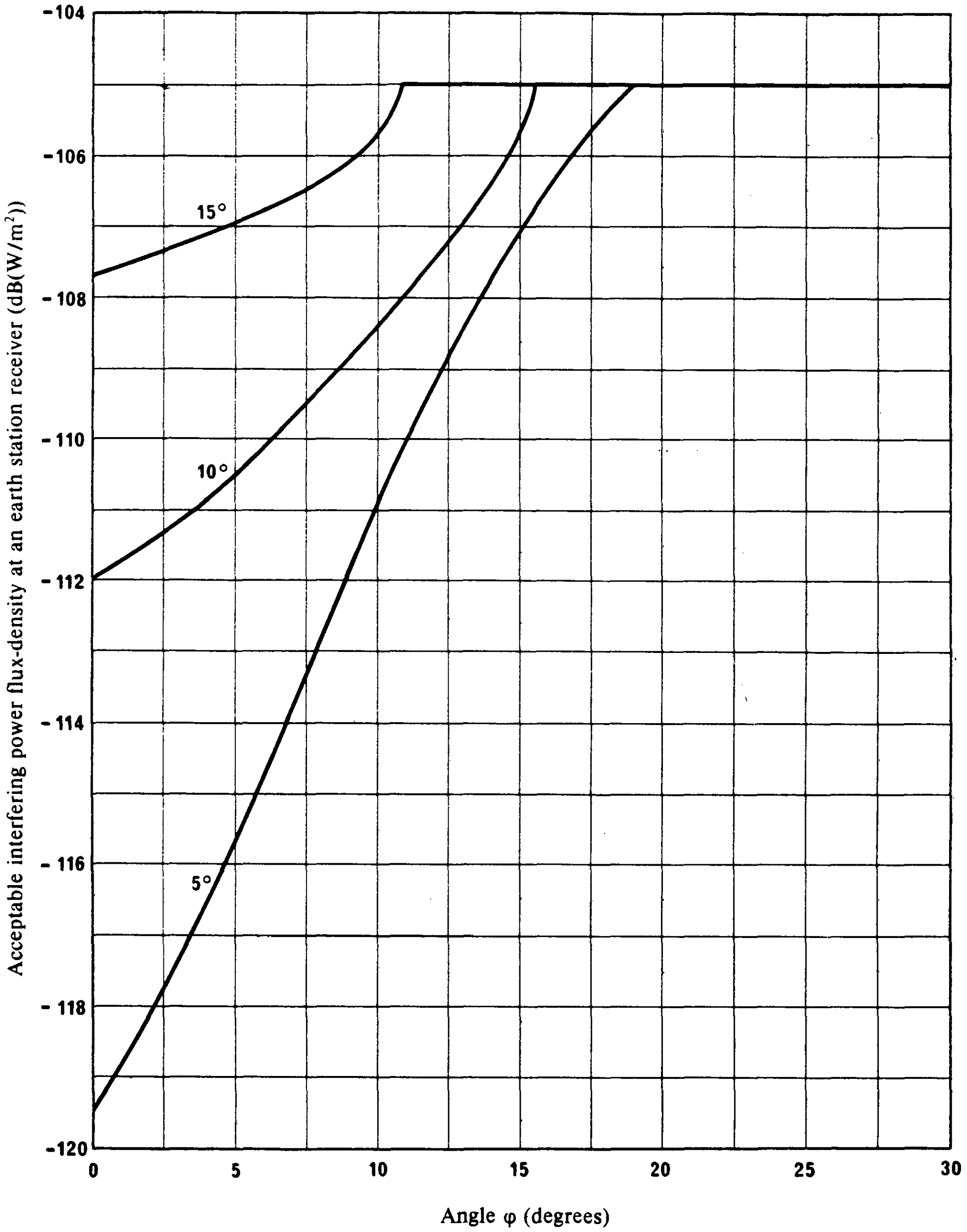


FIGURE 10 – *Acceptable interfering power flux-density from a terrestrial transmitter not to be exceeded for 99% of the time at an earth receiver (individual reception) for the example given in § 5.2*

(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 Report 810, Fig. 2, curve A,
where: φ_0: Antenna 3 dB beamwidth
= 2.0° (for individual reception in Region 3) from Final Acts WARC-BS-77

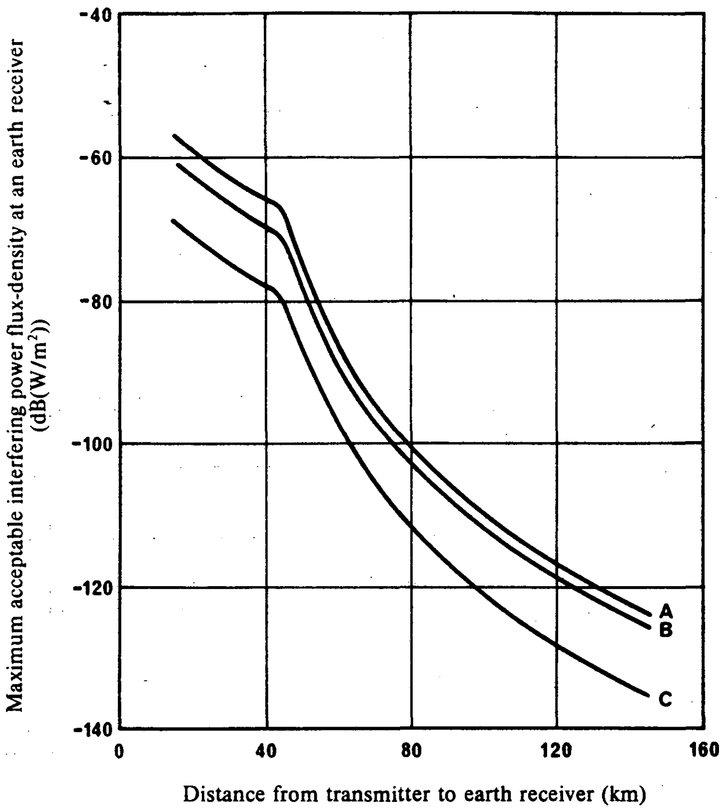


FIGURE 11 – *Required separation distance to protect an earth receiver from terrestrial transmitters*

(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 terrestrial 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 11 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. 11.

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 12.2 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. 11 that, for large areas, frequency sharing within 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 as suggested in [CCIR, 1974-78l]. 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 [CCIR, 1978-82a and b]. The satellite signal receiver employed a mixer input stage [Konishi, 1980] and an IF bandwidth of about 25 MHz. In one example, reception was free of interference when the satellite (BSE) transmission was separated by 16 MHz (band-edge to band-edge) from the nearest of a series of seven AM-VSB transmissions in alternate 6 MHz channels, and the ratio of wanted signal to interfering signal was 0 dB at the receiver input. It appeared from further experiments in the laboratory that intermodulation in the receiver was not a primary limitation. Further measurements are required with a range of typical receivers to provide better selectivity data. From this, guidance on the frequency separation required to protect satellite broadcast reception could be deduced, taking into account the antenna directivity, the signal characteristics and the levels of signal that would apply in practical cases.

5.2.1 *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 6 to Appendix 30 to the Radio Regulations (ORB-85) 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.

Maximum permissible 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.

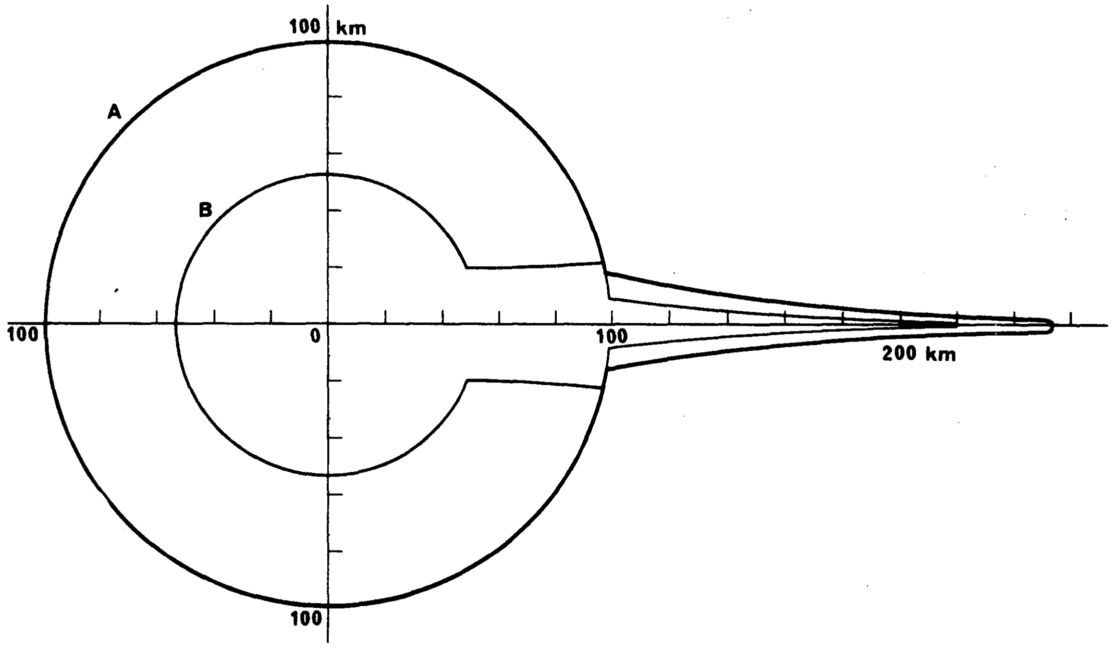
With these relations, the interfering signal power can be calculated, or the required separation distances can be determined. For each interfering transmitter, plot the minimum distance between the two locations against the off-axis angle of the interfering transmitter antenna with the location of the 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 12 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 12*a)* shows the co-channel case, and Fig. 12*b)* shows the case of adjacent-channel interference.

In Figs. 12*a)* and 12*b)*, 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.)

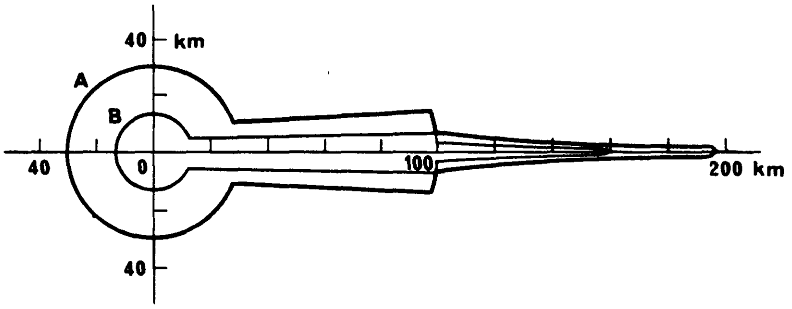
Each contour has a sharp peak in the on-axis direction of the interfering antenna, while it is a circular arc for angles well outside the main beam. Distances corresponding to these two regions are shown in Tables XIII and XIV for both co-channel and adjacent-channel cases, for both the 1 W system shown in Fig. 12, 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 XIII – *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 Max. 10.0	254.0 297.0	100.0 104.1	220.4 263.4	53.1 100.0
Type "B"	0.6	Typical −20.0 Max. −3.0	126.8 200.0	13.0 92.2	100.0 166.4	5.3 37.6



a) Co-channel interference



b) Adjacent-channel interference

FIGURE 12 – *Contours on which the received interfering FS signal power is equal to its maximum permissible limits for a 1 W (0 dBW) US fixed-service system*

BSS earth station elevation angle, θ :
A: θ = 15° (outer contour)
B: θ = 27° (inner contour)

TABLE XIV – *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 Max. 10.0	198.4 241.5	29.5 93.3	164.9 207.9	12.0 38.0
Type "B"	0.6	Typical −20.0 Max. −3.0	100.0 144.5	3.0 20.9	69.8 110.9	1.2 8.5

5.2.2 *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.

5.3 *Effects of propagation*

In making calculations of interference, the effects of propagation should be taken into account using the latest relevant methods of the CCIR. In particular, the effects of atmospheric absorption due to oxygen and water vapour should be included. Appendix 30 of the Radio Regulations and the Final Acts of the RARC SAT-83, Part I, in their respective Annexes (concerning modifications to the respective Plans) provide the PFD levels from the BSS in one region into the other which would trigger coordination with respect to the fixed service. Also Annex 5 of Appendix 30 of the Radio Regulations (1982) sets forth the PFD levels for the protection of terrestrial services in Regions 1 and 3 from the BSS and FSS in Region 2. The Regional Administrative Radio Conference, RARC SAT-83, adopted in principle the use of atmospheric absorption in calculations for determining whether the specified coordination criteria and PFD limitations are met. Also, Resolution No. 9 of the RARC SAT-83 is directed towards the adoption of the use of atmospheric absorption in all intraregional and inter-regional coordination. The calculations in the directions from Regions 1 and 3 to Region 2 are based on the use of atmospheric absorption. Resolution No. 9 is directed, *inter alia*, towards the use of atmospheric absorption in the reverse direction as well.

Report 719 discusses the phenomenon of atmospheric absorption and how it can be modelled. At 12 GHz, atmospheric absorption for angles of arrival, θ, and water vapour density at the receiving station, $\rho(\mathrm{gm/m^3})$, is given by:

$$A_a = (7.226 \times 10^{-3} + 12.75\,\rho \times 10^{-4})\,R_0 \quad \text{dB} \qquad \text{for } \theta \simeq 0°$$

$$A_a = \frac{0.1156}{\sin\theta + \sqrt{\sin^2\theta + 0.0019}} + \frac{0.00511\,\rho}{\sin\theta + \sqrt{\sin^2\theta + 0.0005}} \qquad \text{for } 0° < \theta \leqslant 10°$$

$$A_a = \frac{0.0578 + 25.502\,\rho \times 10^{-4}}{\sin\theta} \qquad \text{for } \theta > 10°$$

where:

R_0 : horizontal path distance ($\theta \simeq 0°$).

Figure 13 gives the atmospheric absorption for low elevation angles for three values of ρ: 2, 7.5 and 11.1 gm/m³. The first represents winter conditions in the higher latitude land masses and the second represents summer conditions (Figs. 9 and 10 of Report 563), and the last represents a global average, as used in Report 719. Note that in general, values of ρ = 25 to 30 gm/m³ can be encountered.

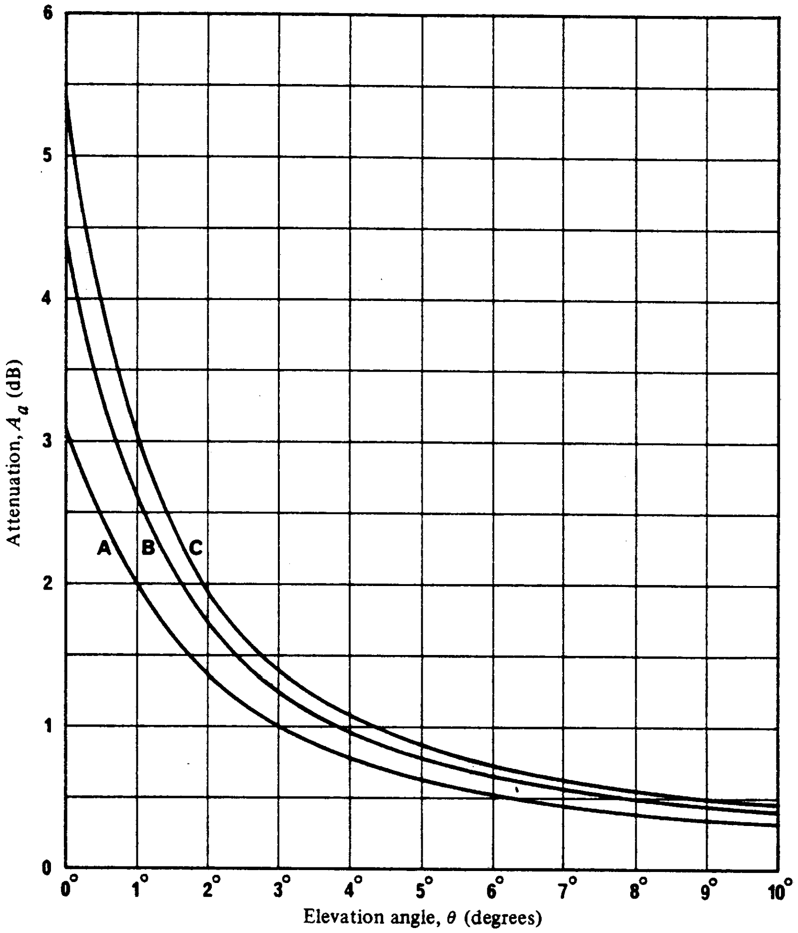


FIGURE 13 – *Atmospheric attenuation (A_a) versus elevation angle θ*

Curves A: ρ = 2.0 g/m³
B: ρ = 7.5 g/m³
C: ρ = 11.1 g/m³
ρ denotes water vapour density

Report 719 indicates that for completely dry atmospheres, about 2 dB of attenuation will be present on 12 GHz space-Earth paths at near zero angle of arrival and about 3 dB on 22 GHz paths. With significant amounts of water vapour present, as is the case during most of the year, the atmospheric absorption at 22 GHz would be very large.

5.3.1 *Conclusions on atmospheric absorption on nearly horizontal paths*

Above 10 GHz, Earth-space and space-Earth paths at nearly horizontal incidence will experience significant attenuation due to the presence of gases in the atmosphere.

Even in completely dry atmospheres at least 2 dB can be expected at 12 GHz due to oxygen alone. At 22 GHz at least 3 dB can be expected.

The presence of this attenuation was not taken into account in the establishment of inter-regional and inter-service limits on power flux-density.

Therefore, this attenuation can safely be taken into account in the determination of the levels of interfering signals to be expected on space-Earth paths around 12 GHz and 22 GHz.

The amount of attenuation to be expected should be determined using the current version of Report 719.

6. Sharing in bands above 12.75 GHz

The WARC-79 allocated three frequency bands above 12.75 GHz to the broadcasting-satellite service: 22.5 to 23, 40.5 to 42.5 and 84 to 86 GHz. In the band 40.5 to 42.5 GHz, the broadcasting-satellite service is the only primary allocation and therefore frequency-sharing from the BSS viewpoint is not necessary. In the band 84 to 86 GHz, the BSS, fixed, mobile and broadcasting services are all allocated on a primary basis. However, footnote No. 907 of the Radio Regulations 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.

6.1 *Sharing in the band 22.5 to 23 GHz between the BSS and other services*

6.1.1 *Interference between the broadcasting-satellite service and the inter-satellite service*

Interference between the BSS and the ISS is treated in Report 951.

6.1.2 *Sharing between broadcasting-satellite and fixed services*

6.1.2.1 *Characteristics of the terrestrial fixed system*

In North America, the band 22.5-23.0 GHz has not yet been extensively used by the fixed service. Typical applications of systems operating in this band fall mainly into two categories, namely, the provision of:

- low capacity telephony circuits such as PABX central office connections. Typical system capacities are 24/48 voice circuits employing digital transmission techniques;
- video links such as remote surveillance, electronic news gathering (ENG) pick-ups, etc. employing analogue transmission techniques (amplitude modulation). System lengths are typically a few kilometres.

A typical terrestrial radio system could exhibit the following characteristics:

Frequency (GHz)	22.4-23.0
Transmit power (mW)	100
Antenna gain (dBi)	34-40
Antenna beamwidth (degrees)	2-3
Receiver noise figure (dB)	8.0
RF bandwidth (channel spacing) (MHz)	50
Modulation: digital (AM/FSK)	voice/data
analogue (FM)	video
System length (km)	0.5-8

6.1.2.2 *BSS transmission system characteristics*

The type of broadcasting-satellite service considered here is high definition television (HDTV). It is still in the development stage, thus there are no established transmission standards defining signal format, modulation and system performance requirements.

However, Report 1075 considers the transmission aspects of HDTV by satellite with Table II of the Report containing examples of analogue and digital HDTV systems using the 22.5-23.0 GHz band. Table XV lists certain of the parameters that are pertinent to sharing.

TABLE XV – *Examples of possible HDTV systems using 22.5-23.0 GHz band*
(from Table II of Report 1075)

Parameter	Analogue	Digital
Type of modulation	FM-TDM	DPCM
RF bandwidth (MHz)	60	195
PFD (at edge of service area) (dB(W/m^2))	– 104.7	– 93.2
Rain attenuation (99% of the worst month) (dB)	4.5	4.5
BSS receiver antenna diameter (m)	2.5	0.62
Satellite e.i.r.p. (boresight) (dBW)	66.3	78.0

The analogue HDTV example with its larger TVRO antenna size and lower satellite power requirement could be used for community reception applications whereas the digital HDTV example, which assumes a small antenna, could correspond to individual reception systems which would be further into the future due to present technological constraints.

These two system examples along with the parameters assumed for the terrestrial radio systems given in § 6.1.2.1 will be used to determine coordination distances required with respect to a BSS receiving location.

6.1.2.3 *Coordination areas for a BSS receiving location*

An indication of the feasibility of sharing on a geographical basis between the BSS and FS can be obtained by determining the coordination area required around a BSS receiving location. (For the case of community reception the coordination distance can be considered with respect to a particular BSS receiving location whereas for direct reception, the coordination distance should be considered with respect to the edge of the service area.)

The coordination area provides a conservative estimate of the separation distance required since worst-case assumptions are used to generate the contours. Factors that could alleviate the interference such as:

- off-axis discrimination of the terrestrial transmitting antenna,
- site shielding from natural terrain and local buildings,

are not considered. Furthermore, worst-case propagation parameters are used.

The method of generating the coordination contours is given in Appendix 28 of the Radio Regulations. The path loss between the interfering transmit station and the BSS receiving location that must be exceeded for p% of the time, $L(p\%)$, can be expressed as:

$$L(p\%) = P_t - P_r(p\%) \qquad (11)$$

where:

P_t: boresight e.i.r.p. of the interfering transmit station,

$P_r(p\%)$: permissible level of interfering power at the input to the BSS receiver not to be exceeded for p% of the time.

$P_r(p\%)$ is related to the wanted signal level, $P_w(p\%)$, and the desired protection ratio, R, by the following:

$$P_r(p\%) = P_w(p\%) - R \qquad (12)$$

Using the values for the system parameters given in § 6.1.2.1 and 6.1.2.2, the required path loss is given by the following:

$$L_p = R - PFD_w(p\%) - D(\varphi) + 78.5 \tag{13}$$

where:

$PFD_w(p\%)$: power flux-density of wanted signal at BSS receiver exceeded for p% of the time,

$D(\varphi)$: BSS receiver antenna discrimination at an off-axis angle of φ degrees.

In the determination of path loss, the following assumptions were made:

- for coordination distances greater than 100 km, mode 1 propagation (i.e. great circle) was used;
- for distances less than 100 km, line-of-sight propagation was used;
- single climatic zone (Zone A2) assumed;
- horizon elevation factor of 0 dB (worst case);
- water vapour density: 1 g/m^3;
- frequency of 22.5 GHz;
- percentage of time: $p = 0.29\%$ (equivalent to 1% of the worst month).

In developing the coordination contours for both analogue and digital BSS systems two situations were considered, namely:

Case A assumptions: (best case)

- interfering signal attenuated by rain in the same amount as the wanted signal;
- BSS receiver located at centre of service area.

Case B assumptions: (worst case)

- interfering signal not attenuated by rain;
- BSS receiver located at edge of service area.

6.1.2.4 *Coordination area for analogue HDTV BSS*

BSS receive antenna characteristics

For the antenna diameter of 2.5 m ($D/\lambda > 100$), assumed for this case, the off-axis co-polar gain is given by the following (Appendix 28 of the Radio Regulations):

$$G(\varphi) = \left\{ \begin{array}{l} 53.2 - 89.9\,\varphi^2 \\ 36.1 \\ 32.0 - 25 \log(\varphi) \\ -10 \end{array} \right\} \text{dBi} \quad \begin{array}{ll} \text{for } 0 & < \varphi \leqslant 0.44 \\ \text{for } 0.44 & < \varphi \leqslant 0.686 \\ \text{for } 0.686 & < \varphi \leqslant 48.0 \\ \text{for} & \varphi > 48.0 \end{array}$$

where φ is the off-axis angle in degrees.

Protection ratio required

As no data are available on protection ratio requirements for HDTV, data pertaining to conventional TV systems were assumed to be applicable. Based on data contained in Annex I to Report 634, the following protection ratios would appear to be appropriate:

Type of interference	*Protection ratio*
Coherent (e.g. AM-VSB TV)	35 dB
Non-coherent (e.g. digital)	25 dB

Figure 14 shows the coordination areas for both best case (case A) and worst case (case B) assumptions and for coherent and non-coherent interference. Table XVI summarizes the upper and lower limits for the coordination distances.

Although maximum coordination distances, which correspond to directions near the boresight, are quite large, these values correspond to a 0° elevation angle. For practical elevation angles of 10° or more these distances reduce to 100 km or less.

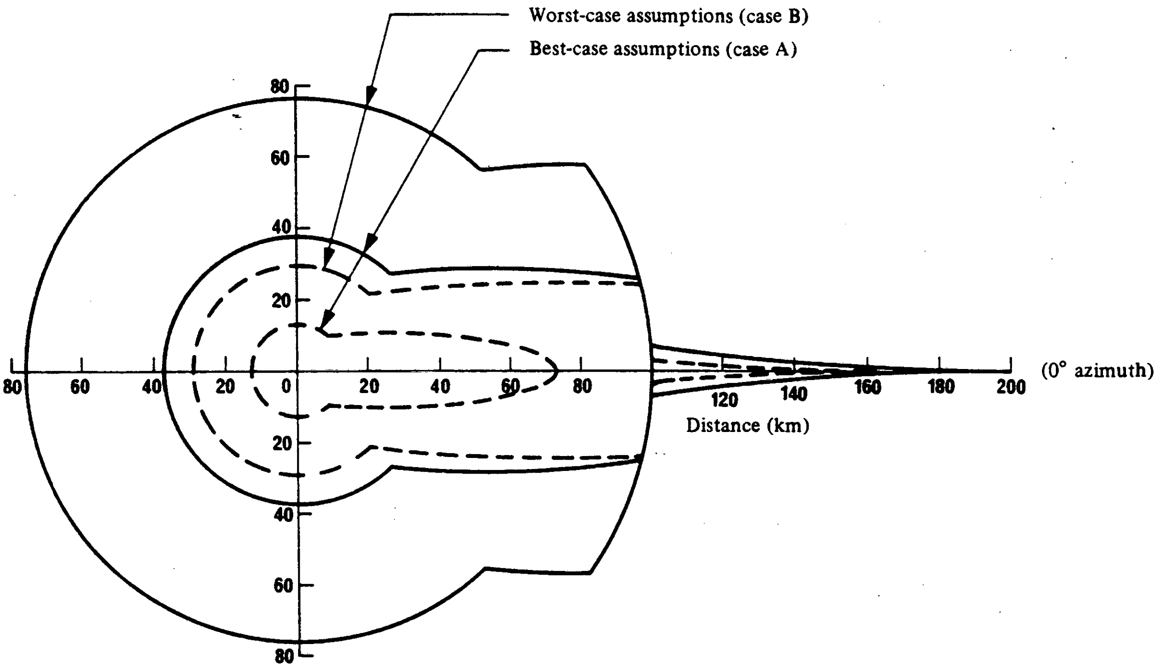


FIGURE 14 – *Coordination areas for analogue HDTV systems*

——— coherent interference (e.g. AM-VSB TV)

– – – non-coherent interference (e.g. digital telephony)

TABLE XVI – *Summary of coordination distances (km) for analogue HDTV*

	Coherent		Non-coherent	
	Maximum	Minimum	Maximum	Minimum
Best case (case A)	100	37	73.4	12.9
Worst case (case B)	197	75.6	168	28.9

6.1.2.5 *Coordination areas for digital HDTV*

BSS receiving antenna characteristics

The antenna diameter assumed for digital HDTV is 0.62 m ($D/\lambda < 100$). Thus the co-polar off-axis gain is given by the following (Appendix 28 of the Radio Regulations):

$$G(\varphi) = \begin{cases} 41.0 - 5.41\,\varphi^2 \\ 27.0 \\ 35.3 - 25\log(\varphi) \\ -6.7 \end{cases} \text{dBi} \quad \begin{matrix} \text{for } 0 < \varphi \leq 1.61 \\ \text{for } 1.61 < \varphi \leq 2.15 \\ \text{for } 2.15 < \varphi \leq 48.0 \\ \text{for } \varphi > 48.0 \end{matrix}$$

Protection ratio requirement

Based on data for digitally-coded conventional television systems (System M/NTSC), the required protection ratio for "just perceptible" interference is approximately 25 dB (see Report 634, Annex I). This value of protection ratio is assumed for the digital HDTV case as well.

Multiple interferers

The necessary bandwidth for the digital HDTV system is large compared to bandwidths used by terrestrial systems (typically 50 MHz spacing between RF channels). Furthermore, since the interference will be noise-like (i.e. non-coherent), its impact on picture degradation is not expected to be dependent on the interfering carrier off-set (i.e. co-channel or non co-channel interference). Therefore to take into consideration the possibility of more than one interferer falling within the HDTV channel, a multiple exposure factor of 10 log (195/50) = 5.9 dB is assumed as a worst-case situation.

Figure 15 shows the coordination areas for the digital HDTV systems assuming best case (case A) and worst case (case B) scenarios and for single and multiple exposure factors. Table XVII summarizes the maximum and minimum coordination distances for all these cases.

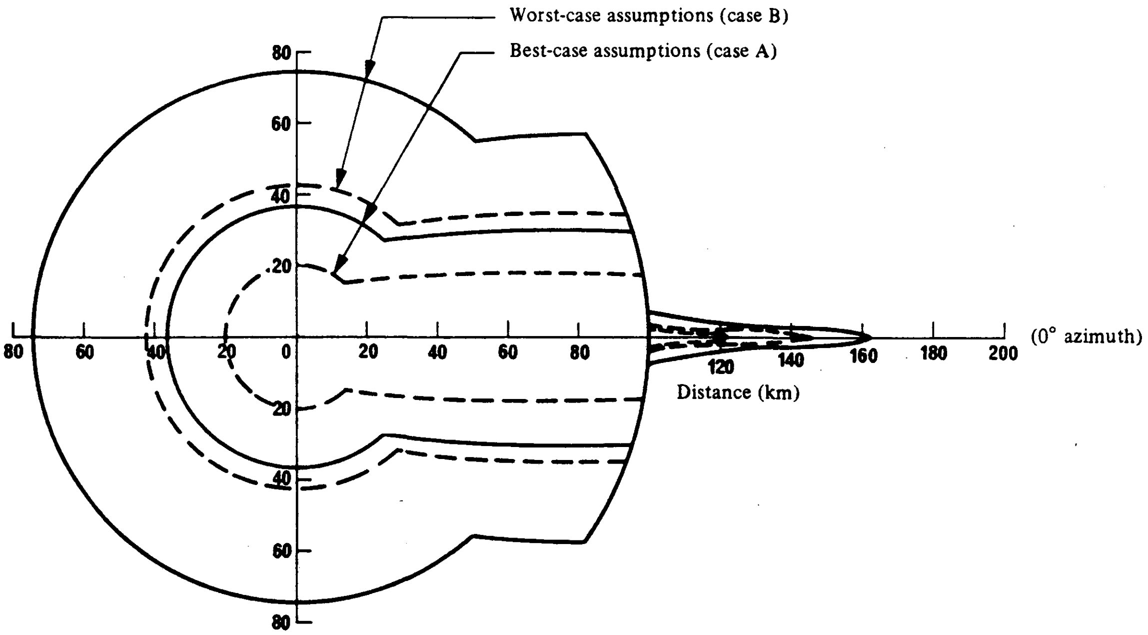


FIGURE 15 – *Coordination areas for digital HDTV systems*

——— multiple exposure factor: 5.9 dB

– – – multiple exposure factor: 0 dB

TABLE XVII – *Coordination distances for digital HDTV receivers*

	Single exposure		Multiple exposure	
	Maximum	Minimum	Maximum	Minimum
Best case (case A) (km)	123.4	19.7	140.7	36.4
Worst case (case B) (km)	145.4	42.6	162.7	74.8

As in the analogue HDTV case, the large values of coordination distances correspond to small off-axis angles and/or low elevation angles. For practical elevation angles of 10° or more the maximum coordination distance reduces to 100 km or less.

In comparison to the analogue HDTV case of Fig. 14, the coordination areas for digital HDTV lie between the worst-case (coherent) and best-case (non-coherent) analogue HDTV coordination areas.

6.1.2.6 *Interference from BSS into terrestrial systems*

As an indication of the sensitivity of terrestrial radio to interference from BSS, the ratio of interfering power to noise power in an RF channel bandwidth at the receiver input is determined in Table XVIII below. The digital HDTV BSS case is assumed to be the worst case due to its high PFD level and the terrestrial radio system parameters used are considered typical for video transmission applications (AM-VSB TV transmission).

TABLE XVIII – *Example of BSS interference into terrestrial radio-relay systems*

RF bandwidth of terrestrial channel (MHz)	5
Receiver noise figure (dB)	8
Boresight antenna gain (dBi)	34
Noise power at receiver input (*kTB*) (dBW)	–127.7
PFD of HDTV at boresight (clear air) (dB(W/m^2))	–85.7
Satellite transmitting antenna discrimination (¹) (dB)	12.7
Bandwidth factor (²) (dB)	15.9
Atmospheric attenuation (clear air) (dB)	4.0
Gain of 1 m^2 (effective antenna aperture) at 22.5 GHz (dB)	48.5
Interference level at receiver input (dBW)	–132.8
(Interference/noise) ratio (dB)	–5.1

(¹) Assumes a minimum elevation angle of 20° at the *edge* of the BSS coverage area and a 1° satellite transmit antenna beamwidth.

(²) For digital modulation the energy is assumed to be spread uniformly over the total bandwidth of the HDTV channel resulting in a reduction of interference power by 10 log (195/5) = 15.9 dB.

An analysis of interference to a terrestrial, medium-capacity system employing 4-phase DPSK modulation and capable of providing up to 672 voice channels for each RF carrier was carried out. Assumptions and system characteristics are given in Annex II.

This analysis indicates that a minimum BER of 1 x 10^{-7} can be met during median (clear-sky) conditions with excess C/I margins. The amount of excess margin depends on the path length of the digital system and the type of HDTV BSS interference. Lower margins can be expected on the longer path lengths (8 km) and from interfering signal analogue HDTV signals with p.f.d. levels designed for individual reception. However, these excess C/I margins imply that no restrictions in terms of terrestrial receive antenna location or orbit avoidance is required with respect to this mode of interference. These positive margins also imply that the assumption of the minimum elevation angle at the edge of the BSS coverage area (i.e. 20°) could be relaxed and still meet the protection criterion for all but the longest path lengths. The margins will be even greater in the case of community reception for HDTV BSS due to the lower p.f.d. levels.

The effect of interference on system performance during rain fading conditions will be to reduce slightly the fade margin to the receive BER threshold. Assuming that the satellite signal will also be faded by at least the same amount as the terrestrial signal, the reduction in the path fade margin will be less than 1 dB.

It should be noted, however, that these conclusions apply only to digital systems employing this level and type of modulation, and similar system characteristics. For example, these conclusions may not apply to systems currently being deployed and under development using a higher level of modulation such as 64 QAM, which is more sensitive to interference, or employing sectorial receiving antennas in which case the rain fades along the two paths may not be fully correlated.

6.1.2.7 *Summary and conclusions*

The feasibility of sharing between the BSS and FS has been examined, and the following conclusions may be drawn:

- analysis of coordination distances for the analogue HDTV BSS case (community reception) indicates that, for elevation angles greater than approximately 10° the maximum coordination distance lies between 73 and 100 km corresponding to azimuths near the boresight direction, and minimum coordination distances between 13 and 37 km for azimuths corresponding to the back lobe of the receiving antenna;
- coordination distances for the digital HDTV case (individual reception case) fall within the maximum and minimum coordination contours for the analogue HDTV case;
- considering the relatively smaller coordination areas required for this band, sharing on a geographical basis will be somewhat easier than in the 12 GHz band;
- the analysis of interference into terrestrial radio-relay systems from the broadcasting satellite given in § 6.1.2.6 indicates that, under worst-case assumptions, an (I/N) ratio of −5.1 dB would result. Further study is needed to determine if this margin is adequate for the types of terrestrial services envisaged for this band.

6.2 Sharing between radioastronomy and the BSS in the region of 22 GHz*

Radioastronomy (RA) has an interest in several bands around 22 GHz:

22.01 to 22.21 GHz
22.21 to 22.50 GHz
22.81 to 22.86 GHz
23.07 to 23.12 GHz

These bands are also of interest to the BSS for wide RF-band HDTV emissions (see Resolution 521).

The protection required by radioastronomy and the width of guard bands that would be required to provide full protection to RA is discussed in this section.

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* This section should be brought to the attention of CCIR Study Group 2.

6.2.1 Required power flux density limits

The power flux density (pfd) limits required to protect radioastronomy (RA) observations are given in Report 224. The limits tabulated are based on the assumption that an isotropic antenna is being used. Since in practical RA observations highly directional antennas are used, an additional factor of 15 dB (over the pfd limits tabulated) may be assumed. This assumption is based on the use of the reference antenna pattern 32-25 log φ to represent the side lobe gain in dBi of the RA antenna. It is further assumed here that the RA antenna will not be pointed closer than 5° from the geostationary satellite orbit (GSO) so that the gain of the RA antenna towards the GSO will not exceed
32-25 log(5°) ≅ 15 dBi.

The relevant pfd limit in this frequency band is calculated as follows: Table I of CCIR Report 224 indicates a spectral power flux-density of -233 dB(W/(m^2·Hz)) which corresponds to an assumed 0 dBi antenna gain.

This power flux-density level is further decreased by 15 dB (to -248 dB(W/(m^2·Hz)) to permit RA observations up to 5° off the geostationary satellite orbit as discussed above.

Report 1075 indicates that the free space pfd of an HDTV satellite service will be of the order of −90 to -100 dB(W/m^2) in the service area. Table XIX shows the spectral power flux density in a 1 Hz bandwidth assuming either uniform spectral distribution (as would be achieved by a digital transmission) or energy dispersal over 4 MHz (as would be achieved with a FM transmission). Further study may be needed to determine whether the standard type of energy dispersal used in FM systems would be adequate to protect the RA service.

Table XIX: Power flux density (pfd) in a 1 Hz bandwidth in dB(W/(m^2.Hz))

Bandwidth over which the energy is spread (MHz)	Spectral pfd dB(W/(m^2.Hz))	
	HDTV pfd = -90 dB(W/m^2)	HDTV pfd = -100 dB(W/m^2)
4	-156	-166
40	-166	-176
50	-167	-177
100	-170	-180

From the results in this table it can be seen that a significant attenuation of the HDTV signal is needed before it can operate in the RA band without causing excessive interference.

6.2.2 Implications

The levels of out-of-band interference should be lower. The modulation systems employed will have spectral shaping, and there can be attenuation from the satellite output filter.

To achieve the desirable level of -248 dB(W/(m^2·Hz)), between 68 and 92 dB of additional attenuation would be required.

6.2.2.1 FM systems

FM systems will have a spectrum which drops off fairly rapidly out of the band. Fig. 16 shows a typical example of a representative spectrum mask. This spectrum is deduced from information in CCIR Report 807-2. This Report gives a radio-frequency spectrum for a typical out-of-band radiation from a television broadcasting satellite. The assumption that a conventional television standard is used represents a near worst case. To extrapolate from conventional standards to HDTV standards, it is necessary to make some approximations. Frequency scaling of signals is valid under some conditions. Calculations were done both for r.f. bandwidths of 54 MHz (see system B in Table IX of Report 1075 ———) and 100 MHz. Thus the frequency scaling can be assumed to be a factor of two in the first example, and four in the second example.

It can be seen from the curves in Fig. 16 that some additional attenuation is necessary to protect the RA*. Fig. 16 also shows that, for an FM system with no additional filtering, the guard band must be between 65 and 120 MHz, depending on which example is used. Futher filtering on the output would be useful.

6.2.2.2 Digital systems

There is a wide range of possible digital systems under study. Some have a constant envelope and can be engineered to provide a spectrum which is not degraded when the signal is passed through a non-linear amplifier. Other digital systems do not have a constant amplitude envelope, the spectrum can be modified by non-linearities, especially in a TWTA, resulting in an increase in the out-of-band spectral components. Two of the examples from Report 1075, QPSK and 16 QAM, can be considered as limiting cases. Fig. 17 shows that a simple QPSK system will have levels of out-of-band radiation too high to allow the RA users to operate properly. Similarly, with the assumptions made, there will be problems with 16 QAM (Spectral envelopes of Fig.17 correspond to post-TWTA signals and 50% cosine roll-off (CRO). Extra filtering is therefore essential for digital systems.

6.2.2.3 Requirements for guard bands and filtering

It is possible to deduce the filtering necessary to protect the RA at minimum frequency separations from the HDTV BSS.

From a study of Fig.16 we can see that the FM systems used in the examples require filters with pass-bands of 50 and 100 MHz. Some rejection is desirable at a frequency offset by about the bandwidth away from channel centre frequency. An attenuation of 20 dB is assumed as a stringent, but probably achievable target, in order to improve the spectrum efficiency.

The output filter needs to provide attenuation to bring the residual levels of out-of-band radiation down to those proposed to protect the RA. From Fig.17 it can be seen that figures for attenuation of about 50 dB are required.

More specifically, a 140 Mbit/s QAM channel would need at least 50 dB attenuation at a minimum frequency offset from channel center of 68 MHz whereas an 140 Mbit/s QPSK channel would need at least 60 dB attenuation at a minimum frequency offset of 70 MHz.

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* The values in Fig. 16 assume energy dispersal.

6.2.2.4 Example calculation: 140 Mbit/s QPSK for the frequency region near 22 GHz

For this latter case, we can derive the total frequency band to be left free for RA operations:

- RA band: 50 MHz
- Minimum band between RA band edge and center frequency of nearest HDTV channel: 70 MHz
- Half channel RF width for an 140 Mbit/s QPSK signal with 50% CRO: 52.5 MHz

B(free) = 50 + 2 x 70 - 2 x 52.5 = 85 MHz.

This leads to a large unoccupied band and to very stringent filters specifications.

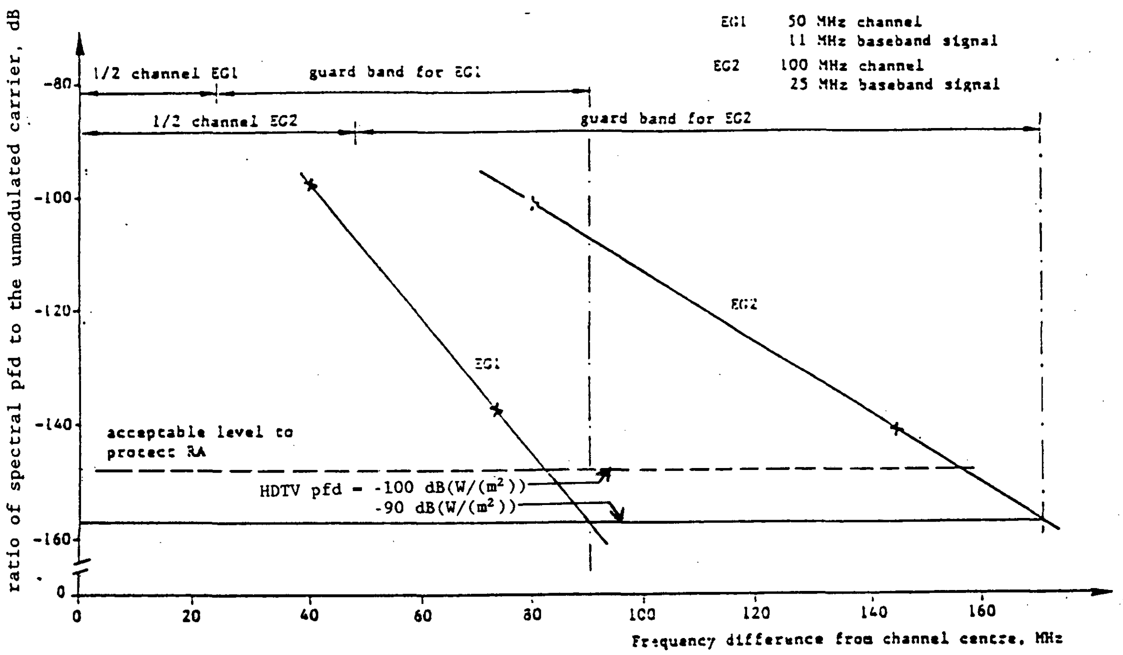

FIGURE 16

Spectrum mask for FM systems

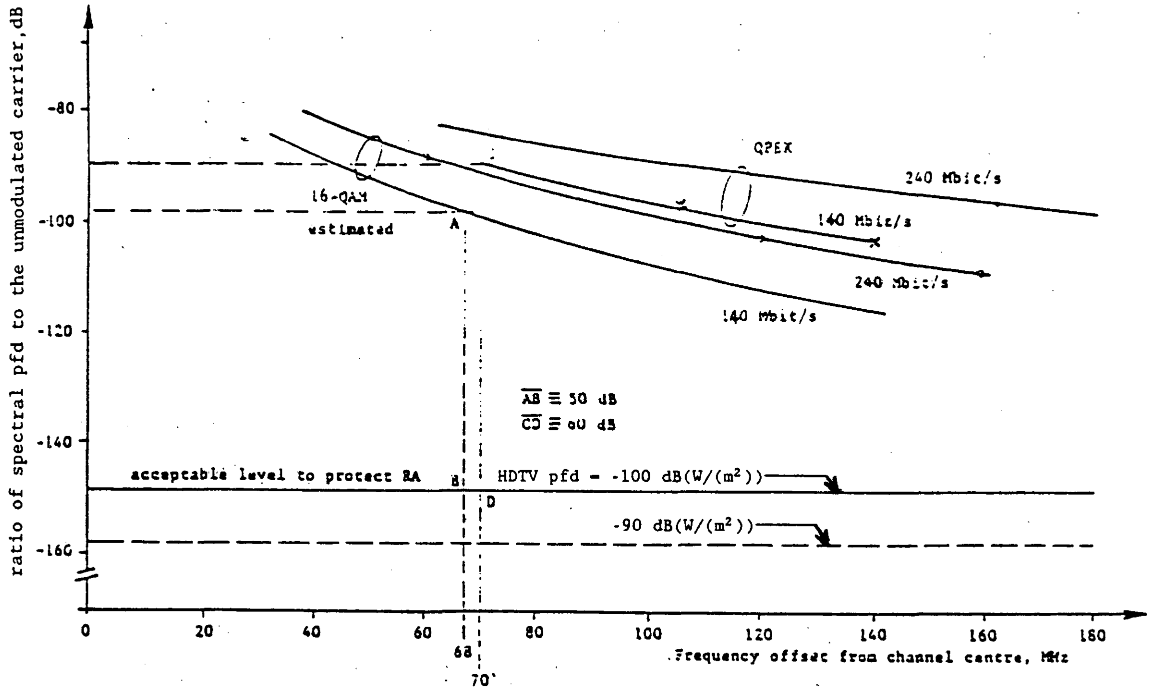

FIGURE 17

Spectral envelope for digital systems

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[1978-82]: **a.** 11/247 (Japan); **b.** 10-11S/114 (Japan).

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[1974-78]: 11/19 (United Kingdom); 11/22 (Switzerland); 11/34 (Japan); 11/108 (Canada); 11/141 (United Kingdom); 11/153 (USA); 11/156 (Germany (Federal Republic of)).

[1978-82]: 10-11S/11 (EBU); 10-11S/12 (United Kingdom); 10-11S/25 (USA); 10-11S/53 (USSR); 11/116 (USSR).

ANNEX I

EXAMPLES OF POWER FLUX-DENSITY LIMITS REQUIRED TO PROTECT THE LAND MOBILE SERVICE AT ABOUT 800 MHz

For a single broadcasting geostationary satellite in a visible orbit position, 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 factor: 10 dB;
- improvement factor: 12 dB;
- antenna gain: 15 dBi;
- 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 geostationary satellites are in visible orbit positions, the power flux-density produced by each satellite must be correspondingly lower than that quoted above.

It would be desirable to obtain more data on parameters of systems in operation or under development from other administrations before a general value of protection to systems in the land mobile service can be arrived at. 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 is feasible at about 800 MHz.

ANNEX II

CHARACTERISTICS OF A 23 GHz DIGITAL TERRESTRIAL SYSTEM AND INTERFERENCE CONSIDERATIONS

This Annex provides the details on the characteristics of the digital terrestrial system discussed in § 6.1.2.6. The assumptions and the method used for the analyses of the impact of interference are also included.

1. 23 GHz digital radio systems for voice/data transmission

With the rapid evolution of the digital voice/data network, the use of the 23 GHz band for voice/data transmission will most likely employ digital transmission techniques. Current device performance limitations at these frequencies will likely limit the choice of modulation to constant envelope techniques (e.g. 2- or 4-PSK) permitting operation near or at device saturation. Such modulation schemes will provide voice data capacity ranging from 96 voice channels (low capacity) up to approximately 672 voice channels (medium capacity) in one RF channel. The basic radio system transmission parameters for these systems are assumed to be as given in § 6.1.2.1 of the present Report.

Typical applications of these systems could be for interlinking buildings within metropolitan areas thus using relatively short paths (1-8 km) in order to limit path fading due to precipitation which can be severe at these frequencies. Considering possible path geometry, elevation angles of the terrestrial radio transmit/receive antennas could range up to ten degrees. The elevation angle of the digital radio receive antenna is important as it affects the location at which the terrestrial receive antenna boresight could possibly be directed towards the interfering satellite.

2. Sharing considerations and interference analyses

At these higher frequencies and with systems employing relatively short path lengths the major factor contributing to path availability will be rain fades. Furthermore, satellite interference of any concern will be in those cases where the terrestrial signal path is near the same azimuth and elevation angles as the interfering satellite signal path, otherwise there will be sufficient discrimination provided by the terrestrial receiving antenna. Hence it is reasonable to assume that the satellite signal will be faded by at least the same amount and at the same time as the terrestrial signal during rain conditions.

The sharing analysis presented herein is based on meeting a required carrier-to-interference ratio (C/I) to insure acceptable system error performance during median or clear sky propagation conditions.

(This approach is different from that used in § 6.1.2.6 of the present Report, which is based on achieving an acceptable interference-to-noise (I/N) ratio thus implying at least partial signal fading independence between the wanted and interfering paths.)

Assuming that the impact of the interference on the system BER is equivalent to that of Gaussian noise, then for 4-phase DPSK modulation a C/I of 13.8 dB will result in a theoretical BER of 1×10^{-7}. Allowing for a 3 dB implementation margin the required C/I in the absence of thermal noise ($C/N = \infty$) is 16.8 dB.

Similarly, assuming a threshold BER of 1 in 10^3 as minimum acceptable performance (i.e. system outage) corresponds to a faded C/N value of 9.8 dB for 4-phase DPSK. This threshold C/N value is in the absence of interference. The presence of interference in the faded condition will have the effect of increasing this threshold C/N value slightly which results in a slightly reduced fade margin. For example, assuming that the satellite signal will fade the same amount as the terrestrial signal, then for a C/I = 16.8 dB the required C/N for a 1 in 10^3 BER is approximately 10.3 dB, which represents a 0.5 dB reduction in the fade margin.

Table XX gives the terrestrial system path characteristics for path lengths ranging from 2 to 8 km and for two sizes of terrestrial transmit/receive antennas. The maximum allowable interfering pfd level at the terrestrial receiver location is based on the C/I given above and assumes no terrestrial antenna discrimination towards the interfering satellite.

TABLE XX - *Terrestrial system path parameters*

Path length (km)	Median receive signal level[1] (dBW)		Fade margin[2] above threshold (dB)		Allowable interference level[3] (dBW)		Allowable interference PFD (dBW/m^2)	
	30 cm	68 cm	30 cm	68 cm	30 cm	68 cm	30 cm	68 cm
2	-74.8	-60.6	34.7	48.9	-91.6	-77.4	-77.1	-70.0
4	-81.1	-66.9	28.4	42.6	-97.9	-83.7	-83.4	-76.3
6	-84.8	-70.6	24.7	38.9	-101.6	-87.4	-87.1	-80.0
8	-87.6	-73.4	21.9	36.1	-104.4	-90.2	-89.9	-82.5

(1) Assumes transmitter output level P_t = 13 dBm

(2) Assumes NF = 8 dB: BER = 1 in 10^3 (threshold): (C/I) = ∞

(3) Assumes median (C/I) = 16.8 dB (≈ 1 in 10^7 BER + 3 dB margin)

TABLE XXI - *HDTV BSS (individual reception) interference levels*

Parameter	Digital	Analogue	
PFD at edge of coverage area	-94.3	-94.7	dB(W/m^2)
RF bandwidth	195	60	MHz
Rain margin	4.5	4.5	dB
Satellite transmit antenna beamwidth	1.0	1.0	deg
<u>Minimum</u> elevation angle at edge of coverage area	20.0	20.0	deg
<u>Maximum</u> elevation angle, terrestrial receiving antenna	10.0	10.0	deg
Boresight PFD (clear air)	-86.8	-87.2	dB(W/m^2)
Satellite transmit antenna discrimination towards terrestrial receiver	9.6	9.6	dB
Additional clear air attenuation	1.26	1.26	dB
Bandwidth dispersal factor[1]	5.9	0	dB

	Terrestrial receiving antenna diameter				
Excess C/I for: Path length (km)	30	68	30	68	cm
2	26.6	33.7	21.0	28.1	dB
4	20.3	27.4	14.7	21.8	
6	16.6	23.7	11.0	18.1	
8	13.8	21.2	8.2	15.6	

(1) Bandwidth dispersal factor applicable to digital HDTV BSS .

<u>Note</u>.- There are some differences between Report 951, sharing between the ISS and the BSS around 23 GHz, and section 7.3.2.2.7 of the report of JIWP 10-11/3 which treats interference from the BSS to the ISS.

REPORT 634-4 *

BROADCASTING-SATELLITE SERVICE
(Sound and Television)

Measured interference protection ratios for planning television broadcasting systems

(Question 1/10 and 11, Study Programmes 1C/10 and 11, 1D/10 and 11
and 2C/10 and 11)

(1974-1978-1982-1986-1990)

1. Introduction

A knowledge of interference protection ratios (the ratio of wanted-to-unwanted signal power at the receiver input) as a function of subjectively assessed picture quality is vital to the planning of television systems. Thus protection ratios for interference between two amplitude-modulation, vestigial-sideband (AM-VSB) signals have long been necessary in planning terrestrial broadcasting systems. Now, the many allocations of the frequency bands to the BSS on a shared basis with various terrestrial and space services have made the subject of protection ratios required by many different modulation methods of great importance. Indeed with the imminence of digital transmissions both as interferers and as wanted signals a knowledge of protection ratios among such signals and between them and analogue signals is also necessary.

This Report summarizes the results of protection ratio tests made by several administrations in cases where the wanted and unwanted signals are modulated by colour television signals or other transmissions such as multiple sound channels. (See Note.) In considering these results, it should be noted that particular combinations of signals are not, in general, confined to a single band of frequencies. Thus the protection ratio measured for interference between frequency-modulation and amplitude-modulation, vestigial-sideband signals is important not only for sharing in the band 620 to 790 MHz but also for the bands 2500 to 2690 MHz and 11.7 to 12.5 GHz.

Note. – Protection ratio data for interference between an amplitude-modulation, vestigial-sideband or a frequency-modulation television signal and the types of signals used in the fixed and mobile services will be found in Report 449.

2. Measurements of protection ratios

2.1 *Subjective measurements for television*

Subjective measurements of protection ratios for television should be made according to Recommendation 600.

2.2 *Objective measurements for sound transmissions*

In all cases of sound broadcasting it is convenient to carry out the measurement of protection ratio by means of an objective method. Such a method consists in carrying out the measurement of the noise after demodulation in order to obtain the condition that the signal-to-noise ratio within the sound channel does not exceed a given value. Table I gives a list of parameters influencing the protection ratio for sound signals together with a suggested reference case to establish a common set of test conditions for measurements made by different administrations.

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* This Report should be brought to the attention of the IEC (WG 8, SC 12A).

TABLE I – *Factors affecting objectively measured protection ratios for sound signals and a set of reference case conditions for these factors*

Factor	Reference case condition	
Receivers Wanted signal characteristics Unwanted signal characteristics Carrier frequency offset	Note 1 Note 2 Note 3 Note 4	
	High quality sound	Sound with television signal
Signal-to-weighted noise ratio (Note 6) The proposed reference case value may be arrived at from the two components being:	⩾ 47 dB	⩾ 42 dB
Signal-to-weighted thermal noise ratio	⩾ 50 dB	⩾ 45 dB
Signal-to-weighted noise ratio due to interference (Note 7)	⩾ 50 dB	⩾ 45 dB
Other interference and sources of sound degradation	Note 5	

Note 1. – The receivers used in the test should represent equipment which is fairly sensitive to the particular type of impairment being investigated. Account should be taken of domestic receivers, and the type of receivers which may be used at re-broadcast relay stations. Measurement of RF and IF filter characteristics should be made to assist in the interpretation of results obtained when there are frequency offsets between the wanted and unwanted signals. As far as possible, filter characteristics should be adjusted to the standards applicable to the wanted signal. Baseband output frequencies should be limited to the minimum required for the television standard used for the wanted signal. Excessive filter bandwidths permit the observation of noise and interference that would not be encountered with properly adjusted receivers.

Note 2. – If the wanted signal is a multiple sound system, several systems can be envisaged requiring the same or less bandwidth than a television channel. An example of such a system is given in Annex I, § 4.

Note 3. – In most cases the unwanted signal has the same characteristics as the wanted signal. There is, however, also a need for the determination of protection ratios between dissimilar systems. In these cases the unwanted signal can have characteristics different from the wanted signal or can be another type of transmission such as multiple sound channels.

Note 4. – For co-channel protection ratio measurements there is no carrier frequency offset: Carrier frequency offset is defined as the difference between the unmodulated carrier frequencies of the unwanted and wanted signals, $(f_{wanted} - f_{unwanted})$, if the same type of modulator is used in both channels. However, if the interference is sensitive to particular offset frequencies, these should be identified by the testing programme. For adjacent channel protection ratios, a series of measurements should be made for frequencies of the unwanted signal varying approximately ± 30 MHz from the wanted signal.

Note 5. – No account should be taken of other sources of interference, etc. (except thermal noise, as mentioned above), when assessing the protection ratio.

Note 6. – The indicated values represent the difference between the maximum signal level and the noise measured according to Recommendation 468. (Quasi-peak value and new weighting network.)

Note 7. – The objective method for the measurement of protection ratios in sound channels is described in Report 796.

3. Protection ratios for a wanted television signal

This section discusses the protection ratios needed for television signals. The protection ratio is a function of the modulation characteristics of both the wanted and unwanted signals. Certain values of protection ratios for television signals have already been used for planning purposes by the WARC-BS-77. These values based on measurements made up to that time are set forth in § 3.1.1. Protection ratio values based on recent measurements have been used for planning purposes by the RARC SAT-83. These values are also set forth in § 3.1.1.

The remainder of § 3.1 cites measurements of protection ratios for television signals subject to interference from other television signals employing both analogue and digital modulation. § 3.2 cites measurements of protection ratios for television signals subject to interference from signals other than television.

Section 3.3 discusses the effects of several deviations in test conditions from the reference case test conditions set forth in Recommendation 600.

Measurements of required protection ratios given in this Report were conducted under a wide variation of test conditions using different subjective criteria. Further studies conducted in accordance with the provisions of Recommendation 600 and for all combinations of wanted and unwanted signal modulation methods to be encountered in practice are desirable, so that values can be agreed on for future planning purposes. Suggestions for certain additional tests are given in Annex II.

3.1 *Interference from a television signal*

3.1.1 *Protection ratio templates used for planning*

Figure 1a and Table II give the protection ratio template used for planning at the WARC-BS-77 which is based on measurements made up to that time.

Measurements made in Canada and the United States of America addressed several aspects of interference between frequency modulated television signals of system M/NTSC. In particular:

- a relationship between the picture impairment level and the single-entry co-channel interference was found;
- the subjective effect of adjacent-channel interferers was analyzed;
- the composite effect of co-channel and adjacent-channel interference was assessed.

Based on the results of these measurements the protection ratio template in Fig. 1b was derived for Region 2 with a co-channel protection ratio value of 28 dB.

Detailed information on test conditions and measurement results is given in Annex I, § 3.1 and in [CCIR, 1982-86a and b].

3.1.2 *Interference between two amplitude-modulation, vestigial-sideband television signals*

Values of protection ratio for this important case will be found in Report 306.

3.1.3 *Interference to an amplitude-modulation, vestigial-sideband television signal from a frequency-modulation television signal*

Data in Annex I, for this case, is summarized in Table III showing co-channel protection ratios (PR_0) for interference that is just perceptible.

More detailed information for different systems is given in Annex I, § 1.1.

3.1.4 *Interference to a frequency-modulation, television signal from an amplitude-modulation vestigial-sideband television signal*

In this case measurements have been made for 525-line M/NTSC and 625-line K/SECAM systems as the wanted signal. For system M, co-channel protection ratio values ranging from approximately 28 to 32 dB are indicated for the reference case. The adjacent channel protection ratios are given in Annex I, § 2, for 18 MHz/V deviation. These results may serve as a guide until more complete measurements are performed.

For system K/SECAM, details are given in § 5 of Annex I.

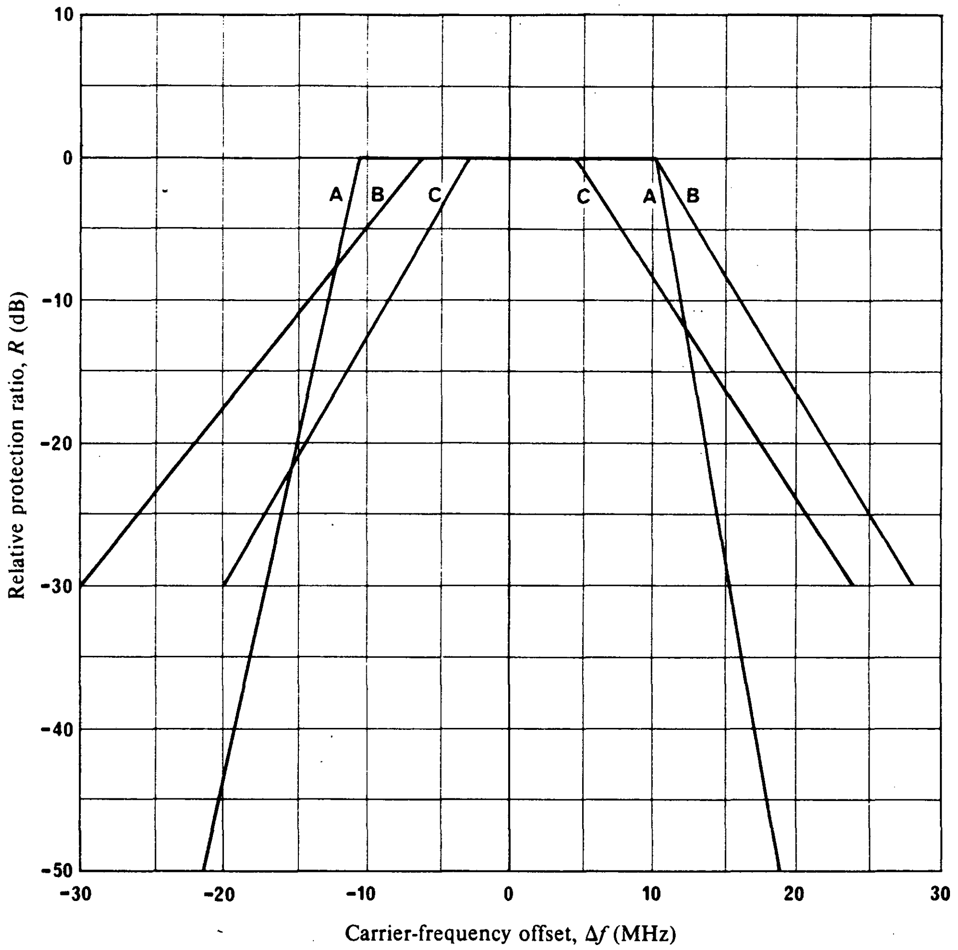

FIGURE 1a – *Reference case protection ratios relative to co-channel values*

Δf: ($f_{interfering} - f_{wanted}$)

Curves A: Television/vestigial sideband modulation-wanted, television/frequency modulation interfering, co-channel value: 50 dB

B: Television/frequency modulation-wanted, television/frequency modulation interfering, co-channel value: 30 dB (Regions 1 and 3)

C: Television/frequency modulation-wanted, television/vestigial sideband modulation interfering, co-channel value: 30 dB

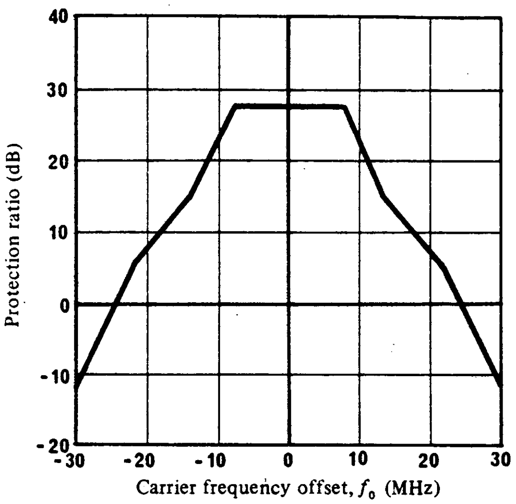

FIGURE 1b – *Protection ratio template (FM-TV) Region 2*

Protection ratio (peak-to-peak frequency deviation: D_v = 12 MHz):

28.0 dB for $|f_0| \leqslant 8.36$ MHz

$-2.762\ |f_0| + 51.09$ dB for $8.36 < |f_0| \leqslant 12.87$ MHz

$-1.154\ |f_0| + 30.4$ dB for $12.87 < |f_0| \leqslant 21.25$ MHz

$-2.00\ |f_0| + 48.38$ dB for $|f_0| > 21.25$ MHz

TABLE II

Wanted signal	Unwanted signal	Protection ratio		Region
		Co-channel (dB)	Adjacent channel	
Amplitude-modulation vestigial sideband	Frequency modulation	50	Fig. 1a, curve A	1, 2, 3
Frequency modulation	Amplitude-modulation vestigial sideband	30	Fig. 1a, curve C	1, 2, 3
Frequency modulation	Frequency modulation	30	Fig. 1a, curve B	1, 3
Frequency modulation	Frequency modulation	28	Fig. 1b	2

TABLE III

Wanted signal	Unwanted signal deviation, D_v(¹) (MHz)	PR_0 (dB)
625-line systems I/PAL, G/PAL	12	54
625-line system K/SECAM	22	46
525-line system M/NTSC and 625-line system L/SECAM	12	50

(¹) D_v: Nominal peak-to-peak frequency deviation.

3.1.5 *Interference between two frequency-modulation television signals*

When the modulation parameters of the wanted and unwanted signals are the same and there is no carrier frequency offset, the value PR_0 of the protection ratio measured under the reference conditions described in Recommendation 600 may be represented by the following formulae:

– for all systems except 525-line M/NTSC

$$PR_0 = C - 20 \log (D_v/12) - Q + 1.1\, Q^2 \qquad (1a)$$

where:

D_v: nominal peak-to-peak frequency deviation (MHz);

Q: the impairment grade, concerning the effect of interference only, measured on the 5-point scale recommended in Recommendation 500 [CCIR, 1970-74a];

C: a constant depending on the television system which is:

12.5, for 625-line systems I/PAL, G/PAL, L/SECAM;

18.5, for 625-line system K/SECAM.

For high Q values, e.g. 4 to 4.5, the measured co-channel protection ratios reported in § 3 of Annex I were found to fit equation (1a) within 1 dB after adjustments were made for deviations from the "reference case". Protection ratio data from Report 449 also was within 1 dB of equation (1a). The limited data available for low Q values (see Annex I, § 3.1) differed from equation (1a) by approximately 4 dB. Equation (1a) is useful for system design where high Q values are generally required. Refinement of equation (1a) for low Q values requires further studies.

– for 525-line system M/NTSC

$$PR_0 = 16.9 - 8.7 \log I_u - 20 \log (D_v/12) \qquad (1b)$$

where:

$$I_u = \frac{5 - Q}{Q - 1} \qquad \text{for } 1 < Q < 5 \qquad \text{(see Report 405)}$$

Equation (1b) is based on data obtained from measurements carried out in Canada and the United States of America using 525-line system M/NTSC [Bouchard *et al.*, 1984; CCIR, 1982-86c]. This equation was found to provide a reasonably good fit to these data over the full range of Q.

Detailed information on interference between two frequency-modulation television signals is given in Annex I, § 3, and in [CCIR, 1974-78a].

3.1.6 *Interference to a frequency-modulated television signal by multiple frequency-modulated television signals*

Measurements have recently been carried out in Canada and the United States of America, using 525-line system M/NTSC in order to examine the method by which multiple co-channel interferers combine. The results of subjective tests show that the combination is nearly power addition.

Additional measurements in the United States of America have shown that multiple adjacent-channel interfering signals combine to produce an effect which is 2-6 dB more severe than power addition.

The combined effect of co-channel and adjacent-channel interferers is a power addition of the individual interference effects over the entire C/I range. At high C/I, the subjective effects are dominated by the co-channel interference, while at low C/I, the adjacent channel is dominant.

Detailed information on interference to an FM television signal by multiple FM television signals is given in Annex I, § 3.1.6.4, 3.1.7.2, 3.1.7.4, 3.1.7.5 and in [CCIR, 1982-86a and b].

3.1.7 *Interference between FM television signals using digital modulation and time division multiplex for the sound and data (625-line systems)*

Subjective measurements (for the image) and objective measurements (for the sound) have been carried out by the EBU [CCIR, 1982-86d] with a view to demonstrating compatibility with the provisions of the WARC-BS-77 of the C-MAC/packet system (see Reports 1073 and 632).

The results are set out in Table IV for the image, in terms of the relative impairment due to the addition of the interfering signal evaluated on the 5-grade impairment scale, and for the sound in Table V, in terms of the bit error ratio.

TABLE IV – *Subjective grades for the image on the 5-grade impairment scale in the presence of interference*

(Mean and standard deviation (SD))

(Co-channel interference at −31 dB and adjacent-channel interference at −15 dB)

Relative impairment of vision quality		Co-channel	Upper adjacent channel	Lower adjacent channel	No interference
C-MAC/packet signal interfering with a C-MAC/packet signal					
High C/N (25 dB)	Mean	4.8	4.9	4.6	4.9
	SD	0.40	0.35	0.60	0.31
Low C/N (10 dB)	Mean	4.8	4.7	4.7	4.8
	SD	0.49	0.46	0.52	0.39
C-MAC/packet signal interfering with a WARC-BS-77 reference signal					
High C/N (25 dB)	Mean	4.9	4.9	4.9	4.9
	SD	0.35	0.23	0.31	0.31
Low C/N (10 dB)	Mean	4.2	4.5	3.9	4.7
	SD	0.71	0.66	0.78	0.52

TABLE V – *Bit error ratio measured in a digital sound channel at low C/N ratio (7 dB)*

Wanted	Interfering	Co-channel −31 dB	Adjacent channel		No interference (¹)
			Upper −15 dB	Lower −15 dB	
C-MAC	C-MAC	2.7×10^{-3}	2.6×10^{-3}	2.6×10^{-3}	2.3×10^{-3}

(¹) Without use of satellite simulation in the wanted channel.

If reference is made to the fact that the worst levels of interference allowed by the WARC-BS-77 in the same channel (−31 dB) and in the adjacent channels (−15 dB) correspond to an impairment grade of 4.5 (with high carrier-to-noise ratio), it may be concluded from these results that the C-MAC/packet system is compatible with the down-link Plan for Regions 1 and 3.

Measurements were carried out in France [CCIR, 1982-86e] to study the compatibility of the D2-MAC/packet system (see Reports 1073 and 632) with the Final Acts of the WARC-BS-77. The measurements were made on the D2-MAC/packet system and a system corresponding to the reference used for the WARC-BS-77 format (PAL/SECAM system with an FM sound sub-carrier).

The results are given in Table VI for the picture in terms of the *C/I* ratio corresponding to the interference visibility threshold.

TABLE VI – *Protection ratios between D2-MAC/packet and PAL/SECAM (WARC-BS-77)*

Wanted signal	Unwanted signal	*C/I* corresponding to the visibility threshold		
		Co-channel (dB)	Lower adjacent channel (dB)	Upper adjacent channel (dB)
D2-MAC/ packet	D2-MAC/ packet	20	11	12
PAL/SECAM (WARC-BS-77)	D2-MAC/ packet	27	12	13

The results apply to the most critical cases for both the wanted and the interfering signals.

In relation to the digital component of the D2-MAC/packet signal, the equivalent impairment expressed in terms of the *C/N* ratio always remains below 0.5 dB for a bit error ratio of 10^{-3} with adjacent channel and co-channel *C/I* ratios of 15 and 31 dB respectively.

These measurements demonstrate that the D2-MAC/packet system satisfies the requirements for protection ratios adopted at the WARC-BS-77.

Measurements were carried out in the UK [Priestman and O'Neill, 1987] to study the compatibility of the D-MAC/packet system using frequency modulation (see Report 1073) with the Final Acts of the WARC-BS-77.

The wanted signal was either of the PAL system (i.e. reference system as defined by WARC-BS-77) or of the D-MAC/packet system using frequency modulation.

In these tests the interfering signal was transmitted through satellite channel simulation equipment consisting of a high power klystron transmitter and a simulated satellite transponder, using a low power travelling wave tube.

The results of these measurements are given in Table VII for the subjectively evaluated protection ratios for the wanted vision channel signal, and apply to the most critical picture combinations.

It can be seen that in all cases there is a positive margin with respect to the protection ratios adopted by WARC-BS-77 (i.e., 31 dB for co-channel interference and 15 dB for adjacent channel interference).

In relation to the digital component of the D-MAC/packet signal, the equivalent impairment expressed in terms of the C/N ratio always remains below 0.5 dB for a bit error ratio of 10^{-3} with adjacent and co-channel C/I ratios of 15 and 31 dB respectively.

These measurements demonstrate that the D-MAC/packet system satisfies the protection ratio requirements adopted at the WARC-BS 77.

TABLE VII - Protection Ratios for the D-MAC/packet System Using Frequency Modulation

Wanted Signal (1)	Interfering Signal (1)	Protection ratio required for just perceptible interference on the wanted channel picture (dB) Co-channel	Lower Adjacent Channel	Upper Adjacent Channel
D-MAC/packet	D-MAC/packet continuous data	17	3	1
D-MAC/packet	C-MAC/packet	27	10	6
PAL System (WARC-BS 77) (2)	D-MAC/packet continuous data	22	7	6
PAL System	C-MAC/packet	29	11	8

(1) The wanted channel and interfering channel pictures were synchronised with a 1/2 line offset between each other.

(2) Deviation sensitivity 13.5 MHz/V.

Additional subjective evaluation tests have been carried out by the EBU concerning the perceptibility of interference when including the scrambling and descrambling processes into the BSS with the C-MAC/packet system described in Report 1073.

These tests conducted according to Recommendations 500 and 600, indicated that the protection ratios for scrambled C-MAC/packet signals can be slightly less stringent as compared to the protection ratios for non-scrambled C-MAC/packet signals*.

The average reductions of the protection ratio (PR) as a result of scrambling are set out in Table VIII.

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* It is expected that similar results would be obtained in the case of the D-MAC/packet system and the D2-MAC/packet system.

TABLE VIII

	Average reduction of protection ratio (dB)
Lower adjacent channel (– 19.18 MHz)	2.6
Higher adjacent channel (+ 19.18 MHz)	1.8
Co-channel	2.0

It can be seen from Table VIII that the inclusion of scrambling reduces both the co-channel as well as the adjacent-channel interferences. It is valid for any of the scrambling schemes and also for degraded *C/N* operation.

The above subjective tests therefore indicate that the interference protection ratios for scrambled C-MAC/packet signals also fully correspond to the WARC-BS-77 specification.

Further tests with C-MAC signals passed through a complete hardware simulation of a satellite broadcasting channel, including both representative feeder and down links, show little difference in the effect of interference in the feeder link to that experienced with the same amount of interference in the down link, with a transponder having a low value of AM/PM conversion (< 2°/dB) [Shelswell, 1984]. Higher values of AM/PM conversion should have an impact on the apparent effect of interference on the feeder link, much in the way that the effective feeder link *C/N* is reduced (see Report 952, § 3.3 and 4.5). This result should be valid for any system, nevertheless further studies are needed.

3.1.8 *Interference between FM television signals using digital modulation and time division multiplex for the sound and data (525-line systems)*

Subjective measurements to characterize the noise and interference performance of the vision portion of the B-MAC system have been conducted in Canada [Chouinard and Barry, 1984]. The interference tests involved a comparison of the susceptibility of both the MAC and NTSC encoded vision signals to either MAC or NTSC encoded interfering signals.

The NTSC vision signal deviating the FM carrier by 12 MHz (peak-to-peak), was accompanied by 3 audio sub-carriers each deviating the main carrier by 2 MHz (peak-to-peak). The pre-emphasis used was according to Recommendation 405. The MAC signal (see Report 1073 for a detailed description) was also deviating the FM carrier by 12 MHz. The data burst during the line-blanking interval was replaced by a 7 MHz synchronization burst at full amplitude. The pre-emphasis used was a slightly modified version of the one specified in Report 1073 with the zero crossing frequency at 2.335 MHz. Both wanted and interfering signals had the same modulation characteristics.

The tests were conducted with a linear RF channel and the frequency demodulation was made with a conventional limiter-discriminator receiver. The pre-detection channel filter was a 4-pole, Chebychev-type filter with an equivalent noise bandwidth of 22.7 MHz and no group-delay equalization. Tests were done in accordance with Recommendation 500 with trained viewers sitting at 5 times picture height and based on the threshold of perceptibility of picture impairments.

3.1.8.1 *Co-channel interference*

The results of the co-channel interference tests averaged over 4 test slides and 17 viewers are given in Table IX. The results indicate the *C/I* (dB) at the just perceptible level of impairment for two interfering signals: the multiburst test signal (MB) and 75% colour bar test signal (CB). The average for these two test signals is also given. The MAC signal was found to be slightly more immune to co-channel interference than the NTSC signal. In the case of the wider deviation specified in Report 1073 for the B-MAC signal, it is expected that the required protection for the B-MAC signal will be 3-4 dB less than the reference NTSC signal. In the case of the mixed interference situation, the interference was found to be no worse than the reference NTSC into NTSC case. With the wider deviation specified for the B-MAC signal, the mixed cases are expected to be less severe by 1-3 dB relative to the reference case. It can thus be concluded that the utilization of B-MAC is compatible with the co-channel interference characteristics of the RARC SAT-83 Plan.

TABLE IX – *Co-channel interference results (C/I in dB)*

		Interfering signal	
		NTSC	B-MAC
Wanted signal	NTSC	MB = 24.3 CB = 26.1 Average = 25.2	MB = 24.4 CB = 26.2 Average = 25.3
	B-MAC	MB = 24.3 CB = 25.1 Average = 24.4	MB = 23.6 CB = 25.1 Average = 24.4

MB: Multiburst video test signal

CB: 75% colour bar test signal

3.1.8.2 *Adjacent-channel interference*

The results of the subjective tests dealing with upper and lower adjacent-channel interference averaged over 4 test slides and 17 viewers are given in **Tables X and XI** respectively. The level of *C/I* (dB) at the just perceptible level of impairment are indicated for two different interfering signals: multiburst (MB) and 75% colour bar (CB) test signals. The average of the results obtained for the two interfering signals is also indicated. The results indicate that a B-MAC signal produces more interference in both upper and lower adjacent channels than NTSC. The protection of a B-MAC signal from another B-MAC signal is found to be 2-5 dB higher than the protection required for the reference NTSC into NTSC case although it is less than the value used for planning the BSS at the RARC SAT-83 (13.6 dB). It should be noted however that the adjacent-channel interference is strictly a domestic problem in the case of the North American BSS since all channels from the same orbital location have been assigned to the same administration in the Plan.

It was also found that the synchronization burst was the constraining factor in only a very few cases. Since the data burst in the B-MAC system is specified at lower amplitude, it is unlikely that the data burst will be found as the constraining factor in interference situations.

TABLE X – *Upper adjacent-channel interference results (C/I in dB)*

		Interfering signal	
		NTSC	B-MAC
Wanted signal	NTSC	MB = 4.3 CB = 4.4 Average = 4.3	MB = 7.4 CB = 7.2 Average = 7.3
	B-MAC	MB = 4.2 CB = 2.4 Average = 3.3	MB = 6.1 CB = 6.8 Average = 6.5

MB: Multiburst video text signal

CB: 75% colour bar test signal

TABLE XI – *Lower adjacent-channel interference results (C/I in dB)*

		Interfering signal	
		NTSC	B-MAC
Wanted signal	NTSC	MB = 5.5 CB = 2.9 Average = 4.2	MB = 7.2 CB = 5.1 Average = 6.2
	B-MAC	MB = 5.7 CB = 3.9 Average = 4.8	MB = 9.1 CB = 9.2 Average = 9.2

MB: Multiburst video test signal

CB: 75% colour bar test signal

3.1.9 *Interference between FM television signals using digital sub-carrier for the sound and data (525-line systems)*

Subjective evaluation tests have been carried out in Japan [CCIR, 1982-86f] using the 525-line system M/NTSC with a peak-to-peak frequency deviation of 17 MHz due to picture signals which are accompanied by a digitally-modulated sound sub-carrier. The viewing distance was four times the picture height. Colour bars were used for the wanted as well as for the interfering signal.

Of the modulation parameters, the bit rate, the peak-to-peak main carrier deviation due to the digitally modulated sub-carrier, and the sub-carrier frequency are respectively 2.048 Mbit/s, 6.5 MHz and 5.727272 MHz. The results show the following:

- mean values for just perceptible interference levels for picture impairment are 29.8 dB and 9.4 dB in the case of co- and adjacent-channel interferences respectively (19.18 MHz channel spacing);
- with respect to sound impairment, there is no degradation in the sound quality even when the degradation in the picture quality is just perceptible.

In consequence it was demodulated by these tests that the above-mentioned modulation system as specified satisfies the requirements for protection ratios adopted at the WARC-BS-77.

3.1.10 *Interference between two dissimilar frequency-modulation television signals*

Tests have been carried out by the BBC and TDF for interference between 625-line PAL and SECAM systems and in Japan for interference between 525-line system M/NTSC and different 625-line systems. As a general result it can be concluded that the measured television protection ratio for two dissimilar systems is not significantly different from the protection ratio measured for the more demanding system interfering with itself.

3.1.11 *Interference to a frequency-modulation television signal from digital signals (television and data)*

Measurements of protection ratios for system M/NTSC were made with a 43 Mbit/s, digital television, 4-PSK interferer. Results indicate that a frequency modulated television system with an apparent signal-to-noise ratio (signal-to-interference ratio) ranging from 45 to 35 dB requires co-channel protection ratios of 24 to 14 dB, respectively.

Details of the measurements are given in Annex I, § 4.1.3.

The protection ratio template used for evaluating FM-TV to FM-TV interference (Fig. 1b) is not directly applicable to digital TV interference with FM-TV. However, under the condition that the digital bit rate to bandwidth ratio (R_{bt}/B) is of the order of 1.7 or less (utilizing staggered 4-PSK modulation), the interference for a given frequency offset is comparable to the corresponding values for FM-TV to FM-TV interference. Limiting R_{bt}/B to less than approximately 1.7 will minimize the effects of spectral spreading on the second adjacent channel.

Hence, a 40 Mbit/s digital 4-PSK signal (with 4 dB of TWTA input back-off) could be transmitted in a 24 MHz channel with only nominal degradation to the second adjacent channel, even if it is co-polar. Further details are given in [CPM SAT-R2, 1982]. FM-TV to digital-TV interference is not a controlling factor in system planning.

Measurements of protection ratios for system D/PAL were made with interference from a single-frequency signal (CW), a PSK signal or an ASK signal with rates of 2.048 Mbit/s and 8.448 Mbit/s respectively. Details of measurements are given in Annex I, § 4.1.3.

Some experiments on C/I requirements for 4-PSK to FM-TV and *vice versa* were carried out [CCIR, 1982-86g] using 4-PSK with a bit rate of 24.6 Mbit/s and FM-TV, 525-line NTSC with digital audio sub-carriers (see Report 1073). The just perceptible interference ratios are shown in Tables XIIa and XIIb.

3.1.12 *Interference to digitally encoded television signals*

For digitally encoded, system M/NTSC television, measurements were made of protection ratios against analogue FM television interference. The results are given in Table XIII, where E_b/N_0 = ratio of energy per bit to noise power spectral density.

TABLE XIIa – *Just perceptible C/I of FM-TV to 4-PSK*

	Just perceptible C/I for picture (¹)		C/I at which influence on BER becomes negligible, for sound (²)
	Colour bar	Woman	
Co-channel (dB)	29.1	25.0	24.0-28.0
Upper adjacent channel (dB)	11.1	7.2	10.0-14.0

(¹) Under the condition of C/N = 26 dB, viewing distance = 4 H, 20 in. colour monitor and 10 experts.

(²) Under the condition of C/N = 8 to 12 dB.

TABLE XIIb – *Just perceptible C/I of 4-PSK to FM-TV*

	C/I at which influence on BER becomes negligible (¹)
Co-channel (dB)	28.0
Upper and lower adjacent channel (dB)	8.0

(¹) Under the condition of C/N = 7 to 11 dB.

TABLE XIII – *Peak protection ratios for frequency-modulation television interference to a digital television signal*

E_b/N_0 (dB)	Protection ratio at 10^{-8} BER (dB)	E_b/N_0 (dB)	Protection ratio at 10^{-6} BER (dB)
15.1	24.2	13.6	22
18.1	14.5	16.6	13

For the same digitally encoded M/NTSC television system, measurements were made of protection ratios against interference from other digitally encoded systems (including both digital television and pseudo-random data) [CCIR, 1982-86h]. For an energy contrast ratio (E_b/N_0) of 14.7 dB, the co-channel protection ratio at 2×10^{-8} BER was approximately 22 dB for interference of equal data rate from both digital television and pseudo-random digital data. These measurements also showed that the relative bandwidth (i.e. data rates) between the wanted and interfering signals has a significant effect on the co-channel and adjacent-channel allowable carrier-to-interference ratio. Interfering signals with a bandwidth less than the desired signal require greater co-channel protection than the interfering signals which have a wider bandwidth than the desired signal. In addition, the fall-off in protection ratio versus frequency offset is more rapid when the interfering data rate is less than the wanted data rate (i.e. small in relative bandwidth).

Details of the measurements are given in § 4.2 of Annex I.

3.1.13 Interference between digital television systems

When digital modulation is used to carry sound or vision signals in digitally-coded form, the perceived quality is dependent on the bit-error ratio (BER). Bit errors will be caused by the combined effects of noise and interference. Unlike the situation with analogue transmission, there is some scope for trade-off between the two. **Noise and interference** are **apportioned in** order to obtain a reasonable link budget and a reasonable protection ratio, **leading to efficient use of the spectrum.**

The trade-off between C/N and C/I for PSK-type digital modulation has been explored in [Newland, 1988]. The effect of a single or dominant co-channel interferer is shown to be similar to that of a sinusoid, and is thus less severe than that of the equivalent amount of added Gaussian noise. As the number of interferers increase then the effect of the interference closely approaches that of the equivalent amount of added noise, as confirmed in [Priestman and O'Neill, 1987]. The results can be extended to take account of adjacent-channel interference if appropriate account is taken of the channel filtering.

As an example of possible trade-off between C/N and C/I (co-channel protection ratio), Table XIV gives typical values with the following conditions.

- digital modulation is a 2 bit /Hz system
- equivalent noise bandwidth: bit rate/2
- required BER = 10^{-5}
- margin (including channel impairment effect) = 1.5 dB
- contribution of adjacent channel interference = 1 dB

Under these conditions the overall $C/(N+I)$ is 15 dB.

TABLE XIV

C/N (dB)	C/I (dB)
16	22
17	19.5
18	18
20	16.5
22	16

Further study of the use of convolutional coding [CCIR, 1986-90a] has demonstrated by experiment that the use of Viterbi decoding can result in an even greater tolerance of mutual interference. For example, with a code having rate 1/2 and constraint length 6, the degradation caused by a single interferer of C/I = 10 dB is equivalent to a loss of only 1 dB in C/N, even for a BER of 10^{-2}. The distinction between single/dominant and multiple interferers remains; multiple interferers should be treated as additive noise.

3.1.14 Protection ratio for HDTV and conventional television systems using modulation in the planned 12 GHz band

Tests were made in the framework of the EUREKA-95 project.

The results of this test have been obtained with the first experimental HDTV chain in 1989 using the French TDF-1 satellite as well as a satellite simulator [CCIR, 1986-90b].

Measurements of first adjacent channel (±19.18 MHz) and co-channel interference levels giving just perceptible impairment on vision have been done in the two following configurations:

- HDMAC interfering with HD-MAC;
- HDMAC interfering with the reference WARC-77 system (SECAM with a sound subcarrier).

An approach known as the method of limits was used during these channel interference studies. This method involves reducing the level of interference progressively downwards, from an obviously perceptible level, past the point where it becomes invisible, and then increasing the level past the point where it re-appears. Subjects are asked, at various stages, to record whether the impairment is visible or not. Seven levels are chosen around the estimated threshold. The visibility threshold is the mean between the last visible level (decreasing threshold) and the first one (increasing threshold).

From these tests, the following preliminary conclusions can be drawn:

- When the wanted signal is the WARC reference signal, then the minimum protection ratios required by the WARC-BS 77 Plan are met with a margin greater than 9 dB. The HD-MAC signal is not more critical than a conventional MAC signal.

- Two HD-MAC signals can co-exist in the WARC-BS 77 broadcasting Plan.

An HD-MAC receiver, using a WARC reference filter (4th order Butterworth with a 3 dB bandwidth of 27 MHz), would not perform adequately with regard to the rejection of incoming interference from other "conventional" WARC signals. However, a SAW filter was incorporated in the receiver to obtain the adjacent-channel protection ratios shown in Table XV, without compromising other aspects of receiver performance.

Tests were made in Japan in 1989 [CCIR, 1986-90c].

Protection ratio measurements were made between two MUSE signals and between MUSE and a 525-line M/NTSC signals.

The results of these tests indicate that the co- and adjacent-channel protection ratios for interference between MUSE and M/NTSC, and between two MUSE signals met the technical criteria for the planning of the BSS in the 12 GHz band, with sufficient margins.

The results of both the MUSE and HD-MAC measurements are given in Table XV.

Note that some of the parameters used in both the MUSE and HD-MAC tests are interim values from Recommendation 710 which can be used until values recommended in the table itself become technically feasible.

Moreover, neither test included "bench-mark" comparisons with conventional television, as discussed below in sections 3.1.5 and 3.1.6 of this Report. Therefore, the results of the new tests should be considered as preliminary.

TABLE XV - Results of measurements of protection ratios for just-perceptible interference involving certain HDTV and conventional television systems

Wanted signal (test slides)	Unwanted signal	Channel protection ratios (dB)			Note
		Lower adjacent*	Co-channel	Upper adjacent*	
NTSC SMPTE #1 SMPTE #14	MUSE	10 12	18 19	11 12	1)
MUSE "Fruits" "Congress hall"	NTSC	8 7	18 20	8 11	1)
MUSE "Fruits" "Congress hall"	MUSE	9 8	24 24	8 9	1)
HDMAC	HDMAC	6	22	7	2) 3)
SECAM	HDMAC	11	25	11	2) 4)

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* Adjacent-channel frequency spacing: ±19.18 MHz.

Notes to Table XV:

1) The significant viewing conditions were as follows:

	MUSE	M/NTSC digital subcarrier system
Test pictures Wanted signal	test slides * Fruits Congress-Hall	Test slides SMPTE #1 SMPTE #14
Unwanted signal	Colour bar	Colour bar
Ratio of viewing distance to picture height	3	6
Picture monitor	30" RGB monitor	20" NTSC monitor
Peak luminance on the screen (cd/m^2)	70	70
Ratio of the luminance of the screen when displaying only black level in a completely dark room to that corresponding to peak white	Approximately 0.01	Approximately 0.01
Room illumination	low	low
Grading scales	Five-grade impairment scale	Five-grade impairment scale
Observers	12 Non-experts	12 Non-experts

* Compositions of these slides are similar to those of SMPTE test slides #1 and #14.

2) The significant viewing conditions were as following :

- Viewing distance : 3 H
- Peak luminance : 80 Cd/m^2
- Contrast ratio : 30:1
- Monitor : 1250/50/2
- Display tube : Shadow mask, 77 cm diag.

Six expert observers were used for all the tests.

The electronic picture transmitted on the unwanted channel has been specially built to be theoretically as critical as possible (electronic grid pattern for HDMAC interfering with HDMAC).

3) For the co-channel measurement, the slide "BOATS" was used as the wanted signal while for the adjacent-channel measurements, the slide "CIRCUS" was used as the wanted signal.

4) For these measurements the slide "BOATS" was used as the wanted signals.

3.2 *Interference from other types of signal*

3.2.1 *Interference to frequency-modulation television signals*

Measurements have been carried out by the TDF for interference to a frequency-modulated television signal from a frequency-modulated sound multiplex signal and a PSK-telephony signal. The results concerning only the co-channel protection ratio, PR_0, are the following:

Wanted signal	FM-TV		
Interfering signal	FM-sound multiplex	4-PSK telephony	
		32 Mbit/s	52 Mbit/s
Co-channel protection ratio (PR_0) (dB)	27	19	19

More information on the characteristics of the signals is given in § 4.1.1 of Annex I and in [CCIR, 1974-78b].

3.2.2 *Interference to AM-VSB signals*

Measurements of multiple audio channels interfering into AM-VSB television, system M/NTSC, were made by the USA. From these tests, where the interfering signals were limited to the frequency band 1 to 3 MHz above the vision carrier, it was concluded that a protection ratio near 50 dB is indicated.

More detailed information is given in Annex I, § 1.2.

3.3 *Deviations from the reference case*

Based on the information given in Annex I, the effects of several deviations from the reference case (see Recommendation 600) can be quantified and qualified as described below.

3.3.1 *Viewer expertise*

The relationship between expert and non-expert viewers has been examined for the 525-line system M/NTSC amplitude-modulation vestigial-sideband protection ratio against barely perceptible frequency-modulation interference. The expert viewers were found to require 2 to 4 dB greater protection ratio (see Annex I, § 1.1). For other wanted and unwanted signals, the relationship may be different and should be determined by experiments.

3.3.2 *Deviation of the main carrier by the sound sub-carrier*

Tests carried out by the BBC for interference between two frequency-modulation television signals, system I/PAL, indicate that a slight reduction of adjacent-channel protection ratio can be achieved by reducing the deviation on the main carrier caused by the sound sub-carrier (from a value of ± 2.8 MHz). Tests carried out in Japan for interference between two frequency-modulation television signals, system M/NTSC, showed that the presence of 1 or 2 sound sub-carriers has a negligible effect on the protection ratio.

3.3.3 *Scanning synchronization*

If the line-scanning frequencies of the wanted and the unwanted transmissions are not frequency-locked, the protection ratio is likely to be slightly higher than the reference condition.

3.3.4 *Picture type*

Measurements in the United States of America [CCIR, 1982-86b] indicate that a decrease of 5 to 6 dB in the measured co-channel protection ratio might result from using typical programme material in place of reasonably critical still scenes.

3.3.5 *Modulation index*

Increasing the modulation index reduces the co-channel protection ratio for two frequency modulation signals as given by equations (1a) and (1b). To compare co-channel protection ratios measured at peak deviations different from the reference case with those measured at the reference case (12 MHz/V) the measured values should be modified by an additive correction constant of 20 log $D_v/12$, where D_v is the peak-to-peak frequency deviation in MHz.

This correction applies approximately to VSB-AM signals affecting FM signals, but a smaller correction applies when FM signals affect VSB-AM signals (see examples in Table XVII of Annex I). It does not apply when appreciable frequency offsets exist.

3.3.6 *Pre-emphasis*

In the case of interference to an amplitude-modulation, vestigial-sideband system from a frequency-modulation system, the co-channel protection ratio decreases by 1.0 dB if pre-emphasis is not used on the interfering signal. To compare with measurements made at the reference conditions, the measured protection ratios, in this case, should be modified by an additive constant of 1.0 dB. In the case of interference between two frequency-modulation systems, pre-emphasis has negligible effect on the co-channel protection ratio whereas for the adjacent channel a somewhat higher carrier offset is required to reach the same protection ratio when no pre-emphasis is used.

3.3.7 *Energy dispersal*

In the case of interference to an amplitude-modulation vestigial-sideband system from a frequency-modulation system the use of energy dispersal reduces the co-channel protection ratio by 1.5 dB per MHz of peak-to-peak deviation caused by energy dispersion. To compare measurements made with energy dispersion to measurements made at the reference conditions, the measured co-channel protection ratio, in this case, should be modified by a constant of 1.5 dB/MHz.

3.3.8 *Small carrier frequency offset*

Generally the protection ratio is constant near zero frequency offset. In some cases variations are introduced by the susceptibility to interference of some components of the signal, such as the colour sub-carrier.

3.3.9 *Effects of noise*

Some administrations feel that system planning could take account of the masking of interference by random noise. In this case, a lower value, PR_1 of protection ratio could be adopted. If the peak-to-peak luminance signal-to-r.m.s. weighted-noise ratio is S/N, results obtained for 525-line system M suggest that:

$$\left.\begin{array}{ll} PR_1 = PR_0 - (49 - S/N) & \text{for } S/N < 49 \text{ dB} \\ PR_1 = PR_0 & \text{for } S/N \geq 49 \text{ dB} \end{array}\right| \qquad (2)$$

where PR_0 is the protection ratio under the reference conditions (see Recommendation 600). Other administrations have obtained results where the presence of noise tends to raise the required protection ratio. Data for the effects of noise are given in § 1.1.1.3, 1.1.1.4, 1.3, 3.1 and 3.3 of Annex I.

Measurements in the United States of America [CCIR, 1982-86b] show the effect of both interference and noise on the co-channel protection ratio. The combined effect of interference and the system signal-to-noise ratio determine the protection ratio for a specified grade of service. Details of the measurements are given in Annex I, § 3.1.7.

Tests were performed in Canada on the impairment due to noise and interference to determine the validity of the law of addition of impairment units. The results show that the law of addition gives slightly lower calculated values of opinion score than the observed values, to a maximum difference of 0.3. Details are given in Report 405.

3.3.10 *Viewing condition*

Most protection ratio measurements have been carried out using a ratio of viewing distance to picture height of 4 to 6, in accordance with Recommendation 500. Measurements carried out in Japan [CCIR, 1978-82a], where a viewing ratio of 1 to 1.5 was used, resulted in a protection ratio of 38 dB for just perceptible interference between two frequency-modulation TV-signals, system M/NTSC.

More detailed information on these tests is contained in § 3.1, § 4.1.2 and 4.1.3 of Annex I.

4. Interference to a sound multiplex from other signals

Co-channel protection ratios have been measured by the TDF for the interference to a frequency-modulated sound multiplex signal from a frequency-modulated television signal, a PSK-telephony signal and a frequency-modulated sound multiplex signal. The results obtained are the following:

Wanted signal	FM-sound multiplex			
Interfering signal	FM-TV	4-PSK telephony		FM-sound multiplex
		32 Mbit/s	52 Mbit/s	
Co-channnel protection ratio (PR_0) (dB)	19	18	18	25

Adjacent-channel protection ratio tests have now to be completed. More information on these measurements is shown in § 4 of Annex I.

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[1974-78]: **a.** 11/25 (EBU); **b.** 11/101 + 11/114 (France).

[1978-82]: **a.** 10-11S/19 (Japan).

[1982-86]: **a.** 10/11S/190 (Canada); **b.** 10-11S/49 + Corr.1 (USA); **c.** 10-11S/55 + Add.1 (Canada); **d.** 10/11S/40 (EBU); **e.** 10/11S/173 (France); **f.** 10-11S/5 (Japan); **g.** 10-11S/136 (Japan); **h.** 10-11S/161 + Corr.1 (USA).

[1986-90]: a. 10-11S/12 (United Kingdom); b. 10-11S/115 + 138 (Germany (Federal Republic of), Finland, France, Netherlands, United Kingdom, Sweden); c. 10-11S/106 (Japan).

ANNEX I

RESULTS OF PROTECTION RATIO TESTS

This Annex summarizes protection ratio data obtained by several administrations for television involving both frequency modulation and amplitude modulation by video signals in formats M/NTSC, B/PAL, G/PAL, D/PAL, I/PAL, K/SECAM and L/SECAM. It also provides data on a sound multiplex system and digital telephony systems used in protection ratio measurements. Table XVI may be used as a guide to the contents of Annex I.

1. Interference to an amplitude-modulation, vestigial-sideband television signal

1.1 *Interference to an amplitude modulation, vestigial sideband television signal from a frequency modulation television signal*

1.1.1 *525-line system M/NTSC*

The following data are based on the preliminary results of tests conducted in the USA and in Japan [Kaneda, 1972]. System M was used for both the frequency-modulation and the amplitude-modulation, vestigial-sideband colour television signals.

1.1.1.1 *Co-channel protection ratio*

In the subjective assessment of the co-channel protection ratio of AM-VSB television signal against interference from the FM-television signal, the salient conditions used for the measurements made in Japan are the following:

- Signal-to-unweighted noise ratio of video signal used is not less than 42 dB.
- Picture slides of SMPTE Nos. 1, 9, 14 and colour bar signal are used.
- Number of observers is 24 including 12 experts.
- Viewing distance is six times the picture height.

1.1.1.2 *Protection ratio as a function of carrier-frequency offset*

Tests performed by the USA and reported in § 1.1.1.2, 1.1.1.3, 1.1.1.4 used the following test conditions. The protection ratios measured were for just perceptible visual interference. Audio-frequency interference was not evaluated. The picture tube diagonal was 38 cm (15 in.). Viewing distances ranged from 135 to 165 cm (4½ to 5½ feet). The centre of the viewed picture was at the viewer's eye level, and the maximum side-viewing angle was 30°. Light measured during peak white luminance was approximately 20 foot-candles (200 lux). The light from the area surrounding the picture tube measured approximately 0.1 foot-candles (1 lux). The wanted amplitude-modulation, vestigial-sideband signal carried "off-the-air" programme material. The interfering frequency-modulation signal carried various stationary test signals and used a peak-to-peak frequency deviation of 18 MHz. The modulating signal polarity was such that the deviation produced by synchronizing pulses was towards lower frequencies. No pre-emphasis was used with the frequency-modulation signal.

The amplitude-modulation, vestigial-sideband protection ratio against frequency-modulation interference is shown as a function of the carrier-frequency offset in Fig. 2 from [Miller and Myhre, 1970]. The amplitude-modulation, vestigial-sideband signal-to-random noise ratio for these tests was 49 dB (weighted). The judgments of just perceptible interference were made by a single expert viewer.

The curves of Fig. 2 show that interference from still scenes is more easily perceived than interference from scenes with motion. The shaded area in Fig. 3 encompasses the data from the individual test curves and indicates the upper and lower limits of the amplitude-modulation, vestigial-sideband protection ratio. To guarantee no perceptible interference from both still and moving scenes, a protection ratio exceeding the upper boundary of the shaded area in Fig. 3 should be used.

TABLE XVI – *Index to the protection ratio measurements given in this Annex*

Section	System	Wanted	Interferer	Test/Interference condition	Administration
1.1.1.1	M/NTSC	AM-VSB	FM-TV	Co-channel/ Just perceptible	Japan
1.1.1.2	M/NTSC	AM-VSB	FM-TV	Frequency offset/ Just perceptible	USA
1.1.1.3	M/NTSC	AM-VSB	FM-TV	Function of AM-VSB S/N	USA
1.1.1.4	M/NTSC	AM-VSB	FM-TV	Just perceptible (Expert/non-expert)	USA
1.2	M/NTSC, K/SECAM, G/PAL	AM-VSB	Multiple sound	Co-channel/ Just perceptible	USA, USSR
1.3	I/PAL	AM-VSB	FM-TV	C/I impairment/ co-channel	BBC
1.4	G/PAL	AM-VSB	FM-TV	Co-channel/ Just perceptible	IRT
1.5	L/SECAM	AM-VSB	FM-TV	Co-channel/ Just perceptible	TDF
1.6	K/SECAM, B/PAL, M/NTSC	AM-VSB	FM-TV	PR_0 calculation for AM-VSB	USSR
1.7	G/PAL, L/SECAM	AM-VSB	FM-TV	Frequency offset/ Just perceptible	(European)
2.1	M/NTSC	FM-TV	AM-VSB	Frequency offset, co-channel/ Just perceptible	USA
2.2	K/SECAM	FM-TV	AM-VSB	(Details in § 5)	USSR
3.1.1	M/NTSC	FM-TV	FM-TV	Frequency offset/ Just perceptible	USA
3.1.2	M/NTSC	FM-TV	FM-TV	Frequency offset/ Just perceptible	Canada
3.1.3	Mixed M/NTSC, PAL, SECAM	FM-TV	FM-TV	Co-channel/ Just perceptible	Japan
3.1.4	M/NTSC	FM-TV	FM-TV	Co-channel/ Just perceptible (1.5 picture height)	Japan
3.1.5	M/NTSC	FM-TV	FM-TV	C/I impairment/ co-channel	USA
3.1.6	M/NTSC	FM-TV	FM-TV	Co-channel interference, adjacent channel interference, noise, multiple interference, noise and interference	Canada
3.1.7	M/NTSC	FM-TV	FM-TV	Co-channel interference, adjacent channel interference, noise, multiple interference noise and interference	USA

TABLE XVI *(continued)*

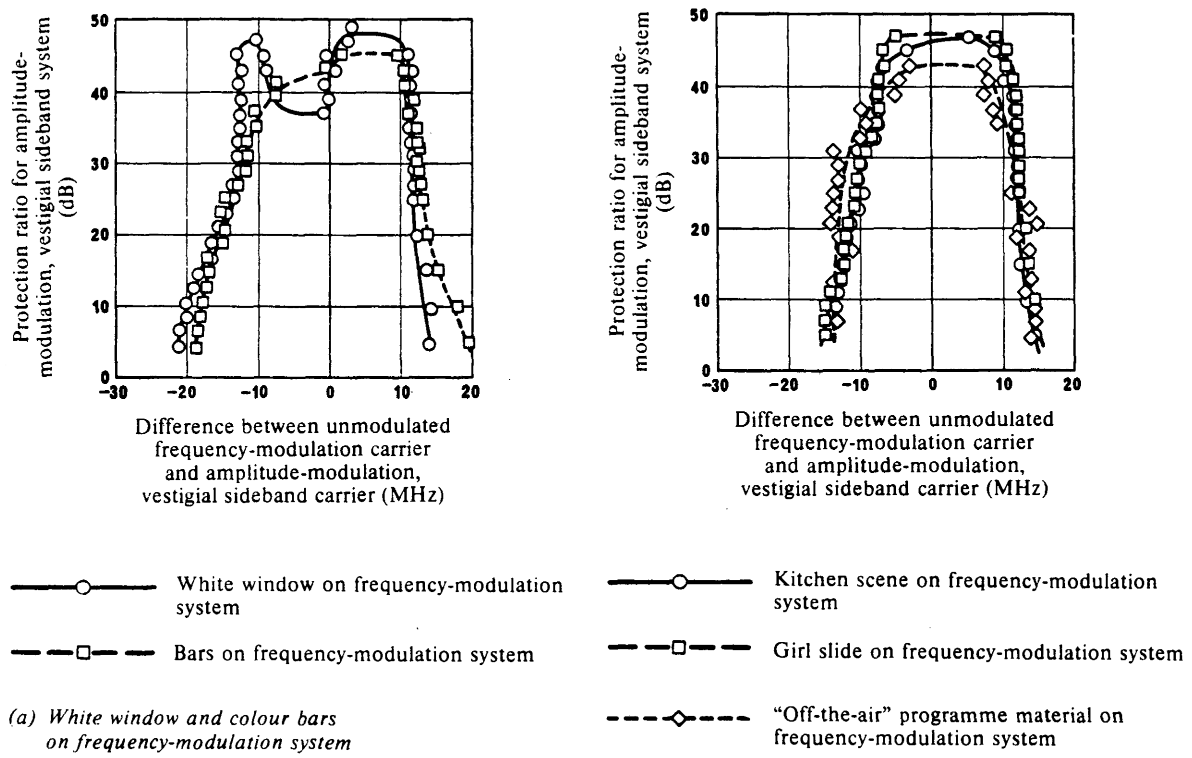
Section	System	Wanted	Interferer	Test/Interference condition	Administration
3.2	B/PAL, G/PAL, I/PAL, L/SECAM	FM-TV	FM-TV	Frequency offsets (WARC-BS-77 template)	(European)
3.3		Wide deviation FM sound	Same	Co-channel/ Just perceptible	BBC
4.1.1	PAL	FM-TV	FM sound multiplex		TDF
4.1.2	M/NTSC	FM-TV	FDM-FM multiplex		Japan
4.1.3	M/NTSC, D/PAL	FM-TV	Digital TV, data	Frequency offset/ Just perceptible	USA, China (People's Republic of)
4.2.1	M/NTSC	Digital TV	FM-TV	Frequency offset/ Just perceptible	USA
4.2.2	M/NTSC	Digital TV	Digital TV, data	Frequency offset/ Just perceptible	USA
4.2.3	M/NTSC	Digital data	Digital TV	Frequency offset/ Just perceptible	USA
5.	K/SECAM	FM-TV	CW	Frequency offset/ Just perceptible	USSR
	K/SECAM	FM-TV	AM-VSB	Frequency offset/ Just perceptible	USSR
	K/SECAM	FM-TV	FM-TV	Frequency offset/ Just perceptible	USSR
	K/SECAM	FM-TV	FM-TV	S/N versus protection ratio, co-channel/ Just perceptible	USSR
6.	TTC interference considerations (protection of TV signals)				
7.	Discussion of results				

Table XVII shows the summary of co-channel protection ratios for just perceptible interference. It appears to be in fairly good agreement with the data described in § 1.1.1.2.

TABLE XVII – *Summary of co-channel protection ratios*

Wanted signal: amplitude-modulation vestigial sideband television Unwanted signal: frequency-modulation television			Wanted signal: frequency-modulation television Unwanted signal: amplitude-modulation vestigial sideband television		
D_v (1) (MHz)	For just perceptible interference level (dB)	For impairment grade 3.5 (dB)	D_v (1) (MHz)	For just perceptible interference level (dB)	For impairment grade 3.5 (dB)
8	52	46	8	36	28
16	49	42	16	30	24
24	48	43	20	28	22

(1) D_v is the peak-to-peak frequency deviation of the frequency-modulation television signal.



(a) White window and colour bars on frequency-modulation system

(b) Kitchen scene, girl slide, and "off-the-air" programme material on frequency-modulation system

FIGURE 2 - *Protection ratio for an amplitude-modulation, vestigial sideband system as function of carrier frequency offset*

$$\frac{(P_{SYNC\ PK\ AV})_{AM\text{-}VSB}}{(P_{AV})_{FM}}$$

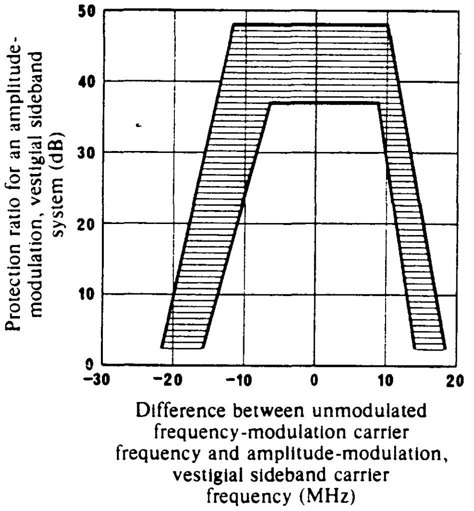


FIGURE 3 — *Protection ratio required for just perceptible interference in an amplitude-modulation, vestigial-sideband system subjected to interference by a frequency-modulation television system*

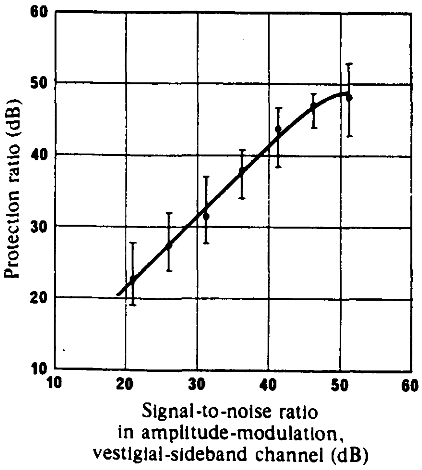
$$\frac{(P_{SYNC\ PK\ AV})_{AM\text{-}VSB}}{(P_{AV})_{FM}}$$

More recently, tests were performed by the USA [Barnes and Miller, 1978]. This series of tests examined a wide range of parameters for system M/NTSC wanted and unwanted signals. The parameters included: frequency offsets, 12 and 18 MHz peak-to-peak frequency deviations for frequency modulated signals, three and four section receiver filters, several test slides and colour bars as the wanted signal, and pre-emphasis for the frequency modulated signals. Because of the extensive number of tests, a single expert viewer was used to make judgments of just-perceptible interference. But, other test conditions were as in Recommendation 600. For the case of amplitude-modulation, vestigial sideband television, with FM interference, the measured co-channel protection ratios were 55 dB. This compares to 50 dB for the earlier measured results reported in this section. This difference is attributed to the change in wanted picture content and the use of pre-emphasis in these tests. It is concluded that the reference case test conditions as per Recommendation 600 produce higher measured protection ratios than the earlier test conditions reported in this section.

1.1.1.3 *Protection ratio as a function of the signal-to-noise ratio*

The amplitude-modulation, vestigial-sideband protection ratio against just perceptible frequency-modulation interference is shown in Fig. 4 as a function of the output picture signal-to-weighted noise ratio on the amplitude-modulation, vestigial-sideband television system [Miller and Myhre, 1970]. The data used in Fig. 4 is from tests with off-the-air programming on both the amplitude- and frequency-modulation systems. For signal-to-noise ratios of less than 45 dB the average protection ratio, as shown in Fig. 4, may be expressed by:

$$R_{AM/FM} = S/N_{WTD} + 2 \qquad \text{dB} \qquad (3)$$



Carrier frequency offset: 0.5 MHz

Peak-to-peak frequency deviation: 18 MHz

Protection ratio for just perceptible interference: 34 observations by one expert viewer, averaged at each value of signal-to-noise ratio (*S/N*)

$$S/N = \frac{\text{White-to-blanking voltage}}{\text{R.m.s. noise voltage in 4.2 MHz (WTD)}}$$

No pre-emphasis on frequency-modulation system

FIGURE 4 — *Protection ratio for an amplitude-modulation, vestigial-sideband system as a function of signal-to-noise ratio in the amplitude-modulation, vestigial-sideband channel*

The ranges of the test data at the various signal-to-noise ratios are shown by the vertical lines through the curve in Fig. 4. Changes in programme material during the tests account for most of the variations in the test data. The interference is more easily perceived in dark-coloured areas than in light-coloured areas. Pictures having large areas of uniform colour show interference more readily than scenes with multi-coloured detail. To guarantee no perceptible interference for varied programme material on both systems, an amplitude-modulation, vestigial-sideband protection ratio exceeding the upper limits of the data should be used. In this case the protection ratio for signal-to-noise ratios less than 45 dB would be expressed by:

$$R_{AM/FM} = S/N_{WTD} + 7 \quad \text{dB} \qquad (4)$$

1.1.1.4 *Protection ratio tests with many viewers*

The amplitude-modulation, vestigial-sideband protection ratio against just perceptible frequency-modulation interference is shown in Fig. 5 for tests with a total of 30 viewers. Each viewer witnessed a random sequence of test scenes having different ratios of wanted-to-unwanted signal power. The viewers were asked to judge only whether or not they could perceive any interference in the picture. The amplitude-modulation, vestigial-sideband picture was "off-the-air" programme material. The interfering frequency-modulation signal was either a kitchen scene, colour bars, the white window, or "off-the-air" programme material. The curve in Fig. 5 is the average of the percentage readings for the four different modulating signals on the frequency-modulation system. The ranges of the percentages over the four tests are shown by the vertical bars. At a given power ratio, the percentage of viewers perceiving no interference is a function of the amplitude-modulation, vestigial-sideband programme material. As in the tests with a single expert observer, still scenes with dark areas or with large areas of uniform colour required a greater power ratio to cause the interference to be imperceptible. Test conditions were:

AM-VSB signal-to-noise ratio: 46 dB (weighted)

Carrier-frequency offset: 0.5 MHz.

Of the 30 viewers, 3 were expert viewers. There were 3 female and 27 male viewers.

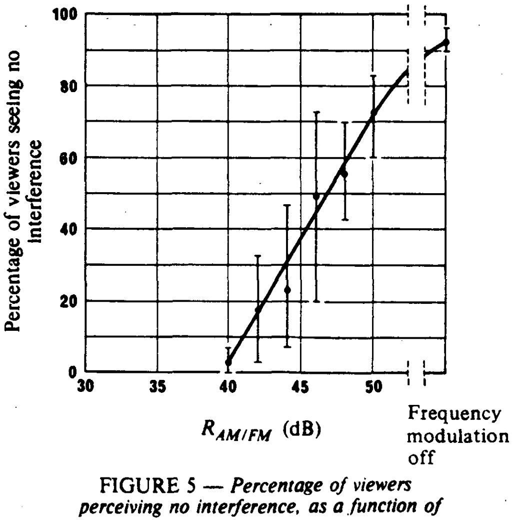


FIGURE 5 — *Percentage of viewers perceiving no interference, as a function of the protection ratio $R_{AM/FM}$*

On the basis of these limited tests, the amplitude-modulation, vestigial-sideband protection ratio, such that 50% of the viewers will perceive no interference, is given by the following expression:

$$R_{AM/FM} = S/N_{WTD} \quad \text{dB} \qquad (5)$$

The expert viewers used to obtain the barely perceptible interference test results shown in the figures were administered this same test. For these expert observers to perceive no interference, the measured amplitude-modulation, vestigial-sideband protection ratio is given by the following expression:

$$R_{AM/FM} = S/N_{WTD} + 4 \qquad \text{dB} \qquad (6)$$

These results indicate the expert viewers used in the other tests to be 4 dB more critical than the group of 30 viewers.

Equations (3) and (6) are based upon two different impairment criteria, and consequently are not directly comparable. Equation (3) expresses the protection ratio measured for an expert observer to notice just perceptible interference, while equation (6) expresses the protection ratio measured for expert observers to perceive no interference.

1.2 *Interference to amplitude-modulation, vestigial sideband television from multiple sound channels*

Tests were performed in the USA [CCIR, 1978-82a] with AM-VSB television as the wanted signal and multiple sound channels as the interference. Test conditions were in accordance with Recommendation 600. The wanted signal was system M/NTSC, AM-VSB television with a signal-to-noise (unweighted) ratio of 40 dB. Narrowband frequency modulated sound channels with 20 kHz peak deviation and wideband channels with 75 kHz peak deviation were used as the interfering signals. The sound channels were placed in the frequency band between 1 and 3 MHz above the vision carrier. Subjective evaluations of television impairments were made by four expert viewers and five non-expert viewers. The viewers determined the protection ratios $R_{AM/FM}$, the ratio of wanted AM-VSB carrier power at sync. peak to total average power in all interfering sound channels for just perceptible interference. The results of the tests are shown in Tables XVIII and XIX.

TABLE XVIII – *Protection ratios ($R_{AM/FM}$)* for just perceptible interference on AM-VSB television with narrowband FM sound channels interfering*

Number of sound channels N	Spacing between channels (kHz)	$R_{AM/FM}$ (dB)				
		Broadcast television programme			Philips slide No. 14	SMPTE slide No. 1
		A	B	C	B	B
2	50	45-52(1)	44-50(1)	39-46(1)	47-53(1)	48-57(1)
4	50	47-56(1)	46-54(1)	42-49(1)	50-55(1)	51-56(1)
10	50	50-53(1)	50-53(1)	43-46(1)	50-54(1)	52-53(1)
20	100	50	50	46	50	49
40	50	53	52	49	50	48

* $R_{AM/FM} = \dfrac{(P_{SYNC\ PK\ AV})_{AM-VSB}}{\sum_{i=1}^{N} (P_i)_{FM}}$

(1) Measured values occurred in range shown. $R_{AM/FM}$ varied with exact location of channels within the 2 MHz bandwidth.

A: averaged over 4 expert viewers, sound carriers unmodulated

B: averaged over 4 expert viewers, sound carriers modulated with a 400 Hz sine wave

C: averaged over 5 non-expert viewers, sound carriers modulated with a 400 Hz sine wave.

TABLE XIX – *Protection ratios ($R_{AM/FM}$)* for just perceptible interference on AM-VSB television with wideband sound channels interfering*

(Philips slide No. 14 on AM-VSB channel)

Number of sound channels N	$R_{AM/FM}$ (dB)	
	A	B
2	44-46 (1)	43-53 (1)
4	46-53 (1)	44-51 (1)
10	49	46

$$* \; R_{AM/FM} = \frac{(P_{SYNC\ PK\ AV})_{AM-VSB}}{\sum\limits_{i=1}^{N} (P_i)_{FM}}$$

(1) Measured values occurred in range shown. $R_{AM/FM}$ varied with exact location of channels within the 2 MHz bandwidth.

A: averaged over 4 expert viewers, sound carriers unmodulated.

B: averaged over 4 expert viewers, sound carriers modulated with 15 kHz sine wave.

Based upon this series of tests, one may conclude:

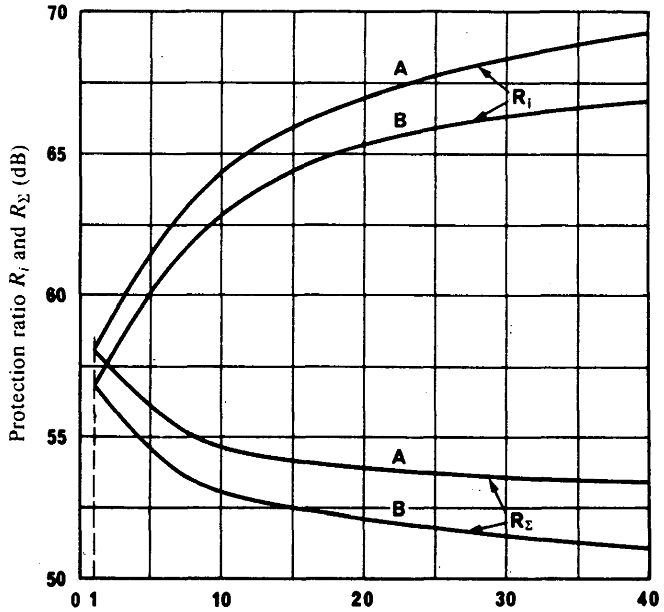
- protection ratios near 50 dB are indicated for system M/NTSC, AM-VSB television with multiple, interfering, frequency-modulation sound channels, where the interference is from either narrowband or wideband sound channels. There is a slight reduction in the measured protection ratio for wideband interfering sound channels compared to narrowband interfering channels.
- the test data support the hypothesis that the total power from a large number of interferers has essentially the same effect as that same amount of power from a single interferer.
- there is a slight reduction in protection ratio (1 to 3 dB) when modulation is applied to the interfering channels.

Studies of protection ratios for a similar case of interaction between a wanted signal and interference were carried out in the USSR [CCIR, 1978-82b] for M/NTSC, G/PAL and K/SECAM colour television systems. The measurement conditions were in keeping with the provisions of Recommendation 600. The observers taking part in the tests totalled 46 persons and included both experts and non-experts. The test pictures used were a real television program and slide SMPTE No. 14. The ratio of signal-to-unweighted noise in the television channel was taken as 40 dB. The interference applied ranged from 1 to 40 unmodulated or frequency-modulated carriers. The carrier frequency modulation was effected by a 1000 Hz sine wave; the peak-to-peak carrier deviation was 40 kHz and the frequency spacing between adjacent carriers was 50 kHz.

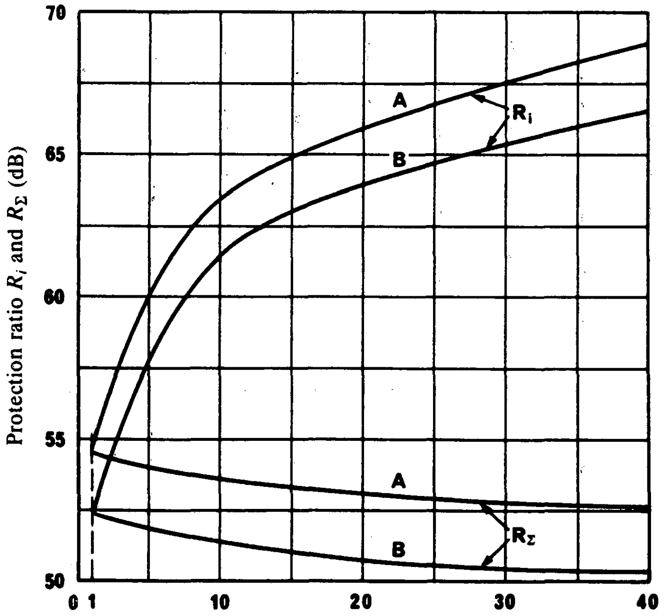
The protection ratio for all cases was determined for the interference perceptibility threshold (grade 4.5 on the CCIR impairment scale).

In the test process, it was established that the relations between permissible protection ratios and the number of interfering signals for the three colour television systems studied were sufficiently close (deviation of measured values not in excess of 1 dB) to permit representation of the final test results as unified curves for all three systems.

These results are presented in Figs. 6a) and 6b) to show the relationship between the permissible protection ratio for the sum of narrowband interfering signals (R_Σ) and for a single (from the given sum) interfering signal (R_i) both as a function of the number of interfering signals for unmodulated and frequency-modulated interfering signals respectively.



a) Sound carrier unmodulated



b) Sound carrier modulated

FIGURE 6 – *Protection ratios R_i and R_Σ for just perceptible interference on AM-VSB television with narrow-band FM sound channels interfering*

Curves A: SMPTE slide No. 14
B: broadcast television programme

$$R_i = \frac{(P_{SYNC\ PK\ AV})\ _{AM\text{-}VSB}}{(P_i)_{FM}}, \quad R_\Sigma = \frac{(P_{SYNC\ PK\ AV})\ _{AM\text{-}VSB}}{\sum_{i=1}^{N} (P_i)_{FM}}$$

The upper curves for R_Σ and R_i in these diagrams were obtained for the SMPTE No. 14 test picture, while the lower curves relate to the real television programme.

The following conclusions may be drawn from the results obtained:

- the effect of interference in the form of multiple narrowband FM signals on an AM-VSB television signal is roughly the same for the various colour television systems and is most perceptible when the interference falls within the luminance signal transmission band;
- the admissible protection ratio for the total interference is reduced with an increasing number of interfering signals; this reduction is greater when the number of interfering signals rises from 1 to 10;
- the removal of modulation from the carriers of the FM interference yields a slight increase in the protection ratio for the total interference (not more than 1.5 dB) when $N > 10$ and a considerable increase (up to 3 to 4 dB) when $N < 10$.

1.3 *625-line system I/PAL*

Figure 7 gives a summary of subjective tests performed by the BBC [Brown, 1971a]. The wanted amplitude-modulation, vestigial-sideband signal was modulated by a still picture of books, a box and silverware, and had a luminance-to-weighted-noise ratio of 43 dB. The interfering frequency-modulation signal was modulated by a colour bar using a nominal peak-to-peak deviation of 8 MHz, pre-emphasis according to curve B of Recommendation 405, and no energy dispersal.

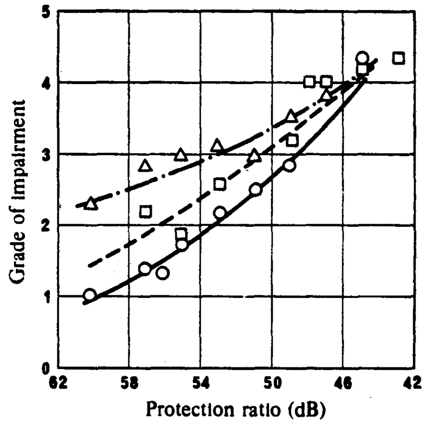


FIGURE 7 – *Grade of impairment caused by a combination of random noise and co-channel interference, present simultaneously*

—○— : greater than 39 dB
– –□– – : 35 to 39 dB inclusive
–·–△–·– : less than 35 dB
signal-to-unweighted noise ratio (dB)

Figure 7 refers to video signal-to-unweighted-noise ratios; for weighted-noise (system I weighting) the numerical value is increased by 6.5 dB.

The results suggest that if the wanted signal has a signal-to-noise ratio of 36.5 dB, noise unweighted, or 43 dB noise weighted, a working protection ratio of 53 dB would cause a change of grade from less than 2.0 (in the case of an unweighted signal-to-noise ratio greater than 39 dB) to about 2.5.

Note. – The scale used is the EBU impairment scale, which is:

Interference	*Grade*
Imperceptible	1
Just perceptible	2
Definitely perceptible, but not disturbing	3
Somewhat objectionable	4
Definitely objectionable	5
Unusable	6

At high signal-to-noise ratios in the BBC tests the protection ratio was 56 dB. It may be noted that from the shapes of the curves in Fig. 7, the impairment caused by interference is not significantly masked by the noise.

Reduction of this protection ratio may be permissible under the following conditions:

- no pre-emphasis: 1.5 dB reduction;
- deviation increased from 8 to 12 MHz peak-to-peak: 2 dB reduction;
- use of energy dispersal: about 2 dB reduction per MHz of peak-to-peak deviation.

On the other hand, an interfering signal modulation of black level was found to require a higher protection ratio (by about 5 dB). Thus, for the reference condition the protection ratio may be taken as 54 dB.

1.4 *625-line system G/PAL*

The IRT in the Federal Republic of Germany have carried out tests on system B/PAL, which for the present purpose can be considered as equivalent to system G/PAL. The signal-to-noise ratio (weighted) was approximately 50 dB. The protection ratio was assessed for an impairment grade of 2, on the 6-point scale. At a peak-to-peak deviation of 8 MHz for the interfering signal, and with no pre-emphasis, the average value of the protection ratio was 59.7 dB. A separate series of tests suggested that, on average, pre-emphasis does not significantly affect the results. (This conclusion differs somewhat from the BBC tests, which suggested that pre-emphasis may be expected to increase the protection ratio by about 1.5 dB. The difference may be due to the different picture content of the interfering signal.)

The observers in this test were all experienced, and the pictures used tended to be fairly sensitive to the effects of interference. On the other hand, it must be remembered that the impairment grade corresponded to greater impairment than the reference condition. Taking these factors into account, the protection ratio for the reference conditions may be taken as about 54 dB (see Recommendation 600).

1.5 *625-line system L/SECAM*

The ORTF, in France, [CCIR, 1970-74a and b] investigated the case where the wanted signal is system L/SECAM, the interfering signal being PAL. In this case, the impairment grade was taken as 4, on the 5-point scale. In some separate tests, it was found that for an impairment grade of "just perceptible" (i.e., grade 2 on the 6-point scale), the protection ratio should be increased by about 5 dB. Using the conversion formula suggested in the Annex to Recommendation 500 this suggests that more than 5 dB should be added to obtain an impairment grade of 4.5 (5-point scale).

Pre-emphasis was included. The low frequency deviation was 3.8 MHz/V, so the equivalent value at the frequency of zero insertion loss (i.e. 1.5 MHz) would be 13.5 MHz peak-to-peak, and another correction is required (see § 3.3.5 of the body of this Report) to obtain results applicable to the reference condition of 12 MHz.

Referring to the reference conditions established in Recommendation 600, the TDF measurements lead to the following results:

Measured protection ratio for grade 4: 45 dB

Allowance to refer results to grade 4.5: +5 dB

Allowance to refer results to 12 MHz deviation: +0.5 dB

Thus, the final value of the protection ratio, applicable to the reference conditions, becomes 50.5 dB.

1.6 *625-line system K/SECAM*

Studies were carried out in the USSR [CCIR, 1978-1982c; Borovkov and Lokshin 1979], with a view to determining the value of protection ratios for AM-VSB television signals for the most widely used colour television sytems.

The test conditions were in keeping with those specified in Recommendation 500 and were as follows:

- wanted AM-VSB picture: colour slides SMPTE No. 14 and Philips No. 8;
- wanted signal: M/NTSC, G/PAL, K/SECAM;
- interfering picture: colour bars;
- interfering signal: deviation (peak-to-peak) 8, 16 and 22 MHz;
- assessment scale: 5-grade impairment scale; perceptibility threshold – grade 4.5 ($Q = 4.5$);
- observers: 40, of whom approximately half were experts;
- viewing distance: 6 picture heights;
- the ratio of the peak-to-peak amplitude of the wanted video signal to the unweighted noise voltage at the receiver output was not less than 40 dB;
- the carrier frequencies of the wanted and unwanted signals were close together so as to maximize the perceptibility of the interference;
- the interfering signal used standard pre-emphasis.

The dependence of picture impairment on the level of the interfering FM signal obtained for the various systems was sufficiently close to be generalized and presented on a single curve (see Fig. 8).

The tests also showed that the dispersal of the energy of an FM interferer by a saw-tooth signal reduces the interfering effect, while the advantage obtained from energy dispersal is reduced as the peak-to-peak amplitude of frequency deviation is increased, as shown in Fig. 9.

In the general case, i.e., with any value of peak-to-peak deviation of FM interference and of dispersal, the following formula (for a picture impairment of $Q \leqslant 4.5$) may be used for calculating the protection ratio of an AM-VSB television signal against interference from an FM television signal:

$$R_q = R_{oq} - 0.45\,(D_v - D_{ov}) - M_d\,D_{dv} \qquad \text{for } Q \leqslant 4.5 \qquad (7)$$

where

R_q: the required protection ratio, (dB);

R_{oq}: the protection ratio for the frequency deviation D_{ov} taken as reference (determined from the corresponding curve on Fig. 8);

D_{dv}: the peak-to-peak amplitude of the frequency deviation due to the dispersal signal (MHz);

M_d: a coefficient determined from Fig. 9.

1.7 *Frequency offset*

If the frequencies of the wanted and interfering signals are spaced by a few MHz, some reduction in protection ratio is possible, the difference depending on whether the interfering signal is of a higher or a lower frequency than the wanted signal. Tests by the BBC, IRT and TDF all showed that the protection ratio varies only with respect to the frequency spacing. Examples are shown in Figs. 10 and 11 which show results obtained by the IRT and TDF respectively (using deviations somewhat greater than the reference condition). Since the spacing between terrestrial channels in systems G, I and L is 8 MHz, the best offset which could be used would be that giving equal protection ratios at ± 4 MHz about the point of symmetry of the intefering spectrum. Figures 10 and 11 show that if this is done, the benefit is unlikely to exceed about 3 dB, compared with the case of using no offset.

2. Interference to a frequency-modulation television signal from an amplitude-modulation vestigial-sideband television signal

2.1 *525-line system M/NTSC*

Results for this case have been provided by the USA [Miller and Myhre, 1970] and Japan [Kaneda, 1972]. In the USA a series of tests was conducted where a frequency-modulation television signal was placed at the same frequencies as an amplitude-modulation, vestigial-sideband television signal. The video output of a frequency-modulation television receiver tuned to the frequency-modulation signal was evaluated for interference. The signals used in the tests were the same as those described in § 1.1.1.2 of this Annex, except that the frequency-modulation signal was now the wanted signal and the amplitude-modulation, vestigial-sideband signal was the interfering signal.

The results of the tests are shown in Fig. 12. The luminance signal-to-weighted noise ratio of the wanted picture signal used in these tests was approximately 54 dB. The judgements of just perceptible interference were made by a single expert viewer. Bandwidth of the frequency-modulation receiver was 30 MHz.

The curves of Fig. 12 show that interference from stationary scenes, having large areas of uniform colour, is more easily perceived than scenes with motion, as in most off-the-air programming. The shaded band in Fig. 13 encloses the curves of the measured protection ratios. To guarantee no perceptible interference from both still and moving scenes, a protection ratio exceeding the upper boundary of the shaded area in Fig. 13 should be used.

Table XVII also shows the results of the subjective assessment test carried out in Japan in the case of barely perceptible interference for a wanted FM-TV signal and an unwanted VSB-AM television signal under the same conditions as described in this Annex, § 1.1.1.1.

Later tests in the USA [Barnes and Miller, 1978] were made using the guidelines of Recommendation 600 except as noted in § 1.1.1.2 of this Annex.

Table XX summarizes the results.

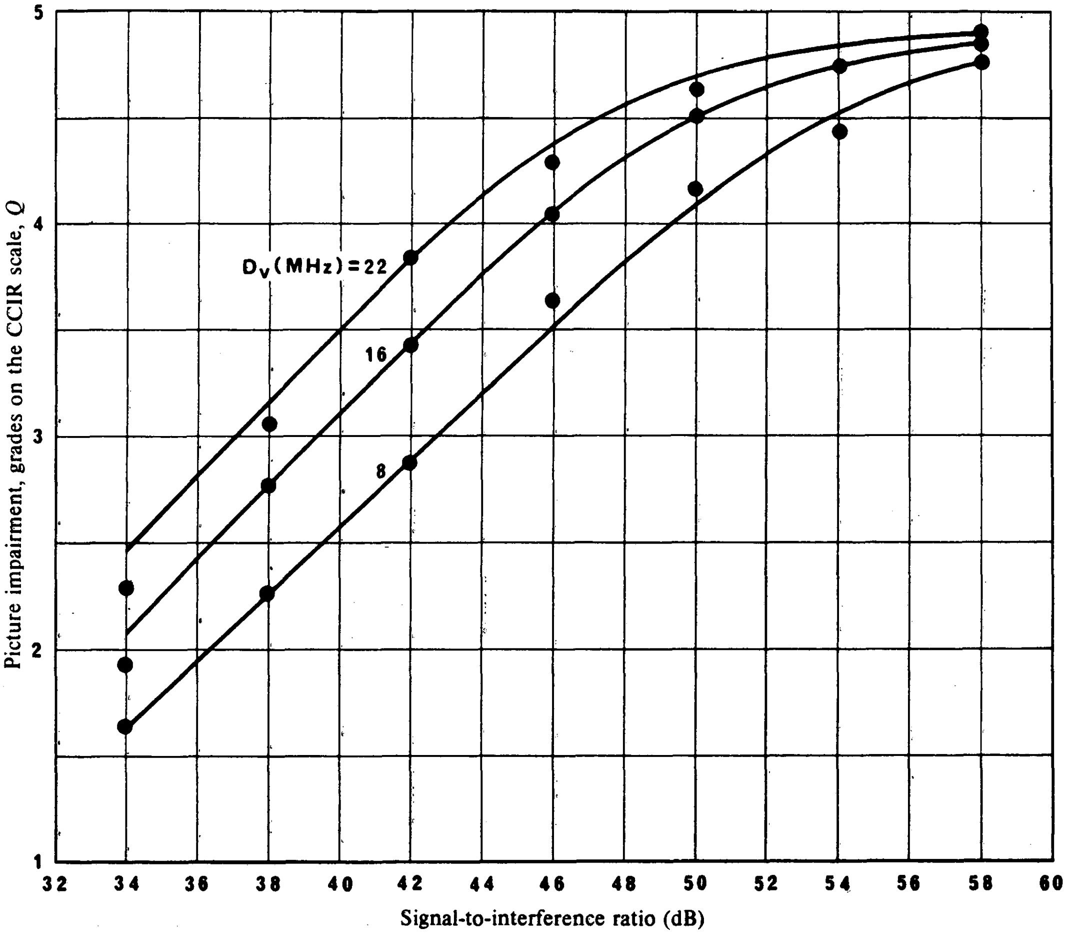


FIGURE 8 – *Television picture impairment (AM-VSB signal) as a function of the level of the interfering FM signal with different peak-to-peak deviation values*

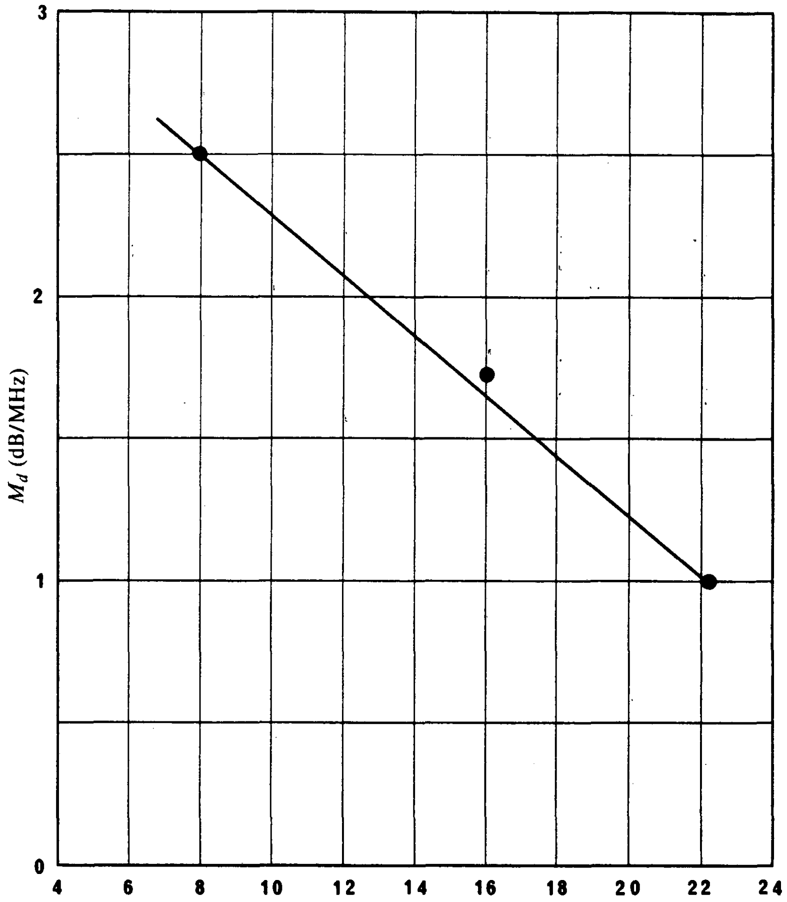
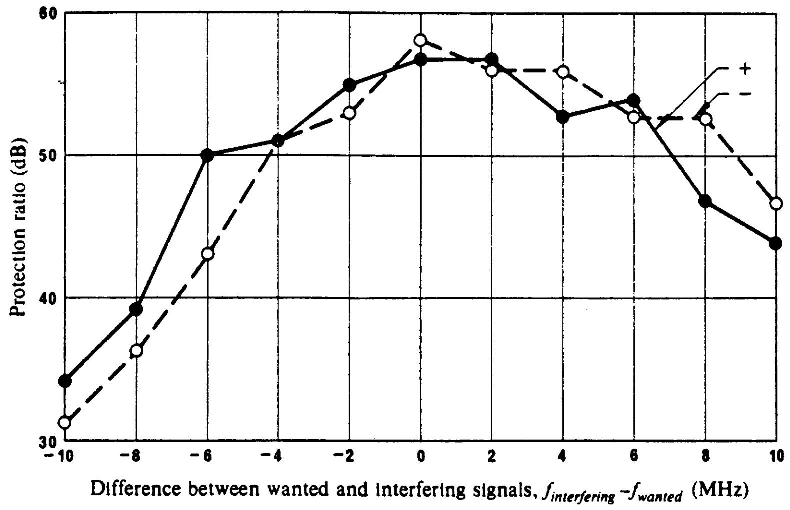


FIGURE 9 – *Coefficient M_d as a function of peak-to-peak deviaton of the interfering signal*



(The signs + and − refer to the two senses of modulation)

FIGURE 10 – *Variation of the protection ratio with respect to frequency spacing for system G/PAL*

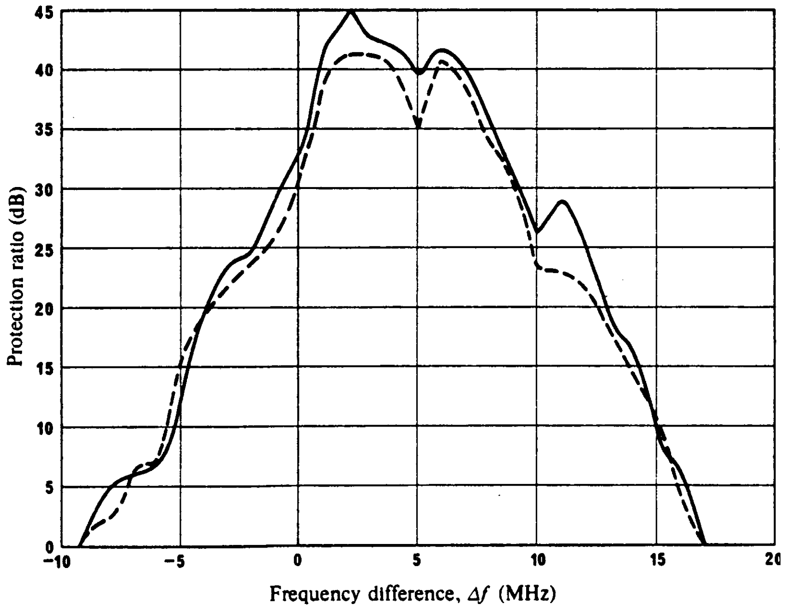
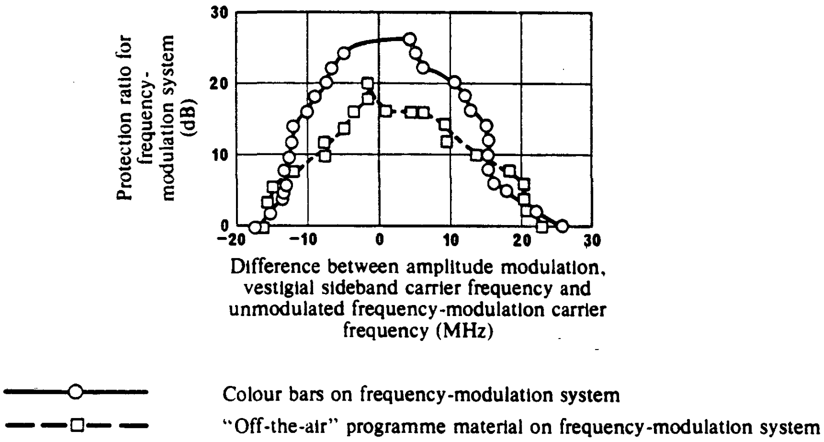
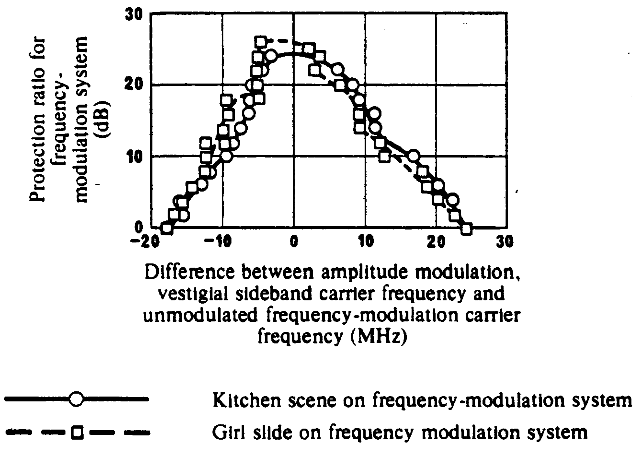


FIGURE 11 – *Variation of the protection ratio with respect to frequency spacing*

Wanted signal:	L/SECAM colour bars (radio-frequency level: 60 dB(μV/m))
Interfering signal:	G/PAL slide, synchronized scanning
———	: Measured without energy dispersal of the G/PAL signal
– – –	: Measured with energy dispersal over 2 MHz of the G/PAL signal



(a) Colour bars and "off-the-air" programme material on frequency-modulation system



(b) Kitchen scene and girl slide on frequency-modulation system

FIGURE 12 – *Protection ratio for a frequency-modulation system as a function of the carrier-frequency offset*

$$\frac{(P_{AV})_{FM}}{(P_{SYNC\ PK\ AV})_{AM\text{-}VSB}}$$

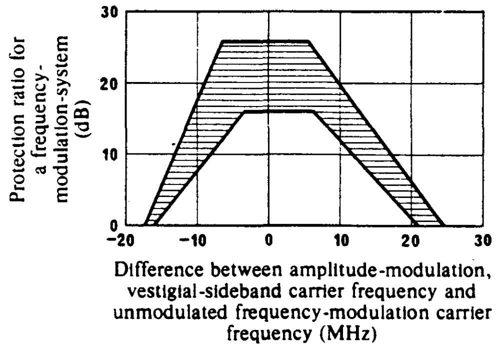


FIGURE 13 – *Protection ratio required for just perceptible interference in a frequency modulation television system subjected to interference by an amplitude-modulation, vestigial-sideband television system*

$$\frac{(P_{AV})_{FM}}{(P_{SYNC\ PK\ AV})_{AM\text{-}VSB}}$$

TABLE XX – *Measured co-channel protection ratios for just perceptible interference, system M/NTSC, SMPTE test slide No. 14 as wanted picture*

Wanted signal	Unwanted signal	Co-channel protection ratio (dB)
FM, 12 MHz deviation	AM-VSB	23⁽¹⁾
FM, 18 MHz deviation	AM-VSB	19

(1) Average for both four and six section Chebyshev filters.

The measured protection ratio is 4 dB less for 18 MHz deviation than for 12 MHz deviation. This suggests that the protection ratio for FM-wanted/AM-unwanted, decreases as 20 log (D_v/12), similar to equation (1a) in the body of this Report.

2.2 *625-line system K/SECAM*

Measurements in the USSR [CCIR, 1970-74c] determined protection ratios for frequency-modulation colour and monochrome signals against interference by CW, amplitude-modulation vestigial-sideband, and frequency-modulation signals. To facilitate intercomparison of the results of the system K measurements, they are presented separately in § 5 of this Annex.

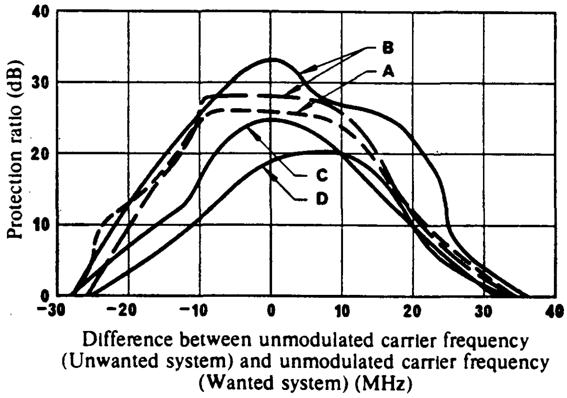
3. Interference between two frequency-modulation television signals

Measurements of interference between frequency-modulated television signals of the types used in the fixed-satellite service and the fixed service are presented in Report 449. Additional measurements for the broadcasting-satellite service are given below.

3.1 *525-line system M/NTSC*

3.1.1 *Two offset frequency modulation signals, tests in the United States of America*

Tests were conducted in the USA with two frequency-modulation signals operating at carrier frequency offsets in the range from −30 MHz to +36 MHz using an experimental arrangement similar to that described in § 1.1.1.2 of this Annex. The video frequency output of a frequency-modulation television receiver tuned to the wanted signal was evaluated by a single expert observer for just perceptible interference when the picture signal-to-weighted noise ratio was 50 dB. The bandwidth of the frequency-modulation receiver was 30 MHz. Figure 14 shows the measured protection ratios as functions of carrier frequency offset with off-the-air programming on the unwanted signal and various programmes on the wanted signal. The curves show that off-the-air programming, when there are scenes in motion, is less susceptible to interference than stationary scenes with large areas of uniform colour.



	Wanted system	Unwanted system
Peak-to-peak deviation	18 MHz	18 MHz
Signal-to-noise ratio (weighted)	50 dB	
Pre- and de-emphasis	none	none

Curve	Programme material	
	Wanted signal	Unwanted signal
A	white window	off-the-air
B	colour bars	off-the-air
C	kitchen scene	off-the-air
D	off-the-air	off-the-air

FIGURE 14 – *Protection ratio for just perceptible interference in a frequency-modulation television system subjected to interference by frequency-modulation television*

$$R_{FM/FM} = \frac{(P_{AV})_{FM} \text{ (Wanted)}}{(P_{AV})_{FM} \text{ (Unwanted)}}$$

The shaded band in Fig. 15 encloses the individual measured protection ratios. To guarantee no perceptible interference from both still and moving scenes, a protection ratio exceeding the upper boundary of the shaded area should be used.

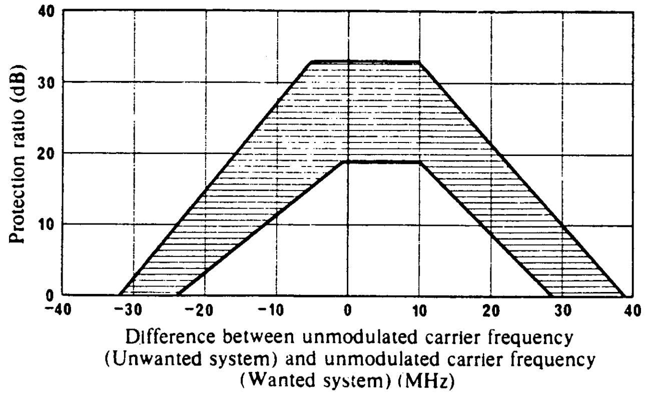
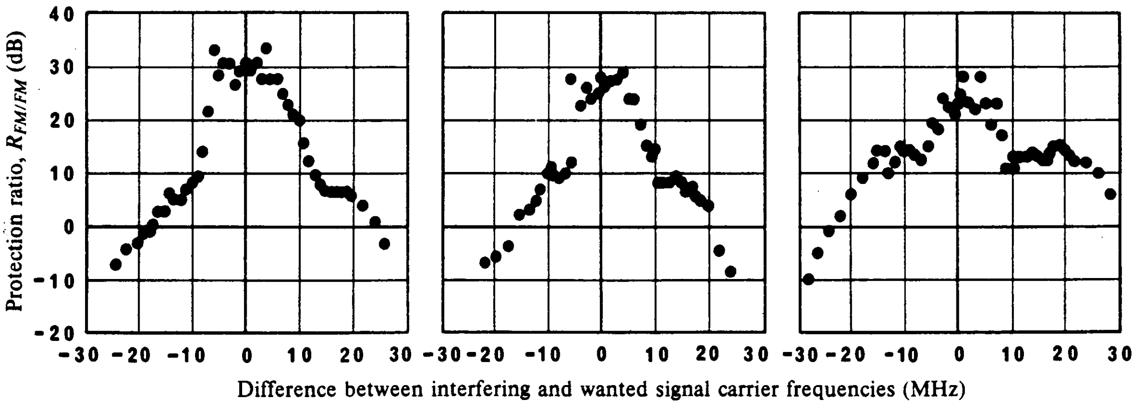


FIGURE 15 – *Protection ratio for just perceptible interference in a frequency-modulation television system subjected to interference by frequency-modulation television signals*

	Wanted system	Unwanted system
Peak-to-peak deviation	18 MHz	18 MHz
S/N (weighted)	50 dB	
Pre- and de-emphasis	None	None

Later protection ratio measurements for two FM television signals, performed in the USA [Barnes and Miller, 1978], were made in accordance with Recommendation 600 as noted in § 1.1.1.2 of this Annex. Figure 16 and Table XXI present the results.



a) *b)* *c)*

FIGURE 16 – *Measured protection ratios for just perceptible interference in an FM television system for FM television system interference*

	Peak-to-peak FM deviation (MHz)	*Number of filter section*
a)	12	4
b)	12	6
c)	18	6

TABLE XXI – *Measured co-channel protection ratios for just perceptible interference, system M/NTSC, SMPTE test slide No. 14 as wanted picture*

Wanted signal	Unwanted signal	Co-channel protection ratio (dB)
FM, 12 MHz deviation	FM, 12 MHz deviation	31 (1)
FM, 18 MHz deviation	FM, 18 MHz deviation	28

(1) Average for both four and six-section Chebyshev filters.

The co-channel protection ratios measured for an FM television signal interfering with another FM television signal agree quite closely with, and thus substantiate, prior extrapolations to the reference-case conditions. Also, the decrease in FM protection ratio by the approximate term of 20 log $(D_v/12)$, as given in equation (1a) of the body of this Report, is substantiated by the measurements.

Figures 16a) and 16b) show that offsetting an interfering carrier by 10 to 12 MHz results in a 15 dB relaxation of the protection ratio. This is improved performance compared to Fig. 1a) in the body of the Report.

3.1.2 *Two offset frequency modulation signals, tests in Canada*

Measurements were carried out in Canada [CCIR, 1978-82d] for the protection ratio between two FM television signals of 525-line system M/NTSC. Test conditions were according to those specified in Recommendation 600. Some of the salient test features and parameters used for the measurements were as follows:

- the test method employed the comparison technique where the reference signal impairment was set according to the 5 level impairment scale (see Recommendation 500) based on TASO results for impairment due to random noise;
- picture slides used were SMPTE Nos. 1 and 14 for the wanted signal;
- split field colour bars were used for the interfering signal;
- 15 observers ranging from non-expert to expert were used;
- no sound sub-carrier was employed;
- no energy dispersal was used;
- pre-emphasis as per Recommendation 401 for system M was used.

A summary of the major results of the co-channel protection ratio measurements is as follows:

- variation of the protection ratio with frequency deviation and impairment level showed good agreement with that predicted by equation (1);
- variation of the wanted signal to weighted noise ratio over the range 42-50 dB at a constant impairment level of 4.5 indicated no masking of interference by random noise. In fact results indicated that at low values of S/N the protection ratio tends to increase, to maintain the signal at a constant impairment level;
- during the measurement programme, it was found that the 4.5 impairment grade as derived from TASO results was not equivalent to just perceptible interference. Further tests based on just perceptible interference resulted in protection ratios ranging from 5.4 to 8.8 dB higher than those obtained for the 4.5 grade TASO.

Results of frequency offset measurements carried out using a 3 pole IF receive filter at an impairment level of 4.5 and adjusted by 8.8 dB for just perceptible interference is shown in Fig. 17.

As indicated by this figure, the protection ratio is most sensitive to offset frequencies which are multiples of the colour sub-carrier.

Additional measurements using a 4 pole receive filter resulted in a lower protection ratio requirement than shown in Fig. 17 for the same value of frequency offset.

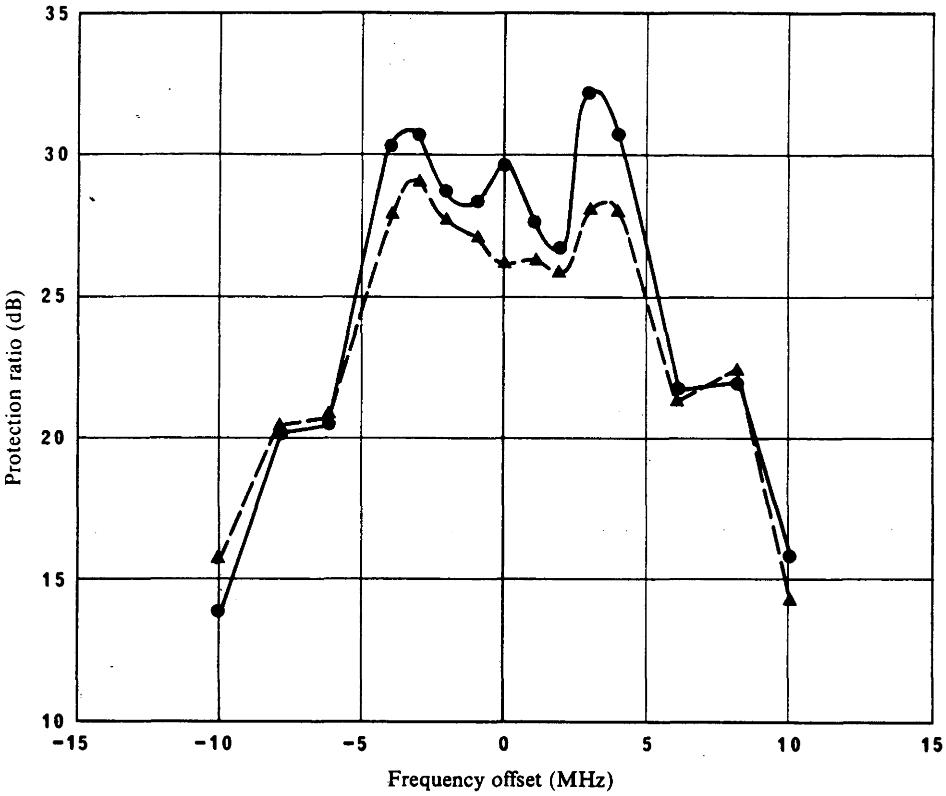


FIGURE 17 – *Protection ratio as a function of frequency offset with a 3 pole IF filter (peak-to-peak deviation of 8.4 MHz)*

—●— : SMPTE test slide No. 1

—▲— : SMPTE test slide No. 14

3.1.3 *Frequency modulation signals of different systems, tests in Japan*

In a study [CCIR, 1974-78a] made in Japan, measurements were made on co-channel protection ratios between two FM television signals of 525-line system M and between FM television 525- and 625-line system signals under the conditions described as follows:

- polarity of frequency-modulation is such that frequency of black level is lower than that of white level;
- receiving bandwidths are 23 MHz for 525-line system M/NTSC signal and 27 MHz for 625-line PAL and SECAM signals, respectively;
- peak-to-peak frequency deviations for the video signals of 525-line system and 625-line system are 12 MHz and 13 MHz respectively;
- there are three cases using television sound sub-carrier(s) for 525-line system M (none, or 4.5 MHz, or 4.5 and 5.05 MHz) and no sound sub-carrier for 625-line television systems;
- characteristics of pre-emphasis of the video signal are those shown in Recommendation 405, system M. The same circuit is used for the 625-line system because of unavailability at the time of measurement;
- the value of protection ratio used in this document corresponds to just perceptible interference, defined as the power ratio of carrier-to-interference at the receiver input when 50% of the observers give the grade 4 and the remainder gives grade 5;

- SMPTE No. 14 picture slide is used for the wanted signal, and No. 1 for the unwanted signal;
- ratio of viewing distance to picture height is 6;
- number of observers is 45 including 22 experts.

Table XXII shows the value of the protection ratio for just perceptible interference, which is defined as the power ratio of carrier-to-interference at the receiver input when 50% of the observers give grade 4 and the remainder give grade 5.

From this table, it may be concluded that there is no significant difference between protection ratios for systems using different television standards. From the measurements reported in [CCIR, 1974-78b] it may be indicated that the presence of 1 or 2 sound sub-carriers has negligible effects on the protection ratio.

TABLE XXII – *Summary of measured co-channel protection ratios (dB) between two FM television signals*

			Wanted signal		
			525-line system M/NTSC	625-line system L/SECAM	625-line system I/PAL
Unwanted signal	↓	Video peak-to-peak deviation (MHz) →	12	13	13
525-line system M/NTSC	12	Without pre-emphasis	31.5	32	32
		With pre-emphasis	31.5	31 (1)	31.5 (1)
625-line system L/SECAM	13	Without pre-emphasis	31.5	—	—
		With pre-emphasis	29.5 (1)		
625-line system B, G/PAL	13	Without pre-emphasis	30.5	—	—
		With pre-emphasis	29.0 (1)		

(1) These data are for reference, because pre-emphasis network was used only for system M.

3.1.4 *Two frequency modulation signals, tests in Japan*

Tests were carried out in Japan [CCIR, 1978-82e] on the interference between two FM television signals, with monitoring of picture quality in a studio with a ratio of viewing distance to picture height of 1 to 1.5 (a closer viewing distance than given in Recommendation 600). This resulted in a protection ratio of 38 dB for just perceptible interference.

The characteristics of the FM television signals were as follows:

- deviation by 525-line video signal: 12 MHz peak-to-peak;
- emphasis: Recommendation 405;
- energy dispersal deviation: 600 kHz;
- 4.5 MHz sound sub-carrier deviation: ± 1 MHz.

3.1.5 *Protection ratio versus impairment grade tests*

Measurements in the United States [CCIR, 1978-82f] have examined the variation in protection ratio as a function of impairment grade. Subjective evaluations of impairments were made for frequency modulation interference to another frequency modulation television system. Test conditions were as follows:

Wanted signal

Frequency modulated carrier, with system M/NTSC colour signals, with pre-emphasis according to Recommendation 405. Frequency modulated sound sub-carrier at 7.4 MHz. 12 MHz peak-to-peak frequency deviation (white to sync peak level) with white producing the highest frequency. No energy dispersai. Four test slides (SMPTE No. 1 and No. 14, and Philips No. 8 and No. 14) were used as the video signals. Video signal-to-noise ratio, 42 dB unweighted.

Interfering signal

Same as wanted signal except that video modulation was programme material with motion. Synchronization locked to wanted picture but offset to place vertical and horizontal synchronization bars within the visible portion of wanted picture. Sound sub-carrier at 7.6 MHz. Tests were co-channel, with the interfering signal at the same frequency as the wanted signal.

Viewing conditions

Consumer quality monitors with 64 cm diagonal screen. Viewing distance five times picture height. Picture brightness and room light controlled. 147 non-expert viewers were used in the tests. Evaluations were made using the five grade impairment scale in Recommendation 500.

Results of the tests are shown in Fig. 18. The curve shows that for the class of observers used in these tests, very little improvement in average impairment grade results from increasing *C/I* beyond 25 dB. The average impairment grade obtained for the test scenes with no interference may have been limited by the video signal-to-noise ratio used in the tests.

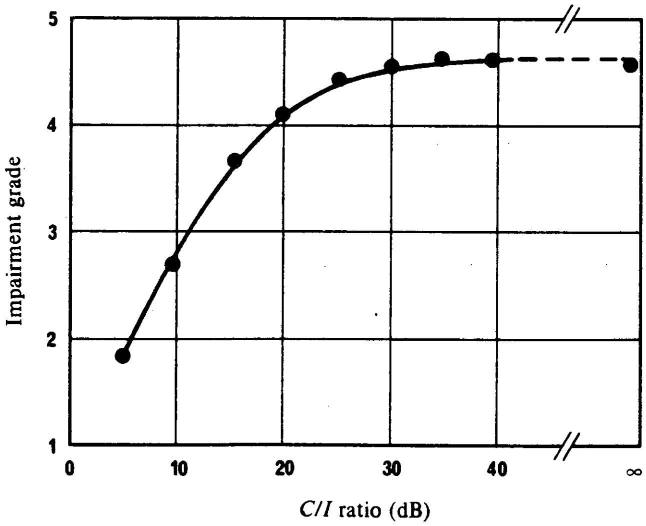


FIGURE 18 – *Impairment grade as a function of carrier-to-interference (C/I) ratio*

Data average for:
4 slides
147 observers

3.1.6 *Measurements carried out in Canada*

In preparation for the RARC SAT-83, measurements made in Canada addressed different aspects of interference between frequency modulated television signals of system M/NTSC. These tests were made with a deviation of 9.52 MHz/V and a receiver pre-detection filter with an equivalent noise bandwidth of 22.7 MHz (4-pole Chebyshev type). Pre-emphasis according to Recommendation 405 was used. The test slides used for the wanted signal were three of the four suggested in Recommendation 600: girl in a green dress, basket of fruit and beach scene. The interference-signal material consisted of unsynchronized off-air programmes.

The test procedures were in accordance with Recommendation 500-2 and Recommendation 600. Twenty-seven concerned viewers were subjected to 15 s viewing time separated by 10 s of 50 IRE Grey scale. A concerned viewer is considered to have a relatively broad knowledge of satellite communications but is not considered to be an expert viewer. Among the original 27 viewers, 2 were found inconsistent and rejected in the analysis of the results. The 5-grade CCIR impairment scale was used throughout the test.

3.1.6.1 *Impairment due to noise*

Figure 19 gives the results for a picture impaired by thermal FM noise for the average of the three slides. The high level of opinion score for the unimpaired picture (top anchor point at an S/N_w of 56 dB) indicates that the test results are not significantly limited by the instrumentation used. The figure indicates that the S/N_w ratio corresponding to an opinion grade of 4.5 is 47.3 dB.

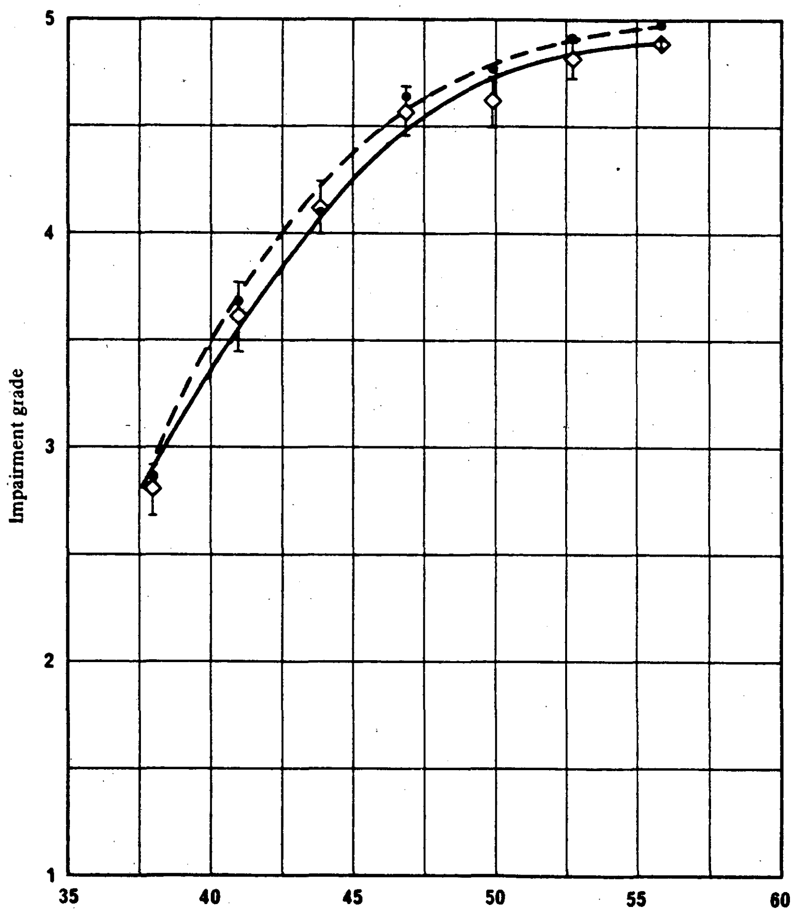


FIGURE 19 – *Impairment due to noise (average of three slides)*

◇ mean score of three slides

● median of three slides

3.1.6.2 *Impairment due to co-channel interference*

Figure 20 gives the results for single-entry co-channel interference. Table XXIII gives the relationship between opinion score and single entry co-channel *C/I*.

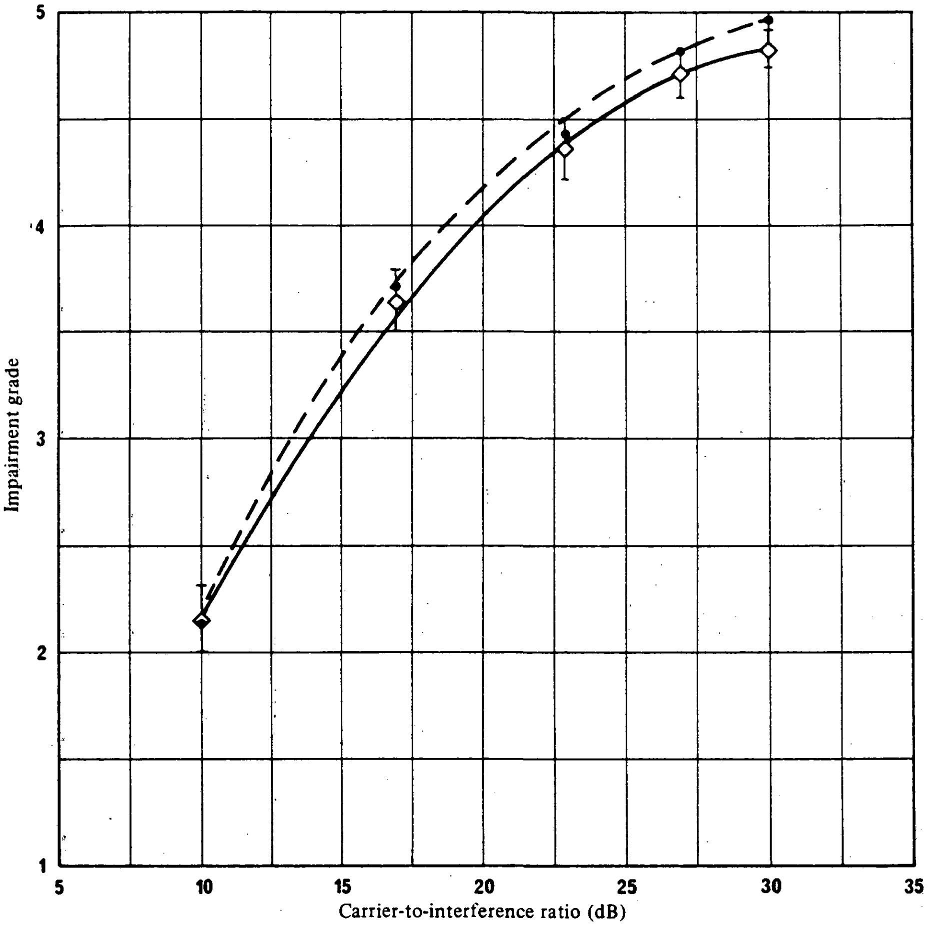


FIGURE 20 – *Impairment due to single-entry co-channel interference (average of three slides)*

◇ mean score of three slides

● median of three slides

TABLE XXIII – *Relationship between opinion score and the mean single-entry co-channel carrier-to-interference ratio for the average of the three slides*

Opinion grade	Single-entry co-channel *C/I* (dB)
4.3	22.2
4.5	24.2
4.7	26.8
4.8	29.0

A series of tests using a peak-to-peak deviation of 19.04 MHz has shown that, over a large range of opinion scores, the protection ratio requirement decreases as the square of the peak-to-peak deviation, thus verifying the normalization factor in terms of carrier deviation contained in equations (1a) and (1b) of the present Report.

The subjective tests on aggregate co-channel interference has shown that the law of power addition of interferers is not met in all cases. It was found that the impairment level produced by three equal power interferers could be obtained from a single interferer with 3 dB to 5 dB larger power with a mean at 3.8 dB for impairment grades between 4 and 5. The power addition would predict 4.8 dB. Nevertheless, the law of power addition is believed to be representative of the worst-case interference for multiple interfering carriers.

3.1.6.3 *Impairment due to adjacent-channel interference*

Tests were performed on the effect of aggregate interference from two adjacent channels, one lower and one upper. This arrangement of carriers was repeated for an inter-carrier spacing of 13 MHz and 15 MHz. Figure 21 shows the results of the tests on aggregate adjacent-channel interference for the 15 MHz spacing.

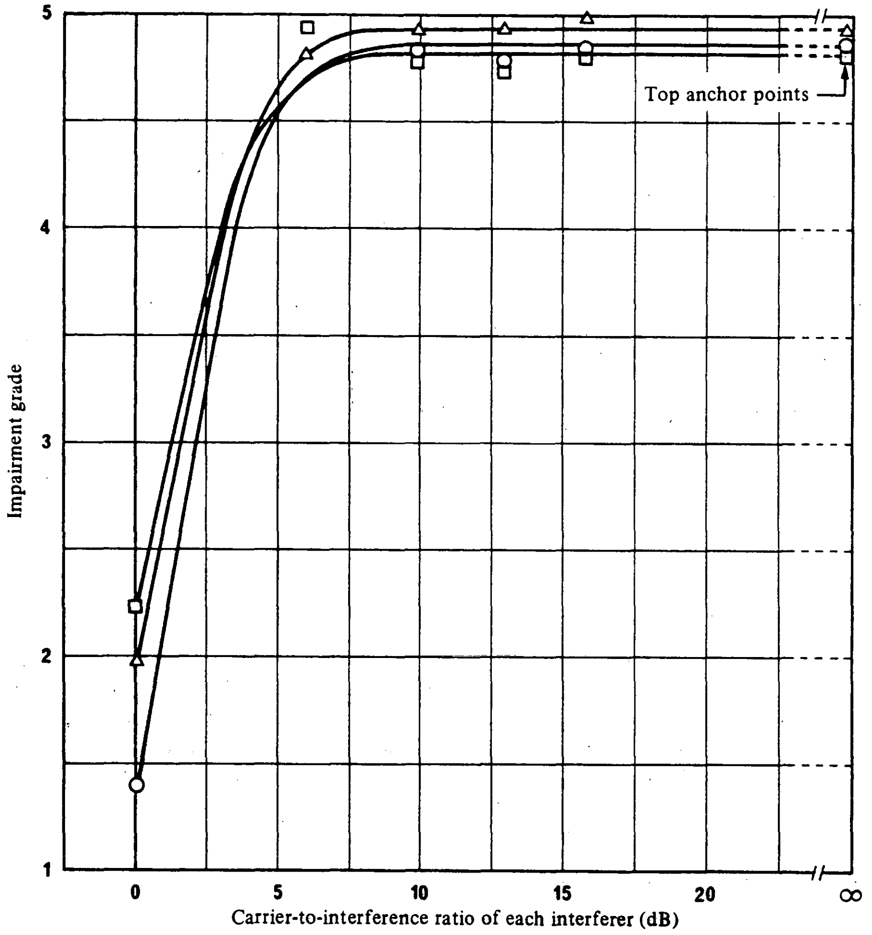


FIGURE 21 – *Impairment due to aggregate adjacent-channel interference for each slide. Two adjacent channels (101) are present, one upper and one lower which are separated by 15 MHz from the wanted carrier*

○ slide 1

△ slide 2

□ slide 3

The figure shows that the opinion score remains close to the unimpaired level for high values of the C/I ratio but decreases rapidly at low values of the C/I ratio. This sudden decrease in opinion score for adjacent-channel interference indicates the necessity of retaining a C/I ratio above the "cliff edge" in an operating system.

3.1.6.4 *Aggregate adjacent and co-channel interference*

Tests were performed on carrier arrangements* 121 and 111 where that ratio of powers between the individual interferers (co-channels) and the individual interferers (adjacent channels) was kept constant at 17 dB throughout the range of C/I ratios studied and where the carrier spacing was 15 MHz.

Figure 22 gives the results for slide 1, "girl in a green dress" for the 121 carrier arrangement. Similar results were obtained for the other carrier arrangement and the other two slides. The figure also shows the adjacent-channel interference only and the co-channel interference only for comparison purposes.

The figure shows that, at high carrier-to-interference ratio, the opinion score is mostly governed by the co-channel interference and that, at low carrier-to-interference ratio, the opinion score is governed by the adjacent-channel interference. The change-over between the two types of interference occurs near the "cliff edge" of adjacent-channel interference, between 6 to 8 dB for the 15 MHz carrier spacing.

3.1.7 *Measurements carried out in the United States of America*

Measurements were conducted in the United States of America in preparation for the RARC SAT-83 which addressed various aspects of interference between frequency modulated television signals of system M/NTSC. The tests were generally in accordance with Recommendations 600 and 500-2. Tests were conducted at two separate laboratories, each employing slightly different system characteristics and procedures. Details of measurements from both laboratories are contained in [CCIR, 1982-86a]. Pertinent differences are identified where applicable. Characteristics common to both sets of measurements were: 12 MHz/V peak-to-peak deviation, viewing distance of 5 times the picture height, critical test slides used for wanted signal, video taped programming used for interfering signal and horizontal and vertical synchronization bars of the interfering signals were locked in the video portion of the wanted signal. The 5-grade CCIR impairment scale was used throughout the tests. Pre- and de-emphasis were used according to Recommendation 405.

3.1.7.1 *Impairment due to noise*

Figure 23 shows the results of subjective evaluations of impairment grade as a function of signal-to-noise ratio with no interference. A simple relationship exists between impairment grade and S/N. A 6 dB increase in S/N results in an increase of approximately one impairment grade level over the region of S/N between 28 and 52 dB weighted for both effects, noise and pre- and de-emphasis. For an impairment grade of 4.5, Fig. 23 indicates a value of approximately 49 dB weighted signal-to-noise ratio.

3.1.7.2 *Impairment due to co-channel interference*

The results of co-channel interference tests are shown in Fig. 24. At an impairment grade of 4.5 the C/I required is approximately 28 dB. Little improvement in average impairment grade is gained by increasing C/I further. Additional tests with a 16 MHz peak-to-peak deviation substantiate the correction factor of 20 log ($D_v/12$), where D_v is the peak-to-peak frequency deviation. For the tests, a signal-to-noise ratio (S/N) of 55 dB, weighted for both noise and pre- and de-emphasis effects, was used.

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* The carrier arrangement XYZ means: X carriers below, Y carriers co-, and Z carriers above the wanted channel.

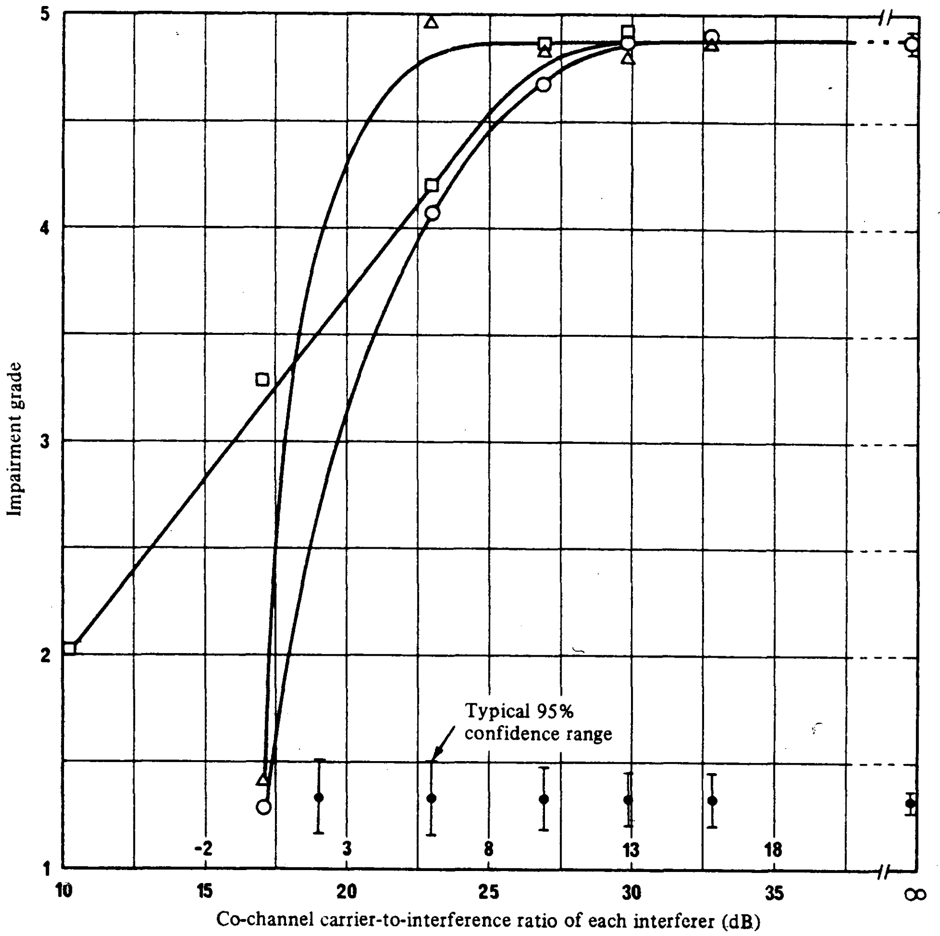

FIGURE 22 – *Impairment due to aggregate adjacent and co-channel interference*

(Carrier arrangement 121) (Δ*f* = 15 MHz)

Slide 1 : Girl in a green dress

□ 020: two co-channel interferers

△ 101: two adjacent-channel interferers (upper and lower adjacent channels)

○ 121: two co-channel and two adjacent-channel interferers

Note. – Upper horizontal scale on the figure refers to adjacent channel.

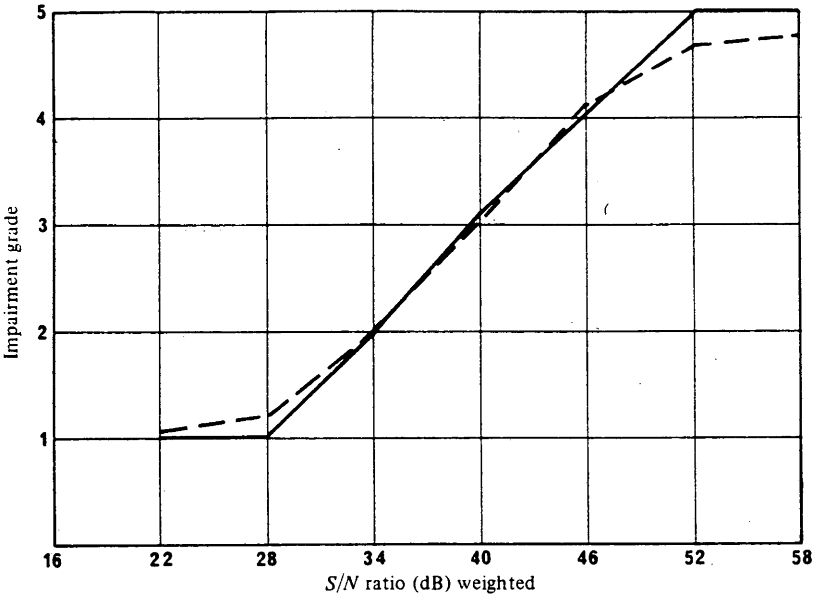

FIGURE 23 – *Impairment due to noise alone for M/NTSC systems*

(No interference, no sub-carrier)

——— median impairment
– – – mean impairment

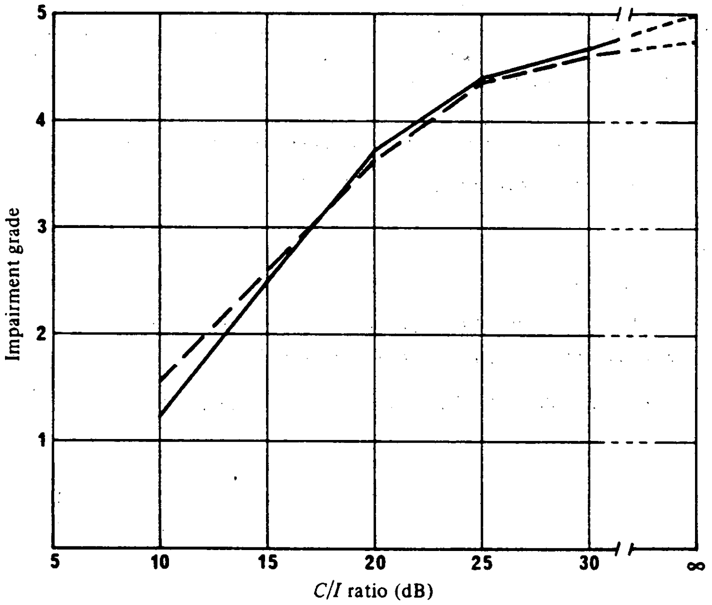

FIGURE 24 – *Impairment due to single-entry co-channel interference*

Δ*f* = 12 MHz peak-to-peak
S/N = 55 dB (weighted)
C/N = 23.8 dB

——— median impairment
– – – mean impairment

Tests were conducted on measured protection ratios for multiple co-channel FM-TV sources interfering with a single FM-TV system. The test results indicate that multiple sources of co-channel interference add on a power basis. Therefore, the subjective effect of multiple co-channel FM-TV interferers is equivalent to a single FM-TV interferer for the same aggregate carrier-to-interference ratio, i.e. when:

$$C/I_{single} = C/I_{\Sigma\ multiple}$$

where:

C/I_{single} : carrier-to-interference ratio for one interferer

$C/I_{\Sigma\ multiple}$: aggregate carrier-to-interference ratio for more than one interferer.

The tests showed that over a range of carrier-to-interference ratios between 10 and 25 dB the aggregate interfering effect of two and four interferers was within 0.5 and 0.75 dB of power addition, respectively.

3.1.7.3 *Impairment due to noise and interference*

In selecting a suitable impairment grade for system planning, the combined degradation of noise and interference must be examined. It is desirable to plan systems which are noise limited rather than interference limited (i.e. the noise is the dominant degrader of the received picture).

Figure 23 shows that in the absence of interference, an S/N of 46 dB (weighted) produces an average impairment grade of 4.1. Figure 24 shows the effect of interference, when there is virtually no noise (S/N of 55 dB weighted was the best obtainable picture in the test set-up). At a C/I of 28 dB, a mean impairment grade of 4.5 was measured. Figure 25 shows the combined effect of noise and interference. At an S/N of 46 dB (weighted) *and* a C/I of 28 dB, a mean impairment grade of 4.0 was measured. Figure 25 shows that for C/I ratios beyond 28 dB very little improvement in the impairment grade is possible. In this combination of noise and interference, the noise is the dominant contributor to the impairment grade reduction.

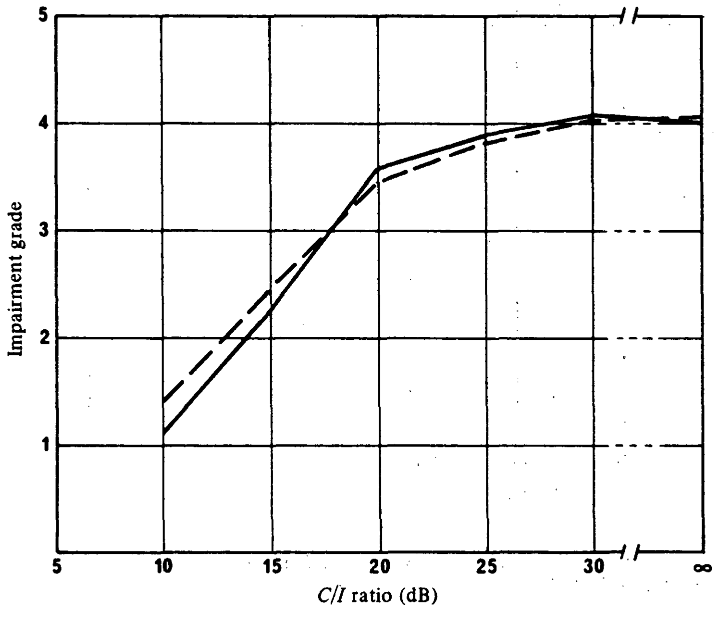

FIGURE 25 – *Impairment due to single-entry co-channel interference plus noise*

Δf = 12 MHz peak-to-peak

S/N = 46 dB (weighted)

C/N = 14.8 dB

——— median impairment

– – – mean impairment

Report 405, Annex II, presents a "law of addition" for unrelated impairments. This "law" predicts that, for an impairment grade of 4.1 from noise alone and an impairment grade of 4.5 from interference alone the resulting impairment grade due to the combined effect of noise and interference would be 3.8. This predicted value is somewhat conservative based upon the measured value of 4.0 from Fig. 25. However, for system planning at S/N ratios other than 46 dB (weighted), the "law of addition" of impairments does provide a reasonable, although conservative, estimate of total impairment grade when used with Figs. 23 and 24.

3.1.7.4 *Impairment due to adjacent-channel interference*

Figures 26, 27 and 28 show the results of measurements to examine the aggregate effect of adjacent-channel interference. Both single and multiple adjacent-channel interferers were investigated. The receive filter was a 4-pole Chebyshev type with an equivalent noise bandwidth of 22.5 MHz. The channel spacing used was 13 MHz.

Concerning impairment grades of interest (4.0 to 4.5), the aggregate interfering effect from one lower and one upper (101) adjacent-channel interferer is 2 to 3 dB worse than power addition when compared to curves for a single adjacent-channel interferer. For the cases of two lower (200) and two upper (002) adjacent-channel interferers, the aggregate interfering effect is 3 to 4 dB and 5 to 6 dB worse than power addition respectively*. Table XXIV presents data for each of the seven conditions relating aggregate C/I levels required to achieve a specified impairment grade.

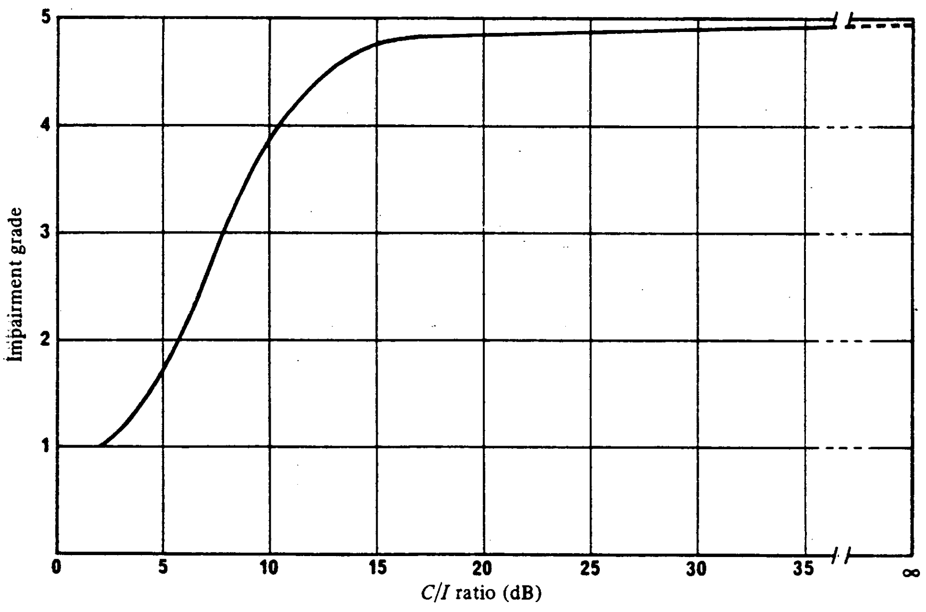

FIGURE 26 – *Impairment due to a single upper adjacent-channel interferer (001) separated by 13 MHz from the wanted carrier*

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* The carrier arrangement XYZ means: X carriers below, Y carriers co-, and Z carriers above the wanted channel

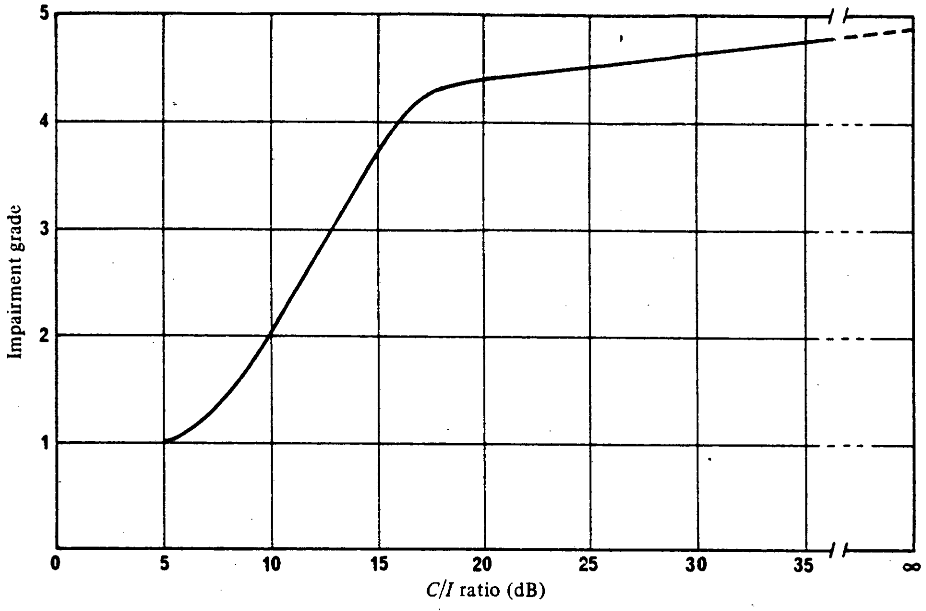


FIGURE 27 – *Impairment due to aggregate adjacent-channel interference. Two upper adjacent-channel interferers (002) separated by 13 MHz from the wanted carrier*

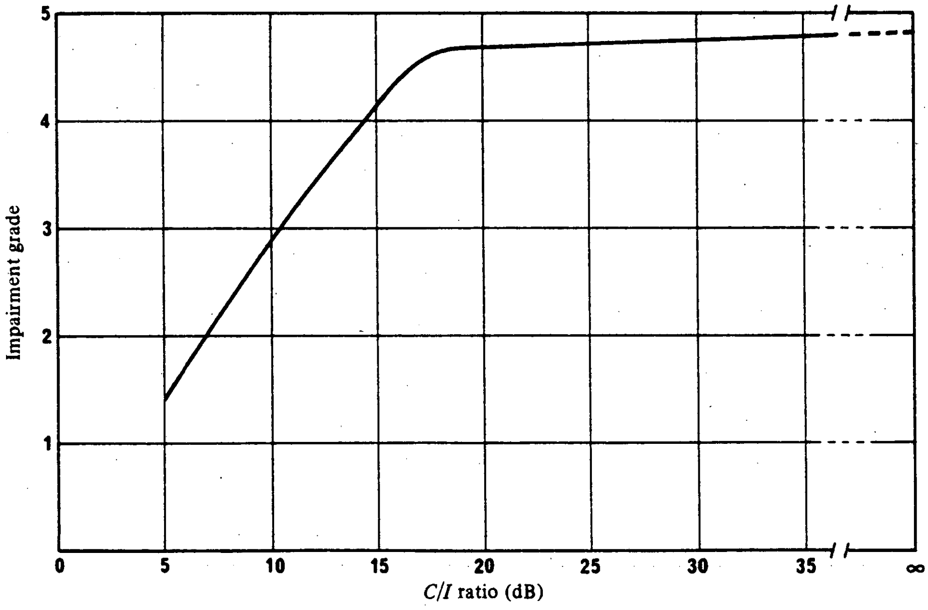


FIGURE 28 – *Impairment due to aggregate adjacent-channel interference. One upper and one lower adjacent-channel interferer (101) separated by 13 MHz from the wanted carrier*

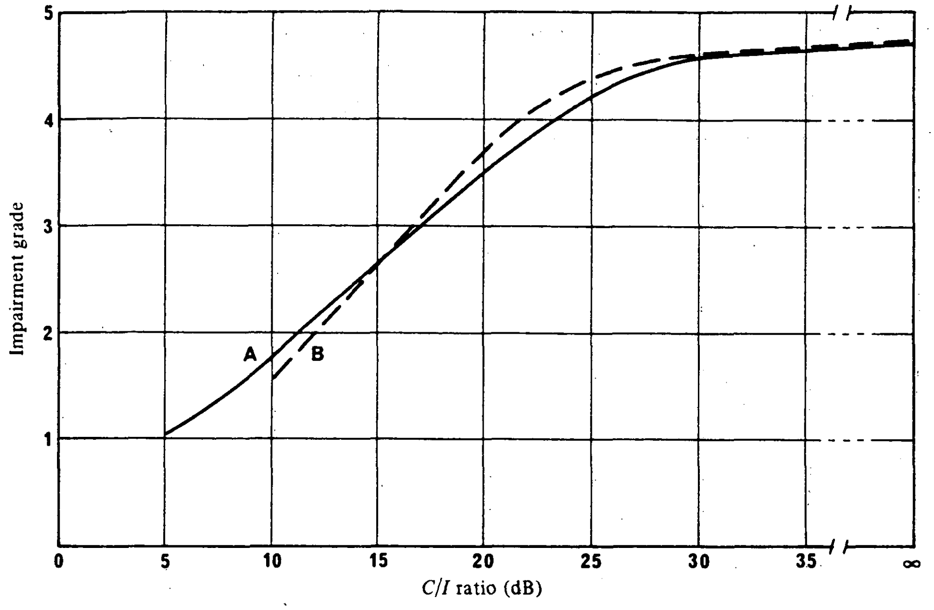


FIGURE 29 – *Impairment due to single-entry co-channel interference for tests conducted at:*

Curves A: NASA Lewis Research Center
B: CBS Laboratories

TABLE XXIV – *C/I ratio required for impairment grades of interest for all cases (dB)*

Case \ Q	3.50	3.75	4.00	4.25	4.50
001	9.0	9.7	10.5	11.7	13.0
100	10.0	11.0	11.75	12.8	13.9
002	14.5	15.3	16.3	17.1	19.0
200	13.0	14.0	15.0	16.0	17.8
101	12.4	13.3	14.4	15.4	16.8
010	19.7	21.4	23.1	25.3	28.7
111	22.7	24.1	25.5	27.5	31.0

3.1.7.5 *Aggregate adjacent and co-channel interference*

The combined interfering effects of adjacent and co-channel interference (111) were examined and the data are presented in Fig. 30. The relative levels were adjusted such that the interfering effect of the co-and adjacent-channels were approximately equal at an impairment grade between 4.0 and 4.5. Each adjacent channel interferer was set 6 dB above the co-channel interferer such that the aggregate adjacent channel interference was 9 dB greater than the co-channel interference. An 8-10 dB difference in aggregate *C/I* levels is obtained by examining Figs. 28 and 29 at impairment grades between 4.0 and 4.5. Therefore 9 dB was selected as the relative difference between the co- and aggregate adjacent-channel interference levels for the 111 case.

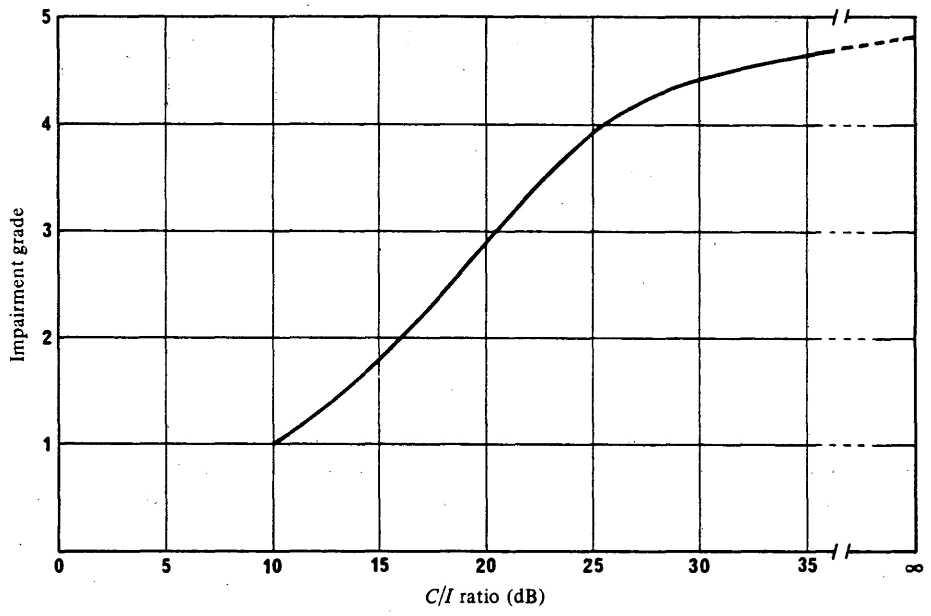


FIGURE 30 – *Impairment due to aggregate co-channel and upper and lower adjacent-channel interference (111). Adjacent-channel interferers separated by 13 MHz from the wanted carrier*

Figure 31 presents curves from Figs. 28 to 30. The 101 case, curve C, has been adjusted by 9 dB to agree with the condition for which the 111 case was tested. If the 010 and 101 cases, curves B and C, are added on a power basis the result, curve D, would lie within 1 dB of the measured 111 case, curve A. For impairment grade levels exceeding 4.0 the difference is less than 0.5 dB. The power addition curve lies to the right of the measured 111 case indicating that the measured results combine on slightly less than a power addition basis. It is believed therefore that co-channel and aggregate adjacent-channel interferers do add on a power basis. This result is dependent on the assumption of equal interference contributions from the co-channel interferer and the aggregate adjacent-channel interferers.

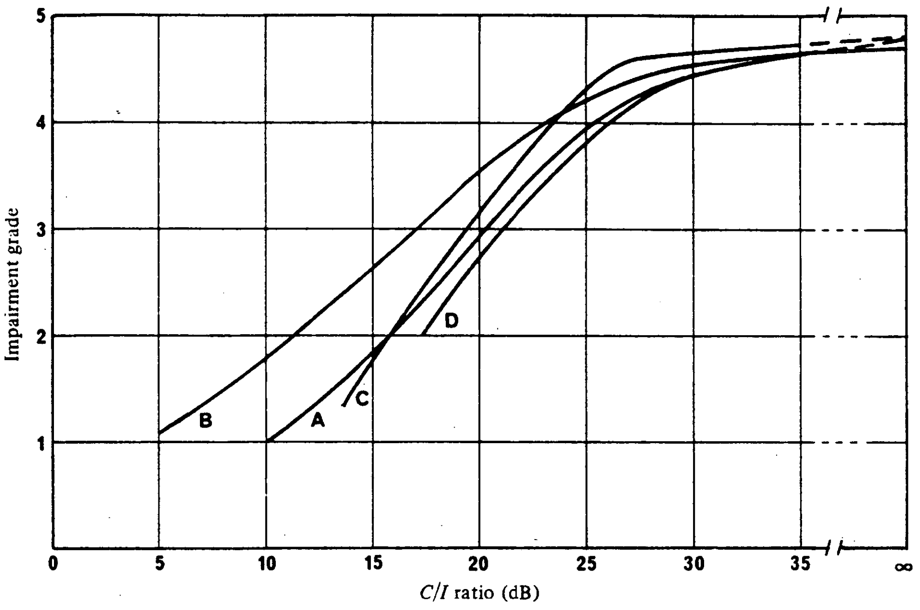


FIGURE 31 – *Comparison of impairment effects*

A: measured (111)

B: measured (010)

C: measured (101)

D: calculated by power addition (010 + 101)

3.2 *625-line system; B/PAL, G/PAL, I/PAL and L/SECAM*

Measurements of protection ratio for two frequency-modulation television signals with the same value for frequency deviation have been made in the United Kingdom by the BBC [Brown, 1971b], in Italy by RAI, in France by the TDF and in the Federal Republic of Germany by the IRT and DBP. A summary of these results [CCIR, 1974-78c] is given in this Report in § 3.1.5 and in Fig. 1a, curve B. The protection ratios were measured with a deviation of the sound sub-carrier on the main carrier which was in every case ± 2.8 MHz. The sub-carrier frequency was 6 MHz for system I, used by the BBC, 5.5 MHz for systems B and G used by the RAI, the IRT and DBP and 7.5 MHz used by the TDF. The protection ratio template (Fig. 1a, curve B) is asymmetrical about the carrier rest frequency. For exercises in planning, it would often be useful to use a common value for the protection ratios relating to the lower- and upper-adjacent channels. In this case the following compromise values can be used.

Channel spacing (MHz)	16	18	20	22	24	26	28	30
Protection ratio (dB)	20	16	13	10	7	4	2	0

More detailed information is given in [CCIR, 1974-78c].

Generally, for measurements performed by the various administrations indicated above, a conventional discriminator was used (staggered-circuit or delay line). Use of a phase locked loop (PLL) discriminator may lead to some differences in protection ratio. Measurements in France [CCIR, 1978-82g] show that in comparison with a conventional discriminator, the use of a PLL discriminator:

- does not change the protection ratio for co-channel interference;
- provides a reduction of 5 dB in the protection ratio for adjacent channel interference with frequency offsets between 12 and 20 MHz;
- increases the protection ratio for frequency offsets between 24 and 30 MHz.

For these measurements, no sound sub-carrier and no energy dispersal waveform were present.

Further studies with a large number of PLL discriminators are necessary for confirming these results and providing additional data in the case of greater frequency offsets.

3.3 *Co-channel protection ratio between wide-deviation frequency-modulation sound carriers*

In the broadcasting-satellite service it may be desirable to use a separate carrier, instead of a sub-carrier, for transmitting the television sound. In this case it may be necessary to use a deviation of about ± 300 kHz [CCIR, 1970-74d]. It is therefore important to know the co-channel protection ratio which should be specified for such signals, and also to find the minimum permissible spacing between the carriers, if several carriers were grouped together in a part of the frequency spectrum.

The BBC has carried out objective measurements of the interference between two frequency-modulation sound signals. The interfering signal was modulated by a 1 kHz tone to a peak deviation of ± 300 kHz, and the resulting signal-to-noise ratio in the wanted sound channel was measured using a modified Niese noise meter (for noise measurements this indicates the ratio of the r.m.s. signal to the r.m.s. noise) together with the recommended CCIR noise-weighting network (Recommendation 468).

For a signal-to-noise ratio of 50 dB, the co-channel protection ratio did not exceed 5 dB, the value depending to some extent on the exact frequency difference between the two carriers (over a range of about ± 200 kHz). For a signal-to-noise ratio of 60 dB, the protection ratio is not greater than 15 dB. The protection ratios determined for the sound signal are much lower than those for the television signal.

More tests were carried out to find suitable values for the carrier spacing (that is, the spacing between the carrier frequencies of adjacent sound channels). As in the case of television signals, it is assumed that the channel width is sufficiently large so that the adjacent-channel protection ratio is −6 dB. In this case, the tests showed that the carrier spacing should be about 0.8 MHz.

4. Protection ratio measurements between FM television and other signals

4.1 *Interference into FM television*

4.1.1 *Protection ratio measurements between frequency-modulation television signals and FM-sound multiplex systems*

Concerning the tests performed by the TDF [CCIR, 1974-78d], the modulation characteristics were the following:

FM-TV

- the video signal and a sound sub-carrier at 5.5 MHz are multiplexed;
- peak-to-peak frequency deviation of the carrier: 14 MHz/V;
- noise bandwidth: 27 MHz;
- pre-emphasis for video: Recommendation 405;
- frequency deviation of the sub-carrier: ± 75 kHz;
- pre-emphasis for audio signal: 50 µs;
- amplitude of the sub-carrier: 230 mV.

FM-sound multiplex

The carrier is modulated by an FDM-FM baseband made of 15 sub-carriers, each frequency modulated by an audio-frequency signal (frequency deviation of the sub-carrier = ± 75 kHz, pre-emphasis for audio-frequency signal = 50 µs).

The radio-frequency bandwidth is 27 MHz. The frequency deviations of the carrier by the different sub-carriers are such that the quality obtained is the same for each audio signal. Other transmission methods for a group of sound channels have also been investigated [Mertens *et al.*, 1976].

4.1.2 *Protection ratio measurements between frequency-modulation television signals and FDM-FM telephony signals*

Tests were carried out in Japan [CCIR, 1978-1982e] on interference between frequency-modulation television signals and FDM-FM telephony systems under the condition of monitoring the picture quality in a studio using a ratio of viewing distance to picture height of 1 to 1.5, which represents a closer viewing distance than given in Recommendation 600.

The characteristics of the FM television signal were the same as given in § 3.1.3 of this Annex and in [CCIR, 1978-1982e]. For an r.m.s. test-tone deviation of 270 and 800 kHz, corresponding to 60 and 970 channels, the measured protection ratios for just perceptible interference were 35 dB and 32 dB, respectively.

4.1.3 *Protection ratio measurements between frequency-modulation television signals and digital signals (television and data)*

Tests carried out in Japan [CCIR, 1978-1982e] using the same viewing conditions and modulation characteristics of the FM television wanted signal as described in § 3.1.3 of this Annex and a 64 Mbit/s, 4-PSK system interfering signal, resulted in a measured protection ratio for just perceptible interference of 25 dB.

Measurements made in the United States of America [CCIR, 1978-1982h; Barnes, 1979] involved interferences between a quadriphase shift keyed (4-PSK) modulated television signal and a frequency modulated television signal. Both signals were system M/NTSC. Other characteristics are given in Table XXV.

TABLE XXV – *Characteristics of digital and frequency-modulation television systems*

System	Digital television	Frequency-modulation television
Modulation	Differentially coded, 4-PSK modulator, coherent 4-PSK demodulator	Frequency-modulation, 12 MHz peak-to-peak deviation, with pre- and de-emphasis
Signal bandwidth (transmit filter)	45 MHz (3 pole, low ripple Chebyshev filter)	20 MHz
Receiver filter	33 MHz, 5 pole, equalized elliptical filter	21 MHz, 6 pole, low ripple Chebyshev
Audio	Multiplexed into data stream	7.5 MHz sub-carrier, 25 dB below video carrier
System output signal-to-noise ratio (unweighted) (dB)	45(1)	50

(1) Subjectively measured.

In the measurements, a 4-PSK modulated digital television signal interfering with an FM television system degraded the received picture and the baseband signal in a noise-like manner. Since there are established measurement procedures for describing a television signal degraded by noise, the effect of digital television interference on an FM television system is described in terms of the apparent baseband signal-to-noise ratio.

Interference was added so as to produce apparent baseband signal to noise ratios of 45, 40 and 35 decibels. The ratio of wanted FM television signal power to interfering digital television signal power, for a specified apparent signal-to-noise ratio, $R_{FM/digital}$, is given by:

$$R_{FM/digital} = \frac{P_{AV\,(\text{FM, wanted})}}{P_{AV\,(\text{digital, interfering})}} \qquad (8)$$

For all measurements, white Gaussian noise was present in the communications channel in addition to the interfering signal.

Results of measurements to determine protection ratios for an FM television link with digitally modulated interferences are given in Fig. 32. The results show that there is a direct relationship between the measured protection ratio and the apparent signal to noise ratio, with protection ratios ranging from 24 to 14 dB for apparent baseband signal to noise ratios ranging from 45 to 35 dB.

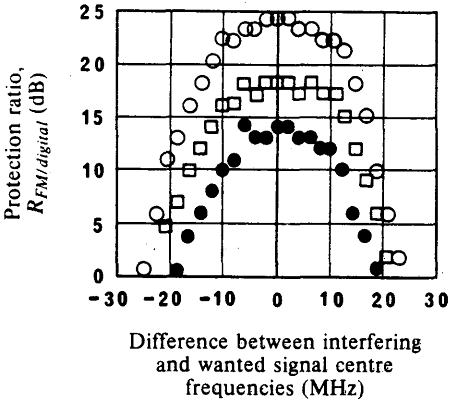


FIGURE 32 – *Apparent FM television system baseband signal-to-noise ratio (unweighted) for 4-PSK modulated digital signal interference*

Interference from a 43 Mbit/s digital television system

○ : 45 dB
☐ : 40 dB
● : 35 dB
Apparent signal-to-noise ratio

The subjective measurements for an FM television signal of system D/PAL subjected to interference by digital signals were carried out in China [CCIR, 1982-86b]. The unwanted signal sharing the same frequency band with the wanted signal was either a single-frequency signal (CW), a PSK signal or an ASK signal. The experiments were carried out according to Recommendations 500-2 and 600. The group of observers consisted of eight expert viewers. Two colour pictures that are standard pictures in China were used in the subjective measurements and the average of the measurement results was taken. The evaluations given by the viewers were only slightly different and have a good repeatability.

The *C/I* ratio for just perceptible interference is defined as the interference protection ratio. The measurement results are shown in Figs. 33 and 34. The results show that the interference from a single-frequency signal is most easily perceived and the protection ratio for a colour picture is about 1 dB higher than that for a black and white picture at zero carrier-frequency difference. There is a maximum at a carrier-frequency difference of 4.4 MHz because the centre frequency of the interference signal is near the sub-carrier frequency of the colour television signal. The protection ratio for PSK (8.448 Mbit/s) signal interference is about 1 dB lower than that for PSK (2.048 Mbit/s) signal interference. Compared with PSK signal interference, the protection ratio required for ASK signal interference is lower by generally less than 1 dB.

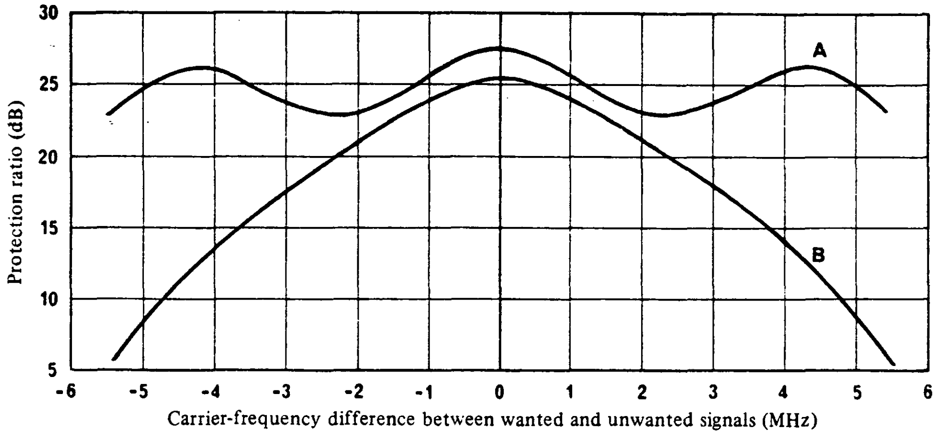


FIGURE 33 – *Protection ratio for just perceptible interference in an FM-TV system (Δf = 8 MHz, peak-to-peak) for CW interference*

A: colour picture

B: monochrome picture

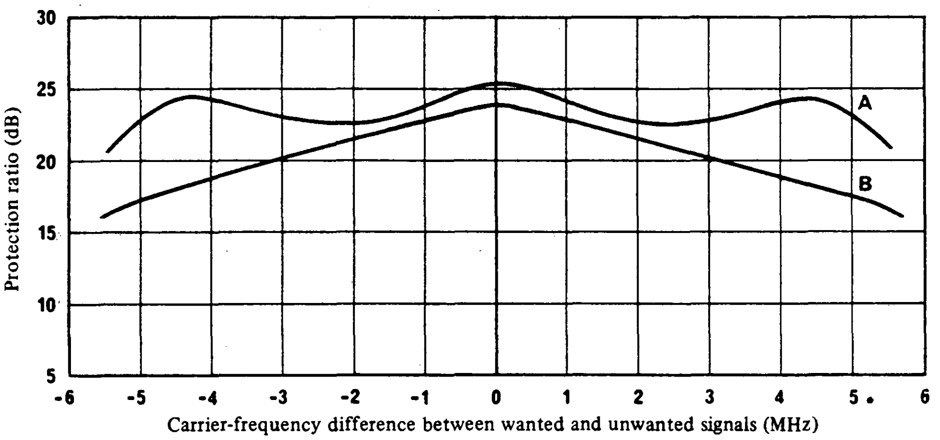


FIGURE 34 – *Protection ratio for just perceptible interference in an FM-TV system (Δf = 8 MHz, peak-to-peak) for PSK (2.048 Mbit/s) signal interference*

A: colour picture

B: monochrome picture

4.2 *Interference to digitally encoded television*

4.2.1 *Protection ratio measurements between digitally encoded television signals and frequency-modulated television signals*

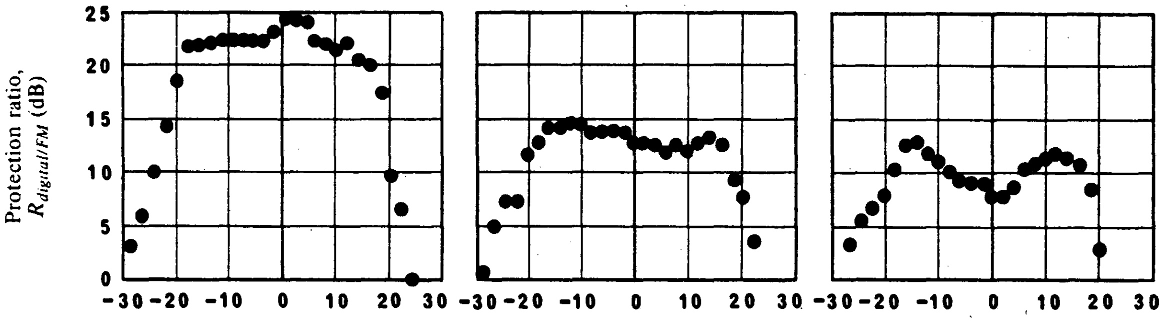
Experiments performed in the USA [CCIR, 1978-82h and Barnes, 1979] for system M/NTSC television included the measurement of protection ratios for digital television with analogue frequency modulation interference.

Additionally, the digital television system used inthese measurements employed one dimensional, fourth order, intraframe, differential pulse code modulation (DPCM), resulting in a data rate of 42.95 Mbit/s for the transmission of a system M/NTSC television signal at high quality. The coded television signal was transmitted using a 4-PSK modulator employing differential coding, and received using a coherent 4-PSK demodulator. The digital television system employed neither error correction nor error concealment circuitry. The characteristics of the digital television and the FM television system are listed in Table XXV.

A bit error ratio of approximately 10^{-8} in the coded digital television signal resulted in short duration impairments to the picture, at an average rate of one every five seconds. The error rate resulted in perceptible, but not annoying, impairments to the picture, as judged by a single expert viewer. For a communication link with ratios of energy per bit to noise power spectral density (E_b/N_0) which, in the absence of any interference, produced error ratios lower than 10^{-8}, FM television signal interference was added so as to raise the error ratio to 10^{-8}. Additional measurements were made to determine the protection ratios which resulted in an error ratio of 10^{-6}. For the specified bit error-ratio, the ratio of wanted digital television signal power to interfering FM television signal power, $R_{digital/FM}$, is given by:

$$R_{digital/FM} = \frac{P_{AV(\text{digital, wanted})}}{P_{AV(\text{FM, interfering})}} \tag{9}$$

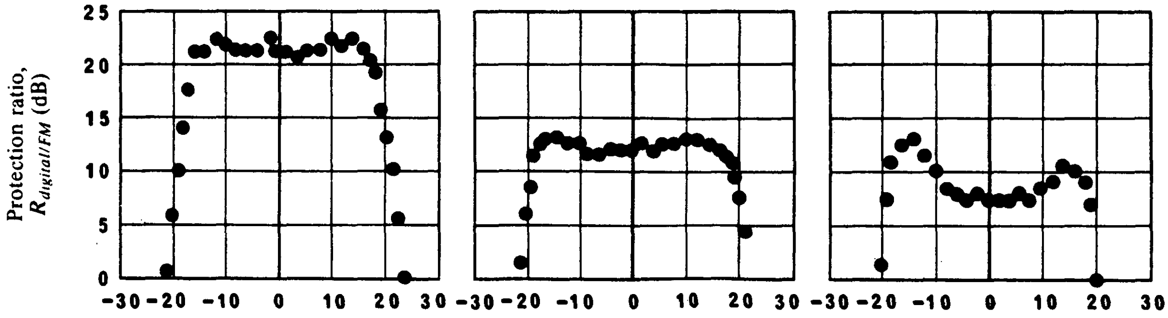
Measured protection ratios for FM television interference to a digital television system are shown in Fig. 35 for a bit error-ratio of 10^{-8} in the digital system, and Fig. 36 for a bit error-ratio of 10^{-6}. Protection ratios are shown for three values of link E_b/N_0. In the absence of any interference, a value of E_b/N_0 = 15.1 dB results in an error ratio of approximately 10^{-9}, and a value of E_b/N_0 = 13.6 dB results in an error ratio of approximately 10^{-7}. As shown in the figures, a small increase in E_b/N_0 (from 15.1 to 18.1 dB (for 10^{-8} error ratio) or from 13.6 to 16.6 dB (for 10^{-6} error ratio)) results in a large reduction in the measured protection ratios (9 to 10 dB). A large additional increase in E_b/N_0, however, results in only a 1 to 2 dB reduction in the measured protection ratios.



Difference between interfering and wanted signal centre frequencies (MHz)

a) E_b/N_0 = 15.1 dB b) E_b/N_0 = 18.1 dB c) E_b/N_0 = 40 dB

FIGURE 35 – *Measured protection ratios for 10^{-8} bit error ratio in a digital television system for interference from an FM television system*



Difference between interfering and wanted signal centre frequencies (MHz)

a) E_b/N_0 = 13.6 dB b) E_b/N_0 = 16.6 dB c) E_b/N_0 = 40 dB

FIGURE 36 – *Measured protection ratios for 10^{-6} bit error ratio in a digital television system for interference from an FM television system*

4.2.2 *Protection ratio measurements between digitally encoded television signals and other digitally encoded signals (television and data)*

Measurements performed in the United States of America for system M/NTSC have determined protection ratios for digitally encoded television with digital television and digital data interference.

The wanted digital television system was the 42.95 Mbit/s DPCM system described in § 4.2.1 of this Annex. The interfering digital television system was a two-dimensional orthogonal transform encoder with a data rate of 16.1 Mbit/s resulting in transmission of a system M/NTSC television signal at high quality. The encoded television signal was transmitted using a 4-PSK modulator employing differential encoding. The digital data interferer was generated using a pseudo-random data generator. This digital signal was modulated using an identical D-4-PSK modulator as the one used with the digital television interferer. In this portion of the test, an interferer data rate of 16.1 Mbit/s was used for the digital data. The characteristics of the desired digital television system are listed in Table XXV. The characteristics of the interfering systems (digital television and data) are listed similarly in Table XXVI.

TABLE XXVI – *Characteristics of signals*

System parameter	16 Mbit/s digital TV	PRBS ([1])	
Modulation	D-4-PSK ([2])	D-4-PSK ([2])	
Signal bandwidth (transmit filter) (MHz)	25 (5 pole, low ripple Chebyshev filter)	(Transversal filter internal to modulator)	
Receiver filter (MHz)		13.4 19.0 30.1	(5 pole, low ripple Chebyshev filters)
Signal bit rate (Mbit/s)	16.11	8.0 16.11 43.0	

([1]) Pseudo-random bit sequence.

([2]) D-4-PSK: Differential 4-PSK.

Section 4.2.1 of this Annex indicates that for the wanted-signal television system, a bit error ratio of 10^{-8} produced interference which was perceptible, but not annoying. However, to aid in the measurement process, a bit error ratio of 2×10^{-8} was used in determining the protection ratio. At this bit error ratio a short duration impairment to the picture occurred at an average rate of one every 2 s. Protection ratio levels were found not to differ significantly (< 1 dB) from those obtained with a 10^{-8} bit error ratio. To allow headroom for interference to be added, the communication link energy contrast ratio was selected such that the bit error ratio, in the absence of any interference, was approximately 10^{-9}. An energy contrast ratio (E_b/N_0) of 14.7 dB produced a bit error ratio of approximately 10^{-9}.

Figure 37 shows that the interference to the DPCM digital television system was (approximately) the same for both the 16.1 Mbit/s digital television system and PRBS data interferers. The co-channel protection ratio is approximately 22 dB.

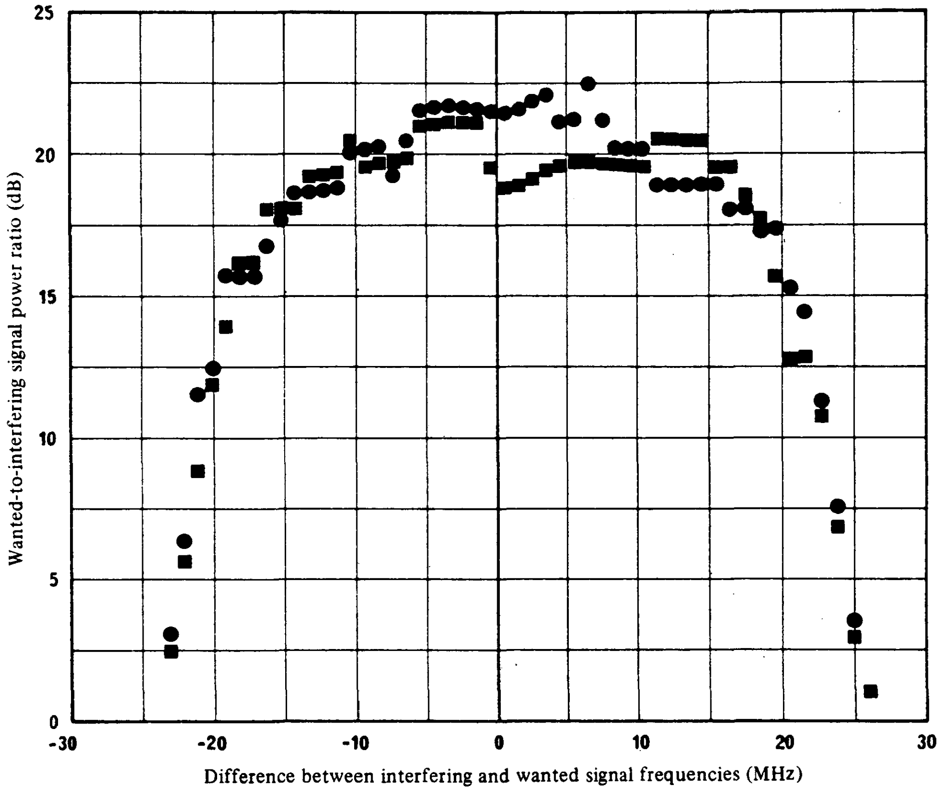


FIGURE 37 – *16 Mbit/s interference on 43 Mbit/s digital television*

E_b/N_0 = 14.7 dB

BER = 2×10^{-8}

Interfering system:

■ : 16 Mbit/s digital television

● : 16 Mbit/s pseudo-random bit sequence

4.2.3 *Protection ratio measurements between digitally encoded data signals and digitally encoded television signals*

Experiments performed in the United States of America included the measurement of protection ratios for D-4-PSK modulated data signals with digital television interference.

The digital systems used were those described in § 4.2.1 and 4.2.2 of this Annex. The wanted system consisted of pseudo-random data (PRBS) which was modulated for transmission using a D-4-PSK modulator and received using a coherent 4-PSK demodulator followed by an error detector. Wanted system data rates of 43 Mbit/s and 16.1 Mbit/s were used. Interferer digital television was supplied by the 42.95 Mbit/s DPCM system and the 16.1 Mbit/s orthogonal transform system previously described.

The purpose of the tests was to determine the trade-offs between the energy contrast ratio (E_b/N_0) and carrier-to-interference ratio (C/I) for a given level of bit error ratio performance. Additionally, the significance of relative bandwidth between the wanted and interfering signals on the allowable C/I was determined.

Table XXVII lists co-channel interference protection ratio levels for 16 Mbit/s digital television interference on a 43 Mbit/s pseudo-random bit sequence (PRBS). The operating condition for the wanted system was varied by changing the E_b/N_0. The values of E_b/N_0 for which measurements were taken were 13.3 dB, 16.3 dB and 40.0 dB (E_b/N_0 = 13.3 dB corresponds to a channel bit error ratio of approximately 1×10^{-9}). For each of these operating conditions, interference was added until the desired performance level (in terms of bit error ratio) was measured at the error detector. Three performance levels were used: 2×10^{-6}, 2×10^{-7} and 2×10^{-8}. Two trends are observable from the data in Table XXVII:

- within a given BER performance level (e.g. 2×10^{-8}) as the operating condition (i.e. E_b/N_0) increases the required protection ratio decreases;
- for a specified operating condition (e.g. E_b/N_0 = 13.3 dB) the required protection ratio increases as the BER performance level approaches the channel error rate.

Both of these trends are the result of the trade-off that exists in digital systems between noise and interference. The better the channel characteristics (i.e. lower noise, higher E_b/N_0) the more interference that can be tolerated.

TABLE XXVII – *Co-channel protection ratios for various energy contrast ratios and bit error ratio performance levels.*

Wanted system – 43 Mbit/s PRBS;*

interfering system – 16 Mbit/s digital television

E_b/N_0	BER performance	Co-channel protection ratio
13.3	2×10^{-6}	15.5
16.3	2×10^{-6}	12.1
40.0	2×10^{-6}	9.3
13.3	2×10^{-7}	18.0
16.3	2×10^{-7}	14.0
40.0	2×10^{-7}	10.0
13.3	2×10^{-8}	21.2
16.3	2×10^{-8}	14.8
40.0	2×10^{-8}	10.0

* PRBS: pseudo-random bit sequence.

Figure 38 gives protection ratios versus frequency offset for the three BER performance levels in Table XXVII (2×10^{-6}, 2×10^{-7}, 2×10^{-8}). The relative difference in protection ratio between the three BER performance levels is generally maintained for any offset.

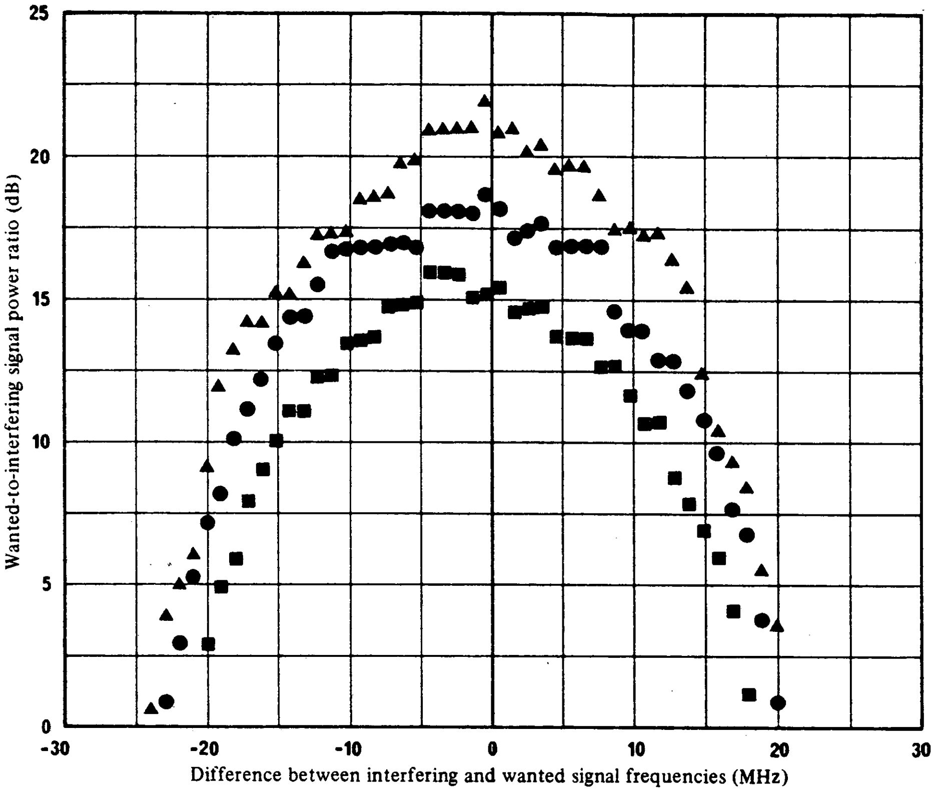


FIGURE 38 – *16 Mbit/s digital television interference on 43 Mbit/s pseudo-random bit sequence*

E_b/N_0 = 13.3 dB

■ : BER = 2 X 10^{-6}
● : BER = 2 X 10^{-7}
▲ : BER = 2 X 10^{-8}

Figure 39 shows the significance of the relative bandwidth between the wanted and interfering signals on allowable *C/I*. Two results can be obtained from the figure:

- interfering signals with a bandwidth less than the desired signal require greater co-channel protection than the interfering signals which have a wider bandwidth than the desired signal;
- the fall-off in protection ratio versus frequency offset is steeper when the interfering data rate is less than the wanted signal rate.

Both of these results have to do with the amount of interfering signal power present in the main spectral lobe of the wanted signal. For a narrow interferer most of the interfering signal power is within the main lobe of the wanted signal and therefore requires more co-channel protection. However, as the wanted and interfering signals are offset in frequency the effect of the narrow interfering signal drops out more rapidly than with a wider interferer.

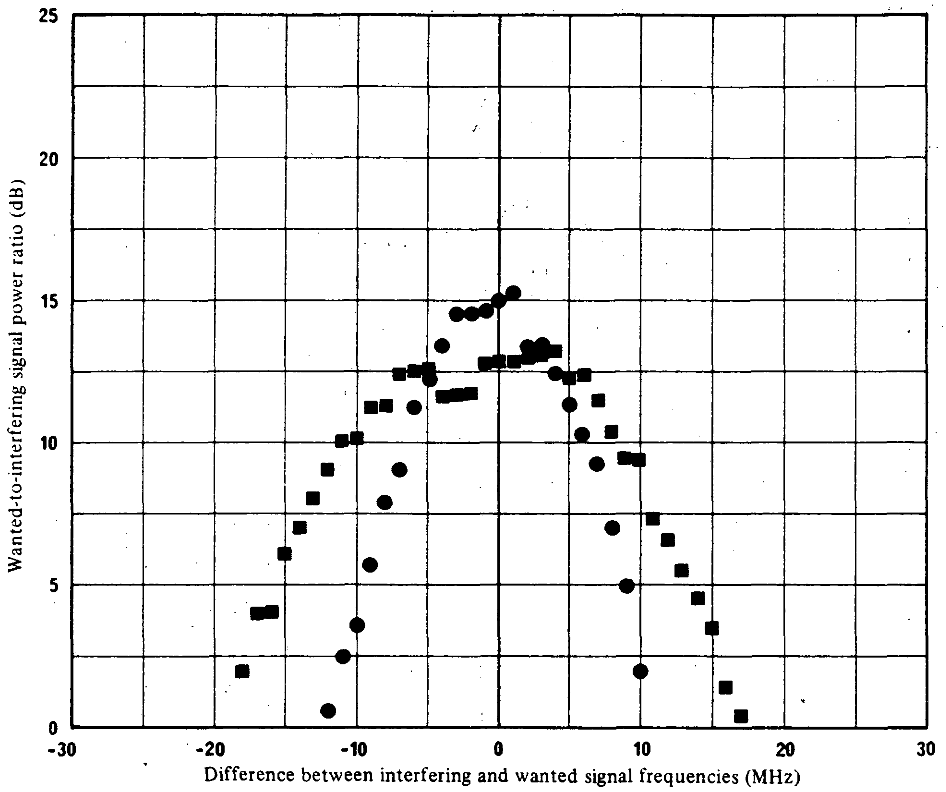


FIGURE 39 – *43 Mbit/s and 16 Mbit/s digital television interference on 16 Mbit/s pseudo-random bit sequence*

E_b/N_0 = 13.3 dB
BER = 2×10^{-6}

Digital television rates:
■ : 43 Mbit/s
● : 16 Mbit/s

5. Protection ratios for 625-line system K/SECAM

Measurements in the USSR [CCIR, 1970-74c] determined protection ratios for frequency-modulation signals against interference by CW, amplitude-modulation, vestigial-sideband and frequency-modulation signals.

5.1 *Measurement conditions*

Protection ratios were determined under the following conditions:

- peak deviation of the wanted frequency-modulation television signal (allowing transmission of sound component on a sub-carrier with a video signal/sound-component signal ratio of 4.5/1) was taken as ± 11 MHz;
- the ratio of the wanted signal to continuous random weighted noise at the frequency-modulation television receiver output was fixed at 57 dB (ratio of picture signal peak-to-peak amplitude, excluding synchronizing pulses, to the r.m.s. noise voltage in the frequency band from 10 kHz to the upper nominal limit of the video-frequency band). To establish this value, use was made of a low-pass filter and a weighting network with characteristics similar to those described in Recommendation 567, Annexes II and III for system K;
- coloured and monochrome test charts, coloured bars and real colour pictures were used for the tests;

- a CW, an amplitude-modulation television signal, and a frequency-modulation television signal were used as interfering signals;
- the video signal of the monochrome test chart was used as modulating signal for the interfering amplitude-modulation and frequency-modulation television signal;
- a binary statement of the type "Yes-No" was used to assess picture quality;
- the test group consisted largely of non-expert viewers. Expert viewers were used to determine the proposed central assessments. The test group consisted of ten to fifteen persons;
- dimensions of test picture: 475 × 375 mm;
- viewing distance: 5 to 6 times the picture height;
- the centre of the screen of the test television receiver was set at eye level of the observers;
- measurements were carried out in conditions of partial darkness;
- the level of illumination of the screen by external light sources did not exceed 0.01 of maximum screen brightness;
- sequence of changes in noise level: random, in 3 dB steps; in each measurement series, the observers were shown five values of signal-to-noise ratio. In consequence, the limits of the variation in noise level gave rise in each case to variations of ± 1 grade in the assessment picture quality;
- protection ratio measurements were made without a band-pass filter at the input to the frequency modulation receiver.

5.2 *Measurement results*

The results of the protection ratio measurements as a function of detuning of the carrier frequencies (carrier-frequency offset) of the wanted and unwanted signals, for transmission in colour (colour bars, colour test chart and real colour picture) are shown in Figs. 40 to 42, while Fig. 43 shows the results of transmission of a monochrome picture (test chart).

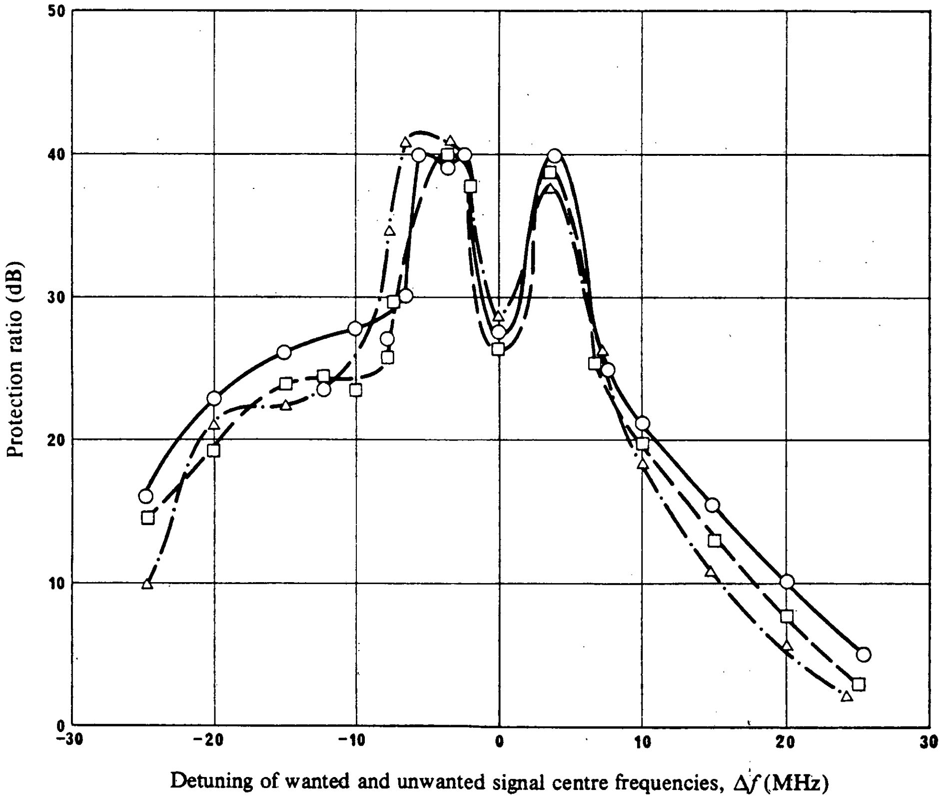


FIGURE 40 – *Frequency-modulation protection ratio against CW interference*

—○— : colour bars
— —□— — : real colour picture
· —— · △ · —— · : colour test chart

modulation on wanted signal

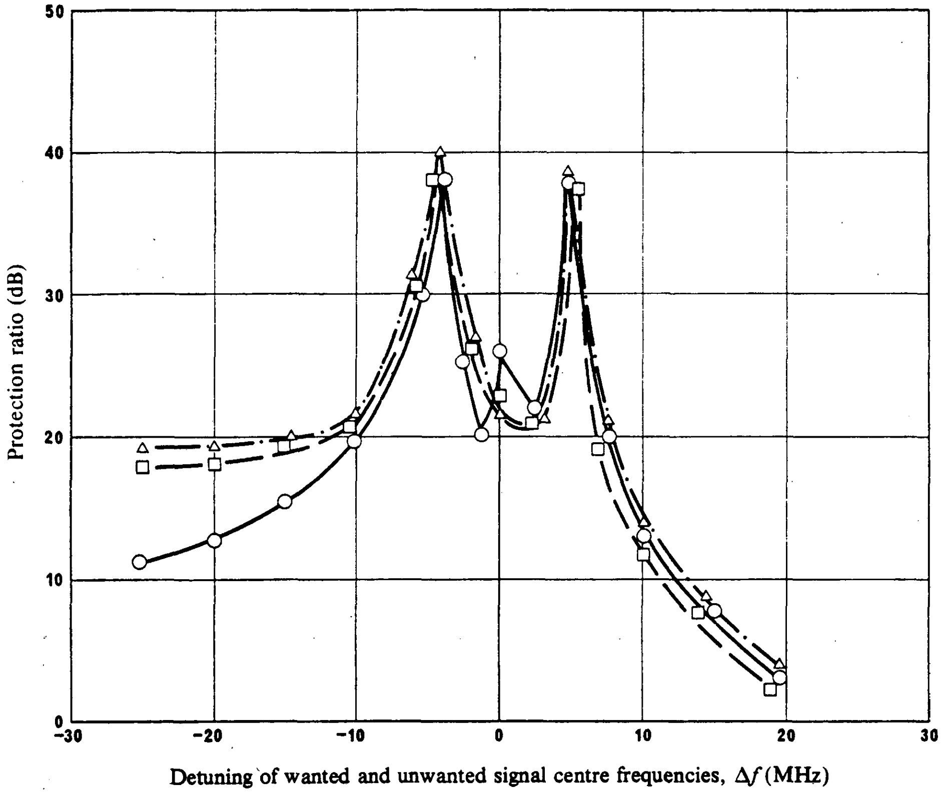


FIGURE 41 – *Frequency-modulation protection ratio against amplitude-modulation, vestigial-sideband interference*

——○—— : colour bars		
— —□— — : real colour picture		modulation on wanted signal
·—·△·—· : colour test chart		

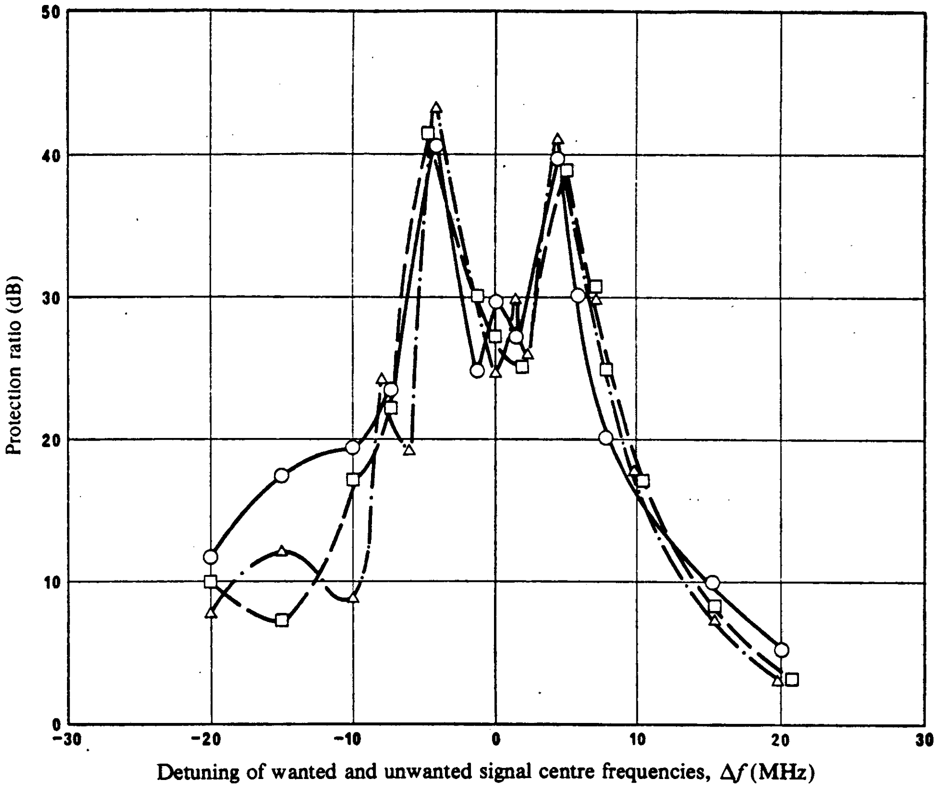


FIGURE 42 – *Frequency-modulation protection ratio against frequency-modulation interference*

—○— : colour bars
– –□– – : real colour picture
·—·△·—· : colour test chart

modulation on wanted signal

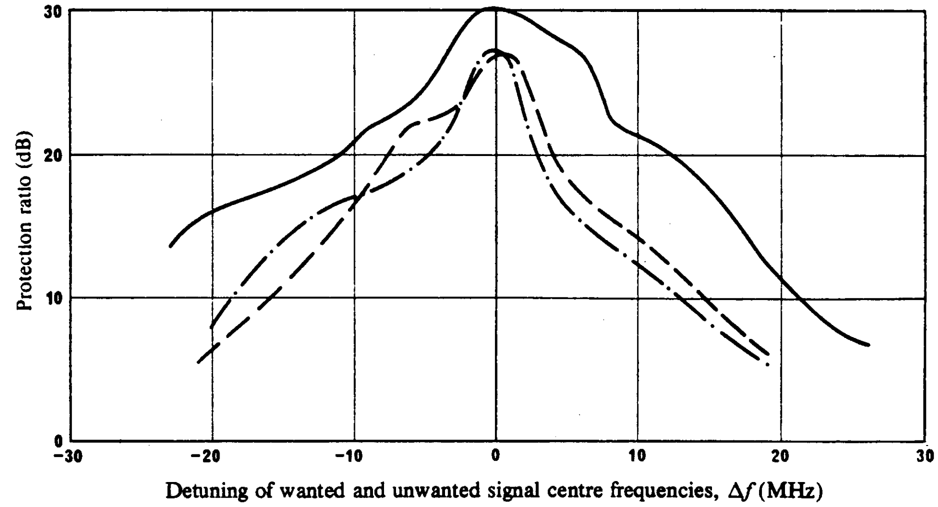


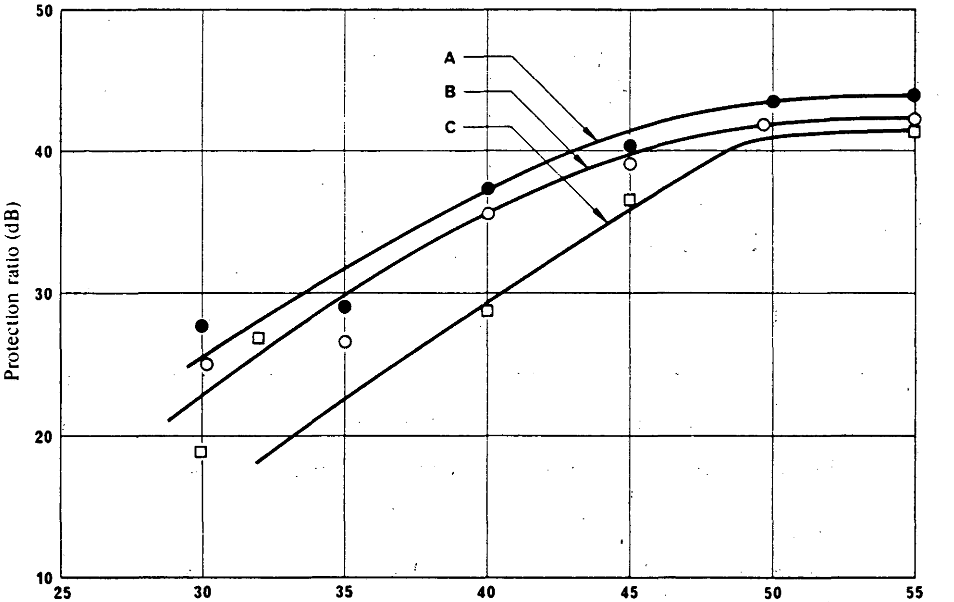
FIGURE 43 – *Protection ratios in the case of frequency-modulation transmission of a monochrome picture (test chart)*

——— : frequency-modulation television interference
– – – – : amplitude-modulation television interference
·—·—·—· : CW interference

modulation on interfering signal

Figure 40 describes the effect of CW interference on the wanted frequency-modulation television signal, Fig. 41, the effect of interference in the form of an amplitude-modulation signal and Fig. 42, the effect of interference in the form of a frequency-modulation signal with a peak frequency deviation ± 11 MHz.

Figure 44 shows the measurement results for protection ratios as a function of the level of random noise at the output of the frequency-modulation television receiver. A colour test chart was used in recording these correlations, while the detuning between the wanted and unwanted signal carriers was fixed by the maximum perceptibility of interference on the screen of the test television receiver.



Signal-to-random noise ratio at the output of the frequency-modulation television receiver (dB)

FIGURE 44 – *Frequency-modulation protection ratios as functions of signal-to-noise ratio*

A: CW interference
B: amplitude-modulation television interference
C: frequency-modulation interference

5.3 *Conclusions*

The following conclusions can be drawn from these results:

In the case of the wanted and unwanted signals in the same frequency channel (with identical centre frequencies), the protection ratio for frequency-modulated signals does not exceed 30 dB, for the reception of both monochrome and colour television signals, and is virtually independent of the picture content.

If the wanted and unwanted signal centre frequencies are detuned, the protection ratio for the reception of monochrome television signals decreases.

For the reception of colour television signals, the protection ratio with frequency detuning initially rises, reaching a maximum (40 to 42 dB) with a detuning of ± 4 to 5 MHz, and then falls. This is due to the occurrence of wanted and unwanted signal frequency beat products in the transmission of colour television signals.

The value of the protection ratio depends basically on the random noise level in the channel at ratios of less than 50 dB between the wanted signal and the weighted r.m.s. noise voltage at the frequency-modulation television receiver output, and is independent of the level of random noise with ratios equal to or greater than 50 dB.

6. Accommodation of space operations service functions (TTC) within the broadcasting-satellite and feeder-link service bands

The use of the guard bands assigned by feeder-link and down-link plans to the broadcasting-satellite service for space operation service functions, raises the problem of compatibility between the two services. Studies leading to agreed protection ratios are required in order to protect television signals, which are transmitted in the nearby channel, from such interference sources. The protection ratio is 20 dB for feeder links; further details may be found in Report 1076.

7. Discussion of the results

Comparisons of the data presented in this Annex are difficult because of the varying test conditions used. For some parameters in the case of interference on an amplitude-modulation, vestigial-sideband system, correction factors have been deduced to enable results to be referred to the standardized conditions established in Recommendation 600. These parameters relate to:

- deviation;
- pre-emphasis;
- quality grade;
- energy dispersal.

For frequency-modulation systems some factors in determining the required protection ratio for common radio-frequency co-channel sharing are:

- quality grade of the protection ratio assessment;
- the picture signal-to-noise ratio of the wanted signal;
- the deviation of the wanted signal;
- the programme content of both wanted and unwanted signals.

The deviation and the signal-to-noise ratio for the unwanted signal have only minor effects upon the protection ratio. Over the range of deviations studied, the protection ratio decreases with increasing deviation of the wanted signal. Wanted signals which have large areas of colour or uniform luminance are more susceptible to interference; similarly unwanted signals having large single spectral components are more perceptible.

Results for 525-line system M/NTSC and 625-line system K/SECAM show that noise in the wanted signal tends to mask coherent interference by degrading the quality of the uninterfered with portion of the picture and by breaking up any interference patterns. Other measurements on 625-line systems show little masking by noise. It is possible that this apparent difference in system vulnerability to interference can be explained in terms of the nature of the pictures carried by the wanted and interfering signals in the various measurements and the use of different noise-weighting when specifying the luminance-to-weighted-noise ratio in different television systems. A definitive answer must await additional test data and analysis.

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[1970-74]: **a.** 11/107 (France); **b.** 11/339 (France); **c.** 11/332 (USSR); **d.** 11/317 (EBU).

[1974-78]: **a.** 11/40 (Japan); **b.** 10/42 (Japan); **c.** 11/25 (EBU); **d.** 11/101 + 11/114 (France).

[1978-82]: **a.** 11/91 (USA); **b.** 10-11S/157 (USSR); **c.** 11/116 (USSR); **d.** 10-11S/61 (Canada); **e.** 10-11S/19 (Japan); **f.** 10-11S/138 (USA); **g.** 10-11S/149 (France); **h.** 11/32 (USA).

[1982-86]: **a.** 10-11S/49 + Corr.1 (USA); **b.** 10-11S/202 (China (People's Republic of)).

ANNEX II

SUGGESTED PROTECTION RATIO MEASUREMENTS

In digital television transmission, protection ratio measurements are needed to determine the susceptibility of digital systems to unwanted analogue modulated signals and unwanted digital signals. The following test matrix is suggested:

Wanted signal	*Unwanted signal*
Digital	Digital
Digital	FM
FM	Digital
Digital	AM-VSB
AM-VSB	Digital

The test conditions and procedures for the determination of the protection ratio recommended in Recommendation 600 have not been formulated specifically for digital modulation. Further studies are needed to define more precisely the test conditions and procedures for digital modulation. In the meantime, priority should be given to performing tests involving digital modulation techniques under the conditions given in Recommendation 600.

REPORT 951*

SHARING BETWEEN THE INTER-SATELLITE SERVICE AND THE BROADCASTING-SATELLITE SERVICE IN THE VICINITY OF 23 GHz

(Question 1/10 and 11)

(1982)

1. Introduction

The WARC-79 has allocated the band 22.5 to 23 GHz in Regions 2 and 3 to the broadcasting-satellite service (BSS), part of which, namely the band 22.55 to 23 GHz, is shared with, among others, the inter-satellite service (ISS).

On the basis of studies carried out in the USA and Japan this Report examines parametrically the orbital spacing required between space stations employing inter-satellite links and broadcasting satellites with respect to interference into the ISS link [CCIR, 1978-82a and b] and interference into the BSS receiver [CCIR, 1978-82c].

These analyses use new system characteristics from an example in Report 215 for high-definition TV using an RF bandwidth of 125 MHz. However, an example for conventional TV is also given in Report 215. The analyses presented in this Report can also be applied to that case. Preliminary calculations done in the United States show that the high-definition case presented here would prove to be the more conservative.

The parameters for the ISS assumed in the two analyses are given in §§ 2.1 and 3.1. As the definition of the ISS is in an early stage, the parameters assumed in the two sections are different. Further study is required.

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

2. Interference to the inter-satellite service by emissions in the broadcasting-satellite service

2.1 *Characteristics of the inter-satellite service*

Inter-satellite links in the 23 GHz band are expected to be primarily over relatively short spans of orbital arc, for example 4°, based on the results of analysis presented in Report 451.

The inter-satellite link receiving system is assumed to consist of an antenna with a gain of 52 dB and a circular beam of 0.4° at the 3 dB beamwidth, and a receiver with an operating noise temperature of 1000 K. The off-axis antenna discrimination is assumed to conform to that given in Report 558. The receiver bandwidth is 850 MHz.

2.2 *Characteristics of the broadcasting-satellite service*

Table XIVa of Report 215 provides example system characteristics of a broadcasting-satellite system for community reception operating at 22.75 GHz. In this analysis, an RF bandwidth of 125 MHz for high-definition FM-TV transmissions and beam centre e.i.r.p. of about 78 dBW have been assumed. In addition, a satellite transmitting antenna beamwidth of 1° has also been assumed since it may result in practical worst-case interference to the ISS receiver. The gain of the antenna is 44 dB, and feed and filter losses are 1 dB, thereby requiring 2.5 kW (34 dBW) of radio-frequency power at the antenna feed.

2.3 *Interference analysis*

The interference geometry is shown in Fig. 1. ISS 2 is transmitting to ISS 1 which is located θ_2 degrees of longitude away. The BSS is located θ_1 degrees of longitude away from ISS 1; and is transmitting to a service area on the equator whose beam centre is γ_0 degrees from nadir.

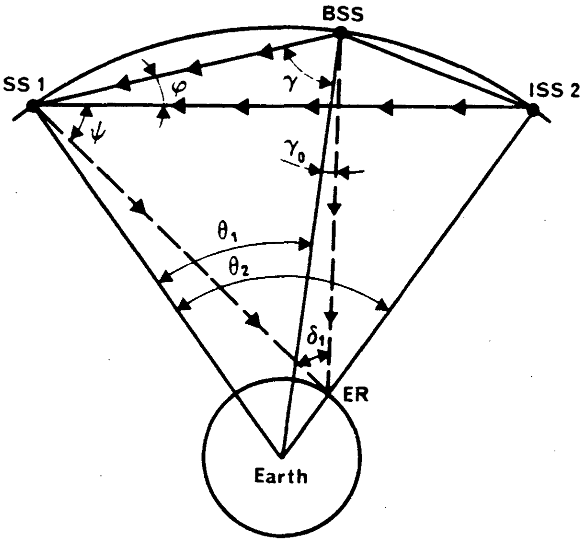


FIGURE 1 – *Interference geometry*

ER: earth station receiver

δ_1: angular separation between the satellites ISS 1 and BSS as seen at the earth station

ψ: angular separation between ISS 2 and the earth station as seen from ISS 1

The interference to the ISS 1 receiving antenna appears at an off-axis angle of φ degrees. Similarly, the e.i.r.p. toward ISS 1 from the BSS is at an off-axis angle of $\gamma + \gamma_0$.

For orbital separations between the ISS and BSS less than 134°, the gain of the BSS satellite transmitting antenna in the direction of the ISS receiver will be isotropic regardless of the BSS antenna pointing direction (γ_0).

Analysis of the interference to noise ratio (I/N) at ISS 1 yields:

$$I/N = R_0 \frac{p_3}{T_1 B_1 f^2}$$

where

$$R_0 = \frac{c^2}{(4\pi)^2 k} \frac{G_1 D_1(\varphi)}{x^2}$$

and

p_3 : the BSS transmitted power delivered to antenna (W)

T_1 : the ISS receiver noise temperature (K)

B_1 : the ISS receiver noise bandwidth (Hz)

f: the frequency (Hz)

c: the velocity of light (m/s)

k: Boltzmann's constant (J/K)

G_1 : the ISS 1 antenna on-axis gain

$D_1(\varphi)$: the ISS 1 antenna discrimination toward BSS

x: the distance between BSS and ISS 1 satellites (m).

The parameter R_0 involves a number of constants, and three terms that depend on the ISS antenna half-power beamwidth and BSS-ISS 1 separation. For given values of these parameters, R_0 has been evaluated and is shown in Fig. 2.

For satisfactory operation, it is assumed that I/N must be less than or equal to a specific value, $(I/N)_0$. The requirement at the ISS receiver for frequency sharing with the BSS is then:

$$I/N = R_0 \frac{p_3}{T_1 B_1 f^2} \leqslant (I/N)_0$$

or

$$R_0 \leqslant (I/N)_0 \frac{T_1 B_1 f^2}{p_3}$$

In decibel notation,

$$10 \log R_0 \leqslant 10 \log (I/N)_0 + 10 \log T_1 + 10 \log B_1 + 20 \log f - 10 \log p_3$$

This equation, coupled with the curves in Fig. 2, and known characteristics of ISS and BSS systems, allows evaluation of the sharing possibilities.

2.4 *Results*

The BSS and ISS characteristics discussed earlier are summarized:

T_1 = 1000 K

B_1 = 125 MHz (see below)

f = 22.75 GHz

p_3 = 2500 W

It is assumed that the ISS bandwidth is greater than 125 MHz and has potential BSS interferers throughout. So the calculation is based upon one interferer per 125 MHz of bandwidth. $(I/N)_0$ is assumed to be one-tenth, for negligible interference.

Then:

$$R_0 \leqslant 274 \quad \text{dB}$$

This value is shown in Fig. 2.

Three cases are analyzed in Fig. 2. Spacings between satellites in the ISS have been assumed to be 4°, 10° and 20°.

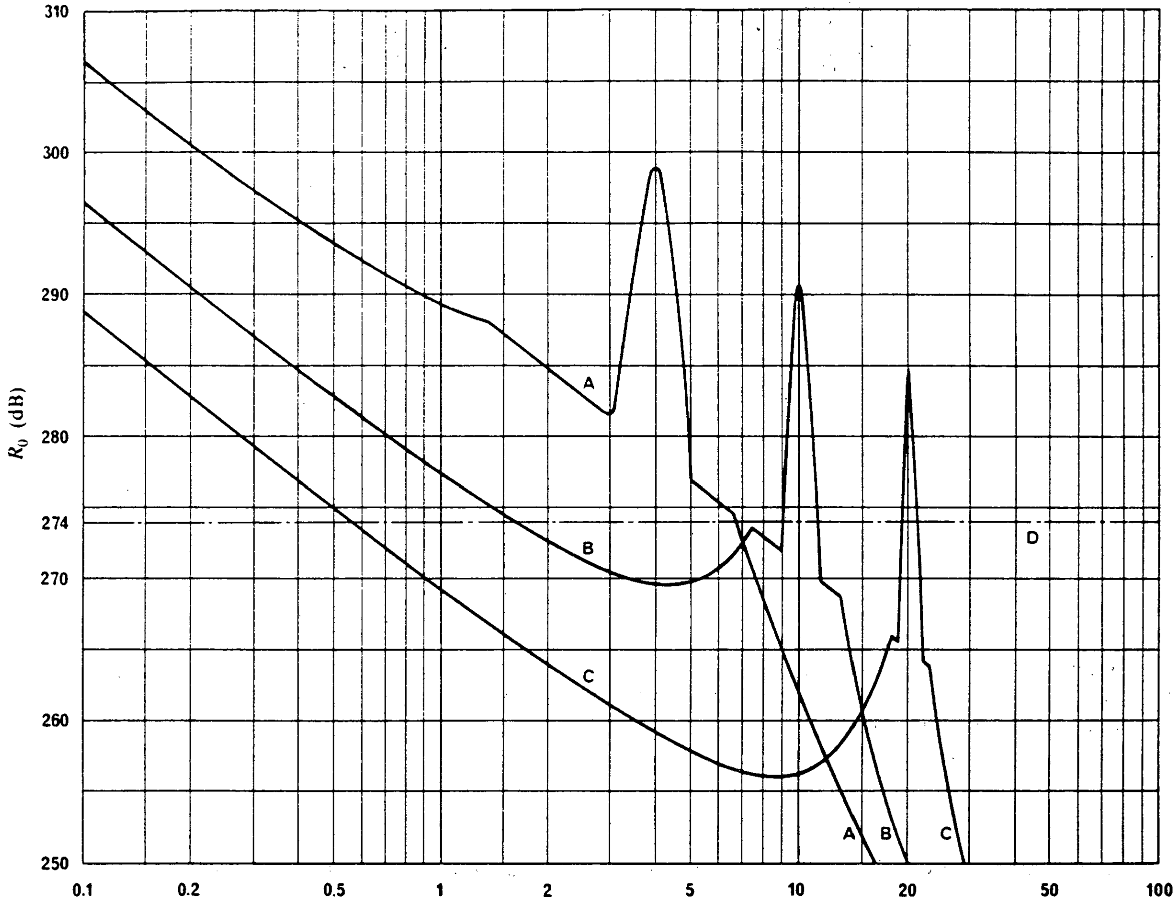


FIGURE 2 – *Parameter R_0 as a function of BSS-ISS satellite spacing for ISS satellite antenna gain = 52 dB*

Curves A: ISS satellite spacing = 4°
B: ISS satellite spacing = 10°
C: ISS satellite spacing = 20°

D: region of negligible interference (below the line marked D)
R_0 is defined by an equation in § 2.3

For a 4° geocentric separation between ISS 1 and ISS 2, it is not feasible to place a BSS satellite closer than about 7° to realize a reasonable I/N of less than -10 dB.

Increasing the geocentric separation between ISS 1 and ISS 2 to 10° permits placing a single BSS satellite between them and still realize an I/N of less than -10 dB. A separation between 1.6° and 9° is required.

Increasing the geocentric separation between ISS 1 and ISS 2 to 20° permits placing a number of BSS satellites in the range between 0.6° and about 19° and still realize a single entry I/N of at least -10 dB.

Figure 3 is used to illustrate what may be called the "displacement effect" in the evolution of the deployment of ISS links. Assume that the orbital separation θ_1 between ISS 1 and ISS 2 is 4°, that ISS 2 is transmitting to ISS 1, and that according to curve A of Fig. 2, the orbital separation between BSS and ISS 1 is 7° so that the I/N at the input to the ISS 1 receiver is at most -10 dB. At some later time, a second ISS link is added such that ISS 2 transmits also to ISS 3 as shown in figure 3. At an orbital separation of 4° between ISS 2 and ISS 3, the I/N at the ISS 3 receiver will be about 6 dB, a 16 dB change in R_0 as shown by curve A of Fig. 2.

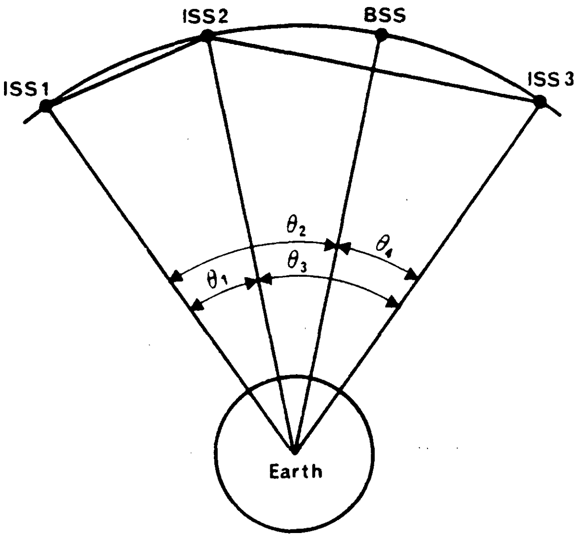


FIGURE 3 – *Displacement effect*

One method to reduce the I/N at the input to the ISS 3 receiver to at most −10 dB is to increase the orbital separation between ISS 2 and ISS 3 to 10°. At this separation, the I/N will be about −12 dB at the input to the ISS 3 receiver. For this method, the net effect of adding the second ISS link is to displace ISS 3 from its preferred 4° spacing to 10° spacing.

3. Interference to the broacasting-satellite service by emissions in the inter-satellite service

3.1 *Characteristics of the inter-satellite service*

Two types of inter-satellite links, i.e., short and long ISS links, are assumed, as described in Report 451. For short ISS links two types of satellite-borne antennas, tracking and non-tracking, are considered. For long ISS links the system parameters are assumed to be based on the examples of the short ISS links.

In the analysis it is assumed that the maximum e.i.r.p. from ISS stations is about 55 to 75 dBW for short ISS links with tracking antennas, 78 to 80 dBW with non-tracking antennas and 78 to 90 dBW for long ISS links, with an antenna diameter of 1 m, and a radio-frequency bandwidth of 100 MHz. Table I indicates the required satellite antenna beamwidth for short link ISS with non-tracking satellite antennas, and Table II shows the required antenna beamwidth in relation to pointing error versus satellite spacing (Table III, Annex I to Report 451).

TABLE I – *Required satellite antenna beamwidth for short link ISS with non-tracking satellite antennas*

Orbital separation between the two satellites (degrees)	2	3	4	6	10	15	20
Required antenna beamwidth (degrees)	12.98	8.47	6.33	4.25	2.64	1.85	1.46

TABLE II – *Required antenna beamwidth in relation to pointing error versus satellite spacing*

Spacing*	Effective pointing error*	Required antenna beamwidth
2°	1.01°	2.02°
3°	0.833°	1.67°
4°	0.739°	1.48°
5°	0.693°	1.39°

* (Table III, Annex I to Report 451)

3.2 *Characteristics of the broadcasting-satellite service*

As an example the system characteristics of a broadcasting-satellite system are assumed, with wide-band analogue modulation suitable for use for, among other things, high definition television in the future, as given in Report 215, Table XIVa. The BSS receiving system is assumed to consist of an antenna of 0.8 m diameter (beamwidth of 1.2°) and an operating noise temperature of 1100 K. The off-axis antenna discrimination is assumed to conform to that given in Report 558. In the absence of other data the carrier-to-interference ratio required for protecting the BSS is assumed to be 40 dB.

3.3 *Interference analysis and results*

The interference geometry is shown in Fig. 1. Three cases have been analyzed with the results shown in Fig. 4 for worst case interference to the BSS receiver (ER). Short ISS links with tracking antennas (Curve A with $\theta_2 < 20°$) and non-tracking antennas (Curve B) and long ISS links (Curve A with $\theta_2 > 60°$) are assumed.

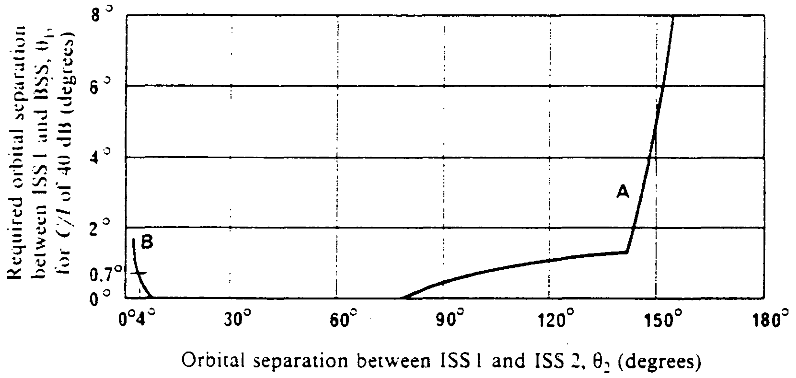
It is seen from the figures that for the short link ISS with tracking satellite antennas there should be no interference at the BSS receiver. However, for short link ISS with non-tracking satellite antennas some interference may arise at the BSS receiver, when θ_2 is less than about 6° and θ_1 is 0°, or when θ_2 is about 4° and θ_1 is less than 1° (as an example), when the ISS antenna beamwidth has to cover excursions of the two satellites with station-keeping accuracy of ± 0.1° for north-south and east-west directions and satellite attitude errors of ± 0.15°. If the ISS satellites with non-tracking antennas have pointing errors as indicated in Table II, there should be no interference at the BSS receiver. For long ISS links the worst interference ratios may become less than 40 dB, for θ_2 greater than 80° and $\theta_1 \approx 0°$.

4. **Conclusions**

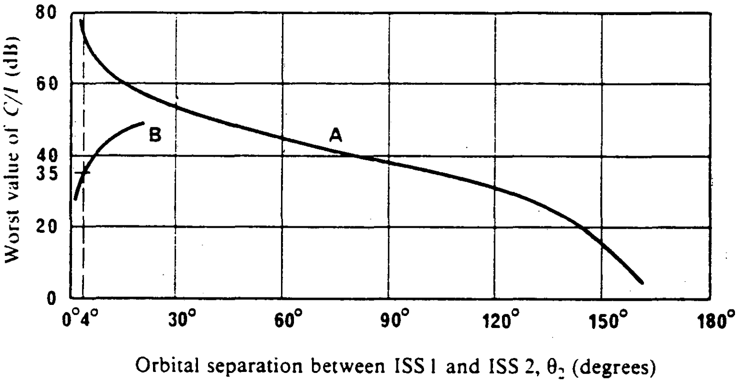
For the technical parameters assumed in this study, which may change in the future, it is concluded that:

- for short ISS links, where the orbital separation is on the order of 4°, it may not be desirable to place a BSS in between; it may be more desirable to place the broadcasting satellite outside the orbital arc occupied by the ISS satellites.
- for ISS orbital separations of 10° and greater, it is possible to place the broadcasting satellite in between. As the ISS orbital separation increases, the range over which broadcasting satellites may be accommodated within the orbital arc between the ISS satellites, and therefore their number, increases.
- as for interference to the BSS receiver by emissions in the ISS, there may be no interference by short ISS links with tracking antennas; however, the worst case of interference may arise from short ISS links with non-tracking antennas for an orbital separation between two ISS satellites less than 6° and between two satellites in the BSS and ISS nearly equal to 0°. If the ISS satellites with pointing errors are as indicated in Table II, there may be no interference.

Additional study is required to determine the amount of interference for broadcasting satellites and ISS satellites of different characteristics.



a) θ_2 as a function of orbital separation, θ_1, between ISS 1 and BSS, for a value of *C/I* of 40 dB



b) θ_2 as a function of *C/I* for $\theta_1 = 0°$

FIGURE 4 – *Orbital separation between two ISS satellites, θ_2, and the worst value of interference ratio, C/I at the BSS receiver*

Curves A: ISS with tracking satellite antennas
B: ISS with non-tracking satellite antennas

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[1978-82]: **a.** 10-11S/26 (USA); **b.** 10-11S/136 + Add. 1 (USA); **c.** 10-11S/115 (Japan).

REPORT 809-3*

INTER-REGIONAL SHARING OF THE 11.7 TO 12.75 GHz FREQUENCY BAND BETWEEN THE BROADCASTING-SATELLITE SERVICE AND THE FIXED-SATELLITE SERVICE

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

(1978-1982-1986-1990)

1. Introduction

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 12 GHz frequency band, Geneva, 1977 took the following action:

- it adopted a detailed orbital position and frequency assignment Plan for the broadcasting-satellite service in Region 1 (11.7 to 12.5 GHz) and Region 3 (11.7 to 12.2 GHz);
- it adopted a set of provisions governing the broadcasting-satellite service in Region 2 pending the establishment of a detailed plan. These provisions included division of the available orbital arc into separate segments for the broadcasting-satellite service and the fixed-satellite service, and a Regional Administrative Conference to be held not later than 1982 for the purpose of carrying out detailed planning for the broadcasting-satellite and fixed-satellite services in Region 2 (see Recommendation No. Sat-8 of the WARC-BS-77 (see also Resolution No. 701 of the WARC-79).

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 as 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 I which makes reference to the applicable footnotes in the Radio Regulations. Table I 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 (see note) is allocated exclusively to the fixed-satellite service which may make its parameters different from fixed-satellite systems in which sharing is required.

Note. – Radio Regulation footnotes 848, 849 and 850 allocate this band on a shared basis to other services in some countries of Region 1.

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 the 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 and *vice versa* is a case of sharing between dissimilar networks with 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.

All Regions have established detailed Plans (Regions 1 and 3 in 1977, and Region 2 in 1983) for the broadcasting-satellite service.

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

TABLE I – *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 (S-E) BSS (FN 836) (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 (S-E) FSS (FN 846) (S-E)	FSS (FN 845) (S-E)
12.5 to 12.7	FSS (S-E) (E-S)	BSS (S-E) FSS (FN 846) (S-E)	FSS (S-E) BSS (FN 847) (S-E)
12.7 to 12.75	FSS (S-E) (E-S)	FSS (E-S)	FSS (S-E) BSS (FN 847) (S-E)

(S-E): space-to-Earth
(E-S): Earth-to-space

FSS: fixed-satellite service
BSS: broadcasting-satellite service
FN: footnote

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 orbital 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:

$$\text{Gain (dBi)} = 32 - 25 \log \varphi \qquad (1)$$

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 apply to the fixed-satellite service in Regions 1 and 3 sharing with the Region 2 broadcasting-satellite service.

Under Resolution No. 503 of the WARC-79, the Region 2 broadcasting-satellite Plan adopted in 1983 had to take into account the planned Region 1 and 3 broadcasting-satellite services in the overlapping frequency band.

3. Required orbital separation between fixed satellites of one Region and broadcasting satellites of another Region [CCIR, 1978-82a and b]

In the band 12.5-12.7 GHz, it is possible that broadcasting satellites in Region 2 could cause interference to fixed-satellite service earth stations in Regions 1 and 3 and similarly in the band 11.7-12.2 GHz the Region 1 and 3 broadcasting satellites could cause interference to Region 2 fixed satellites. 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 transmitting antenna pattern used to develop the BSS Plan for Regions 1 and 3 (Curve A of Fig. 1 in Report 810) is $\geqslant 30$ dB for $\varphi/\varphi_0 \geqslant 1.6$, that is, a separation between the coverage areas greater than 1.6 beamwidths as seen from the satellite. Whilst no such plateau exists in the envelope for the Region 2 transmitting antenna, by careful design of this antenna using shaped beam techniques and possibly including controlled nulls, the actual discrimination can meet or exceed this criterion in particular directions close to the main beam area [CCIR, 1982-86a].

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 and *vice versa.*

For example, consider a situation of a small FSS earth station with an antenna resembling a community reception BSS antenna for which we could use the antenna pattern as given in curve A′ of Fig. 7, Annex 5, Appendix 30 (ORB-85) 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 5), 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 total of 40 dB) will be achieved (using Fig. 7, Annex 5, Appendix 30 (ORB-85) to the Radio Regulations) at φ/φ_0 of 1, which is 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 one region and the FSS in another region, 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:

$$D_{B\,SAT} + D_{F\,Rx} > e.i.r.p._{B\,SAT} - e.i.r.p._{F\,SAT} + PR \qquad (2)$$

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. 7 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. of FSS satellites) reduces the inhomegeneity between such systems and BSS systems.

Report 873 treats the general inter-regional sharing situation by way of several examples of FSS systems. Concern is expressed that sharing may produce difficulties for certain orbital separations between broadcasting satellites and fixed satellites for the particular criteria and parameters which were assumed for the FSS systems in Report 873.

In particular Report 873 deals with interference between the FSS and assignments in the BSS plans for all three ITU regions. In addition, Resolution 42 of WARC ORB-88 incorporated the concept of interim systems in the Region 2 plan.

This Resolution provides for interim systems that could be operated by administrations for up to ten years, with characteristics that differ from the assignments to those administrations in their use of higher e.i.r.p.s, in their modulation characteristics, in their coverage areas or combinations thereof, or in the sense of polarization. These differences could increase the possibility of unacceptable interference (see annex to Resolution 42).

Similarly, as suggested in Resolution 519 of WARC ORB-88, a future competent conference should consider the introduction of some sort of interim BSS systems in Regions 1 and 3 as well.

Studies [CCIR, 1986-90a] have shown that the pfd limits set forth in Resolution 42 may not be adequate to protect all FSS networks employing digital transmissions as discussed in Report 873. Therefore, when establishing any such interim system procedures in Regions 1 and 3, due account should be taken of sharing between BSS systems and FSS networks.

Further studies were based on somewhat different characteristics and specific criteria for the FSS systems. Figure 1 shows the resulting required topocentric angular separations between broadcasting satellites and fixed satellites for each of the FSS systems considered.

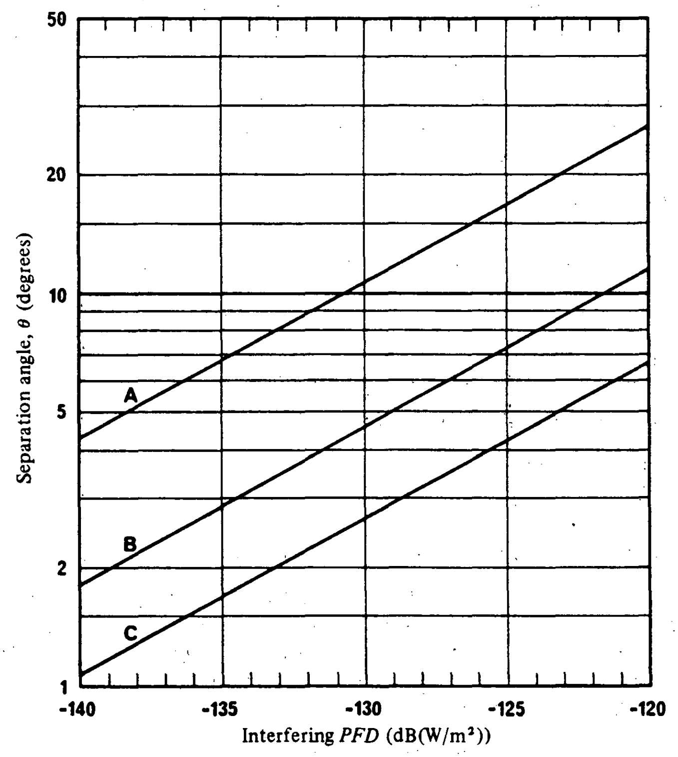

FIGURE 1 – *Separation angle as a function of interfering power flux-density*

$$25 \log \theta = C/I - C/T - 10 \log T + PFD - 11.3$$

Curves A : SCPC-PSK (C/I = 18 dB, C/T = –172 dB(W/K), T = 200 K)

B : FDM-FM (C/I = 28 dB, C/T = –150 dB(W/K), T = 100 K)

C : Wide-band data (N/I = 14 dB, T = 500 K, B = 2.4 MHz)

It is observed that SCPC systems usually will require more protection than wide-band systems.

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. This is clearly not a favourable sharing condition. One way of alleviating the problem would be to agree to use FSS receiving earth stations with a 10 dB lower side-lobe sensitivity where they are located closest to the Region 2 BSS service area. On the BSS side it may be possible to use a very steep BSS satellite antenna side-lobe decay [CCIR, 1982-86a] so as to allow FSS earth stations in Region 1 to relax their side-lobe sensitivity, from the above stringent value, rapidly towards more normal values with increasing distance from the Region 2 BSS service area. 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 the 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.

Figure 2 shows how the side-lobe sensitivity can be relaxed with distance for various assumed BSS satellite constituent beamwidths ("beamlet" widths).

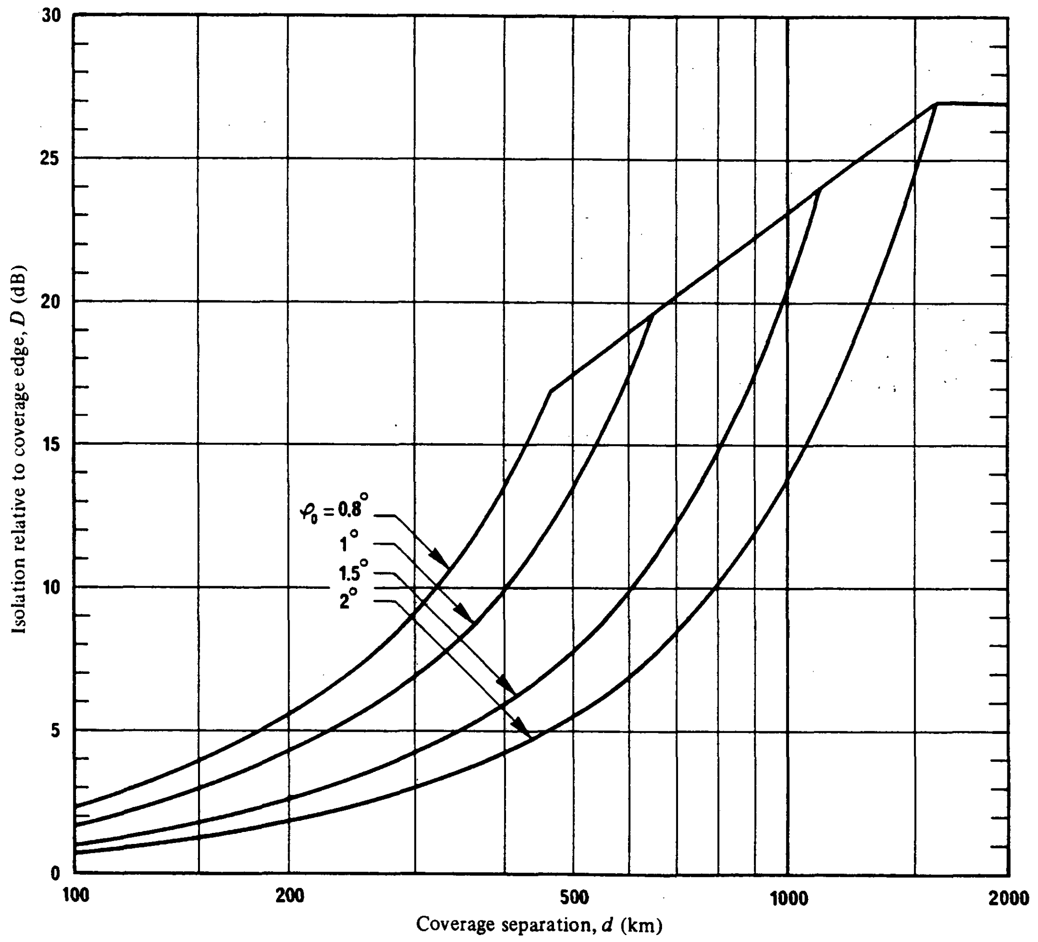

FIGURE 2 – *Coverage edge isolation versus east-west coverage ground separation*

φ_0 : broadcasting satellite constituent beamwidth

Guidelines for actual protection requirements are found in Annex 6 of Appendix 30 (ORB-85) 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.

4. Use of atmospheric absorption in inter-regional calculations

Appendix 30 (ORB-85) of the Radio Regulations and the Final Acts of the RARC SAT-83, Part I, in their respective Annexes 1 (concerning modifications to the respective Plans) provide the PFD levels from the BSS in one Region into the other which would trigger coordination with respect to the fixed-satellite service. Also, in their respective Annexes 4, they provide the PFD levels from the FSS in one Region into the other which would trigger coordination with respect to the BSS. The calculations in the direction from Regions 1 and 3 to Region 2 (Annex 6, § 2, Part I of the Final Acts of the RARC SAT-83) is based on the use of atmospheric absorption. Resolution No. 9 of the RARC SAT-83 is directed, *inter alia*, towards the use of atmospheric absorption in the reverse direction as well.

A discussion of atmospheric absorption is given in § 5.3 of Report 631.

5. Conclusions

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 Plans for the broadcasting-satellite service in Regions 1 and 3 by the WARC-BS-77 and in Region 2 by the RARC SAT-83 impose restrictions on the use of certain orbital positions near and between the space stations of the Plans for certain sensitive fixed-satellite services. These restrictions can be alleviated to some degree by special design of the broadcasting-satellite antenna.

REFERENCES

CCIR Documents

[1978-82]: **a.** 10-11S/27 (USA); **b.** 10-11S/131 (USA).

[1982-86]: **a.** 4/230(10-11S/141) (Canada).

[1986-90]: a. 10-11S/168 (INTELSAT).

REPORT 807-3*

UNWANTED EMISSIONS** FROM BROADCASTING-SATELLITE SPACE STATIONS

(Question 1/10 and 11, Study Programme 2E/10 and 11)

(1978-1982-1986-1990)

1. Introduction

Space stations in the broadcasting-satellite service may radiate high levels of e.i.r.p. and consequently the level of the unwanted emissions may produce interference in networks using adjacent and harmonically related bands for other services. This Report considers unwanted emissions from space stations operating in all bands allocated to the broadcasting-satellite service. In particular, some provisional results of studies are given in this Report regarding unwanted emissions from a broadcasting-satellite space station at the lower and upper edges of the 12 GHz band.

2. Possible sources of unwanted emissions from broadcasting satellites

The sources of unwanted emission into adjacent bands from a broadcasting-satellite transponder operating near the edge of a broadcasting-satellite frequency band are:

- radiation due to frequency conversion;
- third-order intermodulation products caused by insufficient suppression of signals in adjacent channels in the satellite transponder branching network;
- thermal noise power generated by the satellite transponder;
- spreading of the signal spectrum due to non-linearities.

In the following, an attempt is made to deduce the variation of the spectral power flux-density (PFD) as a function of frequency difference from the channel centre. The absolute values of the spectral PFD are related to the maximum PFD required for television broadcasting as given, for example, in Report 215.

Another possible source of unwanted emissions, in this case, beyond adjacent bands, is a harmonically related spurious emission from a broadcasting satellite.

2.1 Spurious emission due to frequency conversion

Spurious emissions generated by the frequency conversion process and the local oscillator source need to be taken into account in the implementation of BSS systems.

Tables I and II show for example the down-link frequencies that would be affected by high order frequency conversion products (up to the 10th order) for specific translation frequencies for Region 2. Similar factors also apply in general to Regions 1 and 3.

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* This Report should be brought to the attention of Study Group 1 and the IEC.

** Unwanted emissions consist of spurious emissions and out-of-band emissions. See Nos. 138, 139 and 140 of the Radio Regulations.

Considering the effects of interference caused by spurious components radiated from one BSS channel into another, the protection margins inherent to the BSS down-link plan should not be significantly degraded by such implementation factors. This is only likely to be a significant factor for interference from a co-located satellite, and in the case of certain values of frequency translation between a feeder link and its associated down link. In Regions 1 and 3, taking into account possible power differences between down-link carriers and the possibility of multiple interfering signals, an appropriate limit for the total spurious emission power radiated from any BSS satellite channel falling within any down-link channel is of the order of 55 dB below that of the main carrier; i.e. the carrier from the channel causing the interference. This figure is readily realizable, for example, in the case of a satellite using a 5.6 GHz frequency translation in the Region 1 and 3 Plan with a single frequency conversion stage. Dual frequency translation will reduce the level of in-band spurious emissions. Such techniques can be used if required. The interference level actually required to protect other channels from this source of interference requires further study.

2.2 *Intermodulation products caused by insufficient suppression of signals in adjacent channels*

With a carefully designed branching filter inserted at a relatively linear portion of the transponder, it should be possible to suppress the signal in the adjacent channels so that the intermodulation products falling into the adjacent band are of an acceptable level.

2.3 *Unwanted emission due to thermal noise power generated by the broadcasting-satellite transponder*

Thermal noise in the down link is caused by interaction of the thermal noise and the RF carrier in the high-power amplifier due to non-linearity, by amplification and transmission of receiver noise, and by retransmission of received feeder-link noise.

Figure 1 represents the calculated results [CCIR, 1974-78a] for the thermal noise spectral PFD as a function of frequency. The two curves shown refer to different filtering conditions as noted in the figure.

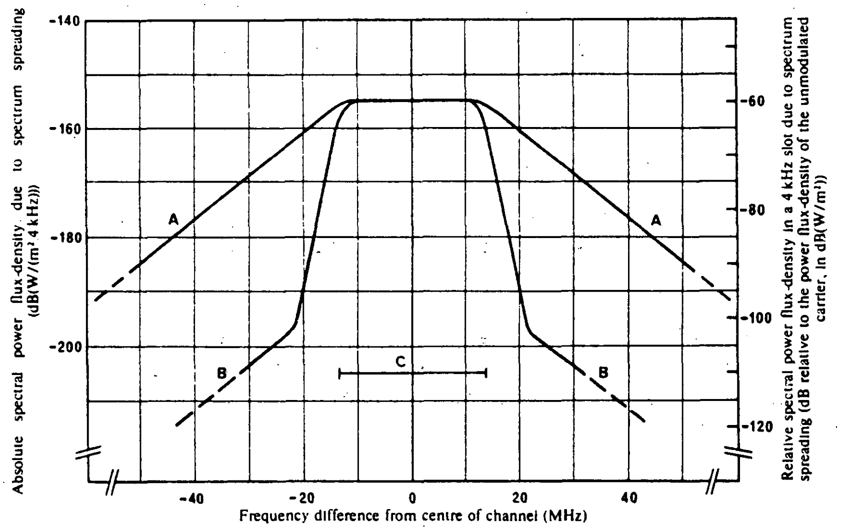

FIGURE 1 — *Typical envelopes of the thermal noise power spectrum radiated by the high-power output amplifier of a broadcasting satellite*

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/m^2) at the centre of the beam area 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.

2.4 *Spreading of the spectrum of the radio-frequency signal 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. This is typically a saturated amplifier which causes AM/PM conversion, so the envelope variations will generate RF intermodulation products, some of which will fall out of band. The transponder output filter is likely to have limited loss, so it will be unlikely to be very effective in removing out-of-band intermodulation products near to the band edge.

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 (see § 2.3).

The actual spectrum radiated by the satellite largely depends upon the television signal transmitted. In Fig. 2 computer calculated results on this subject [CCIR, 1974-78a] are presented for illustrative purposes. The signal used in the calculations of Fig. 2, curve B, was a television test signal in line 330, with a peak-to-peak deviation of 13 MHz. The signal used in the calculation of Fig. 2, curve A, consisted of 100% saturated colour bars. It should be noted that such a signal is not used in normal broadcasting. A sound sub-carrier with a peak-to-peak deviation of 5.6 MHz was associated with both television signals.

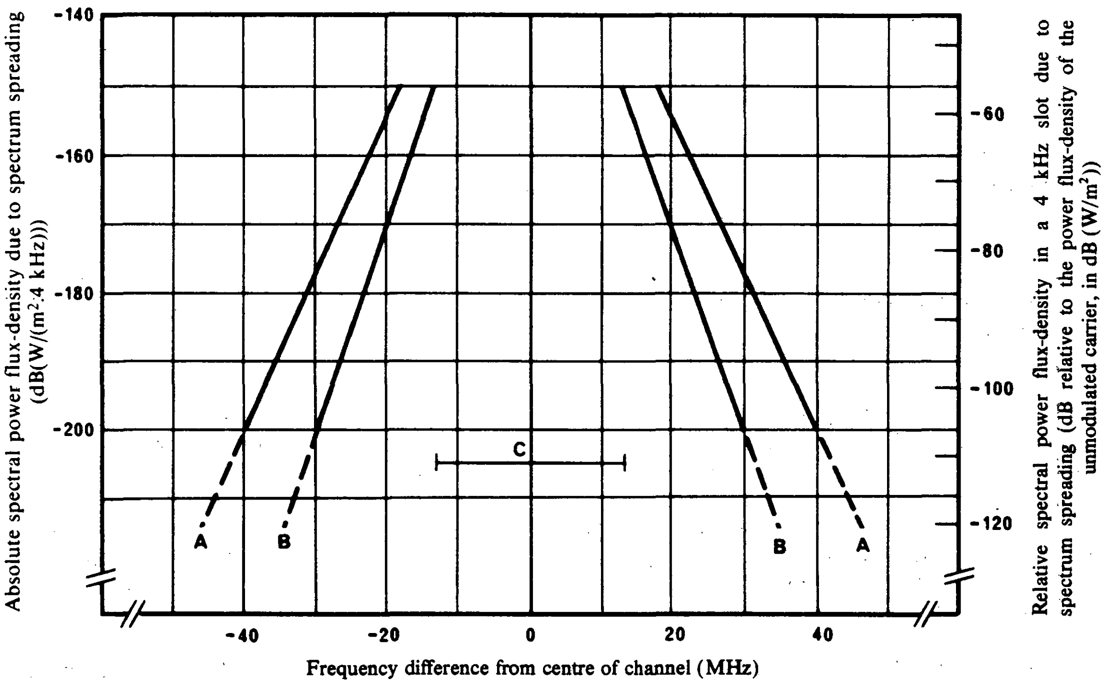

FIGURE 2 – *Typical out-of-band envelopes of the radio-frequency spectrum radiated by a television broadcasting satellite*

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/m²) at the centre of the beam for an unmodulated carrier.

Note 2. – Minimum energy dispersal of ± 7.9 kHz is assumed.

Note 3. – Pre-emphasis according to Recommendation 405 is assumed.

Additional data showing power spectral density envelopes of television signals based upon laboratory measurements in the United States of America [CCIR, 1978-82a] are shown in Annex I. The signal used in these measurements was an FM carrier with a digital (4-PSK) audio sub-carrier (693 kbit/s data rate at a sub-carrier frequency of 5.5 MHz) with a 75% NTSC colour bar. Measurements for both 18 MHz and 27 MHz bandwidths were made with several different signal deviations (including over-deviation). No energy dispersal waveform was used, nor was any significant RF filtering applied.

2.5 *Spurious emissions due to harmonics*

Annex II notes the harmonics of the various bands allocated to the broadcasting-satellite service and other space services which operate at those frequencies. Studies in the USA have shown that if spurious emissions at harmonics of the fundamental frequency are of the order of 60 dB below the level of the fundamental interference to other services operating at these frequencies may not be significant [CCIR, 1978-82b].

General criteria for protection include: power level, fraction of total sky covered and percentage of time exceeded. Protection is usually achieved by geographical sharing; "line-of-sight" sharing is difficult, but maximum allowable line-of-sight e.i.r.p.s are given in Fig. 3.

The likelihood of harmful interference to the services shown in Annex II has not been assessed except for the case reviewed in § 3.3. Further study is necessary.

3. Protection of other services from unwanted emissions

Guard bands necessary to protect the services operating in adjacent bands from unwanted emissions of 12 GHz broadcasting satellites in Regions 1 and 3 are discussed in § 3.9 of Annex 5 to Appendix 30 (ORB-85) to the Radio Regulations.

For space stations in the broadcasting-satellite service in other bands, adjacent services may similarly be protected by establishing appropriate guard-bands. The width of these guard bands will depend on future decisions concerning the minimum levels to be protected, on current filter technology (e.g. roll-off in dB/MHz) and on the bandwidth of the emission from the broadcasting-satellite service.

Also, the width of the guard-bands depends upon equitable application of the principle of sharing the burden of protection, that is, services in adjacent bands should employ designs affording a maximum feasible protection from interference outside the bandwidth required for satisfactory service (see for example No. 301 of the Radio Regulations).

Studies in the USA have shown that unwanted emissions immediately outside the allocated band can be reduced by filters with a roll-off of, for example, 2 dB/MHz, which could continue to an attenuation of 80 dB, depending on filter design, but such attenuation may not be realized at frequencies far removed from the carrier.

3.1 *Fixed-satellite service*

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 co-located and serves the same area.

At 12.5 to 12.75 GHz, a value for a specific FSS system is shown as -171.2 dB(W/(m^2 · 4 kHz)). No such limit is defined for the 12.1 to 12.2 GHz frequency band.

TABLE I – *Space-to-Earth frequencies in BC-SAT Region 2 affected by harmonic mixing product of* $(9f_{LO} - 2f_{FL})$

Space-to-Earth frequency (GHz)	Local oscillator frequency (GHz)	Feeder-link frequency (GHz)
12.11	5.19	17.30
12.13	5.20	17.33
12.16	5.21	17.37
12.18	5.22	17.40
12.20	5.23	17.43
12.23	5.24	17.47
12.25	5.25	17.50
12.27	5.26	17.53
12.30	5.27	17.57
12.32	5.28	17.60
12.34	5.29	17.63
12.37	5.30	17.67
12.39	5.31	17.70
12.41	5.32	17.73
12.44	5.33	17.77
12.46	5.34	17.80
12.48	5.35	17.83
12.51	5.36	17.87
12.53	5.37	17.90
12.55	5.38	17.93
12.58	5.39	17.97
12.60	5.40	18.00

TABLE II – *Space-to-Earth frequencies in BC-SAT Region 2 affected by harmonic mixing product of* $(6f_{LO} - f_{FL})$ and $(3f_{FL} - 8f_{LO})$

Space-to-Earth frequency (GHz)	Local oscillator frequency (GHz)	Feeder-link frequency (GHz)
12.50	5.00	17.50
12.52	5.01	17.53
12.53	5.01	17.54
12.55	5.02	17.57
12.57	5.03	17.60
12.58	5.03	17.61
12.60	5.04	17.64
12.62	5.05	17.67
12.63	5.05	17.68
12.65	5.06	17.71
12.67	5.07	17.74
12.68	5.07	17.75

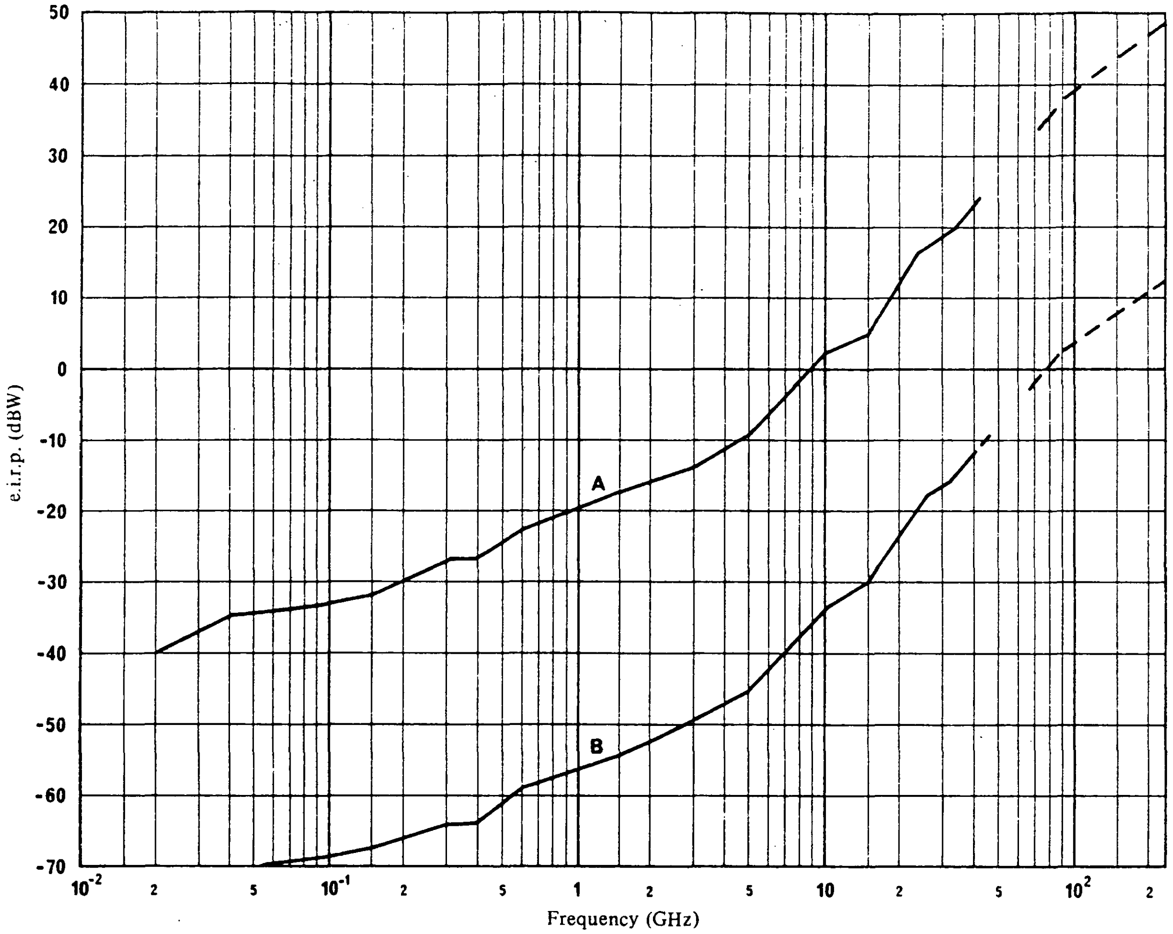

FIGURE 3 – *Maximum allowable e.i.r.p. for sharing transmitters within line-of-sight of a radioastronomy observatory*

Curves A: space transmitter in geostationary orbit

B: terrestrial transmitter at 600 km

To achieve compatibility between unwanted emissions from broadcasting-satellite space stations and permissible levels of interference in the fixed-satellite earth stations, a combination of the following provisions may have to be made:

a) provide for adequate angular separation between the orbit location of satellites in the broadcasting-satellite service and the fixed-satellite service;

b) provide adequate output filtering in the transmitter of the broadcasting-satellite space stations or in the receivers of the fixed-satellite earth stations, or both;

c) provide adequate frequency separation between the centre of the lowest channel occupied by an emission from a broadcasting-satellite space station and the previously defined protected frequency of the fixed-satellite service.

In the interests of minimizing *a priori* constraints on system design in both services, it may be undesirable or impractical to rely on filtering requirements alone, as outlined under b) above; however, a relationship between pertinent system parameters including orbit spacing between satellite locations and frequency separation between "protected frequency" and channel centre frequency, as outlined under a) and c) above, can be developed.

3.2 *Fixed and mobile services*

Unwanted emissions from broadcasting satellites into fixed and mobile services are discussed in Report 789.

3.3 *Radioastronomy service*

Studies have shown that harmonic radiation from certain channels of Regions 1 and 3 broadcasting satellites into radioastronomy bands need to be suppressed with appropriate output filters [CCIR 1982-86a]. Unwanted emissions, expressed as radiated spectral density in any direction to Earth, in the 23.6 GHz to 24 GHz band (channels 5 to 15 in the Plan for Regions 1 and 3) shall be less than −70 dB(W/Hz) and in the 36.4 to 36.5 GHz band (channels 22 to 24 in the Plan for Regions 1 and 3) less than −65 dB(W/Hz), based on the protection requirements set forth in Report 224.

When calculating the magnitude of unwanted emissions, frequency dispersal gain of 61 dB/Hz is assumed for the 24 GHz band based on 2 × 600 kHz, and 63 dB/Hz for the 36 GHz band based on 3 × 600 kHz.

These radiations levels would ensure a world-wide protection of radioastronomy observations against harmonic radiation of broadcasting satellites, provided the gain of the radioastronomy antenna in the direction of broadcasting-satellite positions is no greater than that of an isotropic antenna.

Typically, about 60 dB of harmonic suppression will be required to ensure this protection. Transmit filters of conventional design can provide this protection with little weight or performance penalty.

3.4 *Space operations service*

Consideration is currently being given to accommodating the space operation signals of broadcasting satellites in Regions 1 and 3 within the guard bands at the edges of the bands allocated to satellite broadcasting or to feeder links. These signals may suffer interference from the out-of-band residual spectrum of television signals emitted or received by the broadcasting satellites. In the case of the feeder link, the main source of interference is the signal on the channel adjacent to these guard bands (channel 1 or channel 40). In the case of the down link, the problem is more complex. The television signal on the adjacent channel is also a potential source of interference but other sources exist, in particular the intermodulation products created in satellite repeaters between television signals on different channels (e.g. channels 39 and 40). These may affect the telemetry band.

Tests on these risks of interference, conducted in France [CCIR, 1982-86b], have provided the necessary conditions to ensure a good transmission of space operation signals. Report 1076 concerning the space operation service takes into account the principal results of these tests.

4. **Conclusions**

It is concluded that the unwanted emissions from a broadcasting-satellite space station may not be negligible and, in the case of adjacent band interference, are caused primarily by thermal noise and by frequency modulation of the carrier by the video waveform chosen. The results presented in this Report can be used, where appropriate, to deduce the width of possible guard bands between the 12 GHz band and adjacent bands used for other services. However, caution should be used to avoid applying the results to conditions differing from those presented herein. Additional study and measurements are required on this subject. 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 guard bands could be reduced (WARC-79).

References have also been provided relating to the requirements of the fixed-satellite, fixed, mobile and radioastronomy services in terms of unwanted emissions into adjacent and harmonically related frequency bands, which must be accounted for in the design of the space segment of the broadcasting-satellite system.

REFERENCES

CCIR Documents

[1974-78]: **a.** 11/117 (Italy).

[1978-82]: **a.** 10-11S/139 + Add.1 (USA); **b.** 10-11S/28 (USA).

[1982-86]: **a.** 10-11S/46 (EBU); **b.** 10-11S/9 (France).

ANNEX I

UNWANTED EMISSIONS FROM BROADCASTING SATELLITES – RESULTS OF LABORATORY MEASUREMENTS USING A TRANSPONDER SIMULATOR

1. Introduction

This Annex presents the results of laboratory measurements of the emission characteristics of a satellite transponder with bandwidths and TV signal characteristics typical of systems that could operate in the broadcasting-satellite service (BSS) in Region 2. The results for two different filter bandwidths and several signal deviations are presented.

2. Test parameters

System M/NTSC video on a frequency modulated carrier with a digital (4-PSK) audio sub-carrier was used for the spectrum measurements. Several different video signal deviations were tested, but in all cases the audio sub-carrier was a 693 kbit/s data stream with a nominal bandwidth of 0.8 MHz. The audio sub-carrier was centred at 5.5 MHz in the video baseband.

The composite video baseband was frequency-modulated and bandpass filtered. The output of this filter was up-converted and fed to the satellite simulator. At the output of the simulator, a spectrum analyzer was used to record the signal spectral density. No significant RF filtering was used after the travelling wave tube amplifier (TWTA).

A helix type TWTA was used as the transponder amplifier for these tests. This TWTA is similar to those used on the Intelsat-IV satellites.

All tests were made with the input spectrum generated by a 75% NTSC colour bar signal with pre-emphasis.

3. Test results

The power spectral flux density envelopes of the FM-modulated TV signals are shown in Figs. 4 and 5 (see Note 1). The in-band spectral flux density envelope is shown as a dashed line within the channel bandwidth (see Note 2).

All tests were conducted with the satellite transponder travelling wave tube amplifier operating at saturation. It should be noted that the power spectral flux density envelopes generally exceed the amplitude responses of the respective IF filters. The envelopes reflect the spreading of the spectrum caused by the non-linear operation of the satellite transponder TWTA. The spectrum spreading is significant for the "over-deviation" test conditions.

Note 1. – The absolute spectral power-flux density values shown on each figure are based upon an assumed power-flux density of -105 dB(W/m^2) at the centre of the beam for an unmodulated carrier.

Note 2. – The in-band and out-of-band envelopes shown in Figs. 4 and 5 outline the peak (worst case) values and therefore integration of the curves to determine total power will yield misleading results. Also, it is not advisable to extrapolate the envelope curves beyond the points on the figures.

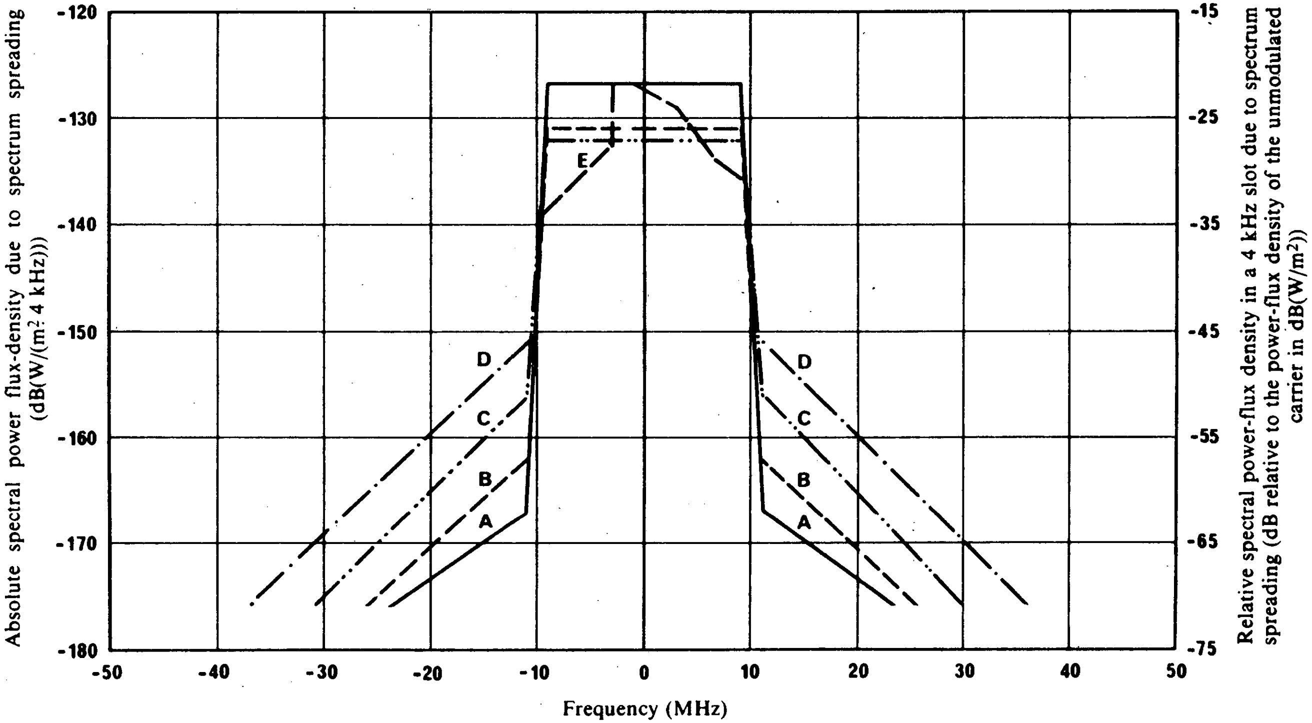

FIGURE 4 – *Power spectral density envelopes for 18 MHz bandwidth*

Curves A: peak deviation = 3.5 MHz
B: peak deviation = 5.6 MHz
C: peak deviation = 8.9 MHz
D: peak deviation = 11.2 MHz
E: in-band spectral flux-density envelope

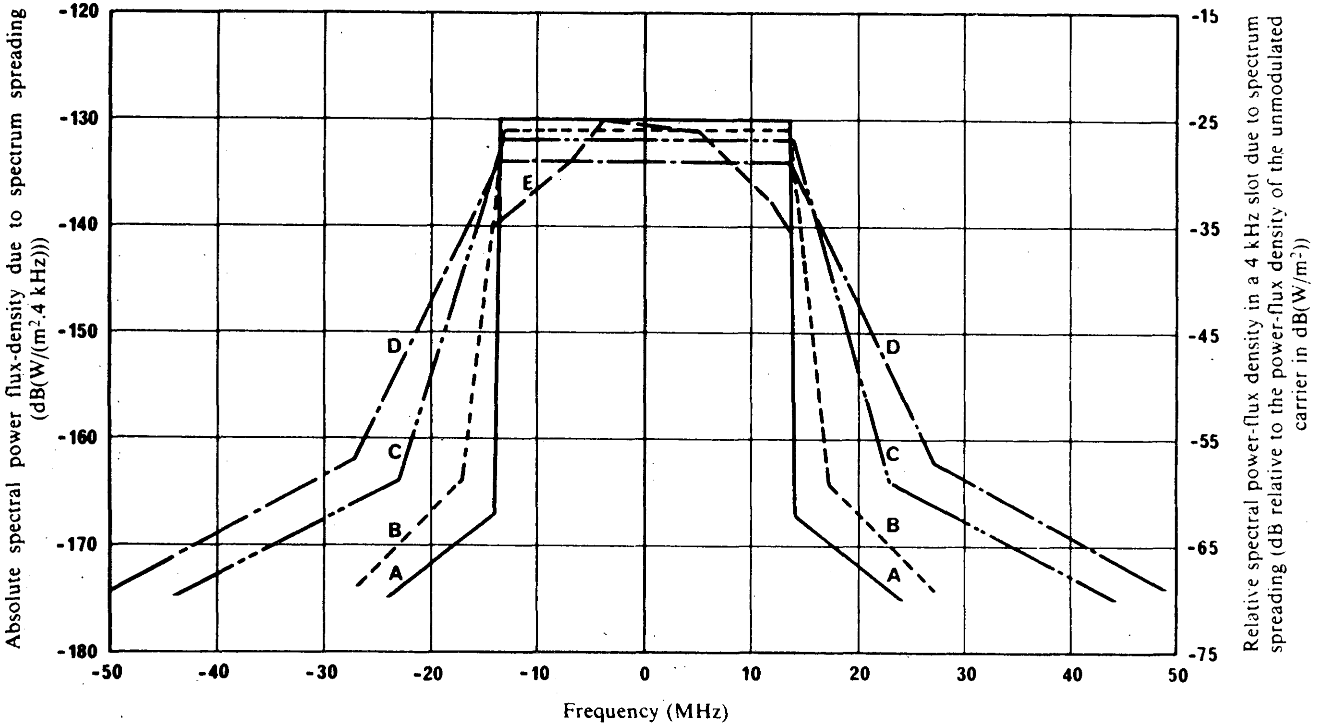

FIGURE 5 – *Power spectral density envelopes for 27 MHz bandwidth*

Curves A: peak deviation = 5.3 MHz
B: peak deviation = 8.4 MHz
C: peak deviation = 13.3 MHz
D: peak deviation = 16.8 MHz
E: in-band spectral flux-density envelope

ANNEX II

SPACE-TO-EARTH AND INTER-SATELLITE SERVICE ALLOCATIONS AT 2ND AND 3RD HARMONICS OF BROADCASTING-SATELLITE ALLOCATIONS

TABLE III

Fundamental frequency in the BSS	2nd harmonics (services)	3rd harmonics (services)
2.5 – 2.69 GHz	5.0 – 5.38 GHz Fixed-satellite Inter-satellite (see footnote No. 797 of the Radio Regulations)	7.5 – 8.07 GHz Fixed-satellite Meteorological-satellite
11.7 – 12.5 GHz (Region 1) 11.7 – 12.7 GHz (Region 2) 11.7 – 12.2 GHz and 12.5 – 12.75 GHz (Region 3)	23.4 – 25.5 GHz Earth exploration-satellite Radioastronomy	35.1 – 38.25 GHz Earth exploration satellite Space research Fixed-satellite
22.5 – 23.0 GHz (Regions 2 and 3)	45.0 – 46.0 GHz Mobile-satellite Radionavigation-satellite	67.5 – 69.0 GHz Mobile-satellite Radionavigation-satellite
40.5 – 42.5 GHz	81.0 – 85.0 GHz Fixed-satellite Mobile-satellite Broadcasting-satellite	121.5 – 127.5 GHz Earth exploration-satellite Space research Inter-satellite
84.0 – 86.0 GHz	168.0 – 172.0 GHz Inter-satellite	252.0 – 258.0 GHz Mobile-satellite Radionavigation-satellite Radioastronomy

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REPORT 1076

CONSIDERATIONS AFFECTING THE ACCOMMODATION OF SPACECRAFT SERVICE FUNCTIONS (TTC) WITHIN THE BROADCASTING-SATELLITE AND FEEDER-LINK SERVICE BANDS

(Question 2/10 and 11, Study Programme 2L/10 and 11)

(1986)

1. Introduction

The Radio Regulations (No. 25) state that spacecraft service functions (TTC) will normally be provided within the service in which the space station is operating. The WARC-BS-77 provided no specific frequency slots for these functions except that it reserved guard bands at the edges of the 11.7 GHz to 12.5 GHz band for Region 1 and 11.7 GHz to 12.2 GHz for Region 3. A compatible frequency plan is assumed for the feeder links in the 17-18 GHz band as well. These guard bands could be used for the TTC space-to-Earth and Earth-to-space assignments.

It should be noted that some countries in Regions 1 and 3 may envisage the exploitation of the 14 GHz band for feeder links in the BSS. The use of guard bands in this frequency region may present difficulties because of sharing constraints with the FSS. Further studies are required.

As a matter of record, the RARC SAT-83 Final Acts specified that space services could be used in the assigned guard bands of 12 MHz at each end of the 12.2-12.7 GHz and 17.3-17.8 GHz bands for Region 2. The desired approach is to isolate TTC and broadcasting links to the extent that neither service is constrained by the other within the limits established by regulatory requirements.

The guard bands are limited when one considers the number of potential BSS satellites which may be located at a single orbital position. If many satellite systems are co-located at a single orbital position where each system may comprise several satellites each requiring TTC channels, excessive interference between the TTC and television broadcasting signals is a possibility. Thus, it appears necessary to develop technical guidelines for TTC frequency assignments. This Report attempts to define some of the important considerations associated with TTC assignment strategies and provides some technical data for estimating interference between TTC and broadcasting and feeder-link signals. The suggested sharing criteria have been derived for Regions 1 and 3 modulation characteristics with use being made of energy dispersal. Consequently, results may not be directly applicable for Region 2 satellites.

Although these guidelines are based on the application of traditional sub-carrier modulation techniques, it should be noted that alternative modulation systems are available. These are discussed in § 4 of this Report.

The alternative to using the guard bands would be to accommodate TTC assignments in either non-used or non-allocated broadcasting and feeder-link channels. Such possibilities will exist for practically any orbital position and frequencies will have to be agreed on a case-by-case basis rather than in a regular manner.

TTC system requirements

2.1 *TTC functions* [CCIR, 1978-82a, b]

The TTC functions to be provided in the Earth-to-space direction are telecommand, ranging and spacecraft antenna tracking by means of radio-frequency sensing. In the space-to-Earth direction the functions are telemetry, ranging and earth station antenna tracking.

The telecommand signals are characterized as non-continuous low data rate transmissons, whereas telemetry signals are usually continuous low data rate transmissions. Ranging is usually accomplished with non-continuous tone or code ranging processors. Antenna tracking is performed with continuous RF sensing on CW or swept carrier signals using the residual carrier of the telecommand or telemetry signals as appropriate.

2.2 *Bandwidth requirements* [CCIR, 1982-86a]

The minimum bandwidth requirement for a TTC channel is determined by the tone ranging techniques and the stability of the on-board local oscillators. Applying temperature control techniques for this oscillator, a bandwidth assignment as low as 400 kHz may be sufficient for a stationary satellite. This value does not include the Doppler effect due to the satellite shift in relation to the Earth during the transfer phase. However, 400 kHz appears to be marginal when considering tone ranging and individual guard bands between TTC channels. One approach to conserving spectrum and providing flexibility is to assign 3 × 400 kHz, or 1200 kHz, to individual atellite broadcasting systems. Each system can internally coordinate their ranging operations with up to three satellites within this composite 1200 kHz band. Guard bands between the composite bands are required to differentiate between satellite systems. Figure 1 shows an example of this approach.

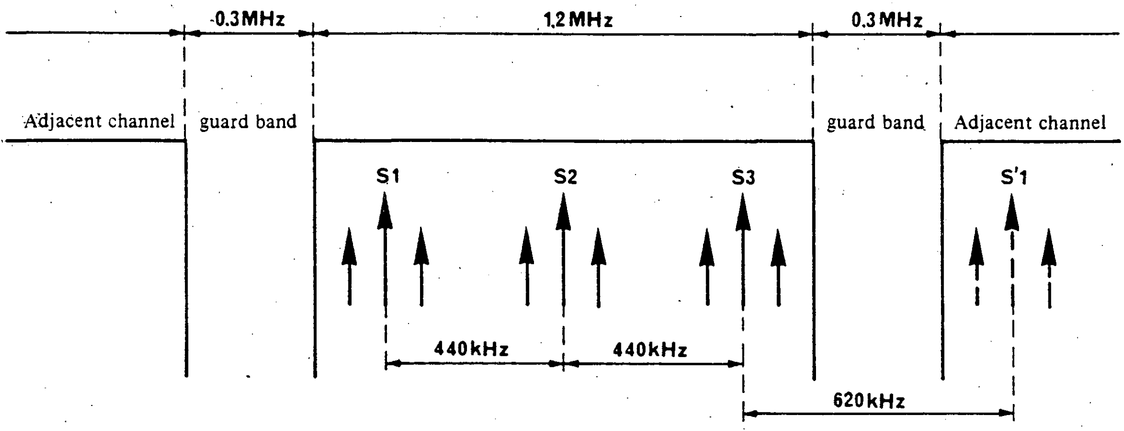

FIGURE 1 – *Signal spacing in space operation channels*

The number of TTC channels that can be accommodated in the guard bands (25 MHz for Regions 1 and 3 and 24 MHz for Region 2) does not appear to be a problem in terms of available bandwidth except for a few cases. The issue is rather how much separation in frequency is required between the closest TTC and television broadcasting channels, and how a sufficient decoupling of broadcasting and TTC signals can be achieved.

2.3 *Operational requirements* [CCIR, 1982-86a]

Distinctly different TTC requirements are needed during the launch, transfer orbit and geostationary orbit phases of a satellite. The latter phase includes nominal operations associated with a stabilized spacecraft, and non-nominal operations usually associated with loss of attitude control.

During nominal spacecraft operations all of the TTC functions need to be provided and some care will be needed to ensure proper signal qualities, the latter being particularly relevant for spacecraft antenna tracking. During satellite launch and transfer orbit and during non-nominal behaviour of the spacecraft in geostationary orbit, reduced requirements may suffice. In particular, spacecraft antenna tracking is not required. The major physical difference between these two modes of operation will be in the gain of the spacecraft antennas. In the latter case omnidirectional antennas will have to be employed and these, therefore, produce the limiting requirements for the e.i.r.p. levels of a general TTC system. Power could be reduced when using the primary service (broadcasting) transmission antennas.

The strategy for TTC frequency assignments discussed in § 4 should allow, in principle, the use of 12 and 17-18 GHz frequencies for TTC during any phase of the satellite life. However, certain limitations in e.i.r.p. levels will have to be respected in order to avoid an excessive interference environment with the BSS or other services. These points are discussed in § 3 and 4. Coordination between affected administrations, however, may resolve problems of a temporary nature on a case-by-case basis.

From the frequency management viewpoint the exclusive application of 12 and 17-18 GHz frequencies is believed to be beneficial in the long term and should actually form the baseline for any assignment strategy. Other constraints, in particular, the availability of TTC earth-station networks, may demand the use of lower frequencies during the transfer phase and during non-nominal in-orbit behaviour of the spacecraft.

The polarization of the 12-18 GHz TTC signals should be the same as for the primary service (broadcasting) signals. This enables the use of the same spacecraft antennas during the nominal spacecraft control periods. Opposite circular polarization between Earth-to-space and space-to-Earth links is preferable from the feeder-link operation viewpoint [Fromm and McEwan, 1981].

Using the same antennas for broadcasting and TTC functions also implies the need for sufficient frequency separation between the TTC and closest broadcasting signal on the same satellite. Preferably, this separation should amount to approximately 100 MHz or more to ease filtering requirements but lower separations of the order of only 30 to 40 MHz may be acceptable.

The links are to be provided for each spacecraft separately, during spacecraft launch and transfer orbit, with two or more earth stations around the Earth and subsequently with one principal earth station during nominal and non-nominal geostationary-orbit operations. Proper margins will have to be included for atmospheric effects. Spare satellites will be mandatory for most operational satellite broadcasting systems and individual TTC assignments will be necessary for each spacecraft. Replenishment studies suggest that up to three spacecraft in orbit may be required for any national satellite broadcasting system. This means that up to 48 TTC channels would have to be assigned in the event all available broadcasting channels are used at one satellite location. However, the typical requirement is expected to be less than 48 TTC channels.

2.4 *TTC earth stations*

The location of the principal TTC earth stations should be possible anywhere within the national territory of the country to be served or even outside. A location near the beam centre is preferable from the spacecraft antenna tracking viewpoint. It would be desirable moreover to use earth-station antennas having diameters which allow re-use of TTC frequencies for satellites which are at different nominal orbital positions.

2.5 *Implications of the Region 2 BSS Plan* [CCIR, 1982-86b]

Report 952 describes the feasibility of co-locating broadcasting satellites by slightly separating satellites which have adjacent cross-polarized broadcasting channels. The suggested nominal separation of 0.4° provides an additional 10 dB of isolation as compared to a co-located satellite for a 5 m earth-station antenna based on side-lobe characteristics recommended by the CCIR for this application. This level of isolation is applicable to TTC stations as well and can provide another element for reducing the interference environment between TTC and broadcasting and feeder-link signals.

2.6 *Alternative modulation techniques* [CCIR, 1982-86a]

Presently, most TTC services use traditional sub-carrier modulation techniques. However, considering the bandwidth limitations if many TTC channels are required, other modulation techniques may offer a solution to the potential interference problem, in particular when considering TTC operations during launch, transfer, and non-nominal spacecraft behaviour. A promising candidate is the use of spread-spectrum techniques in which all satellites at one location would use the same TTC RF signal frequencies, but would differentiate from each other by employing special codes.

3. Frequency sharing and service compatibility considerations

3.1 *Introduction*

Use of guard bands to transmit TTC signals raises questions about the mutual compatibility of the space operation service with any other services in the same or nearby frequency bands. Two types of compatibility should be considered:

- compatibility with the services using the bands adjacent to those allocated to the broadcasting satellite and feeder-link services: in the absence of information, this point is not dealt with in this section. Further studies are required;
- compatibility with the satellite-broadcasting and feeder-link services: TTC signals can interfere with broadcasting services in immediately adjacent channels and can receive interference from out-of-band emissions from the primary service (broadcasting). These mutual interferences suggest that protection ratios should be defined in order to ensure compatibility among services. Such compatibility will be subject to system characteristics and, in particular, of the modulation characteristics of the TTC signals, especially as the classical TTC sub-carrier concepts are expected to be more sensitive to unwanted emissions than spread-spectrum modulation techniques.

3.2 *Protection of adjacent broadcasting channels against TTC signals*

TTC signals should in no case impair broadcasting transmissions. Regarding the feeder links, tests carried out in France [CCIR, 1982-86c] showed that the protection ratio of the adjacent channels against the sum of interfering TTC carriers should equal 20 dB:

$$P_{TV}/(P_{TTC})_{total} \geqslant 20 \qquad \text{dB} \qquad (1)$$

where:

P_{TV}: carrier power of the adjacent channel signal at the payload receiver input;

$(P_{TTC})_{total}$: carrier power of the interfering TTC carriers at the payload receiver input.

However, due to the abrupt decrease in the effect of interference with increasing frequency separation between broadcasting and TTC signals, it has been demonstrated that the following ratio is sufficient:

$$P_{TV}/P_{TTC} \geqslant 26 \qquad \text{dB} \qquad (2)$$

where P_{TTC} is the power of a single TTC interferer carrier at the payload receiver input. Further studies are required to confirm this value.

3.3 *Protection of TTC signals against broadcasting signals*

Taking into account the importance of TTC signals for proper functioning of the satellite, transmission of these signals should not be affected by out-of-band emissions of television signals. For the feeder link, the main source of interference is the signal on the adjacent channel (channels 1 or 40 in Regions 1 and 3). Tests on these risks of interference have been conducted in France [CCIR, 1982-86d]. With the television signals available in the laboratory, tests have shown that the following protection ratio is necessary for a TTC signal at the edge of the feeder-link channel (nominal frequency separation between TTC and feeder link signal equals 13.5 MHz):

$$P_{TTC}/P_{TV} \geqslant -27 \qquad \text{dB} \qquad (3)$$

where:

P_{TTC}: carrier power of the TTC signal at the input of the TTC satellite receiver input;

P_{TV}: carrier power of the feeder-link signal at the TTC satellite receiver input.

The test conditions and detailed results are provided in Annex I.

For the down link, the problem of interference is more complex because of intermodulation products in the satellite repeater and other interference sources. Further studies are required. Provisionally, the protection requirements derived for feeder-link interference may also be applied to the down link.

4. Considerations concerning TTC-frequency assignments

The objective for any TTC-frequency assignment must be to provide maximum flexibility for the design of TTC links while respecting all protection requirements. Maximum flexibility in the given environment is obtained when allowing TTC links to be operated in a given frequency slot with the largest possible range of signal variations. The upper limit in TTC signal level is constrained by the permissible interference into the adjacent broadcasting channel. The lower limit is set by the protection requirement of the TTC link itself. This level is critically dependent upon the TTC modulation parameters. Typical data valid for the Regions 1 and 3 interference environment is discussed in § 3 with complementary information in Annex I.

4.1 *Atmospheric attenuation and depolarization*

Atmospheric attenuation and depolarization will affect satellite broadcasting links, feeder links and TTC links. Proper link margins will have to be incorporated into any particular design. Relevant data can be found in Report 564. The applicable service availability requirement for TTC links may be influenced by specific requirements but for the sake of this study 5 dB and 10 dB rain margins are assumed for the 12 and 18 GHz bands, respectively. For TTC systems, it is desirable to provide an availability exceeded for 99.9% of the worst month. Where the rainfall rate and elevation angle are such that the attenuation exceeds the values assumed, then special means such as site diversity may need to be used.

Atmospheric depolarization is of major influence in determining the maximum permissible e.i.r.p. for TTC signals (sub-carrier techniques). Rain-induced depolarization, in the absence of power control, is normally of little practical concern because of the simultaneous attenuation of the depolarized component. In contrast, ice-depolarization may determine the critical interference situation. In the absence of detailed information, it is suggested that depolarization factors of −20 dB and −15 dB for 12 GHz and 18 GHz links, respectively, should be assumed.

4.2 *Sub-carrier modulation*

When applying the protection requirements derived in § 3 for mutual interference between TTC, broadcasting and feeder links, it becomes obvious that interfering links need to be isolated by means of orthogonal polarizations. This, together with the system requirements discussed in § 2.1 and 2.2 suggest the generalized frequency and polarization assignment concept as illustrated in Fig. 2a. The concept has been developed around the Regions 1 and 3 down-link Plan and assumes tacitly that the feeder-link Plan will be a transposition of the down-link Plan. It makes use of the regularity of the broadcast assignments. Feeder and broadcasting links and spacecraft service links to and from adjoining service areas have been assigned frequencies on orthogonal polarizations.

Certain orbital positions enjoy, for their first and last channels, frequency assignments in only one polarization. In such cases an alternative frequency arrangement for TTC channels can be considered as illustrated in Fig. 2b. This concept is fully compatible with that of Fig. 2a with no extra bandwidth requirement. The difference is that all TTC links are on opposite polarization with regard to the interfering and interfered-with broadcasting feeder-link channel.

As discussed in § 2, any individual satellite system shall be assigned 1200 kHz bandwidth. To allow for decoupling between satellite systems, a guard band of some 100 to 300 kHz should be inserted. This may lead in certain cases to conflicting requirements with the available bandwidth in the guard band, but in most practical cases all TTC signals can be accommodated. Specific concepts for detailed frequency assignments require further study.

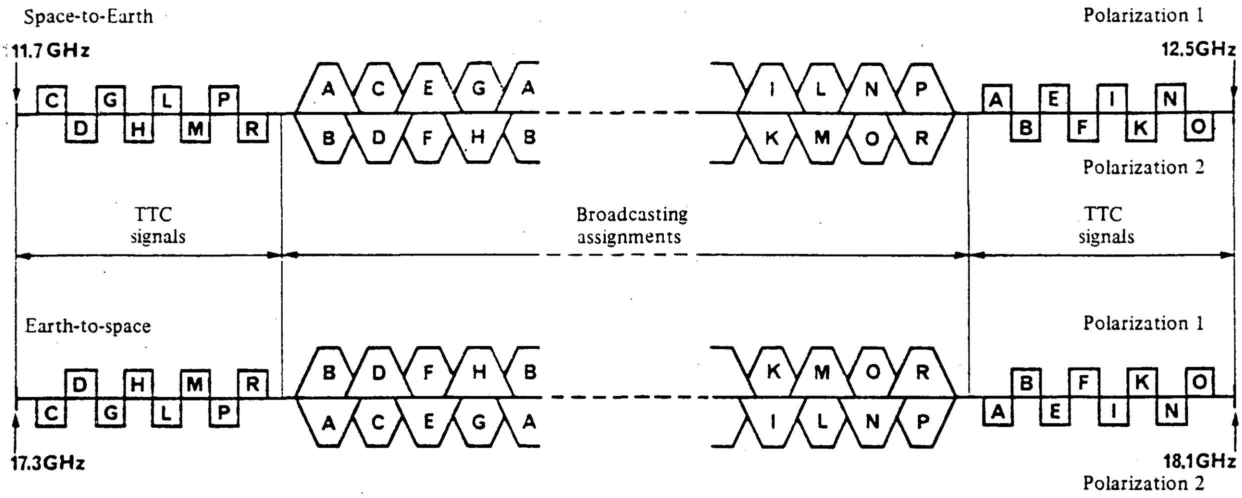

FIGURE 2a – *Proposal for TTC assignments for broadcasting satellites assuming sub-carrier modulation techniques for TTC signals: generalized concept for Region 1 assignments*

Note 1. – A to R denote service areas or countries.

Note 2. – The Region 3 concept can be derived by introducing applicable frequencies and number of channels.

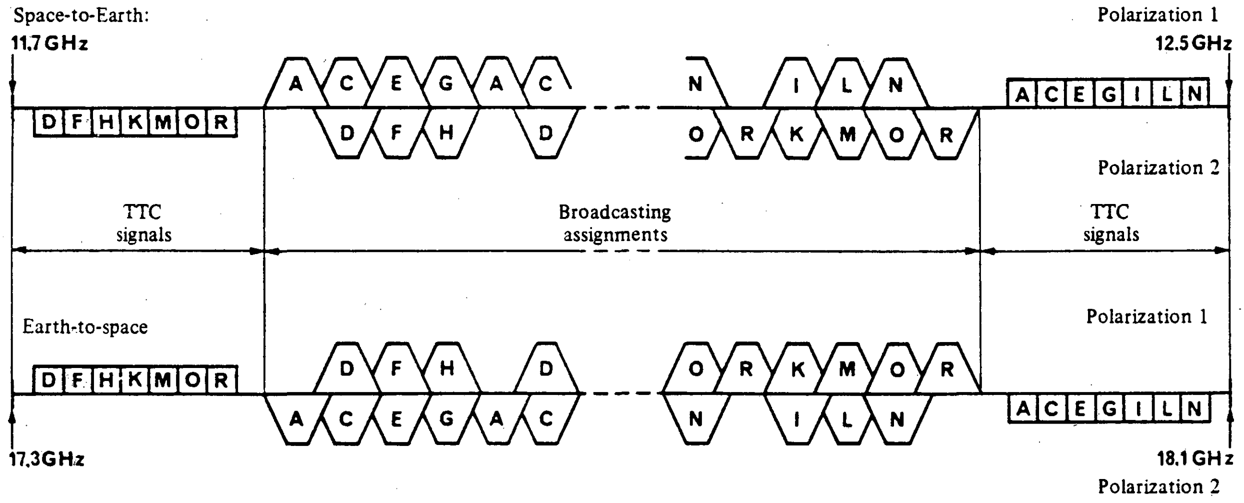

FIGURE 2b – *Proposal for TTC assignments for broadcasting satellites assuming sub-carrier modulation techniques for TTC signals: alternative concept (see text)*

Note 1. – A to R denote service areas or countries.

Note 2. – The Region 3 concept can be derived by introducing applicable frequencies and number of channels.

The protection of the first and last broadcasting or feeder-link channel requires the specification of a maximum permissible e.i.r.p. for sub-carrier TTC signals. From the interference viewpoint this will only be necessary for the TTC channels closest to the broadcasting or feeder-link channel but overall system homogeneity considerations suggest applying a maximum level generally. Margins for atmospheric attenuation and depolarization will also have to be taken into account. However, there appears to be no need to assume simultaneous attenuation on the feeder or broadcasting link and ice depolarization on the TTC link. For further detailed information, reference is made to a similar consideration relevant for feeder links [Fromm and McEwan, 1981]. With this assumption the maximum permissible e.i.r.p. for TTC links is calculated as follows (all values are in dB):

Earth-to-space direction:

$e.i.r.p._{TTC} \leqslant e.i.r.p._{TV} - PR + 15$ dB

Space-to-Earth direction:

$e.i.r.p._{TTC} \leqslant e.i.r.p._{TV} - PR + 20$ dB

where:

$e.i.r.p._{TTC}$: maximum permissible e.i.r.p. of TTC signals;

$e.i.r.p._{TV}$: nominal e.i.r.p. of the interfered-with broadcasting or feeder-link channel;

PR: protection ratio for TTC interfering into broadcasting feeder-link channels (see § 3).

The values "15 dB" and "20 dB" are taken from § 4.1 and represent the worst-case atmospheric depolarizations. Typical link budgets satisfying these requirements are given in Annex II.

The clear-sky overall cross-polarization isolation is about 25 dB because of imperfect antenna performance. This suggests that attenuation margins for broadcasting or feeder links in excess of 5 dB and 10 dB, respectively, would lead to a different specification for the maximum permissible e.i.r.p. of TTC links in both directions:

$$e.i.r.p._{TTC} \leqslant e.i.r.p._{TV} - PR - ATT + 25 \quad \text{dB} \tag{4}$$

where:

ATT: permissible (planned) attenuation on Earth-to-space feeder link (> 10 dB) or space-to-Earth broadcasting link (> 5 dB).

The proposed concepts for TTC frequency assignment avoid frequency re-use and are thus in principle compatible with omnidirectional or similar spacecraft TTC antennas with poor cross-polarization performance. Such antennas would be required if TTC links in the 12 and 18 GHz bands should also be operated during satellite launch, transfer or during non-nominal behaviour of the spacecraft in orbit. Obviously, such operations have to be carried out in compliance with the protection requirements. Otherwise, temporary deviations from these requirements will have to be coordinated among the administrations concerned. In particular, e.i.r.p. levels required for feeder-link TTC signals into omnidirectional spacecraft antennas can exceed the maximum value permitted. This could lead to critical interference situations and special coordination will be required for such cases. Applying the frequency concept with orthogonal polarization decoupling as introduced with Fig. 2b, is expected to facilitate such frequency coordination.

Example link budgets together with other observations are discussed in Annex II.

4.3 *Alternative TTC modulation techniques*

The frequency assignment concept suggested in § 4.2 implies that any alternative TTC modulation technique must be compatible with the bandwidth and e.i.r.p. assignments discussed in § 4.2. If it is a technique such as spread-spectrum modulation, it is not likely to cause any significant additional interference as compared to the sub-carrier signals. Additionally, alternative TTC modulation techniques must be able to coexist with sub-carrier signals. This appears to be possible with spread-spectrum techniques although further detailed studies are required. A preliminary concept, which may make easier the simultaneous operation of nominal TTC links and those required for satellite launch, transfer and non-nominal in-orbit behaviour, is reviewed in Annex III.

REFERENCES

FROMM, H. H. and McEWAN, N. J. [May, 1981] Direct broadcast satellite feeder links: an example of possible implications of the Regions 1 and 3 Plan for feeder links to European broadcast satellite. ITU/Canada Seminar on RARC, 1983, Ottawa, Ontario, Canada.

CCIR Documents

[1978-82]: **a.** 10-11S/178 (ESA); **b.** 10-11S/153 (France).

[1982-86]: **a.** 10-11S/35 (ESA); **b.** 10-11S/26 (United States of America); **c.** 10-11S/8 (France); **d.** 10-11S/9 (France).

ANNEX I

TTC SIGNAL PROTECTION FROM THE ADJACENT TELEVISION CHANNEL IN THE FEEDER LINK

Tests carried out in France have studied the problems of feeder-link interference from the adjacent television channel to TTC signals (command and ranging). Tests were made using the equipment of a space operation service earth station and a model of the satellite command receiver. Conventional sub-carrier modulation techniques were used for the TTC signals. The television interferers were compatible with the technical characteristics of the RF channels specified in the Final Acts of the WARC-BS-77. Energy dispersal (600 kHz) was used. The TV carrier was modulated by the following video and sound signals:

- CCIR test lines (17, 18, 330, 331), white, grey and black lines or SECAM test card;
- two analogue sound sub-carriers.

Measurements were made on the carrier lock, the command bit error ratio and the ranging error. With the video and sound signals available in the laboratory, the worst case of interference was due to discrete lines from out-of-band TV spectrum emissions which were in the TTC band. The power of these discrete lines was equal to −30 dB (reference 0 dB being the total power of the adjacent TV channel). This −30 dB value corresponds to a −50 dB(W/Hz) power density in a 4 kHz band if energy dispersal is considered. This value is compatible with information given in Report 807 about the typical out-of-band envelope of the TV spectrum. In this case, tests have indicated a requirement for a −27 dB protection ratio for the TTC signal when the latter is at the edge of the adjacent television channel.

Because of the limited number of video signals used in the tests, other considerations on the maximum value of the discrete lines in the TTC band have been used to obtain the worst case of interference. In this case, measurements have given a −17 dB protection ratio corresponding to instantaneous discrete lines which could reach a −20 dB level (relative to the total power of the adjacent television channel). Further studies are required to confirm this probably pessimistic value of −20 dB.

ANNEX II

SUB-CARRIER TTC LINKS

1. **Example link budgets for sub-carrier TTC links** [CCIR, 1982-86a]

These link budgets are provided for illustration only. Assumptions are explained where essential. Budgets for specific satellite designs may differ.

1.1 *Earth-to-space links*

1.1.1 *Nominal operations*

Table I presents a link budget that is valid for the nominal operation of the spacecraft in geostationary orbit. Distinction is made between the classical telecommand and ranging function and the specific requirements due to RF sensing which actually determine the link design.

1.1.2 *Non-nominal operation*

Table II presents a link budget that refers to operations during satellite transfer and during non-nominal behaviour of the spacecraft in geostationary orbit.

TABLE I – *Example link budget for nominal operation, sub-carrier TTC links*

	Link parameter	Telecommand ranging function	RF sensing function	Notes
1	C/N_0 (dBHz)	60	60	Required for RF sensing
2	Spacecraft receive antenna gain (dBi)	40	26 (1)	Lower RF sensing gain due to coupling loss
3	Receive thermal noise temperature (dBK)	33	43 (1)	Higher RF sensing noise temperature due to switching/redundancy
4	Receive noise power density (dB(W/4 kHz))	−160	−150	At receive input
5	Receive interference power flux-density (dB(W/(m^2 · 4 kHz)))	−148		Assumes: $e.i.r.p._{TV}$ = 85 dBW, 20 dB cross polarization gain and spectrum at ± 15 MHz off centre (−50 dB(W/4 kHz))
6	Receive interference power density (dB(W/4 kHz))	−154	−168	(5) + (2) − 46 dBm^2
7	Total receive noise power density N_0 (dB(W/4 kHz))	−154	−150	Sum of (4) and (6)
8	Required receive level at receiver input (dBW)	−130	−126	
9	Link margin (dB)	10		Rain attenuation margin (see § 4.1)
10	Required earth-station e.i.r.p. (dBW)	49	67	Higher level may need to be used
11	Maximum permissible e.i.r.p. according to § 4 (dBW)	69		$e.i.r.p._{TV,min}$ = 80 dBW is assumed

(1) Data refer to a particular satellite design and are not generally applicable.

TABLE II – *Example link budget for satellite transfer orbit and non-nominal operations, sub-carrier TTC links*

	Link parameter	Telecommand ranging function	Notes
1	Required receive C/N_0 (dBHz)	45	(¹)
2	Spacecraft receive antenna gain (dBi)	−6	Omni-type antenna
3	On-board losses (dB)	2	Switching, waveguide runs
4	Receive noise power density (dB(W/4 kHz))	−160	T = 2000 K
5	Receive interference power flux-density (dB(W/(m² · 4 kHz)))	−128	Assumes: $e.i.r.p._{TV}$ = 85 dBW, No cross-polarization gain, spectrum at ± 15 MHz off-centre: (−50 dB(W/4 kHz)) (²)
6	Receive interference power density (dB(W/4 kHz))	−182	At receiver input
7	Total noise power density (dB(W/4 kHz))	−160	Sum of (4) and (6) (link is noise-dominated)
8	Required minimum receive carrier level	−151	
9	Implementation margin (dB)	10	Rain attenuation margin (see § 4.1)
10	Maximum spreading loss (dB(m²))	163	
11	Required earth-station transmit e.i.r.p. (dBW)	74	Special coordination may be required (³)

(¹) The common requirement for traditional spacecraft service functions operating in the 2 GHz band is 40 dB net. However, this may not be sufficient for this particular application considering the higher transmission frequency. It is for this reason that a higher value has been assumed here. Still, the actual requirement may exceed that estimated here and consequently further studies are needed before a reliable link budget can be constructed.

(²) The spacecraft receive antenna will have very limited cross-polar isolation, but this is not expected to influence the total noise power density significantly and has therefore been neglected.

(³) If TTC frequency assignments are employed according to Fig. 1a with the potential risk of insufficient decoupling between TTC and adjacent, co-polar feeder links, this decoupling must be achieved by means of the feeder link receive antenna on-board the interfered-with satellite. This decoupling is expected to be of the order of 20 to 30 dB which will normally be obtained with the co-polar radiation patterns of satellite receiving antennas.

1.2 *Space-to-Earth links*

1.2.1 *Nominal operation*

TABLE III – *Example link budget for nominal operation, sub-carrier TTC links*

	Link parameter	Telemetry ranging function	Notes
1	Required receive C/N_0 (dBHz)	55	Sufficient for good quality ranging signal
2	Earth-station receiver antenna gain (dBi)	53	5 m antenna
3	Earth-station receiver noise temperature (K)	500	Low noise receiver
4	Receive noise power density (dB(W/4 kHz))	–165	
5	Receive interference power flux-density (dB(W/(m^2 · 4 kHz)))	–170	PFD_{TV} = –100 dB(W/m^2), 20 dB cross-polarization advantage, spectrum at ± 15 MHz off-centre (–50 dB(W/4 kHz))
6	Receive interference power density (dB(W/4 kHz))	–160	(5) + (2) – 43 dB(m^2)
7	Total noise power density (dB(W/4 kHz))	–159	(6) + (4) marginally interference dominated
8	Spreading loss (dB(m^2))	163	Geostationary orbit
9	Link margin (dB)	5	Rain attenuation margin (see § 4.1)
10	Required minimum satellite e.i.r.p. (dBW)	18	Easily realisable with high transmit antenna gain
11	Maximum permissible e.i.r.p. (dBW)	37	Limit is set by permissible power flux-density limit

PFD: power flux-density.

1.2.2 *Non-nominal operation*

TABLE IV – *Example link budget for satellite transfer orbit and non-nominal operations in-orbit, sub-carrier TTC links*

	Link parameter	Telemetry ranging function	Notes
1	Required receiver C/N_0 (dBHz)	33	Net requirement, no margins included (¹)
2	Earth station receiver antenna gain (dBi)	53	5 m antenna
3	Earth station receive noise temperature (K)	500	Typical performance
4	Receive noise power density (dB(W/4 kHz))	−165	
5	Receive interference power flux-density (dB(W/(m² · 4 kHz)))	−170	PFD_{TV} = −100 dB(W/m²), 20 dB cross-polarization advantage, spectrum at ± 15 MHz off-centre (−50 dB(W/4 kHz))
6	Receive interference power density (dB(W/4 kHz))	−160	(5) + (2) − 43 dB(m²)
7	Total noise power density (dB(W/4 kHz))	−159	(6) + (4). Link is marginally interference dominated
8	Spreading loss (dB(m²))	163	Geostationary orbit
9	Link margin	10 dB	Rain attenuation margin (see § 4.1), and implementation losses
10	Required minimum satellite e.i.r.p. (dBW)	1	
11	Satellite transmit antenna gain (dBi)	−6	Quasi omni-directional coverage
12	Losses (dB)	2	
13	Required transmitter power (dBW)	9	8 W, requires TWT amplifier

(¹) This net requirement is common for traditional spacecraft service functions operating in the 2 GHz band but may not be sufficient for this application when considering the significantly higher frequency band and Doppler shifts. Further studies are needed before a reliable link budget can be constructed.

REFERENCES

CCIR Documents

[1982-86]: **a.** 10-11S/35 (ESA).

ANNEX III

SPREAD-SPECTRUM TTC LINKS

1. Example link budgets for spread-spectrum TTC links [CCIR, 1982-86a]

These link budgets are provided for illustration only. In the absence of a specific concept, calculations are based on the following formula and parameters:

$$(C/N)_{IF} = \frac{C \cdot D}{\frac{1}{2}\, C \cdot N \cdot P \cdot B + kTB + \dfrac{N \cdot B}{4\ \text{kHz}}} \qquad (5)$$

where:

$(C/N)_{IF}$: carrier-to-noise ratio in bandwidth B (Hz);

D: implementation loss, 5 dB;

P: 1/chip rate, $(3.1 \times 10^6)^{-1}$;

B: IF bandwidth, 250 Hz;

N_0: TV out-of-band spectral power density, 60 dB below carrier in 4 kHz, proves to be non-critical for link design due to additional cross-polarization advantage (20 dB);

k: Boltzmann's constant = -228.6 dB(W(K^{-1}));

T: receiver noise temperature (K);

N: number of users, 25;

$(C/N_0)_{IF}$: carrier-to-noise density ratio, $(C/N)B$ (dBHz).

1.1 *Earth-to-space link*

1.1.1 *RF sensing* (includes telecommand/ranging)

Assuming:

$C/N_0 = 45$ dBHz,

Note. – Much higher ratios are not feasible, this may require a special RF-sensing design. The influence of atmospheric fades remains to be assessed.

$T = 20\,000$ K, RF sensing,

and using formula (5) yields:

$$C = -133 \text{ dBW}$$

Employing the link data as for sub-carrier techniques, i.e.:

Satellite receiving antenna gain :	26 dBi
Spreading loss :	163 dB(m^2)
Fade margin :	10 dB

leads to an e.i.r.p. of 60 dBW.

1.1.2 *Telecommand/ranging function only during non-nominal orbit behaviour and transfer*

Assuming:

$C/N_0 = 34$ dBHz,

$T = 2000$ K, TC receiver,

and using formula (5) yields:

$$C = -157 \text{ dBW}$$

Employing the link data as for sub-carrier techniques, i.e.:

Satellite receiving antenna gain :	−6 dBi
Spreading loss :	163 dB(m^2)
Fade margin :	15 dB

leads to an e.i.r.p. of 73 dBW.

This latter e.i.r.p. is higher than that needed for nominal operation and needs therefore to be applied throughout all mission phases.

1.2 *Space-to-Earth links*

The determining link is that required during the satellite transfer and non-nominal in-orbit behaviour:

Assuming:

C/N_0 = 34 dBHz, sufficient for 125 bit/s,

Receive antenna = 53 dBi, 5 m earth-station antenna,

$e.i.r.p._{TV}$ = 63 dBW, reduced by 20 dB cross-polarization advantage

and using formula (5) yields:

$$C = -161 \text{ dBW}$$

Employing the link data as for sub-carrier techniques, i.e.:

Spreading loss :	163 dB(m^2)
Margin :	10 dB

leads to an e.i.r.p. of 2 dBW.

This e.i.r.p., employing an omnidirectional spacecraft transmitting antenna of −6 dBi and cabling losses of 2 dB, requires a transmit power of 10 dBW (10 W). This can be realized with a TWT amplifier.

2. Example frequency plan

An example frequency plan is illustrated in Fig. 3:

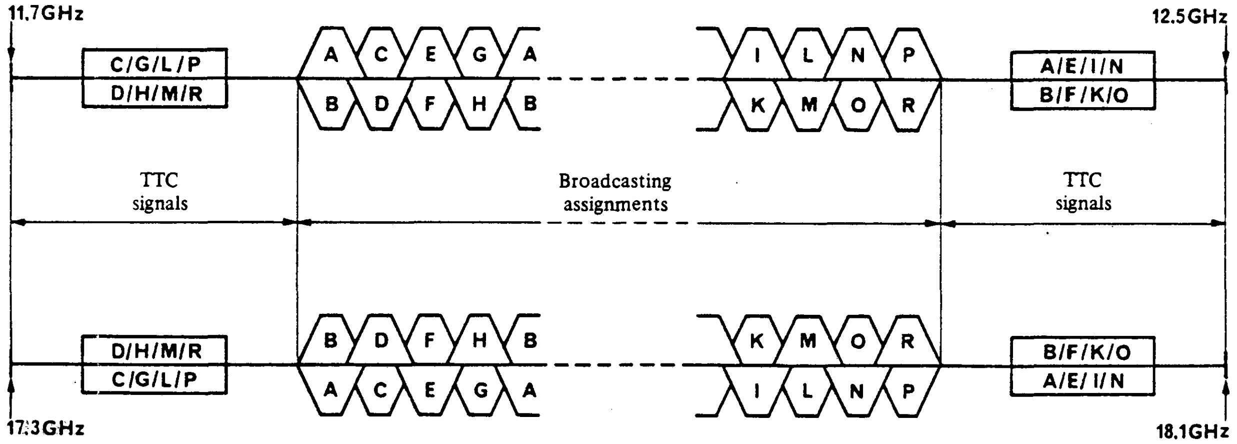

FIGURE 3 – *A proposal for TTC assignments for broadcasting satellites using spread-spectrum modulation techniques for TTC signals*

Note 1. – A to R denote service areas or countries.

Note 2. – These spread-spectrum assignments require a new approach in frequency coordination. Non-interference is achieved by code distinction rather than by frequency separation.

REFERENCES

CCIR Documents

[1982-86]: **a.** 10-11S/35 (ESA).

DECISIONS

DECISION 43-5*

SATELLITE SOUND BROADCASTING FOR PORTABLE AND VEHICLE RECEIVERS and SHARING AND SPECTRUM ASPECTS OF WIDE RF-BAND HDTV SATELLITE BROADCASTING

(1980-1981-1983-1985-1987-1989)

CCIR Study Groups 10 and 11,

CONSIDERING

(a) that Study Groups 10 and 11 are concerned with the broadcasting-satellite service which is directly interested in the efficient use of the geostationary and other satellite orbits due to both the sharing of frequency bands with other space services and the provision of feeder links for its systems by the fixed-satellite service;

(b) that it is highly desirable, with respect to receiver economy, that a unified and compatible family of standards be used for both satellite and terrestrial sound broadcasting;

(c) that there has been considerable progress in the development of satellite broadcasting service (sound), in particular in the area of advanced digital systems;

(d) that Resolution No. 505 resolves that the CCIR shall continue and expedite studies relating to the technical characteristics of a satellite sound-broadcasting system for individual reception by portable and vehicle receivers;

(e) that the Plenipotentiary Conference, Nice 1989 resolved to hold a WARC in 1992 for dealing with frequency allocations in certain parts of the spectrum taking account, _inter alia_, of the Resolutions and Recommendations of WARC ORB-88;

(f) that Resolution No. 520 of WARC ORB-88 invited the CCIR to pursue its technical studies on the broadcasting satellite service (sound) in the frequency range 500 MHz - 3 000 MHz, especially on the following issues:

- i) the impact of choice of frequency on system parameters, especially satellite power requirements, the characteristics of transmitting and receiving antennas and on propagation characteristics;
- ii) the bandwidth required by the service;
- iii) the technical aspects of sharing between services with special consideration to geographical sharing,

and to provide a report to the Conference referred to in CONSIDERING (e) above;

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* This Decision should be brought to the attention of Study Group 4 regarding feeder links and to Study Group 5 regarding propagation factors.

CONSIDERING ALSO

(g) that Resolution No. 521 of WARC ORB-88 invited the CCIR to continue its studies on wide RF-band HDTV for satellite broadcasting using a frequency band in the range 12.7 - 23 GHz and also in the range 11.7 - 12.7 GHz without prejudice to the existing plans, and to provide a report to the Conference referred to in CONSIDERING (e) above;

(h) that Study Groups 10 and 11 have mandated Joint Interim Working Party 10-11/3 to study the system aspects of HDTV broadcasting by satellite in the context of Study Programme 2M/10-11;

(j) that additional studies on suitable frequency bands and sharing constraints with other services are required for wide RF-band HDTV systems for the BSS;

(k) that Resolution No. 521 of WARC ORB-88 has invited the CCIR to undertake further studies of feeder links and down links for wide RF-band HDTV;

(l) that the band 22.5 - 23 GHz has already been allocated to the broadcasting-satellite service only in Regions 2 and 3;

(m) that due account should be taken of other radiocommunication services appearing in Article 8 of the Radio Regulations;

(n) that the CCIR intends to hold a meeting of a JIWP of various Study Groups [ten months] before the 1992 Conference to prepare the CCIR report for the WARC-92,

DECIDE

1. that JIWP 10-11/1 be continued with the following terms of reference:

1.1 to study, in the context of Study Programme 2K/10 and 11, aspects of satellite sound broadcasting for individual reception by portable and vehicle receivers in the band 500 - 3 000 MHz, including:

- Quality of Service;
- types of modulation;
- RF channel bandwidth required per sound programme;
- propagation factors (with the assistance of Study Group 5);
- use of different satellite orbits;
- satellite power required;
- transmitting and receiving antennas;
- receivers;
- feeder links;

- impact of choice of frequency of operation on system parameters;
- total bandwidth required by the service;
- technical aspects of sharing (inter-, intra- and interregional) with other radiocommunication services with special consideration to geographical sharing;
- radiation outside the service area (No. 2674 of the Radio Regulations);
- multiple-user satellite;
- economic factors including common receivers for terrestrial and satellite sound broadcasting;
- the implications of a satellite sound broadcasting system augmented by terrestrial rebroadcast transmission should be studied;

1.2 to present a report on the above points to the meeting of the JIWP mentioned in CONSIDERING (n) above;

1.3 propose amendments to appropriate reports and Recommendations, and taking into account WARC ORB-88 Decisions about sound broadcasting by satellite, report to Study Groups 10 and 11 at their next Interim Meetings in 1991,

ALSO DECIDE

1.4 to undertake, particularly in the context of Study Programme 1E/10 and 11, and in consultation with JIWP 10-11/3, specific studies called for by Resolution No. 521 related to wide RF-band HDTV satellite broadcasting and to submit a report on the following subjects to the JIWP mentioned in CONSIDERING ALSO (n):

- total bandwidth required for the service;
- inter- and intra-service sharing;
- interregional sharing; and
- spectrum allocation and sharing aspects related to the associated feeder links;

1.5 to propose amendments to appropriate Reports and Recommendations, and taking into account Resolution No. 521 of WARC ORB-88, report to Study Groups 10 and 11 at their next Interim Meetings in 1991;

2. that JIWP 10-11/1 work within the provisions of Resolution 24 and that it limit its work to the existing texts of the XVIIth Plenary Assembly from Study Groups 10 and 11 and to new contributions from participants in the work of Study Groups 10 and 11 and JIWP 10-11/1;

3. that the Chairman, the Vice-Chairmen and composition of the IWP will be as shown in Annex I:

ANNEX I

Administrations:

Germany (Federal Republic of)
Australia
Brazil
Canada
Spain
United States of America
Finland
France
India
Iran (Islamic Republic of)
Italy
Japan
Netherlands
German Democratic Republic
United Kingdom
Sweden
Switzerland
USSR

International Organizations:

EBU
EUTELSAT
INTELSAT.

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DECISION 51-4

SATELLITE BROADCASTING OF HIGH DEFINITION TELEVISION (HDTV) SIGNALS

and

ACCOMMODATION OF SEVERAL AUDIO AND/OR DATA SIGNALS EITHER ASSOCIATED WITH TELEVISION SIGNALS OR FOR SOUND/DATA BROADCASTING IN TERRESTRIAL AND SATELLITE BROADCASTING CHANNELS

(Questions 2/10 and 11, 29/11 and Study Programmes 2C/10 and 11, 2F/10 and 11, 2K/10 and 11, 2M/10 and 11, 2N/10 and 11, 47A/10, 47B/10, 51C/10, 51D/10, 51E/10 and 12B/11)

(1981-1983-1985-1987-1989)

CCIR Study Groups 10 and 11,

CONSIDERING

(a) that it is desirable to optimize the use of the satellite and terrestrial channel capacity in relation to the various requirements between picture, sound and data broadcasting services;

(b) that it is desirable, in respect of receiver economy, that unified, easily convertible standards be used for similar applications in satellite broadcasting and in terrestrial broadcasting;

(c) that the definition of emission standards is urgent for satellite broadcasting as well as for terrestrial broadcasting, bearing in mind the time needed for the development of receiving equipment, and the expected implementation dates of various new services,

CONSIDERING ALSO

(d) that HDTV signals can provide a significant improvement in quality and realism over conventional 525/625-line systems;

(e) that there has been considerable progress in the development of HDTV production systems and that Interim Working Party 11/6 is continuing its work to define a standard for production and programme exchange;

(f) that the development of techniques of high definition television broadcasting is rapidly progressing;

(g) that the possible implementation of high definition television broadcasting by terrestrial emission is being considered by some administrations;

(h) that experimental implementation of high definition television broadcasting by satellite emission has commenced and that other administrations are preparing for it, and that this may also have implications for terrestrial broadcasting;

(j) that a world-wide frequency allocation to the broadcasting-satellite service suitable for HDTV emissions would be desirable to facilitate the implementation of high definition television emission via satellites;

(k) that Study Groups 10 and 11, in Study Programmes 2M/10 and 11, have decided to carry out studies relating to the satellite broadcasting of HDTV and have prepared related Report 1075 on system aspects;

(l) that the Plenipotentiary Conference, Nice 1989, resolved to hold a WARC in 1992 for dealing with frequency allocations in certain parts of the spectrum taking account, inter alia, of the Resolutions and Recommendations of WARC ORB-88;

(m) that Resolution 521 has invited the CCIR to undertake further studies of feeder links and down links for wide RF-band HDTV;

(n) that the CCIR intends to hold a meeting of a Joint Interim Working Party of various Study Groups [ten months] before the 1992 Conference to prepare a report for the WARC-92;

(o) that Study Groups 10 and 11 have mandated JIWP 10-11/1 to study the spectrum requirement and sharing aspects of wide RF-band HDTV broadcasting by satellite;

(p) that digital modulation methods appear to be better suited to the difficult propagation conditions in the higher end of the frequency range mentioned in Resolution 521, and to operation in an interference environment while providing a high degree of spectrum efficiency,

CONSIDERING FURTHER

(q) that several CCIR Questions and Study Programmes concern the definition of new standards for the emission of several audio signals accompanying the television picture signal and, in particular, Study Programmes 47A/10, 47B/10, 51C/10, 51E/10 and 12B-1/11 and that JIWP 10-CMTT/1 has been formed to study digital source coding and compression of high quality multi-channel audio;

(r) that audio signals may also be emitted in the absence of a picture signal in a channel designed for television, provided that there is no resultant increase in the interference (see Annex 5 of Appendix 30 (ORB-85) to the Radio Regulations);

(s) that technological developments allow the emission of digital signals to the public to be envisaged, but that the use of digital modulation requires the prior definition of the characteristics of systems concerning source coding, multiplexing, channel coding and modulation of audio signals, in accordance with Study Programmes 51C/10, 51D/10, 51E/10 and 2F/10 and 11;

(t) that there is, in many countries, a need to increase the number of sound broadcast programmes and the number of sound signals associated with the television picture signal, but that in satisfying these requirements, account must be taken of the constraints of spectrum economy;

(u) that the data broadcasting services studied by JIWP 10-11/5 (see Question 29/11 and its related Study Programmes and Study Programme 46H/10) are likely to expand in the near future and that it is desirable to be able to use the same type of system for the broadcasting of data and digital sound;

(v) that a first edition of the CCIR Special Publication "Specifications of transmission system for the broadcasting-satellite service" containing information available up to 1987 has been published.

(w) that new and more detailed information is now becoming available on the emission systems being implemented for the broadcasting-satellite service, but that it will not be possible to consider all of this new information in time for the 1990 Plenary Assembly of the CCIR;

(x) that detailed information should be available for general use without undue delay.

DECIDE

1. that JIWP 10-11/3 be continued with the following terms of reference:

1.1 to study radio frequency and emission technical parameters including modulation, channel coding and multiplexing of HDTV broadcasting with the technical assistance, as required, of IWP 11/6 and JIWPs 10-CMTT/1 and 10-11/5;

1.1.1 to study the subjects of system parameters, and propagation characteristics as they relate to the emission of HDTV. This study should be undertaken on the following types of systems:

- digital wide RF-band systems;
- analogue wide RF-band systems;
- analogue narrow RF-band systems;

1.1.2 to provide technical assistance, as required, to the competent IWPs of Study Group 11, which intend to prepare a companion Report during the same period on the subject of the emission of HDTV;

1.1.3 to undertake the specific further studies and to prepare, in consultation with JIWP 10-11/1, a report called for by Resolution 521 and to submit this report to the meeting of the JIWP mentioned in CONSIDERING (n) above. This report is to include the following:

1.1.3.1 system parameters for wide RF-band high definition television emissions by satellite with emphasis on the effect of the choice of frequency, e.g.:

- quality of service;
- impact of choice of frequency of operation on system parameters;
- modulation (including emission format, multiplexing and channel coding);
- channel bandwidth requirement;

- satellite power requirements;
- satellite and earth station technology;
- receiving system characteristics;
- system characteristics for the associated feeder links;
- type of polarization (propagation effects);
- protection ratios;

1.1.3.2 propagation characteristics, (with the assistance of Study Group 5) e.g.:

- precipitation losses (considering attenuation);
- atmospheric absorption;
- cross-polar discrimination;
- mitigation techniques against propagation effects;

1.2 to study broadcasting techniques of several audio signals and/or data signals either associated with TV signals or for sound/data broadcasting in terrestrial and satellite broadcasting channels;

1.2.1 to continue the examination of modulation standards for the accommodation of picture signal and several audio and/or data signals. The study should include the methods for interconnecting between satellite and terrestrial broadcasting systems;

1.2.2 to study suitable channel coding and multiplexing methods for accommodation, in the structure of HDTV emission formats, the necessary number of sound channels, with adequate quality, as specified by Study Group 10;

1.2.3 for the case of data signals, to study the suitable multiplexing methods in relation to § 1.2.2, keeping appropriate coordination with JIWP 10-11/5, which is responsible for the source coding and the definition of the data broadcasting services;

1.2.4 to study appropriate methods to organize and define the use of the broadcasting channel capacity between different signals such as picture, sound and data;

1.3 to review the information contained in the CCIR Special Publication "Specifications of transmission systems for the broadcasting-satellite service" concerning Recommendation 650 in conjunction with available new information and to prepare an updated revision or supplement to the Special Publication;

1.3.1 to consider the new information in conjunction with the Special Publication and approve, on behalf of the CCIR, the publication of a revised edition of, or supplement to, the Special Publication by 31 December 1990;

1.3.2 to review the need for further revision on completing 1.3.1 and to report to the next Interim Meetings of Study Groups 10 and 11;

1.4 to propose appropriate changes to relevant CCIR Reports and Recommendations and report on the results of the above studies to Study Groups 10 and 11 at their next Interim Meetings in 1991;

2. that JIWP 10-11/3 work within the provisions of Resolution 24 and that it limit its work to the existing texts of the XVIIth Plenary Assembly from Study Groups 10 and 11 and to new contributions from participants in the work of Study Groups 10 and 11 and JIWP 10-11/3;

3. that the Chairman, the Vice-Chairmen and composition of the IWP will be as shown in Annex I:

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Finland
France
India
Iran (Islamic Republic of)
Italy
Japan
Kenya
Netherlands
German Democratic Republic
United Kingdom
Sweden
USSR

International Organizations:

EBU
EUTELSAT
INTELSAT.

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DECISION 93

PREPARATORY WORK FOR THE WARC 1992

(1989)

CCIR Study Groups 10 and 11,

CONSIDERING

(a) that the ITU Plenipotentiary Conference (Nice, 1989), by Resolution No. 1 (PL-B/1) has decided:

- that the World Administrative Radio Conference for dealing with frequency allocations in certain parts of the spectrum be held in the first quarter of 1992;
- that the agenda for this Conference shall be established by the Administrative Council taking into consideration, *inter alia*, the Resolutions and Recommendations of WARC ORB-88 relating to frequency allocations;

(b) that the WARC ORB-88, by Resolutions 520 and 521, has invited the CCIR to carry out certain studies on satellite sound broadcasting and satellite wide RF-band HDTV in preparation for this Conference;

(c) that Study Groups 10 and 11 have prepared Reports relevant to satellite sound broadcasting and to HDTV satellite broadcasting;

(d) that JIWP 10-11/1 has already carried out studies on satellite sound broadcasting within its terms of reference in Decision 43;

(e) that JIWP 10-11/3 has already carried out studies on HDTV satellite broadcasting within its terms of reference in Decision 51;

(f) that the CCIR Interim Meetings for the period 1990 - 1994 will not be held before the CCIR JIWP meeting preparing for the Conference, referred to in Resolution 100,

DECIDE

1. that JIWPs 10-11/1 and 10-11/3 carry out as much of their work as possible by correspondence;

2. that, for the specific purpose of preparing the necessary work for the Conference as outlined in Annex, JIWP 10-11/1 and JIWP 10-11/3 hold one meeting each;

3. that the meetings shall be held at an appropriate time to submit reports directly to the JIWP referred to in Resolution 100 ——— not later than two months before the convening of the JIWP;

4. that, for convenience, the meetings should be held consecutively and, in particular, the meeting of JIWP 10-11/3 before that of JIWP 10-11/1, preferably in the same general geographical area;

5. that such meetings should be arranged on the basis of proposals of the Chairmen of the JIWPs following consultations with the Director of the CCIR.

ANNEX I

The work shall include, but not necessarily be limited to the following:

(a) for wide RF-band HDTV transmissions by satellite in the frequency range 12.7 to 23 GHz:

- impact of choice of frequency of operation on system parameters;
- modulation;
- emission format, multiplexing and channel coding;
- channel bandwidth;
- satellite power required;
- type of polarization;
- protection ratios;
- propagation;
- total spectrum required;
- inter-/intra-service sharing;
- interregional sharing;
- system characteristics for feeder links;
- spectrum needs for feeder links.

Studies should be carried out in accordance with Resolves 3 of Resolution No. 521 (WARC ORB-88), which states: "While the Plans for the band 11.7 - 12.7 GHz can already be used for certain types of high definition television systems, studies should be continued on the long range future suitability of the band 11.7 to 12.7 GHz for wide RF-band HDTV without prejudice to the existing Plans in this band."

(b) for satellite sound broadcasting for portable and vehicle receivers in the frequency range 0.5 to 3 GHz:

- impact of choice of frequency of operation on system parameters;
- quality of service;
- modulation;
- emission format, multiplexing and channel coding;
- channel bandwidth;
- use of different satellite orbits;
- satellite power requirements;
- propagation characteristics;
- characteristics of receive and transmit antennas;
- total spectrum requirement;
- feeder link spectrum requirement;

the technical aspects of sharing between services with special consideration to geographical sharing (inter-, intra- and interregional sharing).

Furthermore, the implications of a satellite sound broadcasting system augmented by terrestrial rebroadcast transmissions should be studied.

92-61-04271-6