REPORT ITU-R BO.1075-2

HIGH-DEFINITION TELEVISION BY SATELLITE

(Questions ITU-R 92/11, ITU-R 100/11)

(1986 - 1990 - 1994)

Preface

Work on HDTV satellite broadcasting is currently following two distinct directions and with two different time scales.

On the one hand, systems are being developed for application in the existing 12 GHz BSS Plans (in correspondence with Appendices 30 and 30A of the Radio Regulations). These systems must work with the relatively narrow bandwidth of the Regions 1 and 3 and the Region 2 Plans, originally designed for conventional PAL, SECAM and NTSC television formats. They must also comply with the interference criteria on which the 12 GHz Plans are based. As a consequence some degradation compared to the studio HDTV signal quality may have to be accepted. Such systems are called "Narrow RF-band HDTV systems" and their introduction is foreseen in the near future. They may be analogue or digital and may or may not be compatible with existing conventional TV standards such as D- and D2-MAC/packet.

On the other hand, research work is underway to develop for long-term application what is called "Wide RF-band HDTV systems". The aim of this development is, in congruence with Resolution 520 of the Radio Regulations, the provision of virtual HDTV studio quality in the viewer's home. Most studies concentrate on a digital approach in the 20 GHz frequency range.

This Report reflects the actual situation with respect to satellite broadcasting of HDTV. It deals in Part 1 with the narrow RF-band systems whereas Part 2 is devoted to the studies in the field of wide RF-band HDTV satellite broadcasting.

PART 1 - NARROW RF-BAND HIGH-DEFINITION TELEVISION BROADCASTING BY BSS IN THE 12 GHZ BAND

1. Introduction

Narrow RF-band HDTV systems are systems which, as a result of accepting a degree of degradation compared to studio HDTV quality, could fit within the 24 or 27 MHz channels of existing BSS Plans in the 12 GHz frequency range.

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, 1986-90, Doc. 11/195 WP 11A]. This will influence factors such as visibility of noise, interference and distortion. Objective target values are needed for these parameters. These objective values are related to subjective impairments.

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

- good quality must normally be available, and
- 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, as the viewer will be paying a premium for quality, both in the higher cost of the receiver, and in the programme costs.

Depending upon the coding and modulation scheme, the quality is related 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 quality grade of 3.5, achieved for 99% of the worst month.

Improvements in receiver technology have led to higher values of figure-of-merit (G/T) and therefore better carrier-to-noise ratio being achievable as described in § 7 of Part 1 of the present Report. In the case of HDTV transmissions in the 12 GHz band, the target value of carrier-to-noise ratio for analogue systems should be in the order of 17 to 20 dB. In the case of digital systems, the required C/N is a function of the order of modulation.

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 of Part 1 of the present Report.

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 is attenuated by hydrometeors (see § 4 of Part 1 of the present Report). 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 geographical 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.

3. Planning characteristics of the 12 GHz band

The characteristics of the 12 GHz Plans are reported in Appendix 30 to the Radio Regulations. The corresponding feeder-link plan is described in Appendix 30A to the Radio Regulations.

4. Propagation factors affecting the use of this band

This section summarizes the various propagation characteristics of the 12 GHz band.

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 ITU-R PN.564.

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.

4.1 Atmospheric absorption

Beyond about 8 GHz, the effects of the atmosphere on satellite transmission are no longer negligible, but the level of atmospheric absorption is below 1 dB at 12 GHz for all practical elevation angles (see Table 1).

Figure 3 of Report ITU-R PN.719 shows the level of absorption as a function of frequency and Report ITU-R PN.564 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 attenuation caused by rain is heavily dependent on the amount of precipitation at the specific location. Report ITU-R PN.564 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 1 may be given as estimates for the attenuation caused by rain, as a function of the percentage of the worst month at 12 GHz.

TABLE 1

Estimated rain attenuation for 99% and 99.9% of worst month, atmospheric attenuation, clear-sky attenuation and cross-polar attenuation for some countries in Region 1 at 12 GHz

FREQ = 12.00 GHz

	SAT	ELEV	$A_{1\%}$	$A_{0.1\%}$	A_{gcr}	A_{cs}	$XP_{1\%}$	$XP_{0.1\%}$
NOR - OSLO	0.0	22.06	1.7	4.7	0.4 -	0.4 -	27.4	19.8
J	20.0	19.97	1.8	5.1	0.4 -	0.4 -	26.7	19.0
59.91 10.75	40.0	14.21	2.4	6.5	0.6 -	0.5 -	24.4	16.6
FIN - QULU	0.0	16.72	1.0	2.2	0.5 -	0.5 -	33.9	26.8
C	20.0	15.06	1.1	2.4	0.5 -	0.5 -	33.2	26.0
65.00 25.40	40.0	10.40	1.5	3.2	0.8 -	0.7 -	30.8	23.4
GB - LONDON	0.0	31.08	1.3	3.6	0.3 -	0.3 -	30.8	23.4
F	20.0	28.16	1.4	3.9	0.3 -	0.3 -	29.8	22.4
51.50 -0.07	40.0	20.36	1.8	4.9	0.4 -	0.4 -	27.1	19.5
IRL - DUBLIN	0.0	29.10	1.5	4.2	0.3 -	0.3 -	29.3	21.8
H	20.0	26.38	1.6	4.5	0.3 -	0.3 -	28.4	20.9
53.33 -6.30	40.0	19.04	2.0	5.6	0.5 -	0.4 -	25.8	18.2
POL - WARSAW	0.0	30.30	1.5	4.1	0.3 -	0.3 -	29.5	22.0
H	20.0	27.46	1.6	4.4	0.3 -	0.3 -	28.6	21.0
52.22 21.00	40.0	19.84	2.0	5.6	0.4 -	0.4 -	26.0	18.3
SUI - BERNE	0.0	36.05	1.8	5.4	0.3 -	0.2 -	28.2	20.7
K	20.0	32.60	2.0	5.8	0.3 -	0.3 -	27.1	19.5
46.95 7.46	40.0	23.59	2.4	7.2	0.4 -	0.4 -	24.3	16.5
I - ROME	0.0	41.63	1.8	5.5	0.2 -	0.2 -	29.3	21.9
K	20.0	37.51	1.9	5.8	0.3 -	0.2 -	28.0	20.4
41.90 12.50	40.0	27.05	2.4	7.1	0.4 -	0.3 -	24.7	16.9
E - MADRID	0.0	43.29	1.4	4.1	0.2 -	0.2 -	32.0	24.7
H	20.0	38.95	1.5	4.4	0.3 -	0.2 -	30.5	23.1
40.41 -3.75	40.0	28.03	1.9	5.4	0.3 -	0.3 -	27.0	19.4
F - PARIS	0.0	33.99	1.0	2.8	0.3 -	0.3 -	33.4	26.2
E	20.0	30.77	1.1	3.0	0.3 -	0.3 -	32.3	25.1
48.83 2.33	40.0	22.27	1.4	3.8	0.4 -	0.4 -	29.5	22.0
ALG - ALGIERS	0.0	47.44	1.8	5.6	0.2 -	0.2 -	30.7	23.3
K	20.0	42.50	2.0	5.9	0.2 -	0.2 -	29.0	21.5
36.70 3.13	40.0	30.42	2.4	7.2	0.3 -	0.3 -	25.1	17.4
SDN - WADIHAIFA	0.0	64.24	0.4	0.8	0.2 -	0.2 -	54.0	48.1
A	20.0	55.73	0.4	0.8	0.2 -	0.2 -	49.6	43.4
22.00 31.50	40.0	38.47	0.5	1.1	0.3 -	0.2 -	42.8	36.2
CNE - YAOUNDE	0.0	85.49	3.8	12.1	0.2 -	0.2 -	57.3	51.7
Q	20.0	66.15	3.6	11.3	0.2 -	0.2 -	32.9	25.7
3.83 11.58	40.0	43.57	3.9	12.2	0.3 -	0.2 -	23.6	15.7
KEN - NAIROBI	0.0	88.49	1.0	3.0	0.2 -	0.2 -	84.9	81.1
J	20.0	66.51	1.1	3.1	0.2 -	0.2 -	43.3	36.7
-1.28 35.80	40.0	43.72	1.3	3.9	0.3 -	0.2 -	32.7	25.4
MOG - ANTANARIVO	0.0	67.81	4.7	15.1	0.2 -	0.2 -	31.8	24.5
P	20.0	58.17	4.5	14.5	0.2 -	0.2 -	27.0	19.4
-18.92 47.52	40.0	39.78	4.6	14.6	0.3 -	0.2 -	21.2	13.3

Note - SAT is the longitude shift of the satellite with respect to the ground station, ELEV is the elevation angle, $A_{1\%}$ and $A_{0.1\%}$ are the attenuations for 99% and 99.9% of the worst month, A_{gcr} are the attenuations during rain from gases and clouds (already included in $A_{1\%}$ and $A_{0.1\%}$), A_{cs} is the attenuation due to gases and clouds in clear-sky, $XP_{1\%}$ and $XP_{0.1\%}$ are the XPD values for 99% and 99.9% of the worst month. The test sites, on the left of the table, are referred by country, location, rain zone, latitude and longitude.

Worst month statistics of attenuation in rain (Table 2) were obtained using simultaneously passive radiometers at 12 GHz for five years in Tokyo. The values include absorption due to atmospheric gases as well as rain attenuation.

TABLE 2

Measured rain attenuation at 12 GHz in Tokyo

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

For high rainfall rate climates, data which have been received by WP 5C indicate that appropriate rain fade margin requirements for 99% of a worst month are as given in Table 3 below.

TABLE 3

Examples of Ku-band* data for some tropical countries

Country	El. Angle	99% of the worst month fade margin
Cameroon	47 degrees	3.8 dB
Kenya	48 degrees	3.8 dB
Nigeria	57 degrees	1.4 dB
Papua New Guinea	73 degrees	2.4 dB

* Ku-band covers the 14/11 and 14/12 GHz fixed service bands. The examples given above are all between 11.6 and 12.75 GHz. They are also relevant to the broadcasting-satellite service in the 12 GHz band.

Note - At lower elevation angles, the required margin can be significantly more.

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 power flux density cannot be guaranteed over the whole of the central area.

Studies by the European Space Agency have shown that this problem can be alleviated 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 duration 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.

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.

4.3 Rain depolarization

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

Depolarization for circular polarization can be predicted by the model described in Report ITU-R PN.564. Recent measurement results were found to be in good agreement with predicted values.

Using the semi-empirical formula given in Report ITU-R PN.564 relating cross polarization to attenuation, Table 1 contains information on cross polarization at 12 GHz.

4.4 Other propagation effects

Although the atmospheric impairments on radiowaves are dominated by rain effects, other mechanisms, e.g. clouds, melting layers and wet snow, may become increasingly important under certain conditions at higher frequencies and lower elevation angles.

It can be seen from Tables 1, 2 and 3 that the typical fade margins are in the order of 3 to 5 dB. At these fade levels, signal dispersion due to rain effects will be negligible even in a climate having the highest rainfall rates. For those locations in high rainfall rate regions where the operating elevation angles are relatively low, care should be taken to account for tropospheric scintillation effects. In addition to the increased margin required to overcome tropospheric scintillation, designers of digital systems may need to take account of the potential loss of synchronization which might occur from time to time in severe scintillation [ITU-R, 1990-1994, Doc. 10-11S/109 (Working Party 5C)].

Cloud effects on radiowave propagation can be described in terms of attenuation, scintillation and depolarization [CCIR, 1986-90, Doc. 10-11S/8 (JIWP 10-11/3) and Doc. 10-11S/63(Rev.1) (JIWP 10-11/3)].

4.5 Propagation experiments

Space-based and terrestrial propagation measurements and experiments have been conducted for many years.

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), 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) and from the OLYMPUS (30, 18/30, 30/20 and 12 GHz) experimental satellite of ESA. These latter programs will provide information on the depth and duration of fades (signal attenuation) for a 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.

According to Working Party 5C, planning for the transmission by satellite of HDTV services in high rainfall rate climates utilizing 12 GHz links can be carried out in exactly the same way as that used for similar transmission systems utilizing this band (e.g. public switched telephony). To this end, WP 5C has assembled a significant database of propagation experiments in these regions and in this band which can be used to assist in the planning of such systems.

5. Transmission techniques

5.1 General aspects

The important features of HDTV production systems as envisaged in Report ITU-R BT.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 ITU-R BO.601;
- improvements in temporal resolution beyond that achievable with Recommendation ITU-R BO.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; and
- 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 or with a lesser amount of bandwidth compression.

One feature which is highly desirable, although not absolutely necessary, is "downward compatibility". As defined in Report ITU-R BT.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 § 6 of Part 1 of the present Report.

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 ITU-R BO.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 four to five times higher than the conventional analogue (Report ITU-R BT.624) and digital standards (Recommendation ITU-R BT.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. 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); and
- pre-emphasis (linear and non-linear techniques).

As described in Report ITU-R CMTT.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 is already done with conventional digital television transmission (see also Report ITU-R BT.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 in the 12 GHz Plans. Currently, real-time codecs for this technique are under development in various countries.

There are three basic methods for bit-rate reduction under study and development: discrete cosine transform coding ("DCT"), vector quantization coding ("VQ") and sub-band coding. DCT is the most widely used and highly developed technique (Recommendation 723). It is used in projects concerning digital TV and HDTV in Europe. Systems have also been proposed in the United States and experimental units are being developed in Japan. VQ and sub-band coding are less developed techniques. The estimates of the bit-rate reduction that can be obtained are therefore based on present work and experts' evaluations.

Different coding methods produce different artifacts (defects). Failure modes and their characteristics for digitally coded and modulated HDTV emission systems are divided into artifacts due to source coding and artifacts due to errors in the received signal. In general, the higher the available transmission bit rate, the lower the probability of perceptible artifacts in the picture due to the vision coding process.

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-channels (3-channels for front and 1-channel for rear) or 5-channels (5-channels 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, 1986-90, Doc. 10/52 (Japan)] while retaining a high sound quality. More efficient coding schemes such as MUSICAM [Theile, et al., 1987] have been developed and a bit rate of 128 kbit/s for a mono channel is sufficient for a sound quality indistinguishable from that of the compact disc.

Sound coding schemes and their evaluation are discussed in Report ITU-R BO.953 and Report 1099.

According to Report ITU-R BO.954, 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

Any HDTV signals intended for 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.

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 of the transmitted signal may be expressed empirically by a modified version of Carson's formula:

$$B = \alpha\Delta f_L + 2f_{max} \quad (1)$$

where B : RF bandwidth (approximate) (MHz)

α : constant for a given system which depends upon the pre-emphasis used (in MAC and MUSE systems $\alpha = 1$) [CCIR, 1986-90, Doc. 10-11S/20 (United Kingdom)]

f_{max}: maximum video frequency (MHz)

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

Increasing the baseband width in a system to provide higher definition pictures has a significant effect on the available video signal-to-noise ratio. Thus, there would generally be a need to increase the carrier-to-noise spectral density ratio when the baseband bandwidth is increased.

In the 12 GHz band, the maximum possible frequency deviation is restricted by interference constraints. Transmission of an HDTV signal with about 10 MHz video bandwidth requires a carrier-to-noise ratio of the order of 17-20 dB. However, if the frequency deviation can be increased while maintaining the required interference requirements of the 12 GHz Plan, the carrier-to-noise ratio (referred to 24 or 27 MHz) can be reduced.

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] (see Report ITU-R BO.1074-1) and adaptive emphasis may also be employed for the same purpose. DC preservation is necessary to utilize the given RF bandwidth effectively.

5.5.2 Digital channel coding

Experiments in the United States have measured the performance of concatenated codes for satellite television broadcasting and found that a moderate (but practical) increase in coding complexity over that associated with single-string codes results in a significant performance improvement. The trade-off between coding rates for a Reed-Solomon code and a convolutional code was carried out by trial-and-error, and it was found that the required E_b/N_o to maintain a given picture quality level was reduced by about 3 dB. The increased complexity in coding now requires two chips instead of the one chip required before. This scheme has been reduced to practice and will be used on the first United States broadcasting satellite system to operate in the 12.2 - 12.7 GHz band when it begins service in early 1994.

The coding method consists of concatenating a Reed-Solomon block code with a Viterbi convolutional code. For the high rate mode, the convolutional code would be rate 7/8 while a rate 2/3 would be used for the lower rate mode. The two convolutional codes used can be derived from a single rate 1/2 convolutional code. By omitting selected bits from the decoding process, the single rate 1/2 convolutional code can be modified, or "punctured", to operate at higher rates while retaining the simplicity of the rate 1/2 decoder and nearly the performance of the best higher rate codes. The ability to change convolutional code rates allows the aggregate code rate to change between approximately 0.77 and 0.58 (from 30 Mbit/s to 22.8 Mbit/s information).

The change in coding gain from 0.77 to 0.58 aggregate rate is approximately 1.3 dB. The change in data rate is approximately 1.2 dB. Therefore, the change in required E_b/N_o is 2.5 dB [ITU, October 1993, 10-11S/158 (United States)].

5.5.3 Digital modulation

The use of digital modulation offers the following advantages compared to analogue TV systems:

- capability to operate with reduced satellite power and receiving antenna diameters without picture/sound degradation;
- enhanced ruggedness against interference and hence lower protection ratio requirements; and
- improvement in spectral efficiency.

Possible methods of modulation are 4-PSK, 8-PSK and 16-QAM, which give a range of trade-offs between power, bandwidth, and ease of sharing.

Of these, 4-PSK and 8-PSK are well established and widely used modulation schemes in satellite communication systems. Moreover the concatenation of multiple error correcting block codes (e.g. Reed-Solomon or BCH codes) and convolutional codes or "trellis coded modulation" (TCM) with soft-decision Viterbi decoding allows very high coding gains to be achieved, of the order of 10-12 dB at the bit error ratio of 10^{-8} to 10^{-9} typically required for digital TV.

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

QPSK can operate efficiently close to saturation (OBO = 0 dB, i.e. with maximum TWTA power; E_b/N_o = 12.0 dB). For 8-PSK the optimum performance was found with 0.5 dB output backoff (E_{bs}/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. By using a TWT linearizer, the required OBO could be reduced to about 3 dB in this case.

QPSK or O-QPSK digital modulation allows operation at significantly reduced C/I ratio conditions which are typically 10 dB lower than for conventional analogue FM. Co-channel operation using orthogonal polarization within the same service area can therefore be envisaged.

Furthermore, owing to the low sensitivity to interference from other digital signals, QPSK or O-QPSK would be expected to allow a higher value of spectrum/orbit utilization in planning, without the need for taking interference from adjacent orbit positions into account.

Higher order modulation schemes like 16-QAM, characterized by higher spectral efficiency than QPSK (considering just an isolated channel), require not only higher C/N ratio values but also higher protection ratios.

For a digital system, the overall HDTV service quality depends jointly 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 the 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 usable picture quality up to a bit error ratio of 10^{-3}.

---

* $E_{bs}/N_o = E_b/N_o$ + OBO: Energy per information bit, available at TWTA saturation.

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

Table 4 gives examples of HDTV narrow-band transmission formats. These systems require extensive signal processing in order to allow the HDTV signal to fit into a single 24 or 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.

Systems N1 and N2 which can be carried in one 24 or 27 MHz channel have been demonstrated. The other systems are at various stages of development.

TABLE 4

Characteristics of example narrow RF-band HDTV satellite broadcasting systems

Parameter	System N1 (MUSE)	System N2 (HD-MAC)	System N3 (HD-BMAC)	System N4 (Generic digital)
Aspect ratio	16:9	16:9	16:9/4:3	16:9
Picture rate (Hz)	30	25(1)	59.94	25(1)/30
Active lines/picture	1032	1152	720	1152/[1032]
Basic sampling frequency (MHz)	Y:48.6 C:16.2	54	75.6	72
Active samples/line:(4)				
luminance	1122	1440	1360	1120/1920
colour difference	376	720	340	560/960
Type of coding	analogue	analogue	analogue and digital	digital
Compression method	motion-adaptive sub-sampling with motion-compensation	motion-adaptive sub-sampling with motion-compensation	adaptive sub-band coding	adaptive predictive DCT block variable length coding
Maximum luminance bandwidth (MHz)(2)	22	21	28.9	25
Maximum colour difference bandwidth (MHz)(2)	7	10.5	9.6	12.5
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	35
Digital sound/data multiplex (Mbit/s)	1.35	1.5 or 3	-	2
Sound signal bandwidth (kHz)	20/15	15	15	20
Sampling frequency (kHz)	48/32	32	32	48
Number of sound channels	2/4	2/4 or 4/8	3	4 to 8
Coding/modulation method	DPCM/ternary	PCM/ duobinary	To be specified	ISO layer II
Companding law	15-to-8 (8 ranges)/ 16-to-11 (8 ranges)	Linear 14/ 14-10 NICAM	To be specified	-
Digital time compression	13.5:1	6.6:1	12.5:1	-
Error protection coding (Mbit/s)	included above	included above	To be specified	~3 Mbit/s

TABLE 4 (cont.)

Symbol rate (Mbaud)	12.15 Ternary	-	11.2	~20
Instantaneous bit rate (Mbit/s)	-	10.2 20.25(5)(6)	22.4 FM	~40 Mbit/s
Type of modulation	FM	FM	To be specified	4 PSK or 8 PSK-TCM
Frequency deviation at crossover frequency of the linear pre-emphasis network	10.2	13.5(7)		-
Required RF bandwidth (MHz)	27/24	27(7)	27/24	27
Polarity of frequency modulation	positive	positive		-
d.c. component	preserved	preserved		-
Energy dispersal (triangular frame synchronous waveform)	600 kHz p.p	600 kHz (7) p.p		-

Notes to Table 4

(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) For future generations of BSS satellite systems, other transmission parameters are under consideration. In particular transmission of HD-MAC in a 33 MHz bandwidth with a frequency deviation of 22 MHz/V at the crossover frequency and an energy dispersal waveform with up to 4 MHz peak-to-peak deviation.

6.1 System N1 (MUSE)

System N1 is the MUSE system developed in Japan for HDTV broadcasting using a single planned channel [Ninomiya, et al., 1987] [CCIR, 1986-90, Doc. 10-11S/28 (Japan)].

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 1.

6.2 System N2 (HD-MAC)

System N2 is the HD-MAC system currently being developed in Europe for use in the 12 GHz planned band [CCIR, 1986-90, Docs. 10-11S/19 (United Kingdom), 11/82 (United Kingdom), 11/154 (United Kingdom), 10-11S/6 (France)].

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 elements and active 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 2.

In addition, digital transmission of the HD-MAC signal (System N2) at 140 Mbit/s has been demonstrated at IFA, Berlin in 1989 [CCIR, 1986-90, Doc. 10-11S/225 (Belgium et al.,)].

6.3 Systems N3 (North American systems)

Several systems are under consideration in the United States. Only one analogue system is described here. Four digital systems are under very active consideration for terrestrial broadcasting, as described in the draft new Report on digital television terrestrial broadcasting (Document 11-1/TEMP/20). The specification of the satellite versions is still under consideration.

6.3.1 System N3 (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 3, section 2.

6.4 System N4

System N4 is an all-digital example based on the combination of predictive coding, DCT and motion compensation for emission of 1250/50 or 1125/60 studio signals. The total bit rate of this system is of the order of 40 Mbit/s. Using 4-PSK or 8-PSK-TCM modulation, the required RF bandwidth is 27 MHz [De Gaudenzi, Elia, Viola, 1991].

6.5 Downward compatibility

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

One approach for compatibility between conventional television and high-definition television is two-channel transmission systems [CCIR, 1982-86, Doc. 10-11S/28 (United States)] [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 Europe, active studies are under way concerning HDTV systems which can be received compatibility by MAC/packet receivers, with the normal quality of the latter signals. If the high-definition television signal possessed characteristics at low frequencies of the spectrum identical to those of the existing MAC signals as in the examples of Table 3 compatibility between the two types of service will be possible.

[CCIR, 1986-90, Doc. 11/356 (Spain)] 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, 1986-90, Doc. 11/346 (EBU)] would support the HD-MAC system as described in § 6.2 of Part 1 of the present Report 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 nominal 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 ITU-R BO.473, neglecting, however, the pointing loss, polarization effects and ageing.

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 noise figure may be rather conservative and 1.8 dB would be more appropriate (see Report ITU-R BO.473-5).

Typical receiving antenna characteristics for 12 GHz are reported in Table 5.

TABLE 5

Typical antenna characteristics at 12 GHz

Diameter (m)	0.9	0.6
Half power beamwidth (degree)	1.9	2.8
Gain (dB) (η = 65%)	39.2	35.6
Clear-sky figure-of-merit (dB (K^{-1}))(1)	15.6	12.4
Noise figure (dB)	1.8	1.8

(1) In the link budget calculation, the usable figure-of-merit as defined in Report 473 should be used.

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 Mbit/s.

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/s 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, 1986-90, Doc. 10-11S/27 (Japan)].

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 lower cost MUSE receivers for home use [CCIR, 1986-90, Doc.10-11S/180 (Japan)].

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 ITU-R BT.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, 1986-90, Doc. 11/6-2037 (Japan)].

In the first designs, horizontal resolution of 1,000 lines, or greater than 1,400 picture elements per active line, and vertical resolution commensurate with 1,250 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 1,250 lines progressive scanning at a 50 Hz field rate (1250/50/1:1) or 1,250 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, 1986-90, Doc. 11/6-2022 (United States)].

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, 1986-90, Doc. 11/6-2022 (United States)].

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 1,000 TV lines [CCIR, 1986-90, Doc. 11/6-2056 (Thomson-C.S.F.) and Doc. 11/6-1055 (Thomson-C.S.F.)].

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 1,250 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 possibility 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, 1986-90, Doc. 11/6-2032 (Japan) and Doc. 11/6-1017 (Canada)].

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 sub-carrier/NTSC systems are being used.

The indoor unit is configured so as to be able to receive both digital sub-carrier/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, 1986-90, Doc. 10-11S/174 (Japan)].

In September 1989, developments of prototypes of a MUSE receiver utilizing a series of custom VLSIs (see § 7.3 of Part 1 of the present Report) 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, 1986-89, Doc. 10-11S/176 (Japan)].

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 a Y, U, V signal on the 1250/50/2 standard with an aspect ratio of 16:9. The upconverter will output a 1250/100/2 signal.

The development of the HD-MAC receivers is based on the experimental decoder that was made for the demonstration 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, 1986-90, Doc. 10-11S/224 (Germany et al.)].

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 2 and Report ITU-R BT. 801), at IFA Berlin in 1989 [CCIR, 1986-90, Doc. 11/410 (CCIR SG 11)].

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, 1986-90, Doc. 10-11S/225 (Belgium et al.)].

Conditional access systems have been developed suitable for the HD-MAC system. They are comprised of 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 pseudo-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, 1986-90, Doc. 10-11S/131 (France)].

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 12 GHz, 400 W tubes have been developed but have not been put in operation. There is a tendency to limit the output power to about 120 W to 150 W per channel, thus not necessarily exploiting the assigned e.i.r.p. values.

8.2 Multiplexer

Multiplexers for use at 12 GHz are well developed.

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 but care must be taken to keep the radiated power in the satellite antenna mask defined by the Plan.

9. Link budgets and satellite power requirements

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

$$e.i.r.p._{transmit} = P_o + G_t + L_f \quad (2)$$
$$= PFD + L_s + A + \alpha$$

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° beamwidth area (see § 8 of Part 1)	(dBi)
L_f	: loss in the feeder and filter in the satellite	(dB)
PFD	: power-flux density requirement at the edge of service area	(dB(W/m^2))
	= $C/N + \beta_u + k + B + 10 \log (4\pi/\lambda^2) - G/T$	
L_s	: spreading loss = $20 \log (4\pi d^2)$	(dB)

A	:	rainfall attenuation (see § 4 of Part 1)	(dB)
α	:	atmospheric absorption	(dB)
C/N	:	required carrier-to-noise ratio (see section 2)	(dB)
β_u	:	impairment due to feeder-link noise ≈ 0.5 dB	(dB)
k	:	Boltzmann's constant = -228.6 (dB(W(Hz.K)$^{-1}$))	
B	:	equivalent noise bandwidth (see § 6 of Part 1)	(dB(MHz))
λ	:	wavelength	(m)
G/T	:	figure-of-merit of receiver (see § 7 of Part 1)	(dB(K)$^{-1}$)

An estimation of the e.i.r.p. requirements may be made using the values of Table 6 for spreading loss (L_s), wavelength factor (10 log $4\pi/\lambda^2$), atmospheric absorption (α) and rainfall attenuation (A) for temperate climates.

TABLE 6

Radioelectric parameters at 12 GHz

Parameter	12 GHz/band (dB)
L_S	162.5
10 log $4\pi/\lambda^2$	43.0
α	0.1
A	1.5
L_S + 10 log $4\pi/\lambda^2 + \alpha$ + A	207.1

Example of link budget is given in Table 7 for a narrow RF-band analogue and digital system.

TABLE 7

Examples of link budgets of HDTV satellite transmission

Category	Symbol	Narrow RF-band analogue	Narrow RF-band digital
1. System			
Frequency of carrier (GHz)		12	12
Type of modulation		FM	digital
Approximate equivalent rectangular bandwidth (MHz)	B	27	27
Carrier-to-noise ratio[1)] before demodulation (dB)	C/N	20 (for 99% of worst month)	11 (for 99.9% of worst month)
Additional noise of feeder link (dB)	βu	0.5	0.5
2. Receiving installation (60 cm diameter)			
Figure-of-merit (dB(K^{-1})) - nominal	G/T	12.1	12.1
- usable	G/T	11 (99% of worst month)	10 (99.9% of worst month)
Required pfd at the edge of beam area (dBW/m^2)	pfd	-106.8	-110
3. Propagation			
Spreading loss (dB)	L_s	162.5	162.5
Additional propagation[2)] losses (dB)	A + α	1.6 (99% of worst month)	5.1 (99.9% of worst month)
Required e.i.r.p. from satellite at beam edge (dBW)	e.i.r.p.	62.3	57.3
4. Satellite transmitter			
Antenna beamwidth (degree)[3)]		1.0	1.0
Antenna gain at the edge (-3 dB) of service area (dB)	G_t	41.8	41.8
Loss in feeders, filters joints, etc. (dB)	L_f	2.0	2.0
Required satellite (dBW) transmitter power	P_o	22.5	17.5
(W)		177	56.0

Notes to Table 7

1) The design criteria in establishing the necessary C/N values are the following:

- Analogue system: Nominal quality of clear sky (C/N = 22 dB)
  Good quality for 99% of worst month (C/N = 20.5 dB)
- Digital system: Service continuity is up to 99.9% of worst month (C/N = 11 dB)
  For about 99.8% the nominal quality (C/N ≥ 13 dB) is then assured. (For an unimpaired picture and sound, 13 dB of C/N is needed. This value includes 1.5 dB implementation margin, 1.5 dB TWTA degradation, 1 dB interference degradation and 1 dB additional margin.)

2) The earth station elevation angle is assumed to be 40°. The rain attenuation corresponds to an average temperate climate in Europe as an example (see § 4 of Part 1 of the present Report). The atmospheric absorption is taken as 0.1 dB.

3) This is an example for a 1° beamwidth. The actual antenna characteristic has to 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. 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.

10.1 Subjective assessments

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 1. 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 8 and Table 9 (these conditions are basically based on Recommendation 500). The results of assessment tests are shown in Figs. 2 and 3. 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.

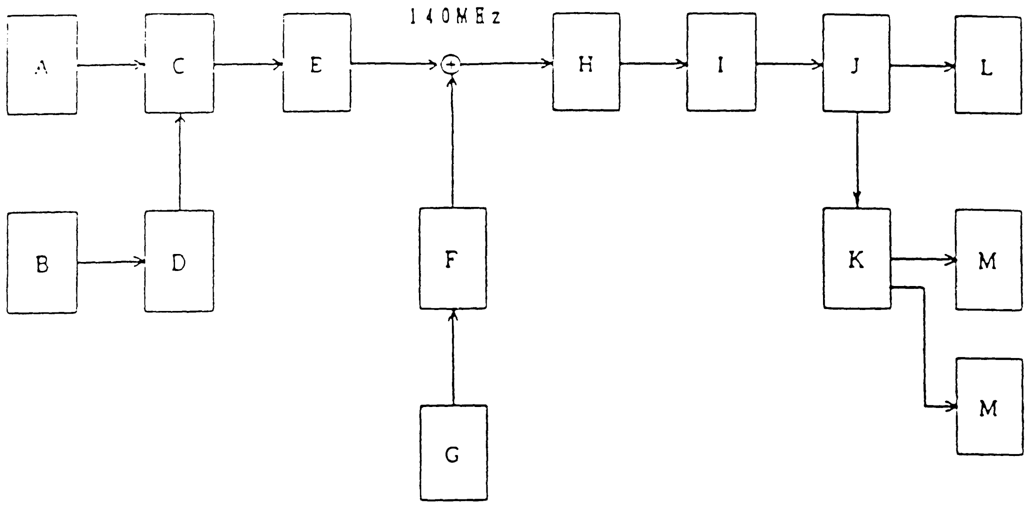


FIGURE 1

Experimental set-up for subjective assessment 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 8

Viewing conditions

Test pictures	Test slides fruit, 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 9

Listening conditions

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

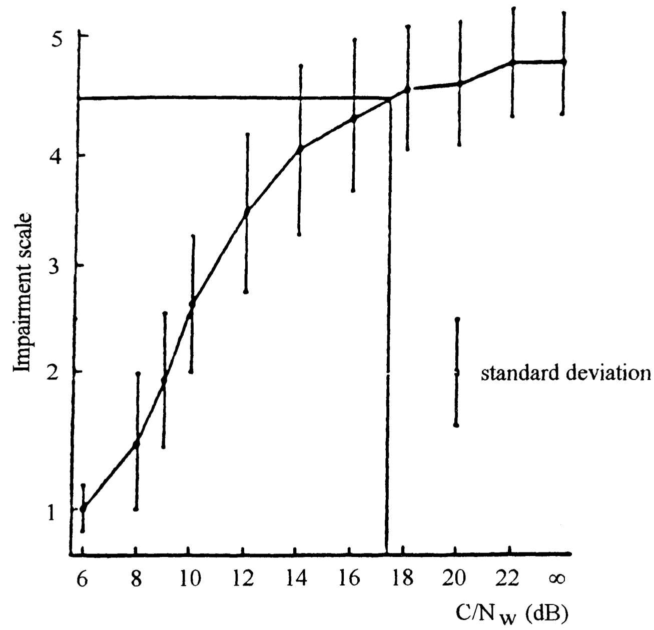


FIGURE 2

Result of picture evaluation test

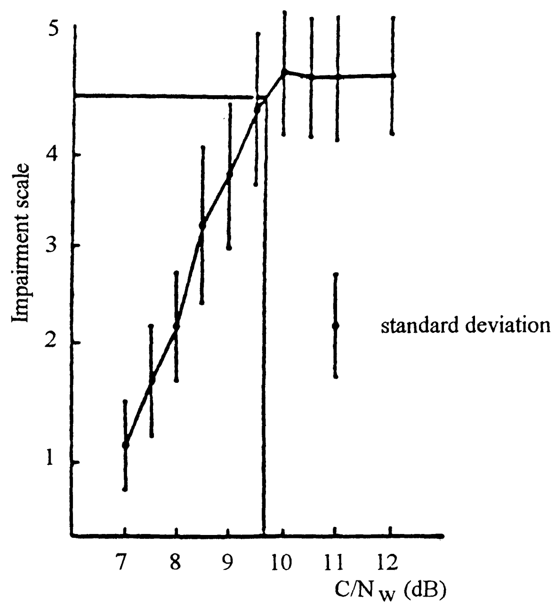


FIGURE 3

Results of sound evaluation test

Subjective assessment has 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 W (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 : 3 H
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. 4. 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 HD-MAC 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 HD-MAC (§ 10.1.1 of Part 1 of the present Report) there was no visible impairment on any of the analysed pictures.

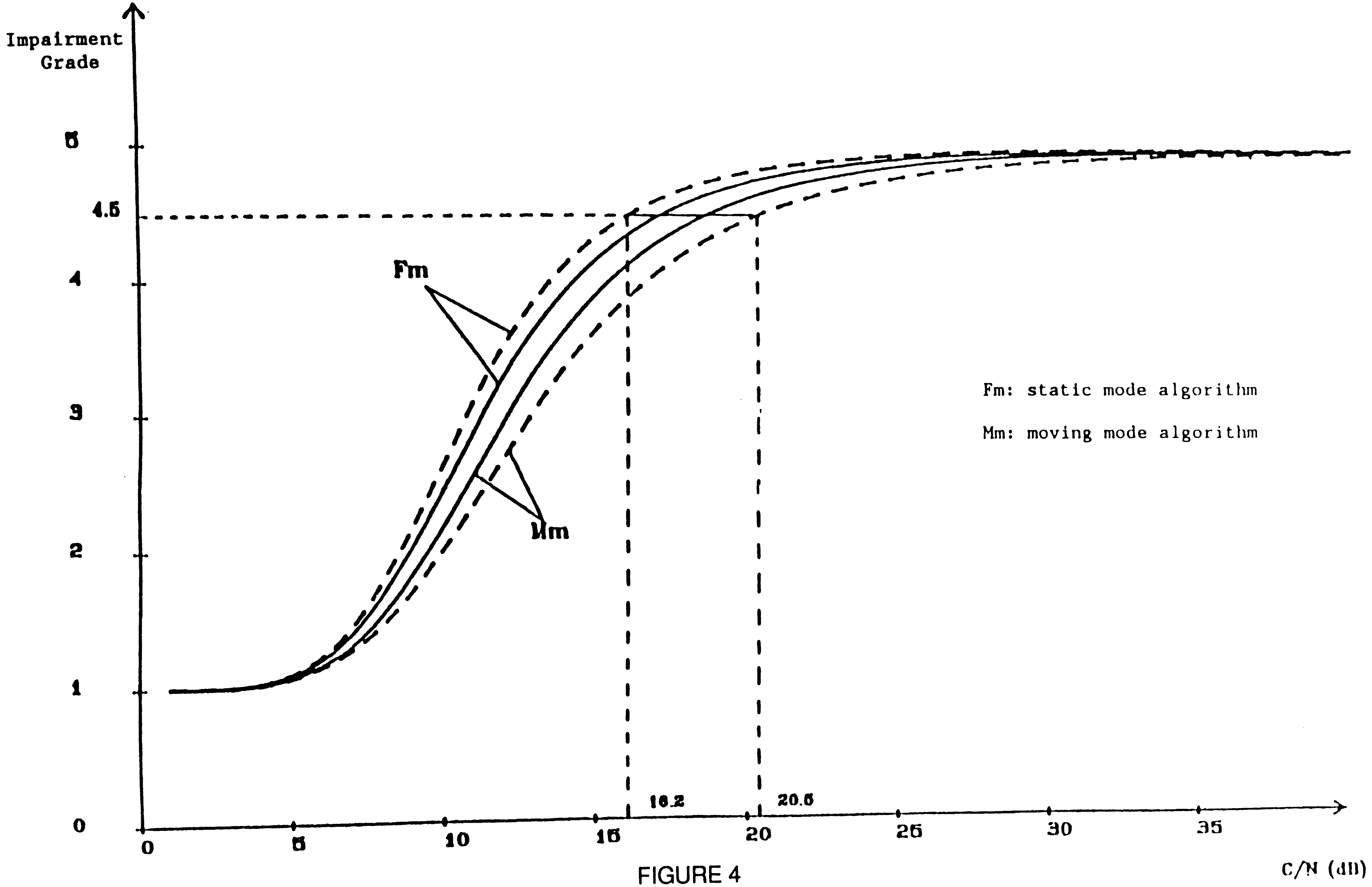


FIGURE 4

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 logarithmic 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, 1986-90, Doc. 10-11S/179 (Japan)].

10.2 Experiments

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 3. 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 3.

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 4 describes the experiments in detail.

11. Interference within the same service

11.1 Required protection

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

For the MUSE systems subjective assessments were carried out in accordance with Recommendation 600. Figures obtained with a typical 5th order Butterworth filter are shown in Table 10 (better results will be obtained with a surface acoustic wave filter which is being introduced into satellite broadcasting receivers) [CCIR, 1986-90, Doc. 10-11S/106 (Japan)].

For HD-MAC, results presented in Table 10 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, 1986-90, Doc. 10-11S/103 (France)].

TABLE 10

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 No. 1 SMPTE No.14	MUSE	10.0 11.7	18.0 18.7	10.14 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 11

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*
HD-MAC	Boats	HD-MAC (grid)	-	20.5 ± 1	-
	Circus		6 ± 0.8	-	5.2 ± 0.8
SECAM	Boats	HD-MAC (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 ITU-R BO.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, 1986-90, Doc. 10-11S/12 (UK)]. 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 overall C/(N+I) 13 dB including 1 dB for the contribution of interference from adjacent channels [De Gaudenzi, et al., 1991]

The following sets are examples for the resulting trade-offs between C/N and the co-channel interference:

C/N (dB)	13	14	15	16	18	20
C/I (dB) (co-channel)	31	20	17.5	16	14.5	14

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

12. Conclusions

The following specific conclusions can be drawn:

a) analogue narrow RF-band HDTV systems are feasible in the 12 GHz BSS band;

b) digital systems based on 4-PSK or TC-PSK with up to about 40 Mbit/s can be supported in the WARC-BS 77 Plan, but also other more efficient modulation schemes (e.g. 16-QAM) are under consideration;

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

d) all HDTV systems need a certain amount of bandwidth compression;

e) the 12 GHz band is now planned in all regions on the basis of conventional television systems;

f) narrow RF-band systems (operating in a 24 - 27 MHz channel according to the 12 GHz plans) are characterized by high degree of bandwidth compression;

g) the analogue narrow RF-band systems described (MUSE, HD-MAC) meet the Plan requirements of the 12 GHz band. It is expected that digital narrow RF-band will also meet the Plan requirements as far as the interference to the reference system to the Plan is concerned;

h) it can be expected that digital systems would require protection ratio significantly lower than analogue systems and consequently offer potential planning advantages; and

i) use of sophisticated bandwidth reduction techniques that are required for narrow RF-band HDTV systems can give good picture quality, but with added receiver complexity.

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

References

COMINETTI, M., MORELLO, A., and VISINTIN, M. [October 1989] - Digital transmission of television signals by satellite. Technical Symposium, ITU-COM 89, Geneva, pp. 523-527.

DE GAUDENZI, Elia, Viola: Digital Broadcasting Systems [1991]: A new frontier for satellite communications, ESA Journal, 1991, Vol. 15.

IREDALE, R. [October 1986] - A proposal for a new high-definition NTSC broadcast protocol, Proceedings of the 12th Technical Conference of the SMPTE.

LONG, T. and STENGER, L. [1986] - The broadcasting of HDTV programmes. EBU Tech. Rev. No. 219.

NEWLAND, J.D. [1988] - Investigation of mutual interference between digitally modulated signals. BSS Research Department Report No. BBC RD 1988/13.

NINOMIYA, Y. et al. [1987] - Concept of MUSE system and its protocol, NHK Laboratory Note No. 345.

NISHIZAWA, T. and TANAKA, T. [June 1982] - New approach to research and development of high-definition television. NHK Tech. Monograph No. 32, 98-101.

SAUERBURGER, H. [1987] - Breit- und schmalbandige, kompatible, einkanalige HDTV-Ubetragung, Fernseh- und Kinotechnik (41), pp. 23-32.

SAUERBURGER, H. and STENGER, L. [May 1984] - Zweikanal-Verfahren zur Ubertragung von HDTV-Signalen. Jahrestagung der FKTG, Hamburg, Federal Republic of Germany.

SHELSWELL, P. and DOSCH, C. [October 1986] - Satellite broadcasting of HDTV - Some basic considerations. EBU Tech. Rev., No. 219, pp. 315-325.

STOREY, R. [1986] - HDTV motion adaptive bandwidth reduction using DATV. BBC Research Department, Report 1986/5.

THEILE, G. et al. [March 1987] - Low-bit rate coding of high quality audio signals. Reprint 2432 (C-1), 82nd convention of AES, London.

TSINBERG, M., AZADEGAN, F. and FISCH, E. [June 1989] - Introduction of an NTSC compatible HDTV system: HSD-NA. International Conference on Consumer Electronics.

Bibliography

FUKUGHI, H. [January 1985] - Frequency scaling of depolarization at centimeter and millimeter waves. Electronics letters, IEE, Vol. 21, No. 1, 10-11.

GLENN, W.E. [1987] - New developments in a compatible high definition television transmission system, 1987 NAB Engineering Conference Proceedings.

HANDA et al. [March 1986] - Trends and development of low noise amplifier using new FET device. AIAA 11th Communication Satellite System Conference, 308-312.

ITO, S. [November 1986] - Characteristics of attenuation by rain and atmospheric gases on an Earth-space path at 22 GHz band in rainy weather (in Japanese). Trans. IECE of Japan, Vol. J69-B, No. 11, 1548-1555.

KUTKA, R. and WAIDHAS, W. [29 February - 2 March 1988] - A formation to calculate the optimal quantization of DCT coefficients for HDTV coding. 2nd International Workshop on Signal Processing of HDTV, L'Aquila.

SHIBATA, et al. [1986] - 20 GHz-band low-noise HEMT amplifiers, IEEE MTT-S Int. Microwave Symposium Dig., pp. 75-78.

ANNEX 1

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 5 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 6 (a) for stationary portions of the picture. It should be noted that this is a basic illustration in reference to Figure 5, and the actual transmissible range of the system will be explained later with Figure 8 (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 6(c) for moving portions of the picture.

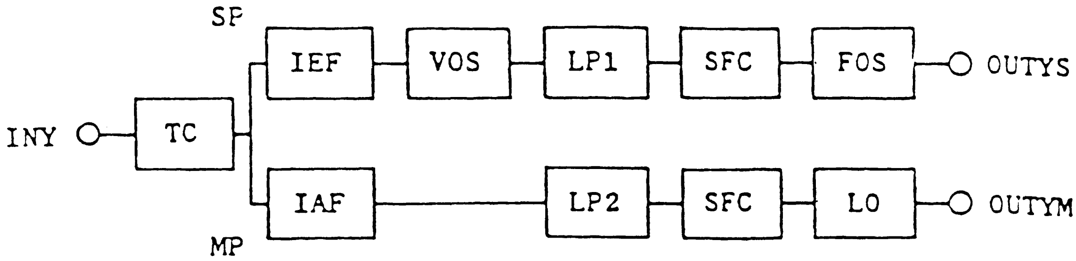


Figure 5
(a)

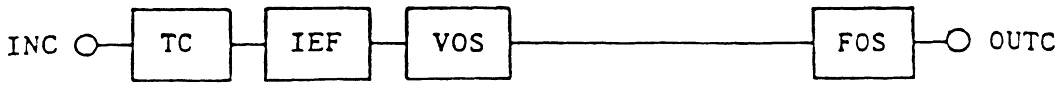


Figure 5
(b)

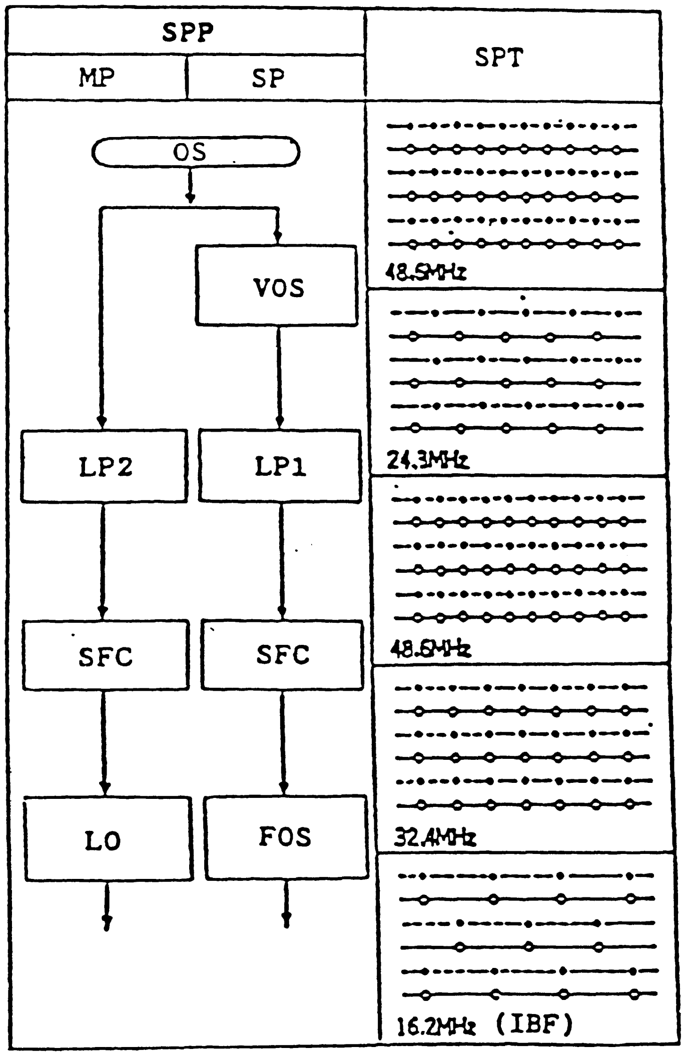


Figure 5
(c)

Figure 5 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
—O—: 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 6 (a), whereas it is halved to be 1/(4h) for moving portions as shown in Figure 6 (b), because the 2:1 interlace scanning is applied to the original HDTV signal.

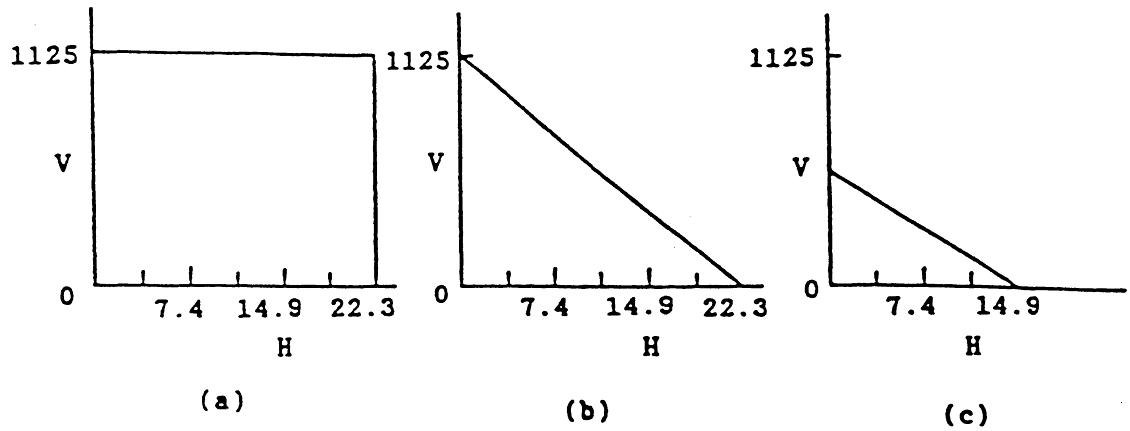


Figure 6 Transmissible range in spatial frequency domain
(a) Original sampling
(b) Interframe and interfield interpolation for stationary portions
(c) Intrafield interpolation for moving portions
H : horizontal frequency (MHz)
V : vertical frequency

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 9 shows the waveform).

Before the signal is subsampled, as explained above with Figure 5, 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 11.

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 7, and the frequency spectra at major points of the process are indicated in Figure 8. These figures are shown in the case of a still picture.

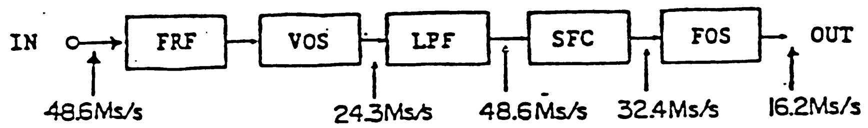
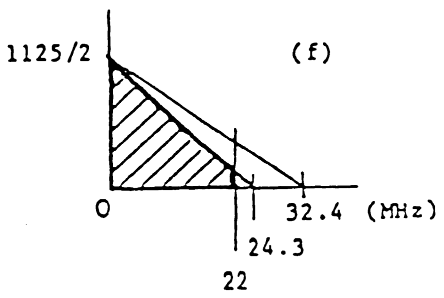


FIGURE 7 - Filtering arrangement of MUSE system (for luminance signal)
IN : luminance signal input
FRF: interfield prefiltering
VOS: field-offset subsampling
LPF: 12 MHz low-pass filtering
SFC: sampling-frequency conversion
FOS: frame-offset subsampling
OUT: output signal



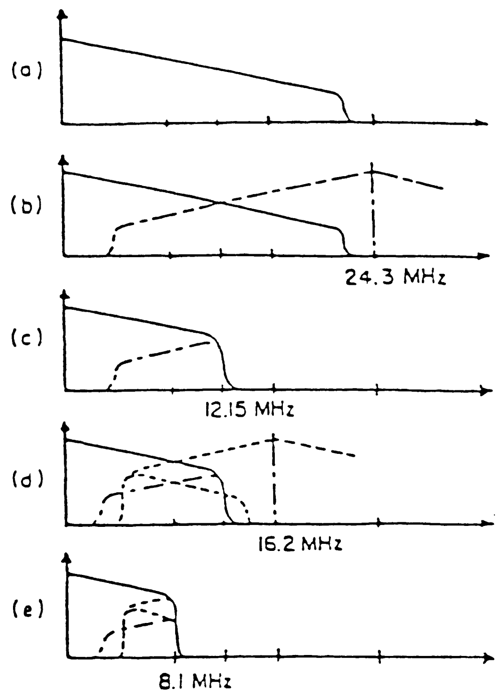


FIGURE 8 - Frequency spectrum of MUSE system (for luminance signal)
(a) Input signal
(b) Field-offset sub-Nyquist sampling at 24.3 MHz
(c) Low-pass filtering at 12 MHz
(d) Frame-offset sub-Nyquist sampling
(e) Output signal
(f) Transmissible frequency range of MUSE system
Abscissa: Horizontal spatial frequency (expressed in MHz)
Ordinate: Vertical spatial frequency

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 8(c).

At the next stage shown in Figure 7, 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 8 (e), and results in stable operation of the motion detection with a small amount of sacrifice in the trasmissible range as shown in Figure 8 (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 9 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.

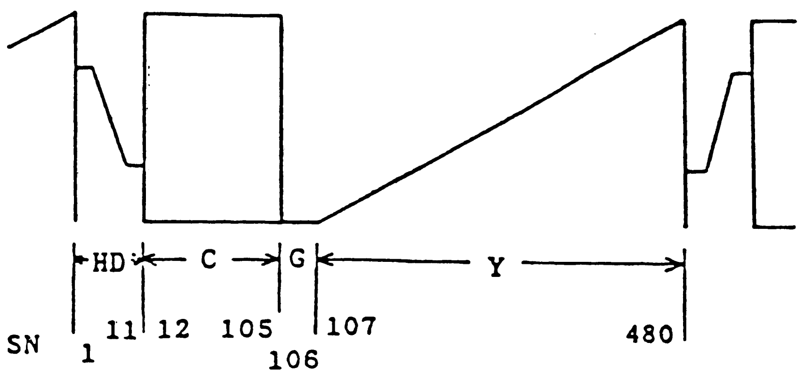


Figure 9 - Video signal in TCI format

HD	: line-synchronizing signal	G	: guard area
C	: colour-difference signals (line-sequential)	Y	: luminance signal
		SN	: sample number

Basic video characteristics of the MUSE system are summarized in Table 12.

The line-synchronizing signal is shown in Figure 10 (a) and the frame-synchronizing signal in Figure 10 (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 11. 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 13 with the format of the digital sound/data signals.

TABLE 12 - 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 13 - 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	

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.

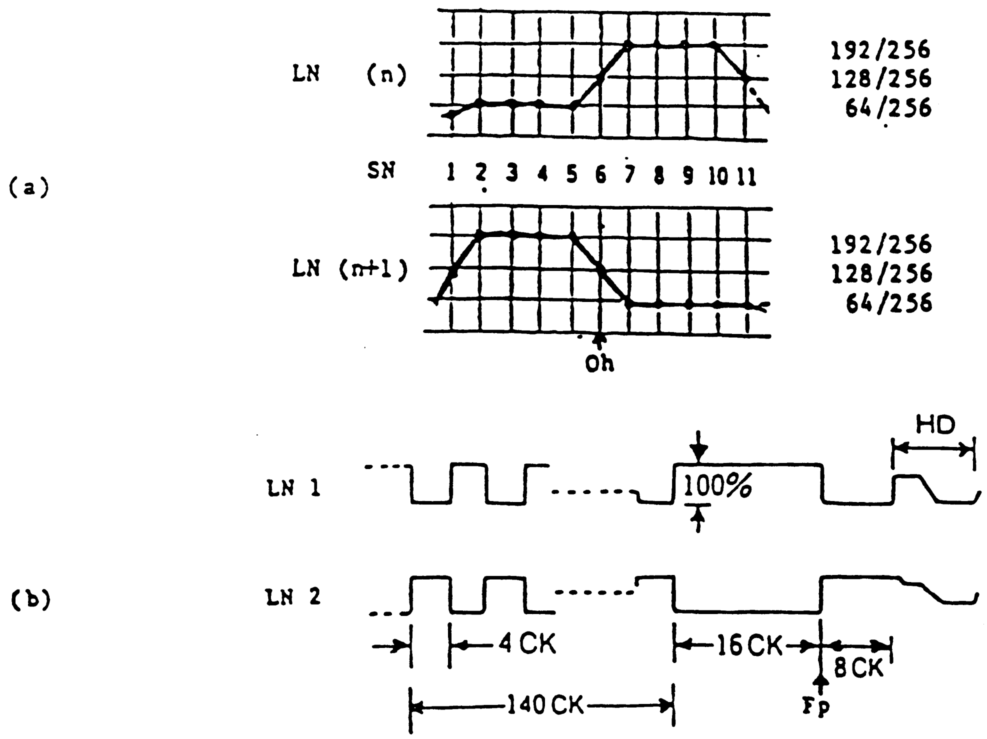


FIGURE 10 - Synchronizing signals
(a) line-synchronizing signal
LN (n): n th line
LN (n+1): (n+1) th line
SN : sample number
Oh : timing reference for line synchronization

(b) frame-synchronizing signal
LN : line number
HD : line-synchronizing signal
Fp : frame-pulse point
CK : one clock-time duration at 16.2 MHz

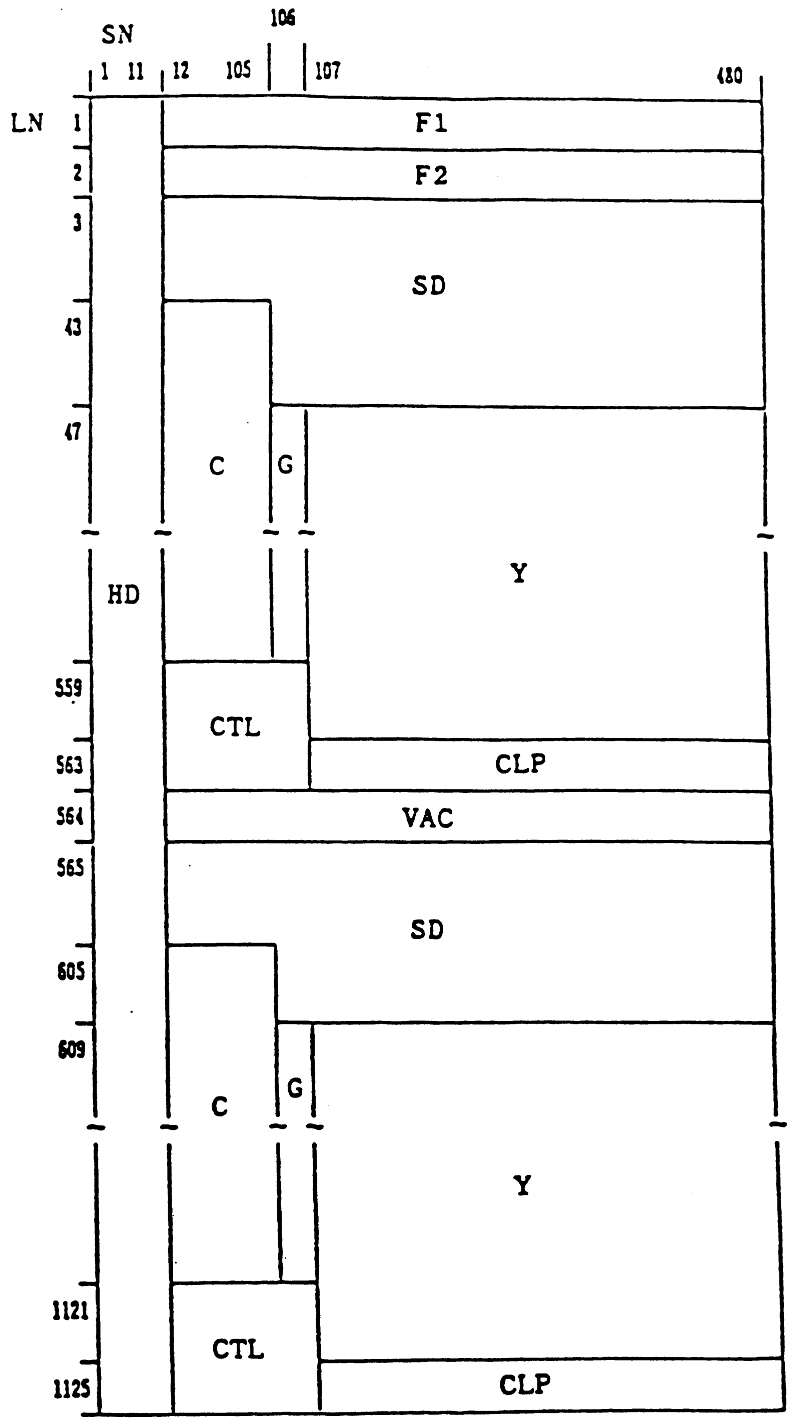


Figure 11 - Signal allocation map

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 12 and 13 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.

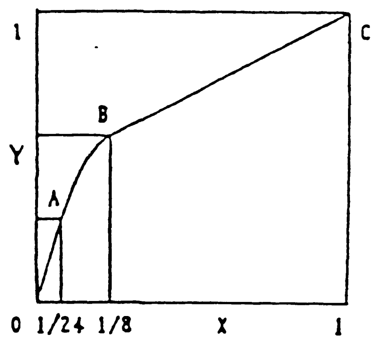


FIGURE 12 - Characteristics of non-linear circuit for transmission of colour-difference signals

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 O - 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

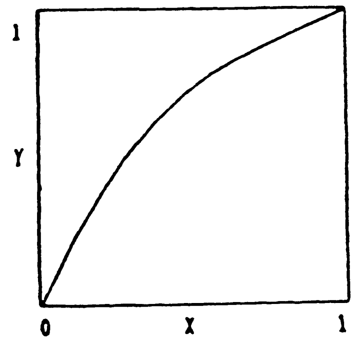


FIGURE 13 - Characteristics of non-linear circuit for transmission of luminance signal

Abscissa: Input level X

Ordinate: Output level Y

The curve is defined as follows when the signal level is normalized to unity:

$$X = (3/5)Y^2 + (2/5)Y$$

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 14.

Figure 15 shows characteristics of the non-linear processing in Figure 14. Figure 16 shows frequency response of the de-emphasis circuit defined in Figure 14.

The basic modulation parameters for the satellite broadcasting of MUSE within a 27 MHz channel are given in Table 14.

8. MUSE applications

Technical considerations and some results of application to a satellite broadcasting system can be found in [CCIR, 1986-90b and c].

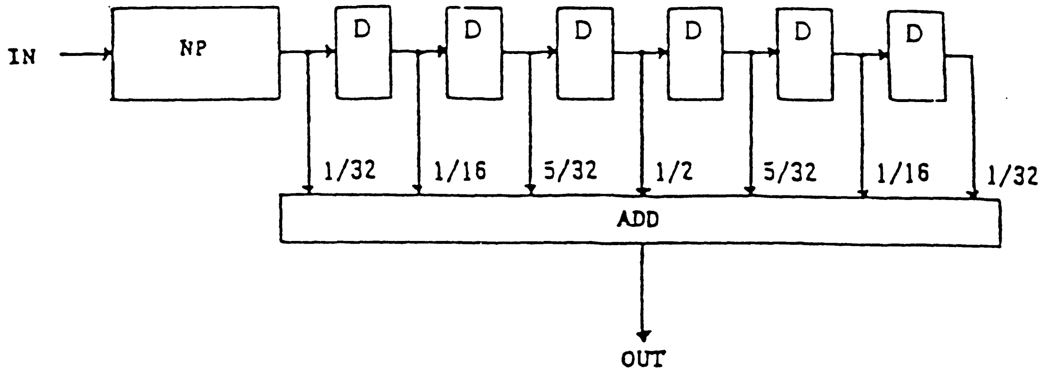


FIGURE 14 - An example of de-emphasis circuit to be used in the receiver

IN : input signal
NP : non-linear process (see Figure 15)
D : one-clock delay element at 16.2 MHz
ADD: adder
OUT: output signal

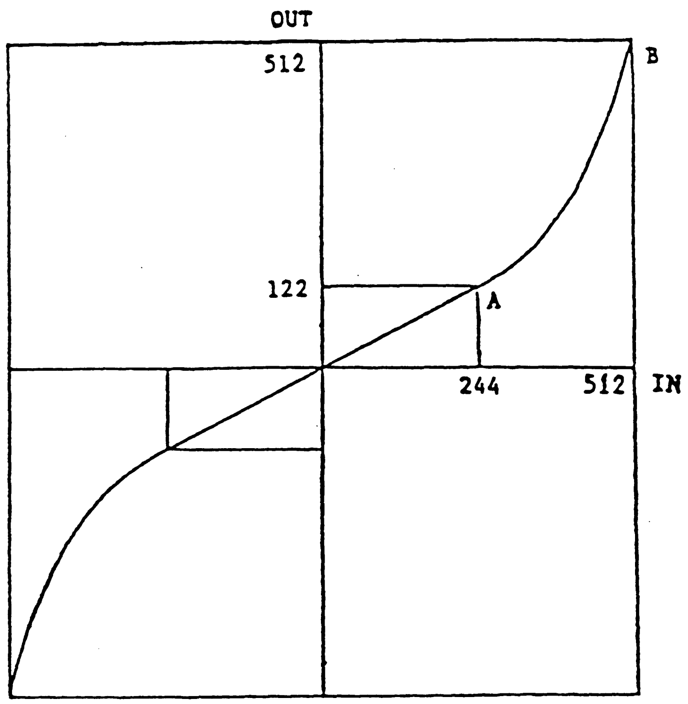


FIGURE 15 - Characteristics of non-linear process placed before de-emphasis shown in Figure 14

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

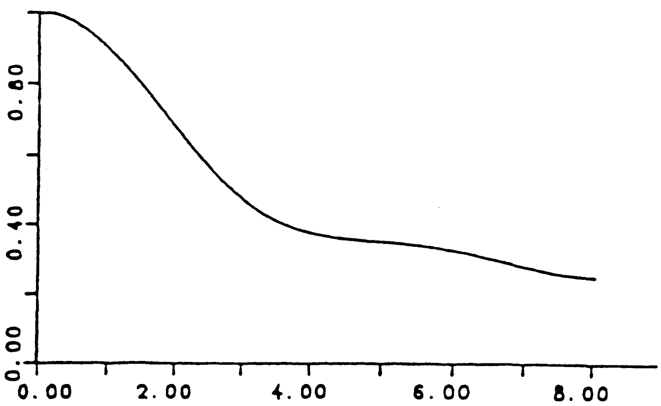


FIGURE 16 - Frequency response of de-emphasis shown in Figure 14
Abscissa: Frequency (MHz)
Ordinate: Response (normalized value)

TABLE 14 - 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

REFERENCES

NINOMIYA, Y. et al. [1987] - Concept of MUSE system and its protocol, NHK Laboratory, Note. No. 345.

CCIR Documents

[1986-90]: a. 10/52 (Japan); b. 10-11S/27 (Japan); c. 10-11S/29 (Japan).

ANNEX 2

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 μs each. The multiplex is composed of three main components (see Figure 17):

- the HDMAC vision signal;
- the line blanking interval (LBI) data burst, which carries the sound/data multiplex;

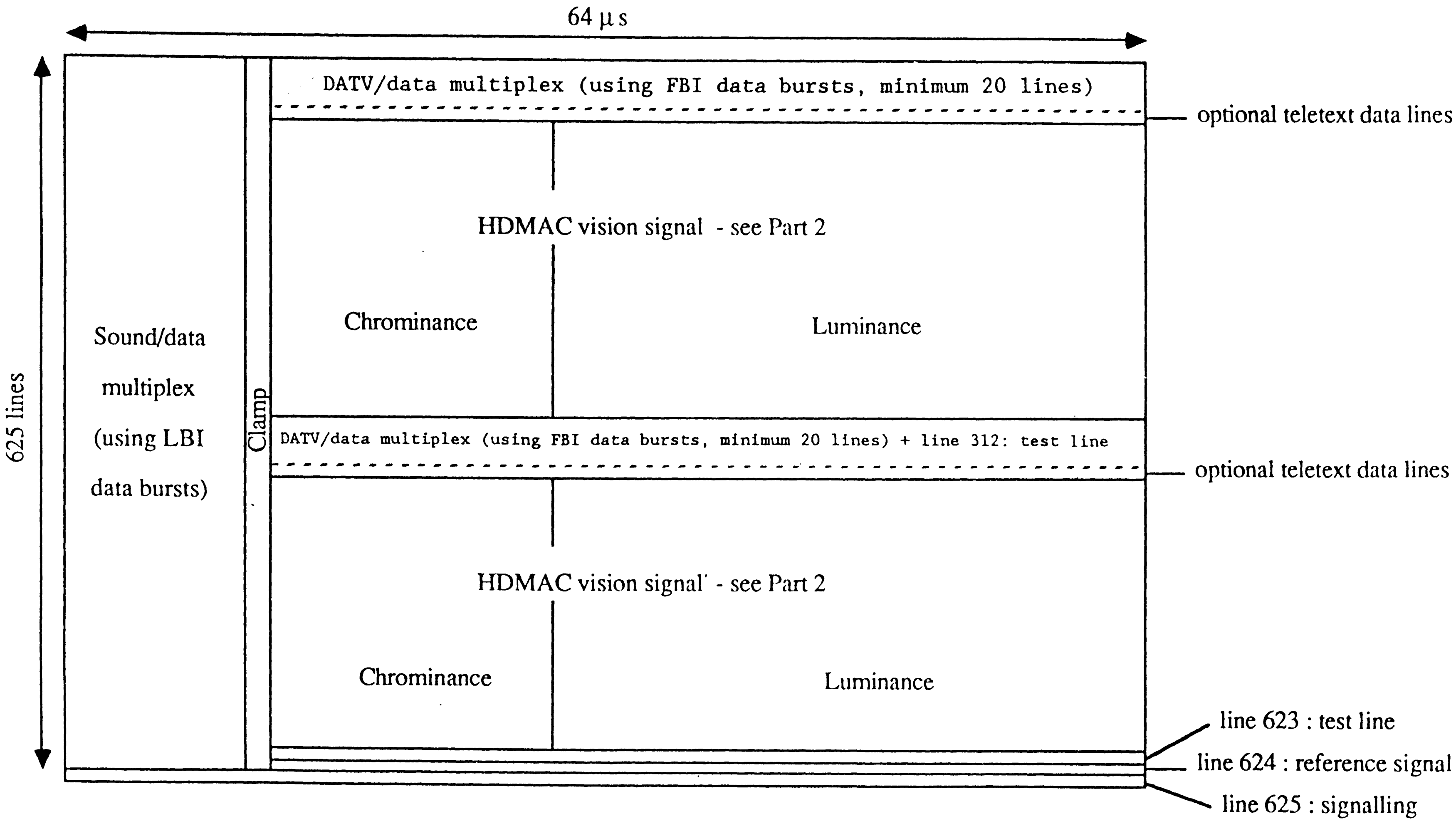


FIGURE 17

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 15). The modulation parameters of the emitted HDMAC signal are given in Table 16.

2.4 General video characteristics of the HDMAC vision signal

See Table 15.

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 18 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 15

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 16

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 19 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 20. The pre-emphasis network is described by Figures 21 and 22.

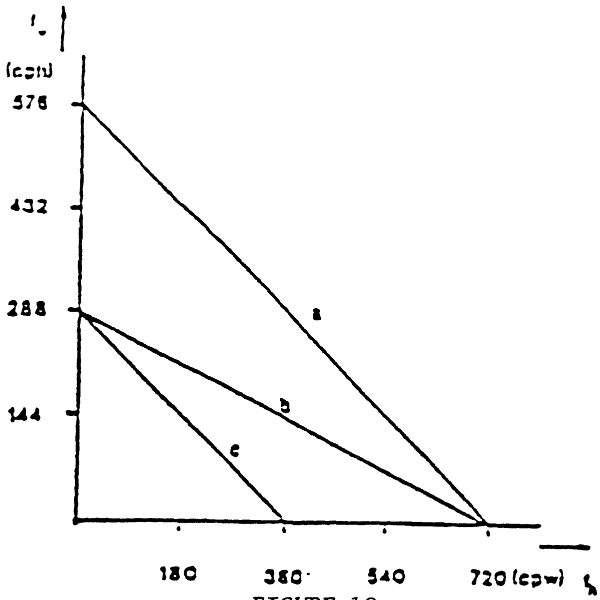


FIGURE 18

Transmissible range in spatial frequency domain for the luminance sampling patterns

(a) 80 ms mode
(b) 40 ms mode
(c) 20 ms mode

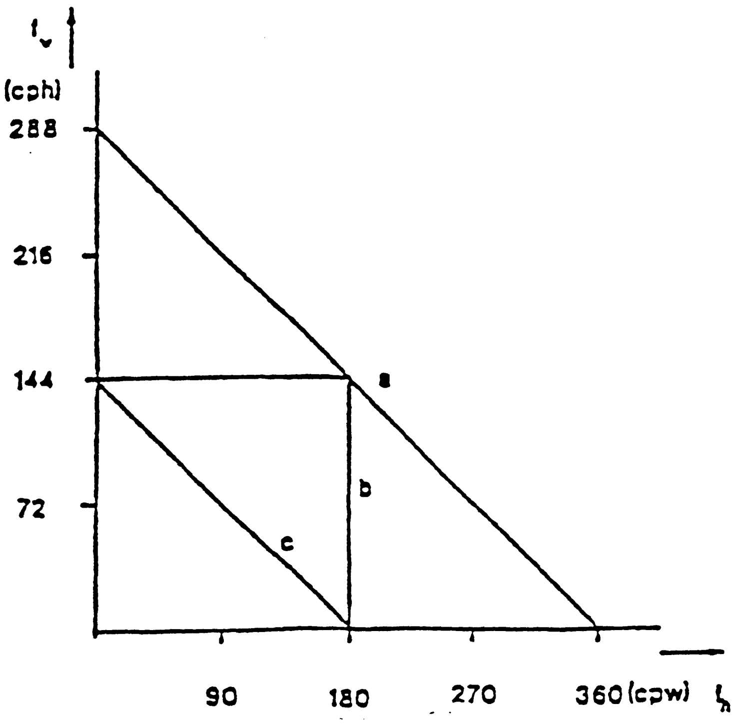


FIGURE 19

The transmissible range of the colour-difference spatial frequency spectrum

(a) 80 ms mode
(b) 40 ms mode
(c) 20 ms mode

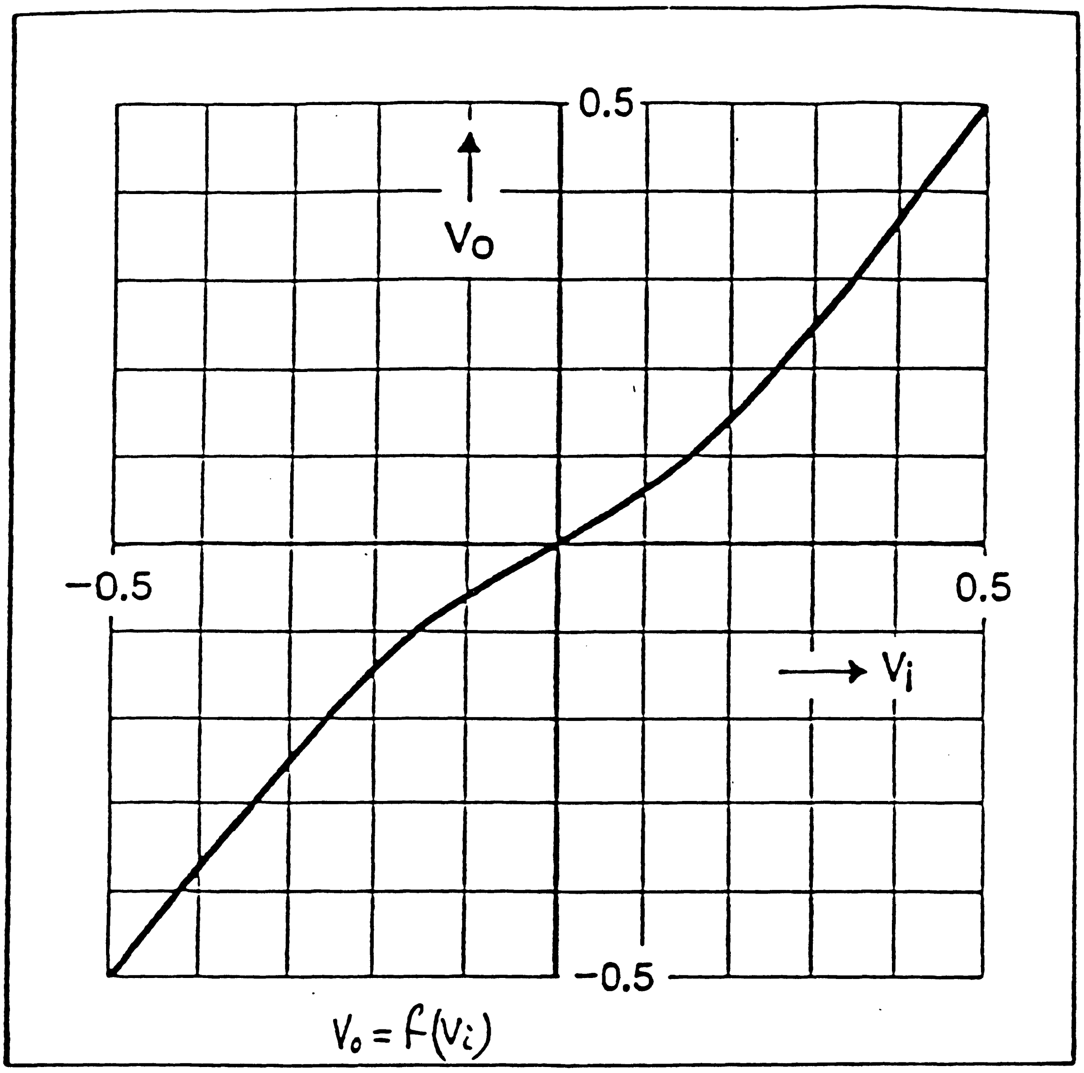
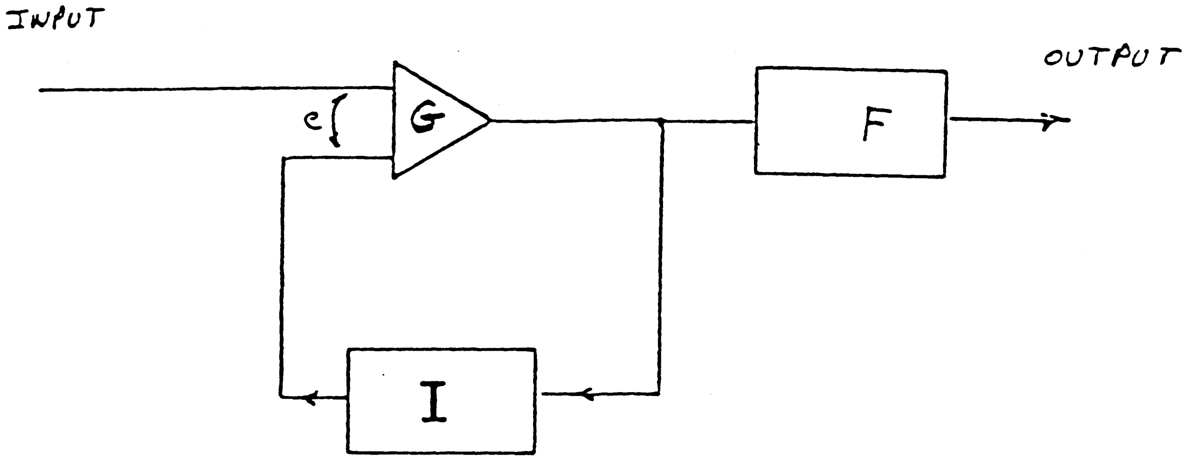


FIGURE 20

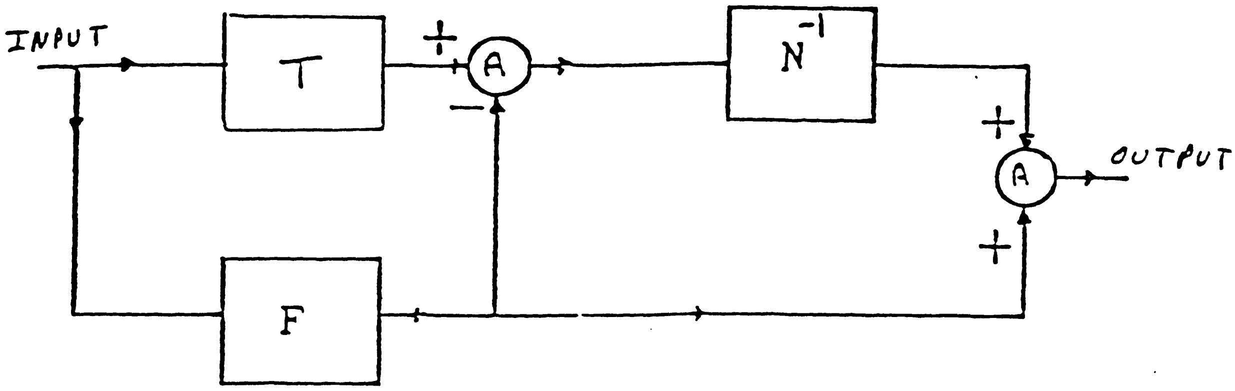
Non-linear function N^{-1}



I: de-emphasis network
F: low pass filter
G: gain of amplifier >> 1
e: error signal

FIGURE 21

Analogue pre-emphasis configuration



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

FIGURE 22

E7 de-emphasis block diagram

REFERENCES

ARRAGON, J.-P., *et al.*, Instrumentation of a compatible HDMAC coding system using DATV. IEE Conference Publication No. 293, 1988.

HURAULT, J.-P., ARRAGON, J.-P., Development of advanced HDMAC coding algorithms. Philips France. IEE Conference publication No. 293, 1988.

PELE, D. and CHOQUET, B., Estimation of apparent motion fields in HDMAC. CCETT France. IEE Conference Publication No. 293, 1988.

Storey,R. 1986. HDTV motion adaptive bandwidth reduction using DATV.
BBC, U.K.
IEE Conference Publication No.268.

VREESWIJK, F.W.P., *et al.*, HDMAC coding of high definition television signals. Philips Netherlands, France and UK. IEE Conference Publication No. 293, 1988.

<u>CCIR Documents</u>

[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 3

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 23, 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 24, the odd source lines $S_1, S_3, S_5, \ldots$ of Field 1 are transformed to progressive lines $P_1, P_3, P_5, \ldots$ and even source lines $S_2, S_4, S_6 \ldots$, to progressive lines $P_2, P_4, P_6 \ldots$, 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

$$LS_{no} = S_{2n-3} - S_{2n-1} \quad \text{Odd source lines}$$

$$LS_{ne} = S_{2n} - S_{2n-2} \quad \text{Even source lines}$$

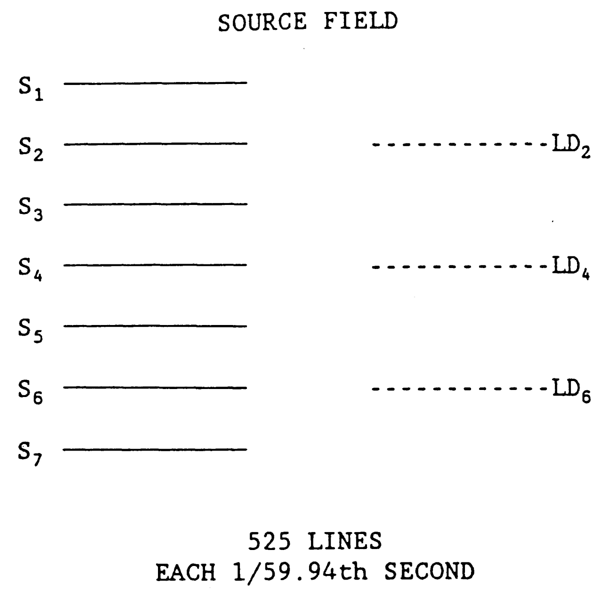


Figure 23 - HDS-NA satellite signal - Scanning geometry for 525-line progressive source.

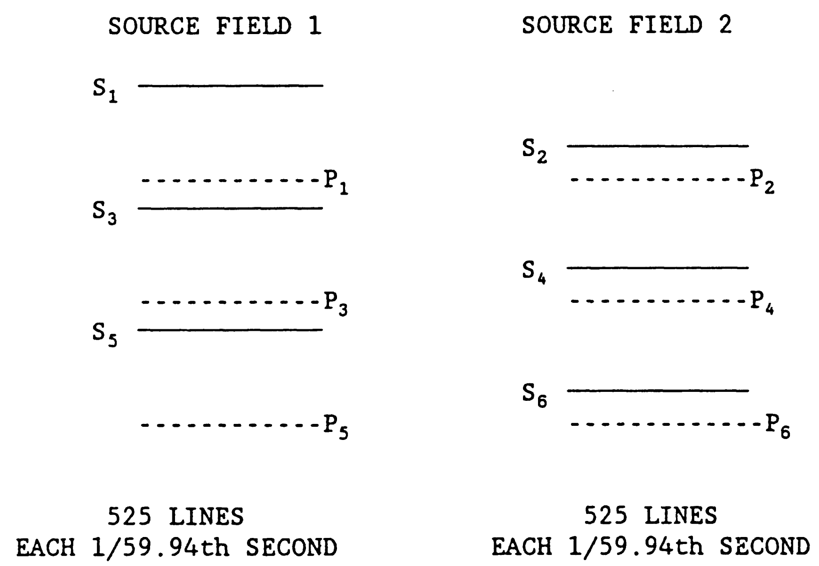


Figure 24 - HDS-NA satellite signal - Scanning geometry for 1050-line interlaced source.

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 25, 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/EH 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 17 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.

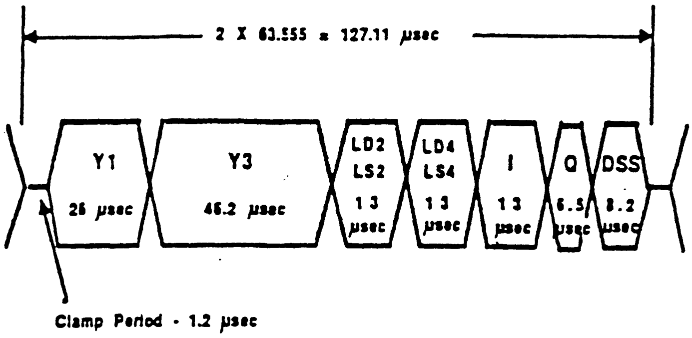


Figure 25 HDS-NA Satellite Signal - Superline, showing the position of the video and data packets

Table 17 - Characteristics of HDS-NA satellite signal components

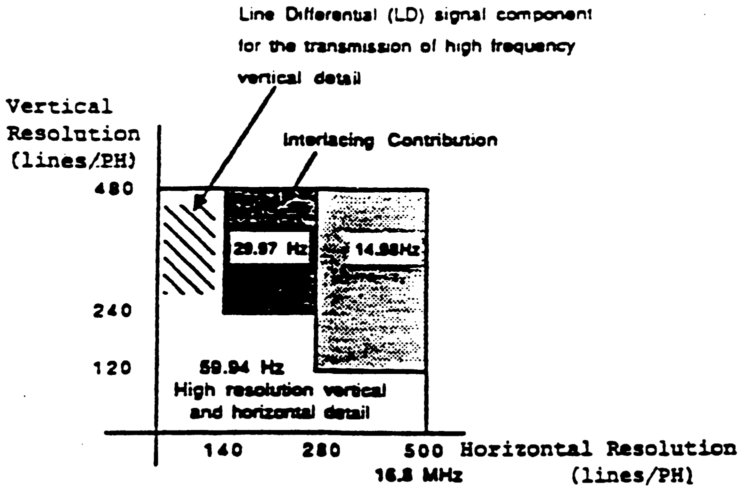
COMPONENT	COMPRESSION RATIO	DURATION (usec)	BASEBAND FREQUENCY Before Compression (MHz)	BASEBAND FREQUENCY After Compression (MHz)
Y_1	1:1	26	9.54	9.54
Y_3	9:16	46.2	16.8	9.54
LD_2 LS_2	2:1	13	4.75	9.54
LD_4 LS_4	2:1	13	4.75	9.54
I	2:1	13	4.75	9.54
Q	4:1	6.5	2.375	9.54
DSS		8.2		
Clamp		1.2		

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 26. 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.

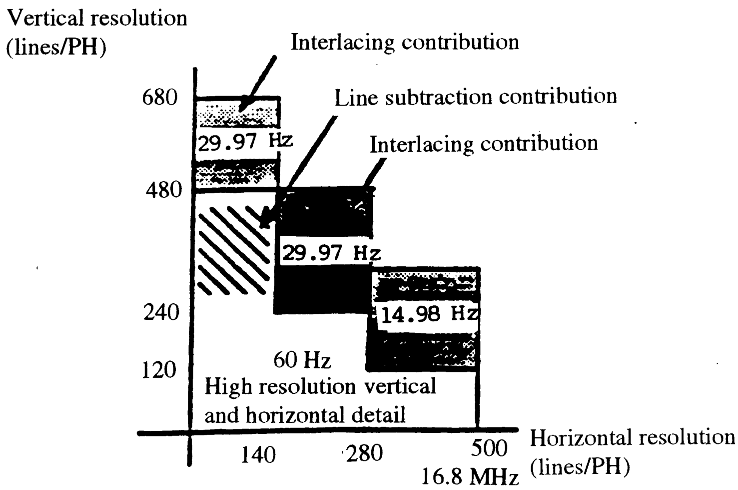
Figure 27 gives the two-dimensional spectral distribution when a 1050-line interlaced source is used. The vertical resolution is nominally 680 lines, and the diagonal resolution is reduced. The amount of data delivered for sound and conditional access information is the same as available when a 525-line 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 26 - 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 27

HDS-NA satellite signal - spatial spectrum distribution

Source signal is interlace (2:1), 1 050 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 28).

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 29. 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.

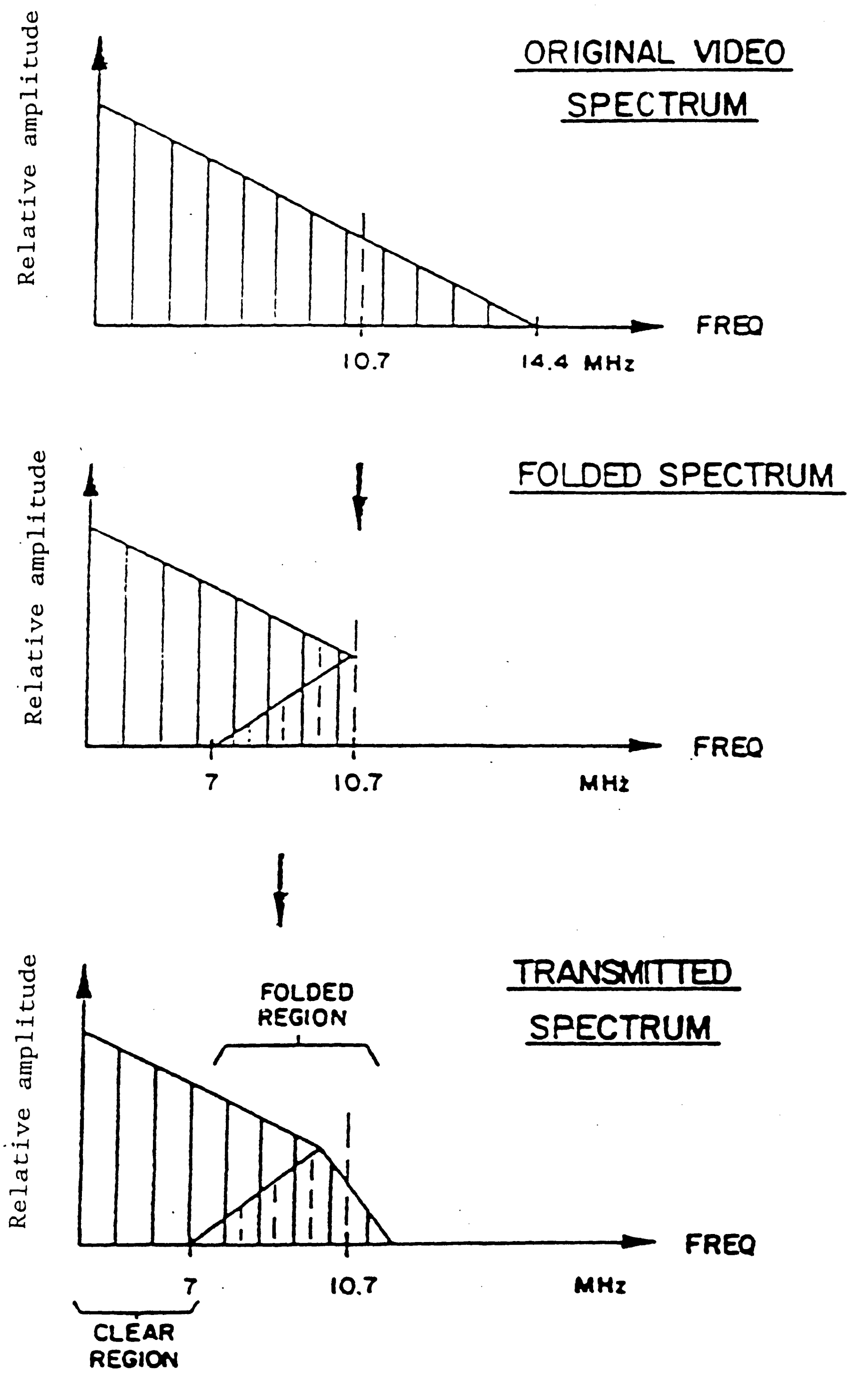
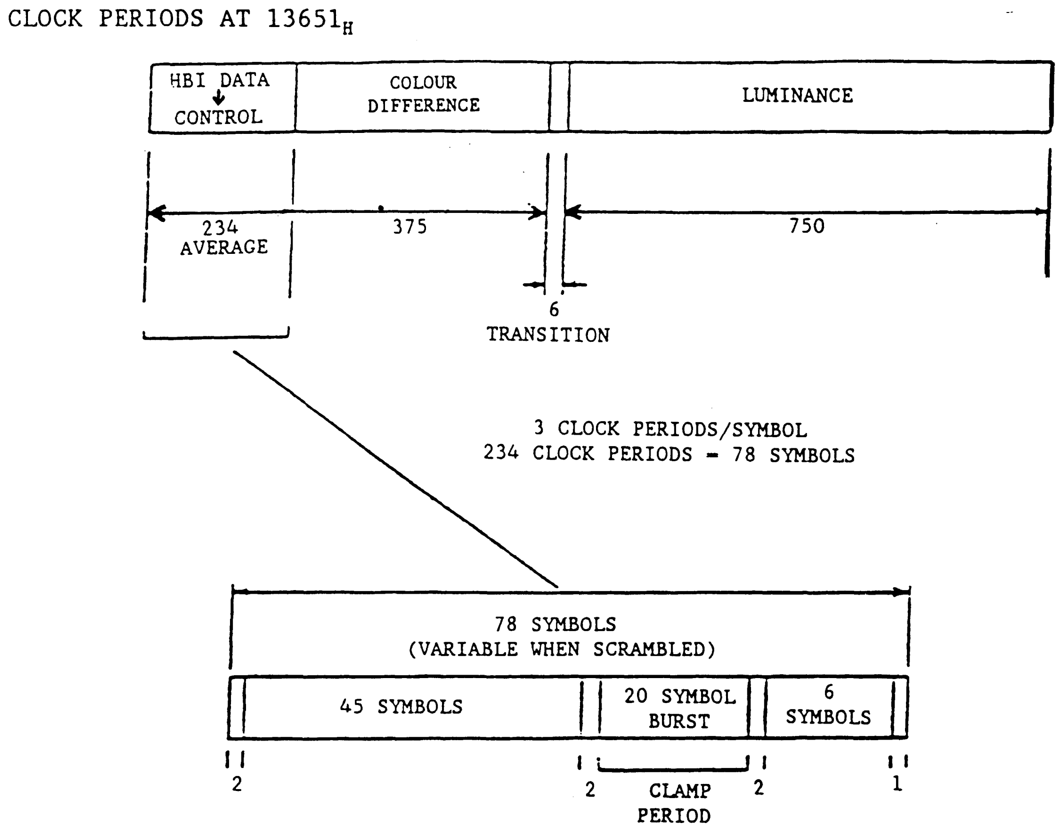


FIGURE 28

Spectrum folding



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 29

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 30. 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 31. 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.

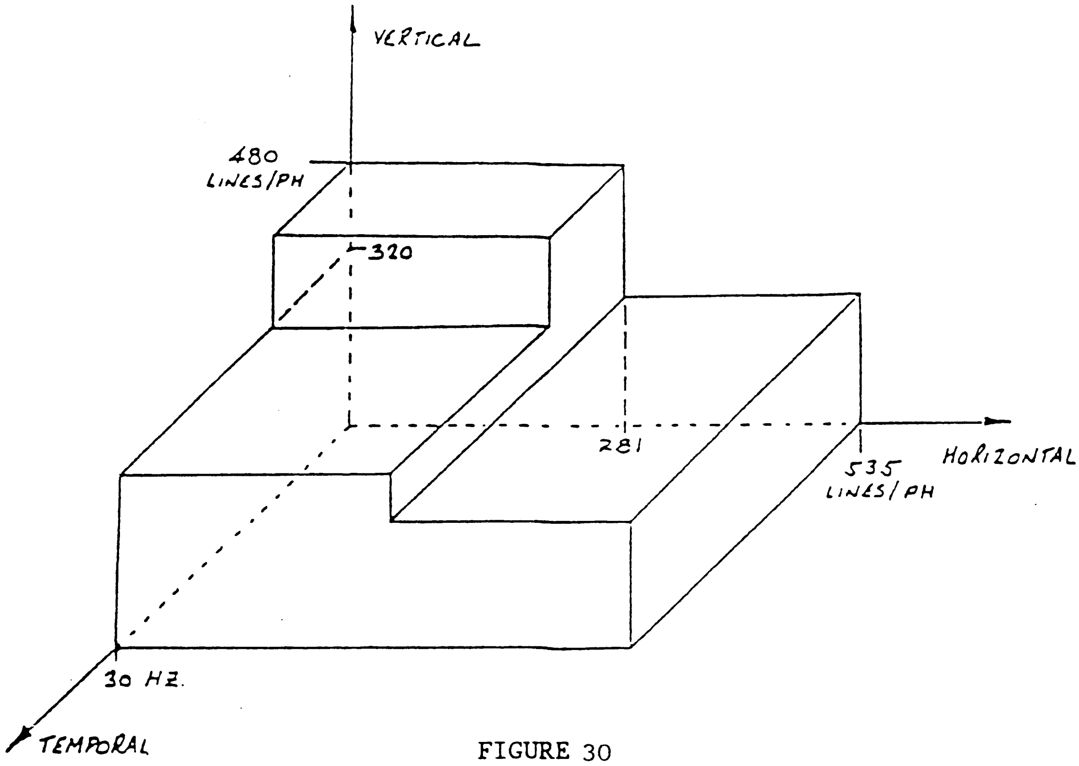


FIGURE 30

HDB-MAC luminance resolution (static and dynamic)

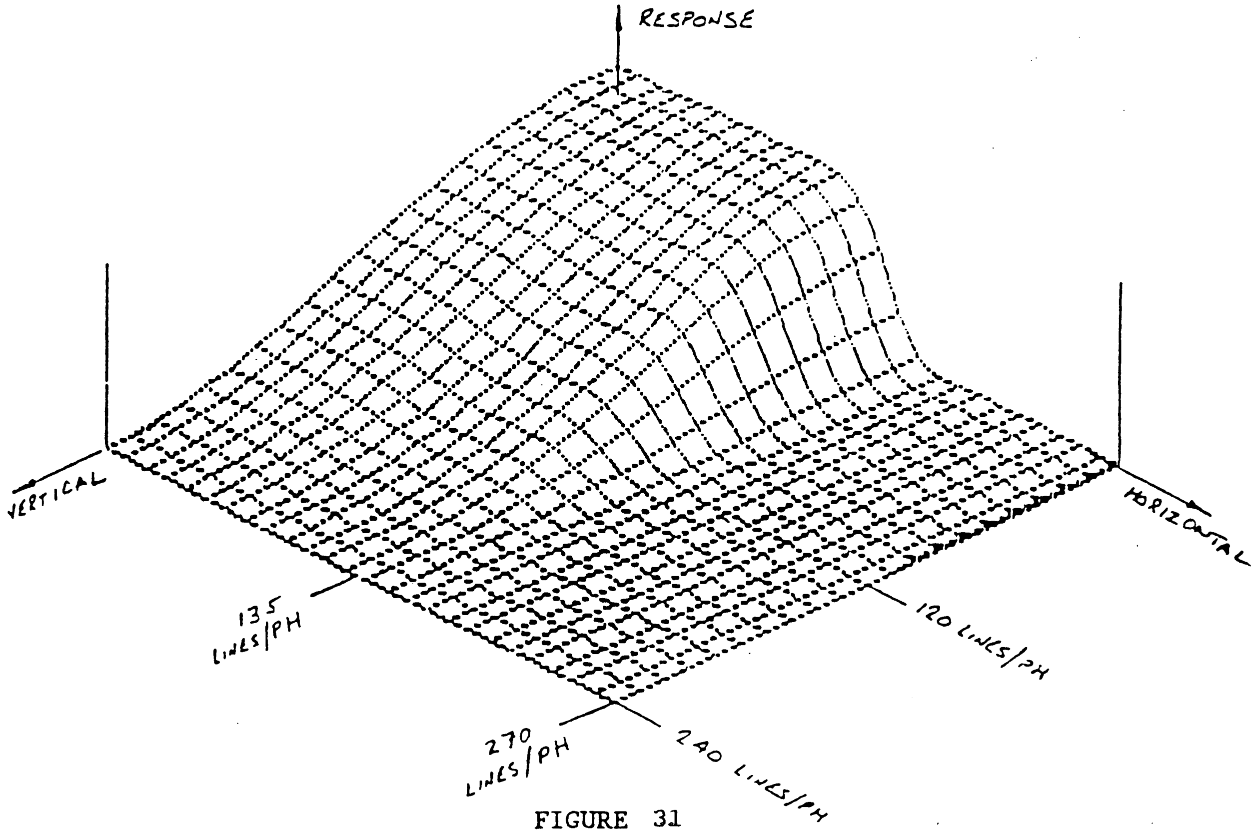


FIGURE 31

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 32. 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 33. (The following resolution symbols are used in Figure 33: 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 34

3.4 Transmission processing

Transmission encoding steps shown in Figure 35 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 35 is more even distribution of average power over the 6 MHz channel. Most of the power of a conventional signal is

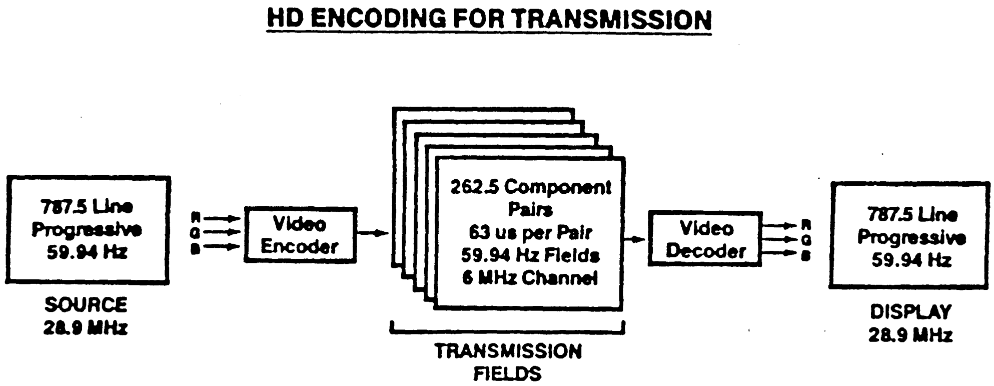


FIGURE 32

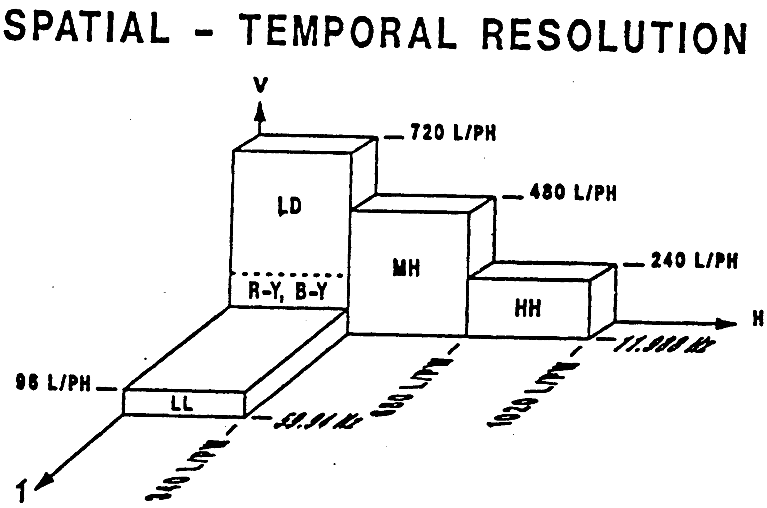


FIGURE 33

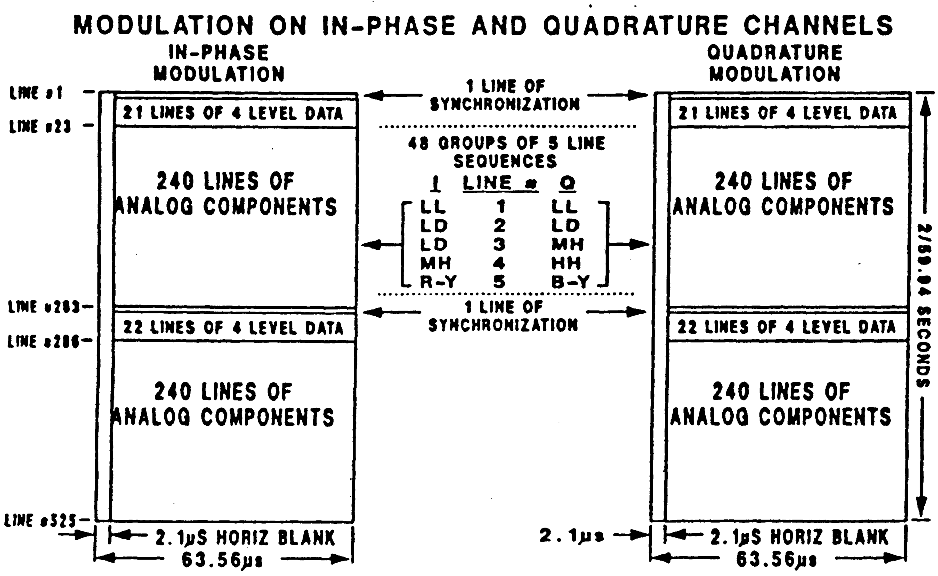
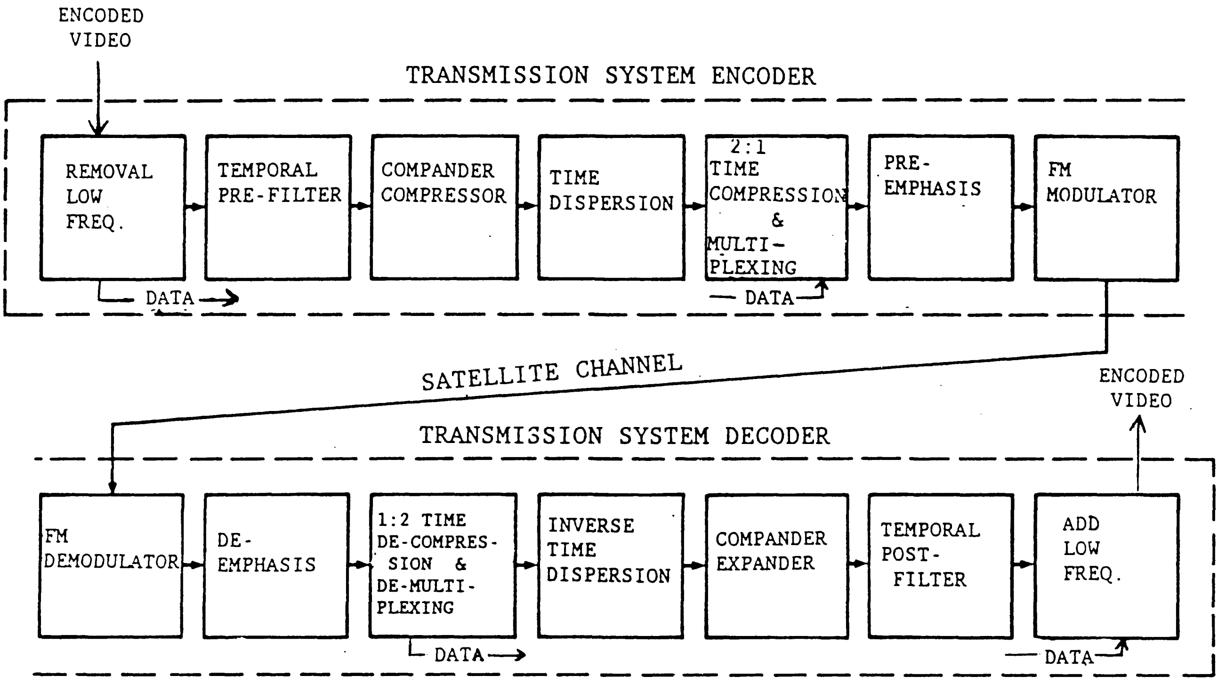


FIGURE 34



SC-HDTV system

FIGURE 35

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 36 and 37. 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 38), 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 39) 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 40 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 41.

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.

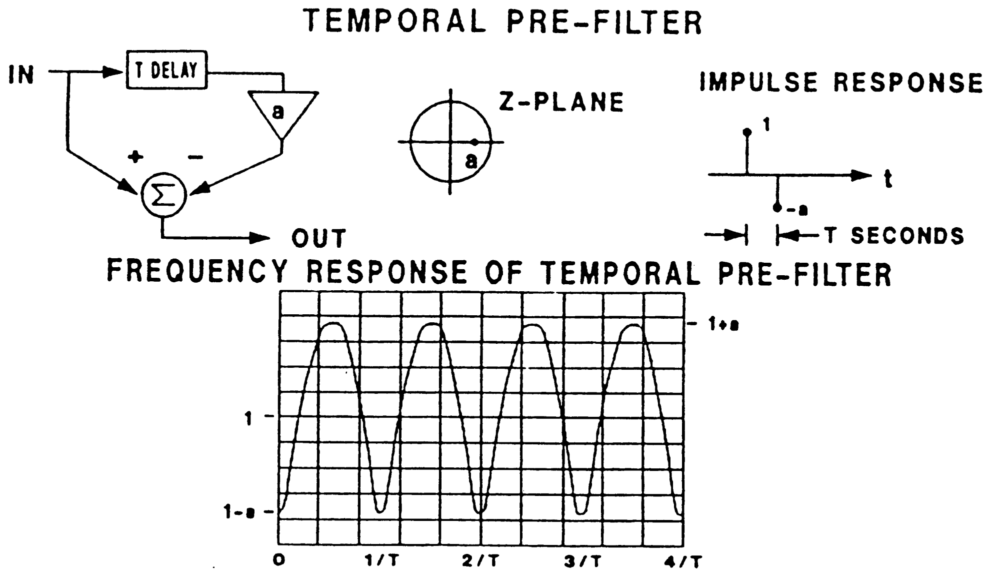


FIGURE 36

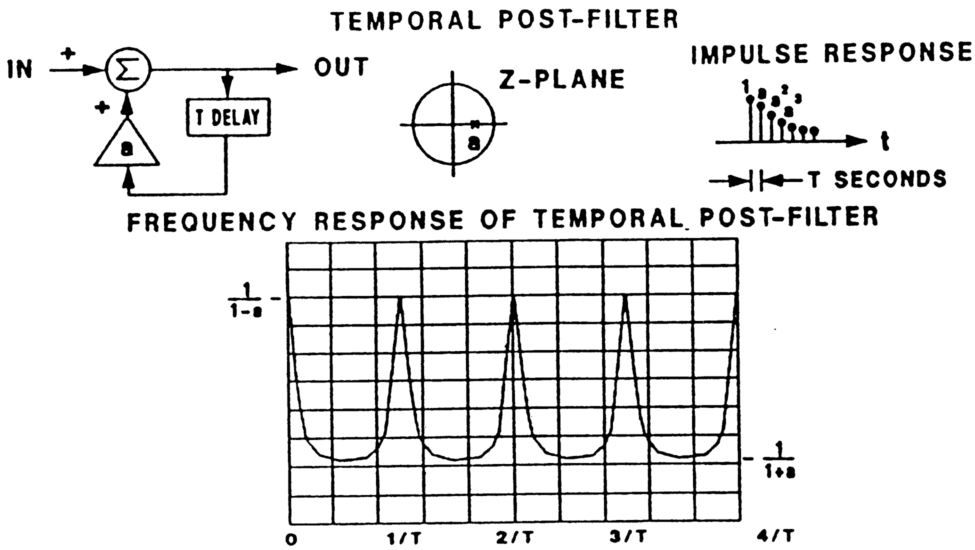


FIGURE 37

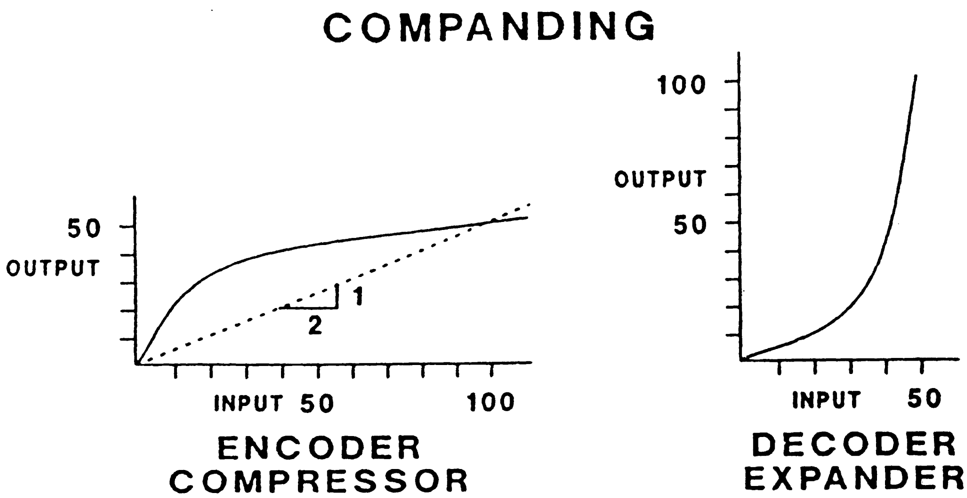


FIGURE 38

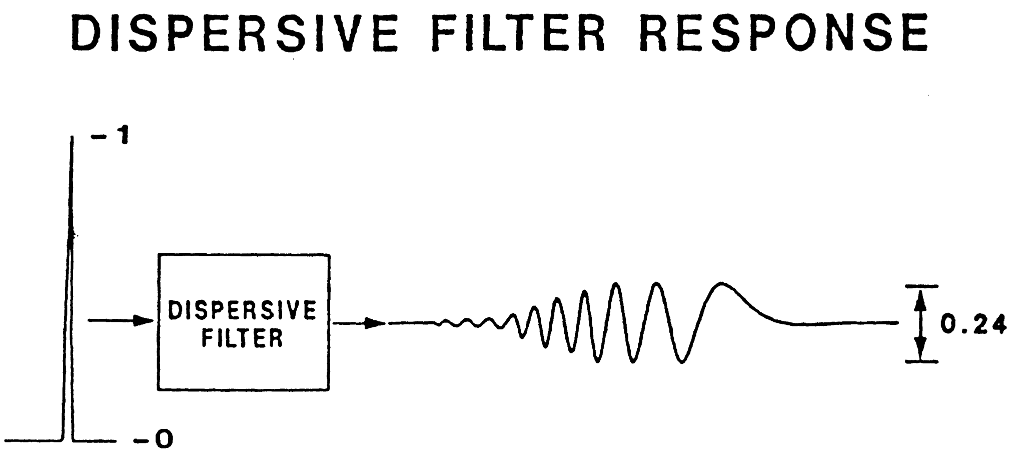


FIGURE 39

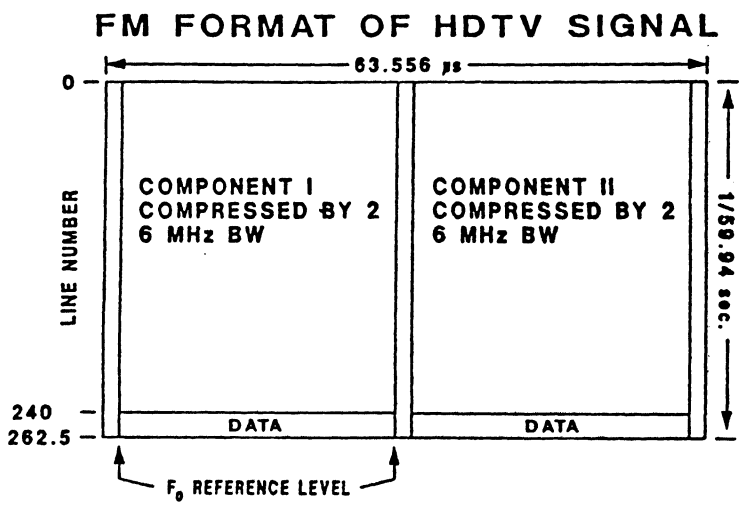


FIGURE 40

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 42 performs decryption.

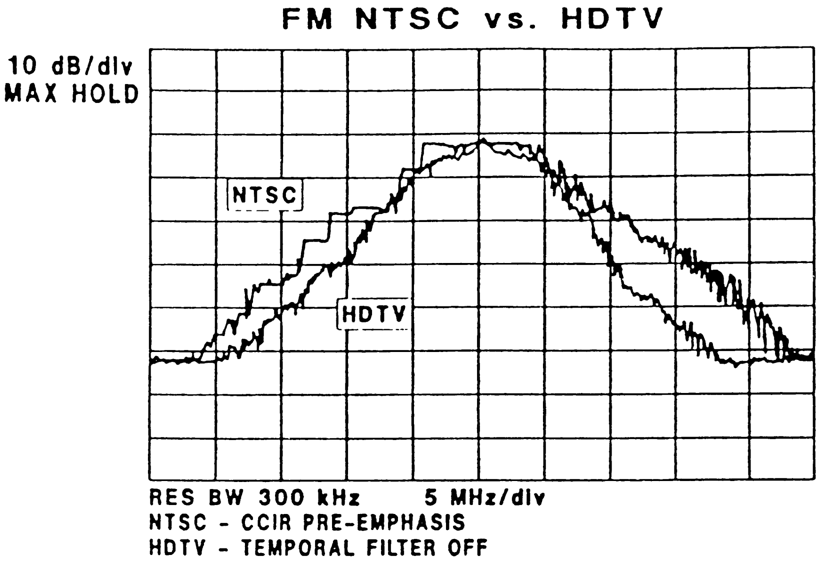


FIGURE 41

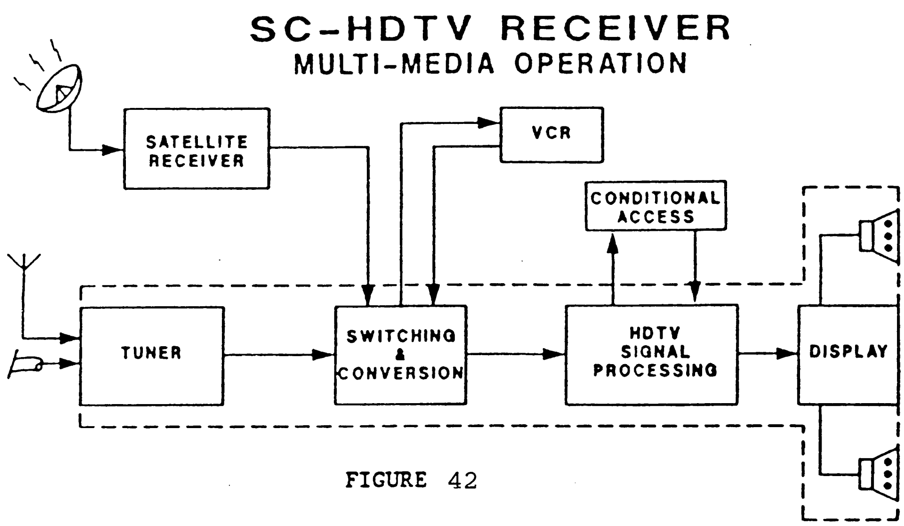


FIGURE 42

BIBLIOGRAPHY

1. "Introduction of an NTSC Compatible HDTV System: HSD-NA" M. Tsinberg, F. Azadegan, E. Fisch, International Conference on Consumer Electronics, June, 1989.
2. "An HDTV MAC Format for FM Environments" C. Basile, International Conference on Consumer Electronics, June, 1989.
3. "System and Technological Details of Terrestrial/Cable NTSC Compatible HDTV" A.P. Cavallerano, International Conference on Consumer Electronics, June, 1989.

ANNEX 4

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 43 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 14. 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 18. 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).

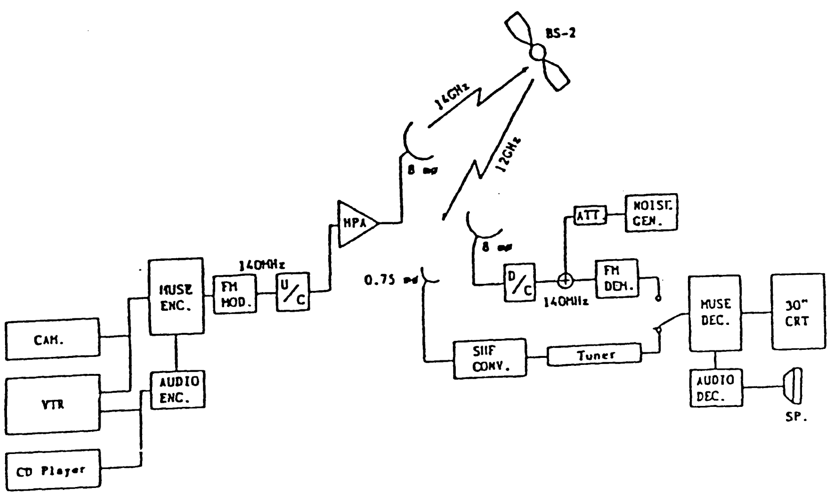


FIGURE 43

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 incorported. 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 18

Link budget for MUSE transmission of 1125/60 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/m^2)	-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.

BIBLIOGRAPHY

NINOMIYA, Y. *et al.* [1987] - Concept of MUSE system and its protocol, NHK Laboratory Note no. 345.

REFERENCES

CCIR Documents

[1986-90]: a. 10-11S/181 (Japan); b. 10-11S/177 (Japan).

PART 2

WIDE RF-BAND HDTV BROADCASTING BY SATELLITE

CONTENTS

1. Introduction

On the occasion of their fourth Inter-Union Conference in 1988, all the Unions representing the broadcasting organizations of the entire world were unanimous in their recommendation for the adoption of a set of common worldwide 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. Part 1 of the present Report also contains some information that is generally pertinent to HDTV via satellite.

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 Reports to the second session of the WARC-ORB 88 and WARC-92 in view of the consideration of a possible worldwide frequency allocation to the BSS. The principal results of these studies are included hereafter.

2. Service objectives

2.1 Intrinsic service quality

The service quality for the wide RF-band HDTV satellite broadcasting service should be targeted to:

- be virtually transparent to the HDTV studio production system. This implies virtually no perceptible reduction of the spatio/temporal resolution or additional artifacts to the HDTV image as viewed from a distance of three times the picture height;
- convey a quality that can be perceived by the viewer as subjectively equivalent to that of the HDTV image and sound as produced in the studio.

These objectives may be made explicit as follows:

- little or no reduction in quality, on average, relative to the studio standard; mean difference between the scores for the test and the reference conditions of less than

12% using the double-stimulus continuous quality scale [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-25].

The quality available from consumer HDTV studio equipment will improve in time with better equipment characteristics. Equally, the resolution available from HDTV displays is likely to increase with time. The quality expectation of the public is also likely to rise in time. The performance claimed above for the HDTV-BSS will thus have to evolve accordingly. In addition, new services might be introduced in the future such as stereoscopy and some form of holography. Therefore, a certain amount of headroom will be needed to take account of all these possible developments. This headroom can be assumed to be in the potential improvement of the source coding algorithms. These better algorithms should not only be thought of as a way to reduce the bit rate required for a given quality, but also should be used to increase the quality of reproduction as necessitated by improvements in studio, displays and higher expectation of the viewing audience.

The quality performance defined above will be needed in the future for the wide RF-band HDTV-BSS in order to allow it to provide a quality similar to what is expected to be delivered by the other HDTV delivery media such as optical fibre networks (e.g. B-ISDN) and recorded media (e.g. disks and cassettes). The wide RF-band HDTV-BSS has the potential to provide the same quality of service to all viewers anywhere in relatively large service areas. Availability of a suitable frequency band for this service would allow for orderly implementation of such service, and should allow it to match the quality of other delivery media.

Nevertheless, systems providing lower quality service than the objective described above may be found to be adequate for the particular competitive environment and the time frame in which they will operate. These "not necessarily transparent" systems would fit in narrower channels, for example, those associated with the 12 GHz BSS Plans, terrestrial channels, VCRs, etc. For static picture material, the above quality objective can be achieved with narrower channel systems, but poorer motion portrayal would likely result. The wide RF-band HDTV quality objective would only be met for programme material requiring high quality motion portrayal by the use of higher bit rate resulting in wider transmission bandwidth or much more complex source coding and compression schemes.

Working Group 11E is planning to evaluate the quality of HDTV systems as a function of the programme content criticality and its probability of occurrence. This will define the "picture content failure characteristic" of a system and will provide a more useful measure of a system than a simple quality rating [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-25]. The wide RF-band HDTV systems are assumed to be capable of transmitting any image produced by a camera or image generation device which would be representative of typical programme material.

2.2 Service reliability

There should be two levels of service reliability defined for a wide RF-band HDTV-BSS. These are:

1) the percentage of the time during which the above quality objective is secured (normally 99% of the worse month); and

2) the percentage of the time during which the service is still viewable albeit of reduced quality (this depends on the failure characteristics of the system and the BSS fade statistics at the specific receiving location). Below this level, the system performance would be considered as being totally inadequate.

It would be desirable that the system be optimized to allow a relatively smooth transition to outage over a certain number of decibels of further degradation above the 99% of the worst month point so that the system fails gracefully, thus providing a higher availability even though the quality is reduced, provided that this is not done at the expense of increased satellite power or receiving antenna size. Normally, 99.9% of the worst month is the goal for service availability, but at the upper end of the frequency range considered for the service, only a lower availability figure might be available in many cases.

2.3 Other service requirements

Commonality of the wide RF-band HDTV format characteristics should be maintained as much as possible with the studio standard parameters. Such commonality should also be secured with HDTV formats used on other delivery media to avoid unnecessary complex receivers. If a digital emission format is used, it is desirable that the bit stream is transmitted on digital transmission networks without unnecessary transcoding.

3. Propagation factors

This section summarizes the propagation factors relevant to future wide RF-band HDTV services from broadcasting satellites. The data is based on the latest ITU-R propagation models given in Reports ITU-R PN.564-4, ITU-R PN.563-4 and ITU-R PN.721-3. Some caution is necessary when applying these models to the frequencies around 20 GHz, since experimental propagation data is mainly available in the range 11-13 GHz*.

The frequency range which is considered from the point of view of propagation covers the frequencies in the range 10 - 31 GHz. This range includes suitable frequency bands for feeder links and down links for wide RF-band HDTV satellite services.

The propagation factors described below represent the principal cause of degradation to HDTV service performance and service availability. Consequently, the service objectives, in terms of permissible degradation and the percentage of time for which the required quality is achieved, have to be carefully chosen. The modulation and channel coding parameters have to be selected so as to provide maximum achievable service quality and to minimize outage time for a given set of propagation factors (e.g. rain climatic zone, elevation angle, frequency, etc.).

To assist, as far as practical, in reducing adverse propagation effects, as a general guideline for the design of HDTV broadcasting systems, it is desirable that the satellite elevation angle be maximized. This is particularly important for countries with high rain rates and/or high-latitude areas. However, these measures may not be sufficient to overcome the problems in high rain rate areas.

3.1 Rain attenuation

Attenuation due to rain represents the dominant propagation factor in the frequency range considered. When the carrier is attenuated by rain, the signal quality may be degraded and during heavy rainfall the service may fail.

Figures 44, 45 and 46 give the rain attenuation data for 99% of the worst month as a function of frequency and for the range of elevation angles between 10° and 40° (rain zones C and K) and 20° to 50° (rain zone N).

---

* Experimental data on 20/30 GHz for Europe and North America are expected in late 1992 from the Olympus Propagation Experiment (OPEX). Propagation data on 20/30 GHz for Japan are available in Reports ITU-R PN. 564 and ITU-R PN.1144.

For percentages of time higher than 99%, the values of rain attenuation increase significantly. As an example, for rain zone K and a frequency of 22 GHz, the attenuation increases by 12 dB between 99% and 99.9%; between 99.0% and 99.7% the attenuation increases by only 4.5 dB.

3.2 Rain depolarization

Rain-induced depolarization occurs as a result of the non-spherical shape of the raindrops.

Depolarization for circular polarization can be predicted by the model described in Report ITU-R PN.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 ITU-R PN.564-3 has not been tested for frequencies above 35 GHz.

Figures 47, 48 and 49 give the XPD* values for 1% of the worst month as a function of frequency and for the ranges of the elevation angles between 10° and 40° (rain zones C and K) and 20° to 50° (rain zone N) for circular polarization. Note that there is a discontinuity in the curves which is a consequence of the propagation model proposed by ex-CCIR Study Group 5.

For percentages higher than 99%, the values of cross-polar discrimination decrease significantly. As an example, for rain zone K and a frequency of 22 GHz, the rain cross-polar discrimination decreases by 9 dB between 99% and 99.9%; between 99.0% and 99.7%, it decreases by 5 dB.

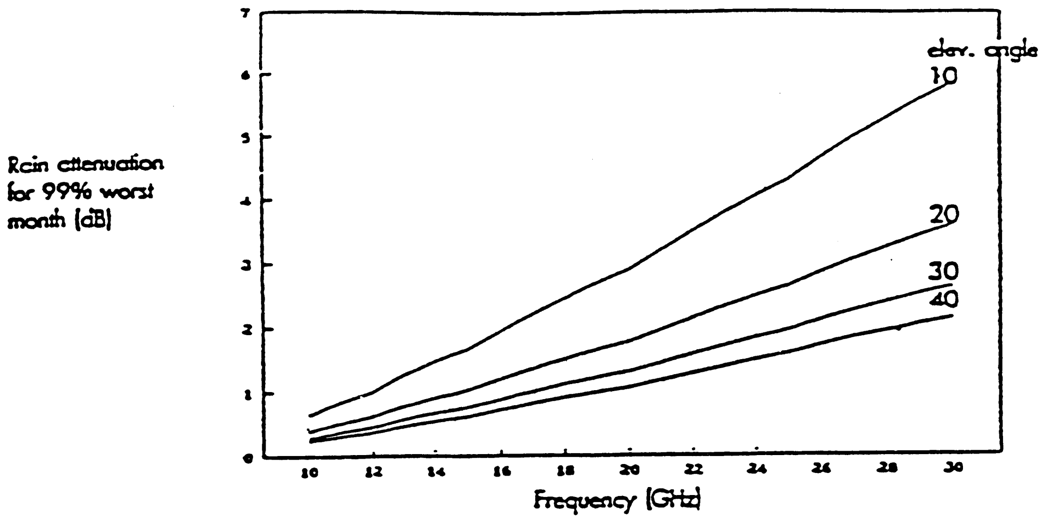


FIGURE 44

Rain attenuation statistics for rain climatic zone C

---

* XPD is defined as the ratio between the co-polar component and cross-polar component of the signal reaching the receiving antenna, when the radiated power has only a co-polar component (see Report ITU-R PN.722).

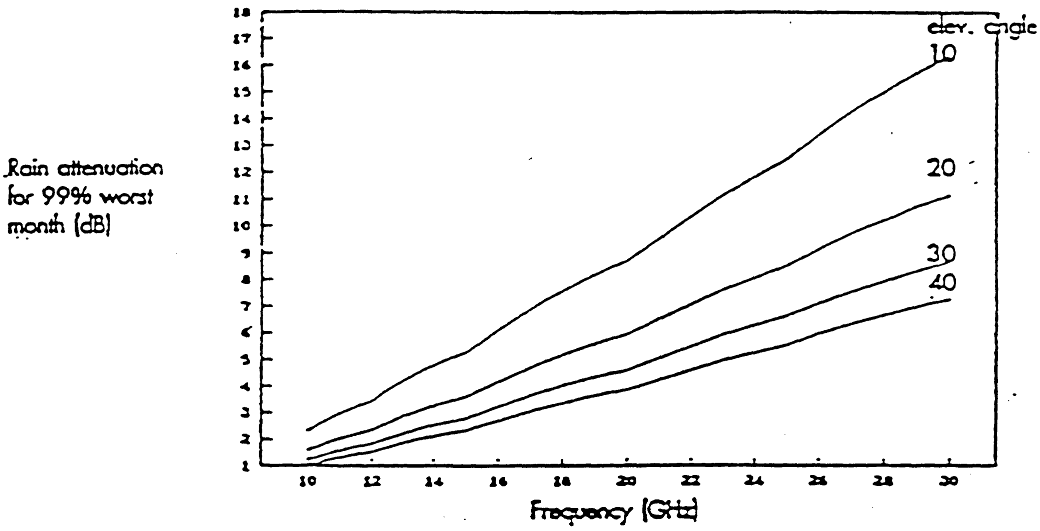


FIGURE 45

Rain attenuation statistics for rain climatic zone K

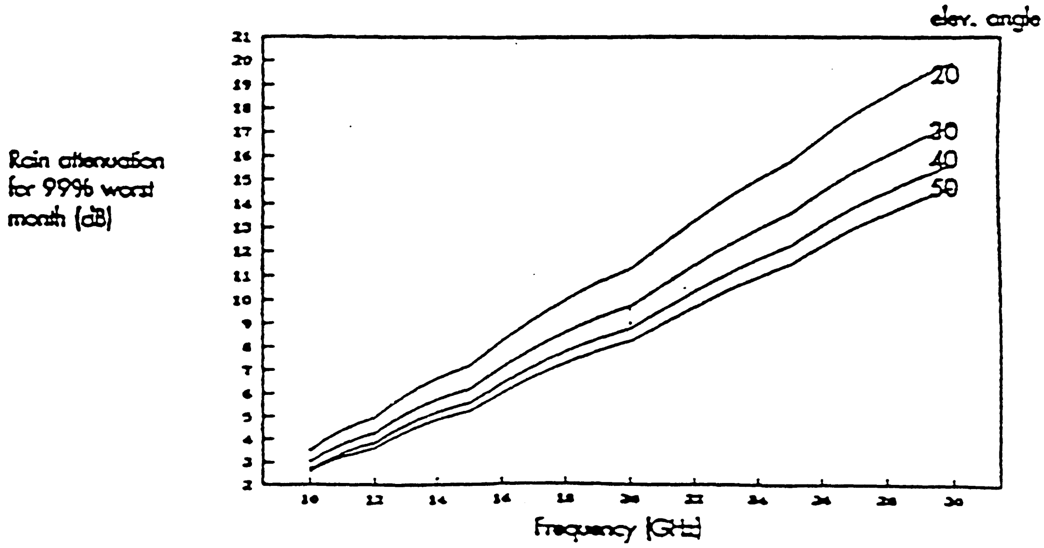


FIGURE 46

Rain attenuation statistics for rain climatic zone N

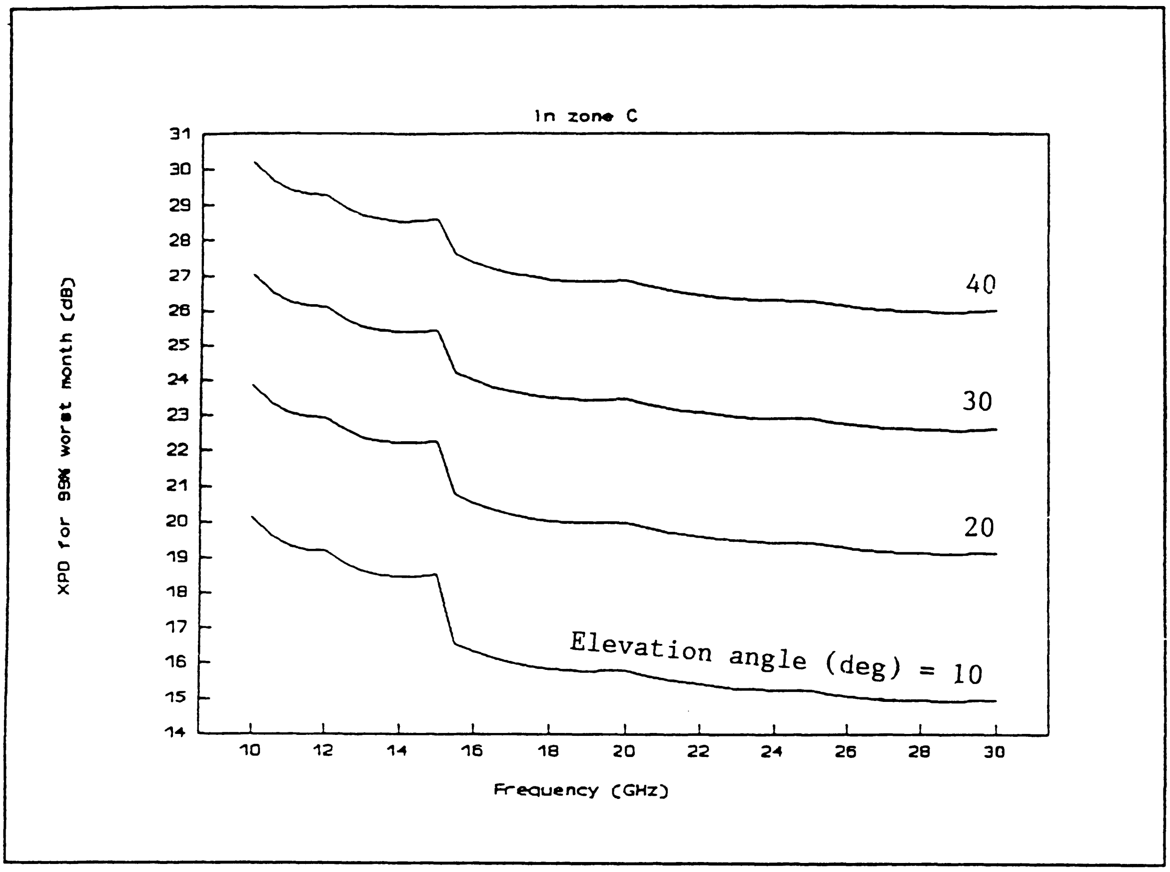


FIGURE 47

Cross-polar discrimination for circular polarization (Rain Zone C)

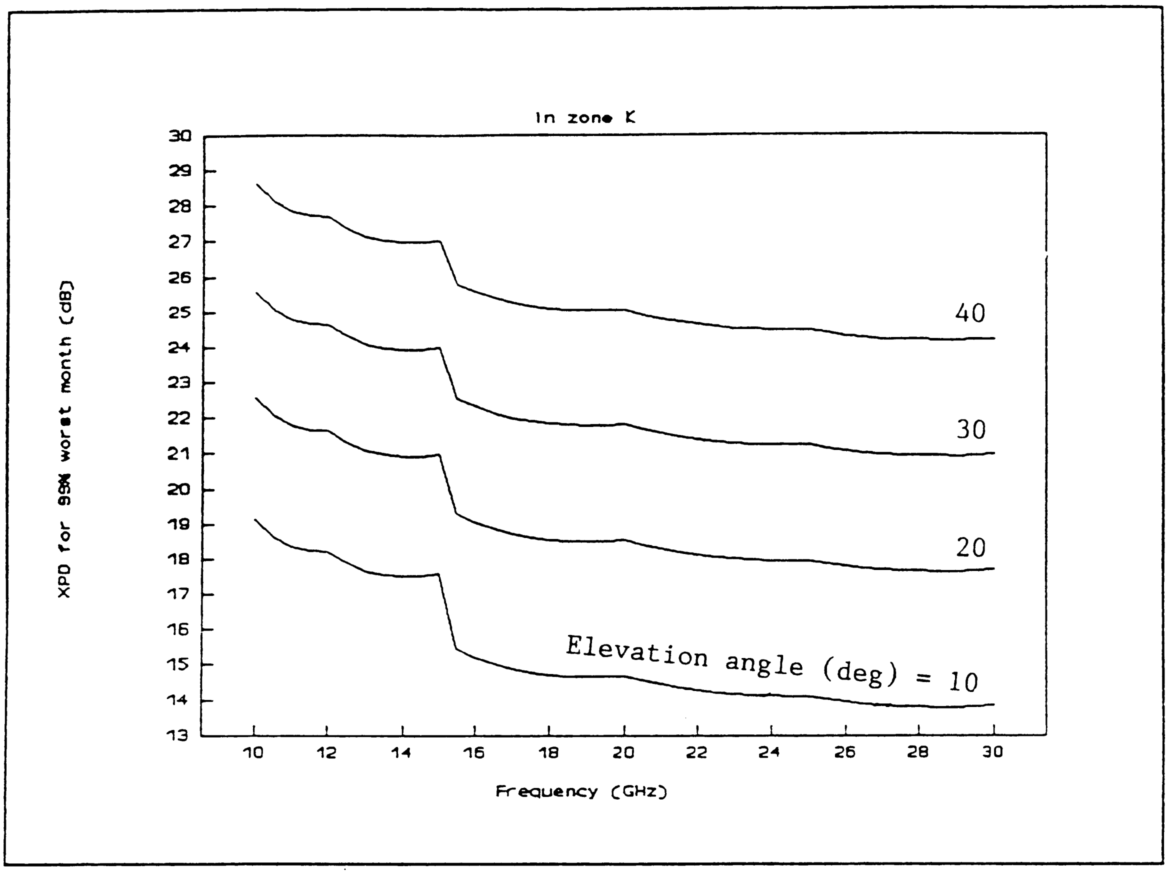


FIGURE 48

Cross-polar discrimination for circular polarization
(Rain Zone K)

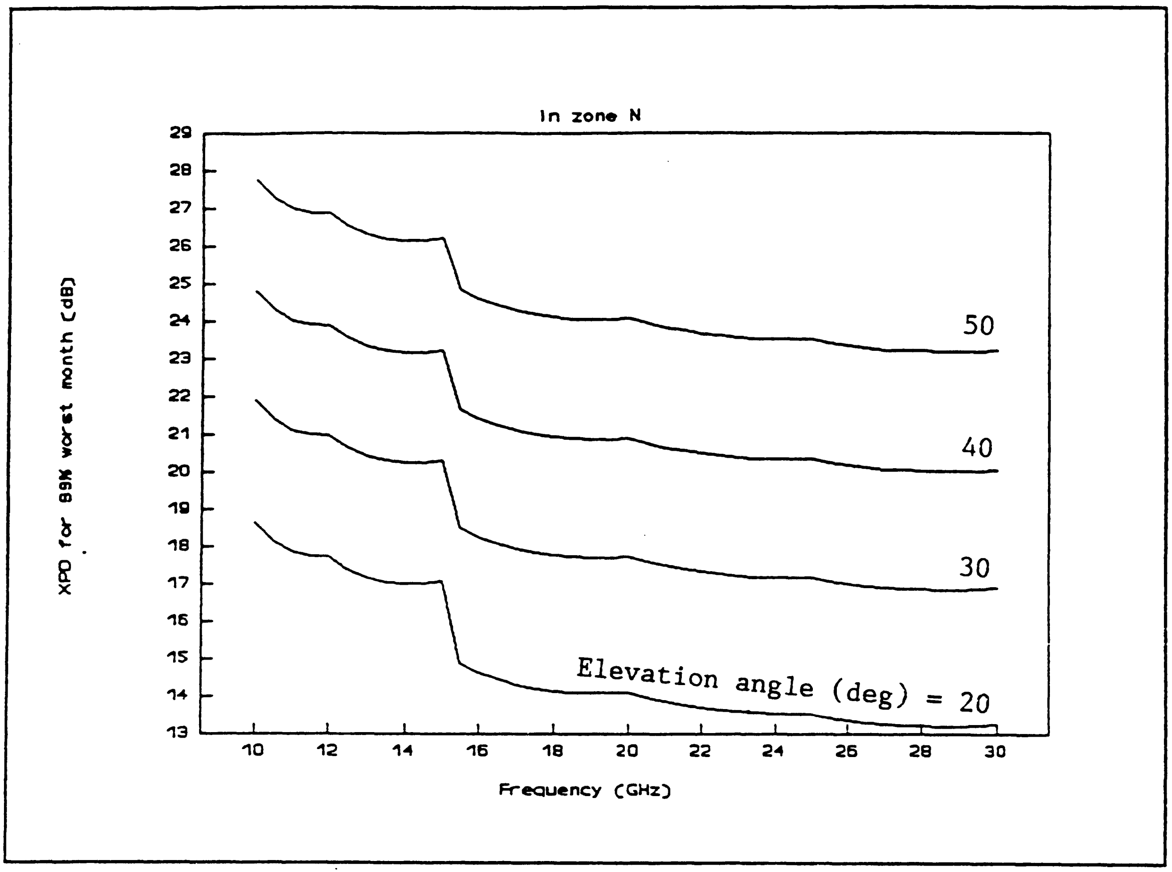


FIGURE 49

**Cross-polar discrimination for circular polarization
(Rain Zone N)**

3.3 Gaseous absorption and cloud attenuation

As explained in Report ITU-R PN.721-3, the aggregate effect of gaseous absorption and cloud attenuation for elevation angles between 5° and 40° is shown in Fig. 50. It can be seen from the graph that the peak of the absorption due to gases lies in the vicinity of 22.3 GHz. At this frequency and at an elevation angle of 1° the gaseous absorption amounts to 25 dB.

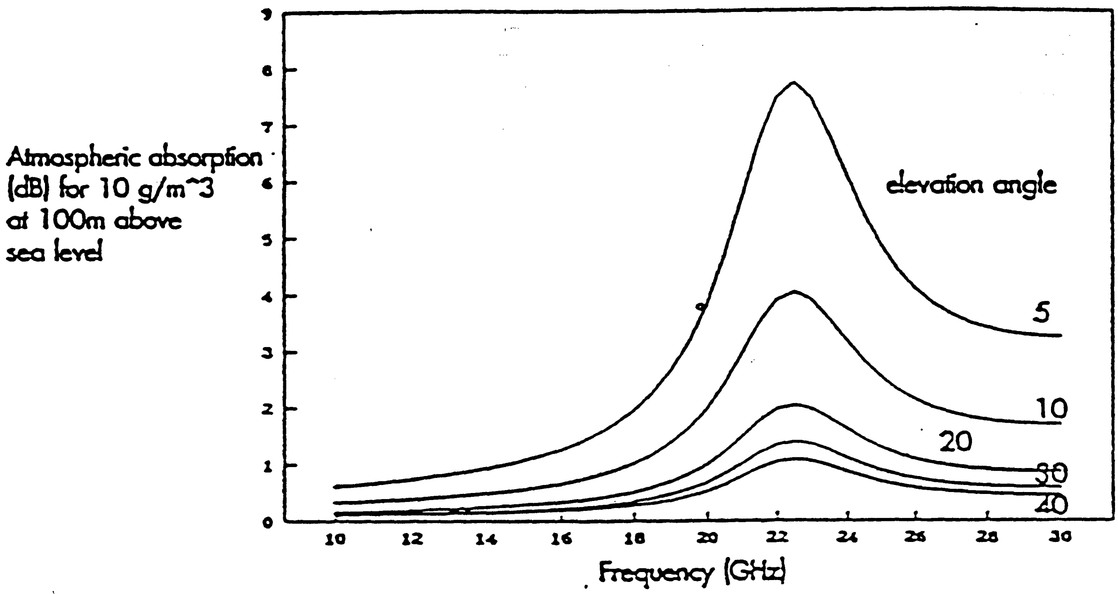


FIGURE 50

Clear air atmospheric absorption

3.4 Other propagation effects

3.4.1 Tropospheric scintillation effects

Amplitude scintillations are caused by random fluctuations of the refractive index in the troposphere. Report ITU-R PN.718-3 gives the model to estimate cumulative statistics of the scintillation fade depths. For the frequency range considered and elevation angles from 10° to 40°, the scintillation fade depth values typically fall below approximately 1 dB. However, the scintillation effects may become more severe at higher frequencies and for low elevation angles.

Tropospheric scintillation effects which are relatively small at elevation angles above 30° can become a significant impairment at low elevation angles. In addition to the increased margin required to overcome tropospheric scintillation, designers of digital systems may need to take account of the potential loss of synchronization which might occur from time to time in severe scintillation [ITU-R, 1990-1994, Doc. 10-11S/109 (Working Party 5C)].

3.4.2 Rain scattering effects

Rain scatter occurring on the signal path of a feeder link earth station was evaluated to determine the minimum separation between a feeder link transmitter and HDTV earth station receivers, all operating at the same frequency. The hydrometer scattering can redirect interfering signal energy in the vicinity of a feeder-link earth station. This effect may have some significance in reverse-band operation (see § 13 of Part 2 of the present Report).

3.4.3 Signal distortion across the bandwidth due to rain

On terrestrial links, in-band distortion of the signal can be caused by multi-path effects which are frequency selective. On Earth-space paths at elevation angles above a few degrees, multipath effects are not present and in-band distortion does not occur. Slant path dispersion effects will therefore not be frequency selective; distortion of a signal, if it occurs, will be caused by differential phase and attenuation effects across the instantaneous (occupied) bandwidth of the transmitted information. The wider the bandwidth, the greater the potential for dispersion effects.

Experiments conducted in the United States (COMSTAR) at high elevation angles and in the United Kingdom and the United States (INTELSAT V and VI) at low elevation angles have shown that there are negligible dispersion effects across instantaneous bandwidths of several hundred MHz in clear sky. Since the instantaneous bandwidth of the existing and proposed HDTV systems (both analogue and digital) are less than 100 MHz, and in many cases are well below 50 MHz, clear air dispersion effects can be ignored completely.

Rain, particularly intense rain, can cause signal dispersion effects provided *both* the instantaneous bandwidth *and* the rainfall rate are large. Studies have shown, however, that these effects only become non-negligible if the frequency is in excess of 30 GHz and the rainfall rates are in excess of 100 mm/h. That is, the path attenuation is in the order of 60 dB or more, considerably higher than the rain margins considered to be economic for satellite systems in general.

3.5 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: CS (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 GHz, 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 programmes 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.

3.6 Impact of propagation on system design

Propagation effects have a number of different impacts on feeder- and down-link C/N ratios.

Attenuation on the feeder link will reduce the power available at the input of the satellite, but it will not affect the G/T of the satellite receiver. However, in the case of deep fades on the feeder link there is a repercussion on the feeder link C/N and hence on the overall noise performance of the satellite link.

Attenuation on the down link will reduce the power available at the input of the receiving earth station. Further, the rain will also cause an increase in antenna system noise temperature, which will reduce the G/T of the receiving earth station. This increase in antenna noise temperature is described in § 4 of Part 2 of the present Report.

The increase in satellite e.i.r.p. required to compensate for high values of rain attenuation may make it difficult to provide adequate service availability, given practical limitations on transponder power.

Depolarization due to rain may occur on both feeder and/or down links. This may degrade the service quality due to the decrease of the total polarization isolation.

With modern antenna technology, the atmospheric depolarization effect (XPD) had become the limiting factor for the reuse of a given frequency on the orthogonal polarization. Reuse is possible only if XPD is significantly higher than the protection ratios required by the system. The depolarization effect may render it difficult to use higher frequencies for the service. In the case of feeder links using higher frequencies at about 30 GHz where XPD would be reduced to a typical value of some 15 dB (see Figs. 47, 48 and 49), it would not be possible to use polarization discrimination for a given orbit position. Consequently, the total bandwidth required for the feeder link services may be twice that for the down-link services.

The depolarization due to ice crystals at frequencies higher than 20 GHz is still a largely unknown phenomenon and care should be applied when considering frequency re-use in this range.

It should be noted that, in general, the propagation factors (rain attenuation, gaseous absorption and cloud attenuation, rain depolarization) are more and more critical for system design as the frequency increases. However, the gaseous absorption has a local maximum at 22.3 GHz so that frequencies slightly above 23 GHz are not significantly worse than those at 22 GHz, as far as the gaseous absorption is concerned (see Fig. 50).

3.7 Mitigation of adverse propagation effects

Several techniques to mitigate adverse propagation effects are available. Although techniques for both down links and feeder links have been proposed, current application has been limited to feeder links.

Useful techniques for feeder links include: up-link power control, site diversity and compensation for depolarization.

Up-link power control may be expected to restore about 10 dB on account of rain fades. For example, a reference beacon signal, at a frequency near to the up-link frequency or in the down-link band, may be employed for the up-link power control system. In the case that beacons are needed, appropriate frequencies should be determined.

For sites requiring higher margins, a site diversity arrangement with a separation distance of more than 10 km may be necessary. Report ITU-R BO.952-2 gives further details of the diversity operation of feeder links.

Report ITU-R BO.952-2 details theoretical studies on the application of compensation for feeder link depolarization. Possible techniques for down links include:

- shaping of the spacecraft transmit antenna pattern to provide increased e.i.r.p. to areas subject to higher propagation losses;
- further development of this technique is proposed in [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-7 (Japan)] in which dynamic rain attenuation compensation up to several dB can be carried out by using variable power dividers and phase control;
- for very low elevation angles where strong tropospheric scintillations are observed most of the time, the use of two small, closely spaced antennas in a "height diversity" configuration will produce good results [Bryant and Allnatt, 1980].

3.8 Type of polarization

In the WARC-77 Plan, circular polarization has been used to avoid the need for adjustments on the polarization tilt angle on domestic (individual) receiving installations. The operational practice of 11 GHz band FSS television distribution services in Europe and North America has shown that these adjustments may not represent a major difficulty, even for non-professional installers.

On the other hand, linear polarization has some distinct advantages with respect to circular polarization. One advantage is that there is a cross-polarization improvement factor which varies with polarization tilt angle and amounts to 15 dB for local polarization tilt angles of 0° and 90°. Two further advantages of linear polarization are:

- that it is easier to achieve adequate co-polar sidelobe suppression and cross-polar discrimination in the receiving antenna; and
- the attenuation of the vertically polarized component is less than that of the horizontal component by an amount which may be significant in deep rain fades.

Consequently, it is suggested that further studies be carried out on the merits of linear polarization for the future wide RF-band HDTV broadcasting service.

4. Receiving system characteristics

4.1 Figure-of-merit

The figure-of-merit (G/T) of the receiving equipment is one of the important elements in determining satellite system characteristics. It is primarily determined by antenna gain and noise figure of the receiver. It is important to recognize the difference between nominal and usable G/T. Operation of systems should be based on usable G/T (see Report ITU-R BO.473-5).

4.1.1 Receiving antenna

To achieve high G/T, a trade-off between a large antenna producing high gain but narrower beamwidth and higher pointing accuracy is needed.

In order to maximize the capacity of any allocated bands, the satellite spacing should be reduced as much as possible. In this case, the beamwidth of the receiving antenna should be narrow enough to reject interference from adjacent satellites more than the required protection ratio considered in the system design. In addition, to reject on-axis cross polar interference, the polarization discrimination rejection of the receiving antenna should be higher than the atmospheric depolarization considered in the system design.

On the other hand, any antenna is subject to mispointing caused by inaccuracy of installation, aging, wind loading and ice. Moreover, a larger antenna requires additional room and labour for installation, and may have negative esthetic impact. In general, it is inconvenient.

Taking into account the above factors, an antenna size in the range of 0.5 to 1 m is required in the frequency range of interest.

4.1.2 Low-noise front end

Low noise amplification devices operating in the vicinity of 20 GHz are being developed. The HEMT (high electron mobility transistor) is the most widely used technology. At 20 GHz, a single HEMT noise figure (NF) of 1 dB and an amplifier NF of 2 dB have been achieved [Shibata, et al., 1986].

A 22 GHz low-noise down converter for the satellite broadcasting receiver has been developed using commercially available HEMTs and materials. It has achieved a noise figure of less than 2.8 dB [Imai and Nakakita, 1989].

A summary of the situation is given in Fig. 51. It is understood that the expected value of the noise figure for mass production in the near future is around 2.5 dB at 20 GHz.

4.1.3 Figure-of-merit estimation

Nominal G/T, which does not include rain fades, aging and mispointing, and usable G/T of the receiving equipment are defined in Annex I to Report 473. Results of calculations of figures-of-merit based on the assumptions discussed in the previous sections are given in Fig. 52.

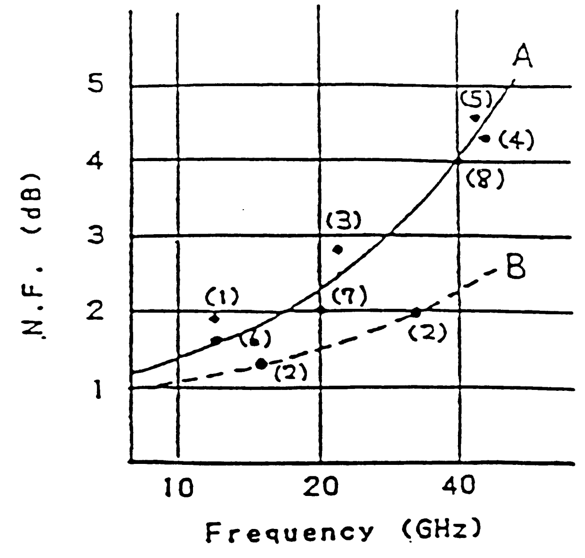
As an example, a nominal G/T of around 18 dB(K^{-1}) for a 75 cm antenna could be achieved at 20 GHz, while the usable G/T decrease to 15 dB(K^{-1}) for 10 dB fade.

4.2 Feasibility of current decoder and demodulator implementation

The technical and operational feasibility of a complete digital system for point-to-multipoint satellite distribution of HDTV has been demonstrated by the field trials carried out by RAI, during the Football World Cup, Italia '90, in the framework of the Eureka 256 project [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-6 (EBU)]. It is considered that these results can also be applied, scaling them up, to high-quality (wide-RF band) HDTV emission.

The HDTV signals were originated at the various stadiums in the formats currently under consideration by the CCIR, encoded at 1440 pels/line, transmitted at about 70 Mbit/s with QPSK modulation via the Olympus satellite (Channel 24, 42 MHz RF bandwidth). Those coming from Rome were transmitted through a 6 m up-link earth station located at the RAI Production Centre and connected with the stadium via an optical fibre link (2 x 34.4 Mbit/s channels). Transmissions originated in Turin, Florence, Milan and Naples were up linked via a transportable 3 m earth station. The HDTV signals were received from the satellite using a 1.8 m antenna, decoded and displayed to a selected audience on large screen projectors in eight receiving sites in Italy: Rome two,Turin two, Milan, Venice, Peruggia and Naples.

A complementary demonstration was done in Spain by Retevision. A single 2.8 m receiving station was used in Barcelona (direct satellite reception was not possible in other areas with reasonable antenna sizes). The signal was transferred via a dedicated optical fibre to Madrid (about 620 km) and demonstrations were presented in both cities.



Curves A: Current production value which could be expected for mass production.

B: Best reported laboratory value.

FIGURE 51

Noise figure performance as a function of frequency

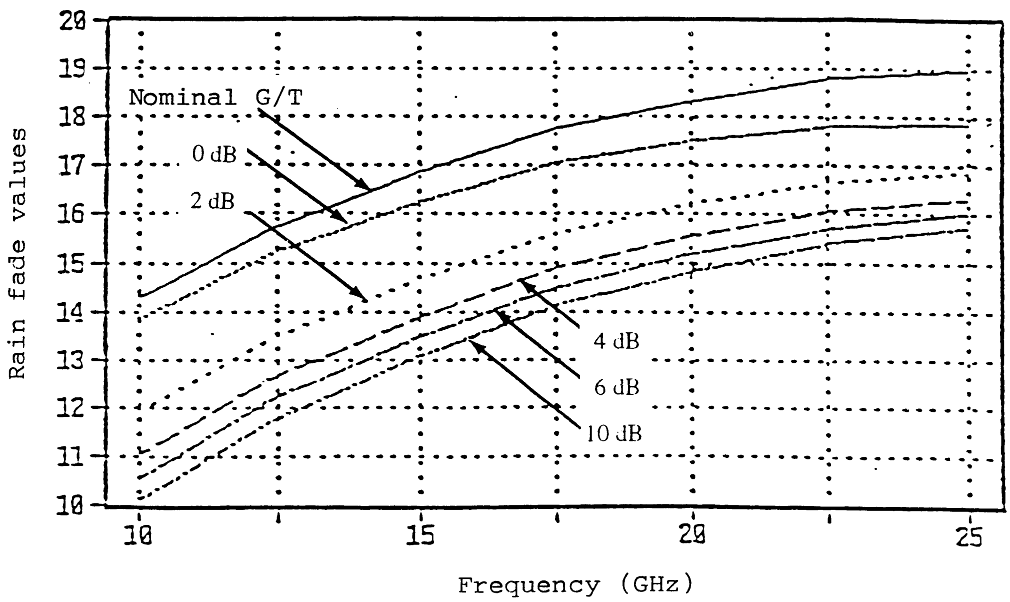


FIGURE 52

Usable G/T vs. frequency

Note - Antenna : 75 cm diameter and 70% efficiency are assumed
Noise figures : Assumes Curve A of Fig. 51 in [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-38(Rev.1)]
Pointing loss : 0.3 dB constant loss due to misalignment plus 0.3 deg of pointing error are assumed

These experiments demonstrated [CCIR, 1986-90, Doc. IWP 11/7-310 and Doc. IWP 11/9-043 (Italy, Spain)] [Barbieri and Cominetti, 1990] the excellent performance of the digital HDTV codec in a variety of transmission circuits that usually occur in a normal operational environment: satellite link, fixed and transportable earth stations, optical fibre link, and local distribution network.

The main conclusions of this experiment were:

- the overall quality of the received pictures, observed on a professional HDTV monitor, was assessed as being comparable, for the programme material used, to the studio quality achievable by current source and display technologies;
- the performance of the transmission chain in terms of ruggedness against transmission errors and reception margin was better than expected, even in very unfavourable propagation conditions.

The EBU is currently investigating a programme of work which will lead to a live over-satellite demonstration of a complete wide RF-band 140 Mbit/s digital HDTV system at the WARC-92 Conference. The purpose of this demonstration will be to prove the feasibility of such a system, in an effort to encourage administrations to allocate a new band around 20 GHz for HDTV, and to make possible worldwide use of this band for HDTV.

4.2.1 Decoders

Three European projects, [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-6 (EBU)] RACE-Hivits, IRT-Siemens and Eureka 256, are currently developing codecs for digital HDTV transmission. These codecs will be used in the EBU demonstration mentioned above.

The Hivits codec works at 140 Mbit/s and is based on the hybrid DCT transform and motion compensation. The input/output of the codec is the HDI format (1920 samples per active line). Its hardware implementation will be available in the last quarter of 1991.

The IRT-Siemens codec is intended specifically for HDTV emission at 140 Mbit/s. It is also based on the hybrid DCT transform and motion compensation and uses 1920 samples per active line. For the WARC-92 demonstration, the decoder will be implemented in hardware, but the encoder will be simulated and the transmission data recorded on a D1 VTR.

Eureka 256 is developing a flexible codec working from less than 70 Mbit/s up to 140 Mbit/s. It is based on the same coding algorithms. A first hardware implementation of this codec (70 Mbit/s, 1440 samples, without motion compensation) is already available and has been demonstrated during the World Cup '90. The definitive version (1920 samples and motion compensation) will be available in the second half of 1991. All these codecs make an extensive use of VLSI in order to cope with the requirements of speed, power consumption and equipment size. Some ICs are already available from different sources (DCT chips). The use of semi-custom ASIC has often been required in order to achieve the best approach in terms of developing time and cost.

All the techniques developed by these projects are applicable to high-quality (wide-RF-band) HDTV emission.

4.2.2 Demodulators

The implementation of the complex algorithms being considered for modulation and channel coding also requires an extensive use of V.L.S.I. technologies at the demodulator [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-2 (EBU)]. Systems based on QPSK modulation are easier to implement, at least in the medium term, than systems based on trellis coded 8-PSK systems. A larger implementation margin must possibly be allowed for the coded 8-PSK systems than for QPSK ones. This is due to the greater sensitivity of the higher order modulation systems to imperfect implementation of the demodulator and its associated filtering. For both systems there is a need to develop low-cost, high-speed, soft-decision Viterbi decoders.

140 and 70 Mbit/s QPSK modems and 70 Mbit/s 8-PSK modems are already available. There is a move in the modem design towards the introduction of full digital technologies which will permit more reliable modems.

Single chip soft-decision Viterbi decoders are also available for rate 1/2 and 3/4 (K = 7) convolutional codes, for a maximum useful bit rate of about 17 Mbit/s. Higher bit rates can be obtained using a parallel structure. A 100 Mbit/s single chip Viterbi decoder for trellis coded 8-PSK has recently been developed in Germany. The analogue-to-digital conversion for soft-decision decoding requires about 3-5 bit precision and is feasible with present-day chips.

Single chip BCH and RS coder/decoders are also available for bit rates in excess of 200 Mbit/s.

These technologies are all applicable to digital demodulators and channel decoders, for high quality HDTV emission.

5. Source coding for vision

5.1 Introduction

Present HDTV studio formats are characterized by more than 1,000 active lines and around 2,000 samples per line. The corresponding digital studio quality HDTV signals require about 1 Gbit/s for an interlaced picture and about 2 Gbit/s for a progressively scanned picture.

Practical satellite emission will require a substantial reduction of these bit rates, given the expected future worldwide demands for a number of HDTV programmes and the demands on the radio-frequency spectrum caused by the increase in other radiocommunication services.

This section will discuss only bit-rate reduction through source coding. Further bandwidth reduction can be achieved by sophisticated modulation methods as described in § 7.3 of Part 2 of the present Report.

The source coding should provide "transparent picture quality", i.e. a picture quality that is subjectively visually identical to studio quality, at a viewing distance of three times picture height. However, different coding methods produce different artifacts, and although work is going on in the CCIR, there are yet no agreed criteria to test for transparency. The estimates of the bit-rate reduction that can be obtained are therefore based on present work and experts' evaluations.

5.2 Bit-rate reduction methods

There are three basic methods for bit-rate reduction under development: Discrete Cosine Coding (DCT), Vector Quantization Coding (VQ) and sub-band coding. These methods are discussed in this section.

5.2.1 Discrete cosine transform coding

This is the most widely used and highly developed technique (see Recommendation 723). It is used in all European projects concerning digital TV and HDTV. [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-6 (EBU)] [Barbieri and Cominetti, 1990] [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-21 (RAI)]. Systems have also been proposed in the United States and experimental units are being developed in Japan [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-14 (Japan)] [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-23 (United States)].

In this approach, a small area of picture samples, usually in blocks of 8 x 8, or 16 x 8 pixels are converted by a mathematical operation, into another domain, closely resembling the discrete Fourier domain [Barbieri et al., 1990] [Guichard and Nasse, 1987] [Digicipher, 1990] [Barbero et al., 1989].

The DCT is applied to luminance and chrominance blocks to exploit spatial correlation. Temporal correlation is exploited, where possible by coding the differences between the present block and a prediction block obtained from the previous fields (DPCM). A further improvement is obtained by using the motion compensation techniques.

To preserve high picture quality, several mechanisms are used:

- intrafield/intraframe/interframe - adaptive coding modes;
- interframe or interfield motion compensation;
- spatial frequency cut-off and quantization;

(A different quantization characteristic is used for transform coefficients depending on their position, scanning path selected, criticality of block, coding mode and buffer occupancy.)

- block scanning and variable length coding (VLC);

(The statistical amplitude distribution of the DCT coefficients is non-uniform. Entropy encoding of the coefficients can be done and with selection of a suitable scanning path through the blocks allows the exploitation of run lengths of zero values. In conjunction with the Variable Length Coding, further statistical data reduction can be achieved by assigning the more frequently occurring coefficient values to shorter codes.)

This method is shown in Fig. 53.

5.2.2 Vector quantization coding

Vector quantization is a technique that has been under study and development by several organizations.

In this approach, the picture is divided into small blocks (e.g. 4 picture elements x 4 lines). A vector represents the combination of the signal values of each block. In order to minimize the necessary size of the codebook and the quantization calculations, vectors are normalized prior to quantization. In this normalization the input vectors are converted into vectors with zero mean and unit standard deviation. The mean and standard deviations are then quantized using a scalar quantizer.

In an encoder, each vector is compared with codewords stored in the codebook to find the best matched codeword. The index of best matched codeword, the mean and standard deviation are transmitted from an encoder to a decoder, using variable-length codes. To minimize coding distortion, a prediction technique like DPCM is used prior to vector quantization.

Adaptive prediction techniques such as intrafield, interframe and motion-compensated interframe modes are used as shown in Fig. 54.

In a decoder, the inverse process is performed to reproduce a decoded picture.

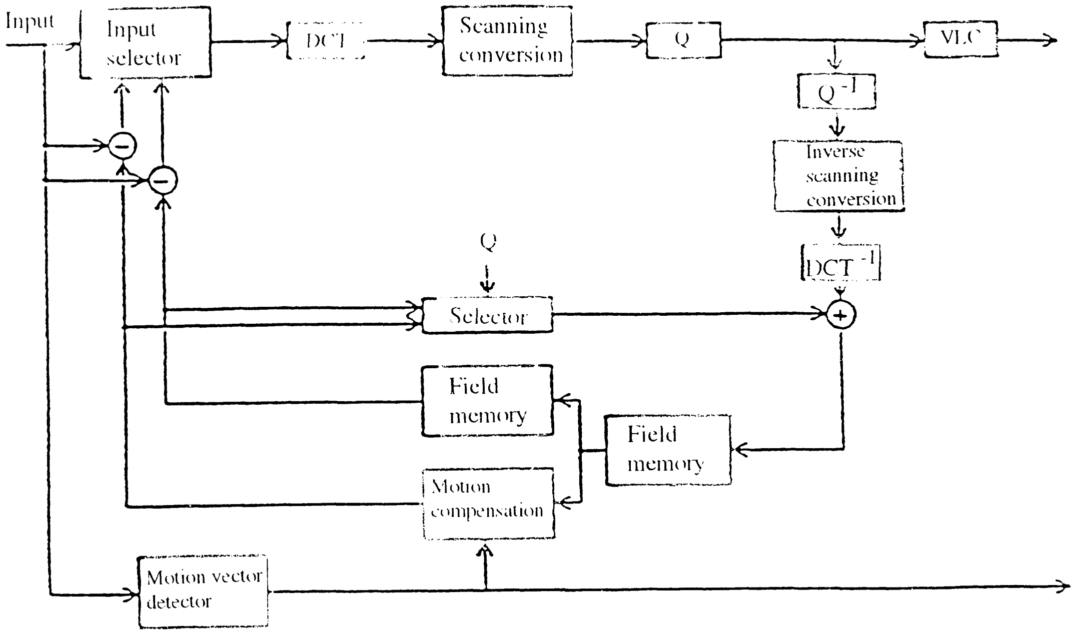


FIGURE 53

Notional block diagram of discrete cosine transform (DCT) coding

Q: quantizing VLC: variable length coding

5.2.3 Sub-band coding

Sub-band coding is a less well-developed technique.

The basic principle of sub-band coding is to split up the image signal into a number of frequency sub-bands using digital filters in the spatial and temporal domain [Woods and O'Neil, 1986].

After filtering, each sub-band is decimated (i.e. selection and retention of the most significant and most critical information in a sequence) so that the component falls into the lowest sub-band bandwidth. This makes each sub-band image full-band at the lower sampling rate.

Sub-bands are selected on the basis of energy content and critical information. At the receiver, the sub-bands are decoded and up-sampled, fed through interpolation filters and added to reconstruct the image. With an appropriate choice of filters, perfect or near perfect reconstruction can be achieved.

One advantage of sub-band coding is that errors in decoding any particular sub-band are restricted to that sub-band. Thus, in the reconstructed image an error is masked to a certain extent by information from the other sub-bands. Another advantage is that the noise spectrum can be shaped by varying the bit assignment between the sub-bands.

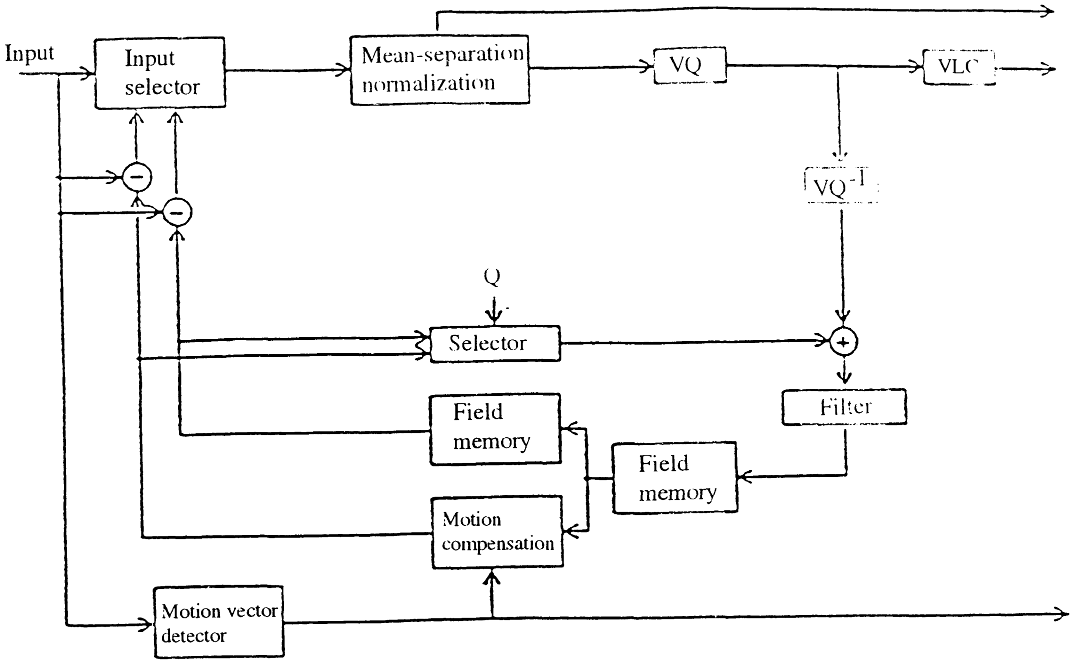


FIGURE 54

Notional block diagram of vector quantization (VQ) coding

Sub-band filtering itself does not produce any data compression. Sub-band coding achieves a separation of data so that coding of each sub-band can be optimized. Non-critical sub-bands and non-critical information within sub-bands can be removed, thus reducing the bit rate. In order to reduce bit rates further, various other techniques, such as DCT, DPCM can be applied to each sub-band. The majority of energy is located in the low-pass filtered low-band areas with upper sub-bands containing edge information.

One system proposed in the United States allows full frame transmission of low frequency low sub-band components (good motion), whilst upper sub-bands are transmitted at lower rates but with good detail for static images.

5.3 Coding artifacts and failure characteristics

Failure modes for conventional analogue frequency modulated television signals are well understood, quantifiable and can be optimized by adjusting the frequency deviation. Hence, for a given channel characteristic, empirical techniques exist to identify and optimize the system failure mode and the probability of occurrence. However, there does not exist an easy method to optimize and find a similar measure for the evaluation of the performance and characterization of failure modes including their probability of occurrence for digitally coded and modulated television signals.

Failure modes and their characteristics for digitally coded and modulated HDTV emission systems are characterized into artifacts due to source coding and artifacts due to errors in the received signal. The latter artifact is related to the transmission channel characteristics and the system modulation and error correction schemes employed.

5.3.1 Coding artifacts

Bit-rate reduction processes rely on eliminating, to a more or less extent, redundant and/or irrelevant information of the vision (or sound) studio signal. In doing this, inevitably coding artifacts are introduced. The challenge for the system designer is to determine the coding algorithm such that these artifacts remain virtually imperceptible under the defined viewing conditions. However, for some very critical images containing a high content of moving parts this might not be achieved and some visible artifacts will appear in the decoded picture; for example, reduction in resolution of fine details, diagonal information and especially dynamic motion portrayal. For high quality transmissions a sufficiently high bit rate needs to be made available in order to achieve in practice an unimpaired picture under nominal receiving conditions for a high percentage of the picture content expected to occur in broadcasting applications.

5.3.2 Failure characteristics

Unlike analogue frequency modulated TV systems which experience a gradual transition to outage, digital systems are normally characterized by a high basic quality which is fairly constant, while the error rate is below a threshold value which is set by the system design. However, when this error rate threshold is reached and exceeded, the system performance deteriorates rapidly. Commonly used digital coding schemes reported in [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-6 (EBU)] employ hybrid DCT coding combined with entropy (VLC) coding of the block coefficients. Some schemes also employ motion estimation and compensation. The error correction scheme normally considered, and recommended in CCIR Recommendation 723 for component coded digital television signals for contribution quality application, is a Reed-Solomon RS(255,239) code with 8-bit symbols and an interleaving factor of two. This code provides good protection against channel errors, particularly in the case of error bursts with only a modest (< 7%) overhead. For higher protection against channel errors, powerful channel coding techniques, based on concatenation of FEC codes or trellis modulation (with soft-decision Viterbi decoding) can be adopted. These techniques may require higher overhead but allow significant reduction of the satellite transmit power. No work has been reported that links source and channel coding in an attempt to provide a more gradual failure mode such as occurs in analogue coded and modulated systems.

Depending on the coding scheme and the error propagation characteristics with respect to VLC and video framing schemes employed, channel errors can affect one or more blocks of the decoded picture, thus increasing the error visibility once the error correction scheme becomes overloaded. Also, some residual errors can be present after the error correction in the decoder. It is possible to minimize the effects of error propagation by carefully designing the data organization and framing structure. In addition, error concealment strategies can be applied in the decoder.

Thus, it is generally recognized that the failure modes of video coding and emission systems and their characteristics will depend not only on the FEC scheme employed, but also on the design of the framing scheme of the system, the error propagation characteristics of the video framing and the VLC schemes, and the error concealment strategies provided.

5.3.3 Subjective assessment of failure characteristics

In addition to characterizing the failure modes of digitally coded and modulated wide RF-band HDTV emission systems, it will be necessary to establish a normalization procedure to permit evaluation of the performance expected of them within the broadcasting environment. [CCIR, 1986-90, Doc. JIWP 10-11/3-25] proposes a performance evaluation criteria based on picture-content failure characteristics. Conceptually, a picture-content characteristic establishes the proportion of the material likely to be encountered in the long run for which the system will achieve particular levels of quality. The method proposes to establish a performance ranking of the system, which would be subject to normal transmission impairments expected in a broadcasting environment, with respect to a series of critical pictures and would relate this to the probability of occurrence of these critical pictures in broadcasting applications.

Such a failure characteristic can be used in three ways:

- to optimize parameters of a system at the design stage to match it more closely to the requirements of the service;
- to consider the suitability of a particular system (i.e. to anticipate the incidence and severity of failure in an operational environment);
- to assess the relative suitability of alternative systems on a normalized basis.

JIWP 10-11/6 notes, however, that while the method provides a means of measuring the picture-content failure characteristic of a system, it may not fully predict the acceptability of the system to the viewers of a television service. To obtain this information, it may be necessary for a number of representative viewers to watch programmes encoded with the system of interest and to evaluate their comments.

5.4 Present and future capabilities

In general, one could state that the higher the available transmission bit rate, the lower the probability of perceptible artifacts (defects) in the picture due to the vision coding process.

In order to transmit an HDTV broadcast signal, the quality of which is subjectively virtually transparent to that of the studio or production signal, most experts today agree that some 110 - 120 Mbit/s would be sufficient for the coding of the vision signal. The vast majority of pictures (including highly critical motion portrayal) would be free of perceptible coding artifacts. It should be noted that for any bit rate reduced vision system, images could be found or determined which would overload the information capacity of the system. For example, a picture which is composed of white Gaussian noise will be reproduced more or less incorrectly because of its complete lack of correlation in the picture content.

Computer simulation which was carried out in Japan, the United States and Europe on both hybrid DCT and vector quantization consistently confirms that for a rate of about 120 Mbit/s (video only), an excellent picture quality can be achieved without noticeable degradation [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-14 (Japan) and Doc. JIWP 10-11/3(90)-29 (Germany)] [Ardito et al., 1990].

At a rate of 60 Mbit/s (video only) the computer simulations indicated that hybrid DCT methods with motion compensation would achieve good picture quality for most of the images except for a slight degradation with specific test pictures [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-14 (Japan)]. Hardware test transmissions in Italy and Spain, although not including motion compensation, seem to confirm these computer studies [CCIR, 1986-90, Doc. IWP 11/9-043 (1990) and IWP 11/7-310 (1990) (Italy, Spain)] [Barbieri and Cominetti, 1990].

Results of formal tests on HDTV codecs have not been reported up to now. Contributions [CCIR, 1986-90, Doc. IWP CMTT/2-188 (1990) (Italy) and Doc. IWP CMTT/2-192 (1990) (Spain)] have been submitted on the results of subjective tests on a 4:2:2 version of the EUREKA 256 codec, operating at 17 and 34 Mbit/s. These results indicate that a good basic quality, better than grade 4.5 of the CCIR impairment scale, is attained for most of the critical test material at a bit rate corresponding to about 1.6 bit/pel. The codec under test was not yet equipped with motion compensation, which should provide a significant improvement in a large part of the programme material [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-6 (EBU)].

Although work on vision coding systems is in progress, it seems, at least with the known and investigated coding methods, not very likely that a bit rate significantly lower than 100 Mbit/s (for example, 60 Mbit/s) would provide for the transparent quality as defined in section 2 of this Report. Nevertheless, 60 Mbit/s might ultimately provide a signal quality acceptable to most viewers. One should, however, keep in mind that with time requirements on signal quality will tend to rise in conjunction with improved studio signals and better display techniques. It seems therefore prudent to base capacity considerations for "high-quality HDTV" on about 110 - 120 Mbit/s (vision signal only).

It should be noted that additional information must be transmitted for the accompanying programme sound, ancillary data, framing, synchronization and baseband error correction coding (FEC1, see § 7.3 of Part 2 of the present Report on channel coding). A multiplex containing some 110 to 120 Mbit/s for the vision signal could be accommodated within a 140 Mbit/s signal. Likewise, 105 Mbit/s for the total baseband multiplex would support about 95 Mbit/s of video information, and about 60 Mbit/s of video information would fit into a 70 Mbit/s multiplex [Cominetti and Moro, 1990].

5.5 Conclusions on source coding for vision

There is a very close relationship between the required picture quality and the necessary bit rate for vision coding. Computer simulations, hardware evaluation and field tests done so far have revealed that about 110 Mbit/s (video only) would fulfil the requirements for highest possible quality (transparent studio quality). This bit rate would also provide, once compression techniques progress further, some headroom to cope with future improved (progressive) studio signals and/or enhanced display techniques.

Whether bit rates well below this figure would also meet highest quality requirements has not been shown yet. Work in progress indicates that coding techniques would eventually lead to video baseband bit rates in the order of 60 to 90 Mbit/s. These rates can certainly be achieved if the requirements on quality are somewhat relaxed, that is to say, if one accepts for certain very critical pictures some perceptible coding artifacts.

For capacity considerations of a given RF band, it seems prudent, at least for the time being, to base calculations on some 110 to 120 Mbit/s (vision only).

Any refinements in coding techniques leading to lower bit-rate requirements will result in a corresponding increase of capacity. For example, 90 Mbit/s (vision only) would allow 50% more HDTV channels, with 60 Mbit/s (vision only), a target which experts think could eventually be achieved for high-quality HDTV. In this case, the available number of channels would be doubled (assuming identical channel coding and modulation techniques).

5.6 Source coding for sound

The sound aspects are very important in the design of wide RF-band HDTV systems because multichannel sound of high quality will be used. This is likely to require a significant part of the total capacity. The relevant information is provided in Reports ITU-R BO.953-2 and ITU-R BS.1199.

6. Baseband multiplex

The baseband multiplex consists of a combination of the vision signal, the sound and additional data. These services can be analogue or digital. The bandwidth or bit-rate reduction techniques that are now being used will also require additional information to be transmitted to enable the receiver to operate. This information will probably be digital (e.g. DATV). There may also be programme-related services which may be needed, such as the sub-titles.

In the design of the system, it is necessary to ensure that the separate parts of the multiplex are transmitted in such a way that they are easily processed in the receiver. It is also necessary to reflect the different importance given to the separate items when considering failure of the system under conditions of propagation fade or interference limitations.

It is highly desirable to maintain a nominal overall bit-rate through all signal distribution channels, including the satellite link and the cable networks.

An example of a bit-rate scheme for a high-quality HDTV baseband multiplex could be as follows:

- Picture information including motion vectors	125 Mbit/s
- Sound information	2 Mbit/s
- Additional data services (e.g. HDTV-Teletext)	1 Mbit/s
- Framing and baseband error-protection ("outer code")	11 Mbit/s
Input bit-rate to channel coder/modulator	139 Mbit/s

7. Modulation and channel coding

7.1 Required properties

In the frequency range under consideration (12.7 - 23 GHz), wide RF-band HDTV satellite-broadcasting systems have to be designed to cope with the adverse propagation characteristics expected throughout the frequency range, and especially at the top end of this range.

In addition, frequency re-use is important in order to allow the maximum spectrum efficiency.

Consequently, the most important properties of a wide RF-band HDTV modulation system for the BSS are:

- it must be tolerant of high levels of noise. This will allow realistic systems to be designed, without excessive requirements on satellite TWT power or receiving dish size;
- it must also be tolerant of high levels of interference. This will allow efficient spectrum re-use which is important if a frequency allocation is to be made and a satisfactory service is to be developed.

The characteristics of the satellite transponder also impose a constraint on the choice of a suitable modulation method:

- the satellite amplifier is likely to be a travelling wave tube (TWT) driven close to saturation, and therefore operating in a non-linear mode. This fact should be taken into account when determining the relative suitability of modulation and channel coding techniques.

The choice of modulation system will be a trade-off between various parameters. It is important to maximize tolerance of noise, distortion and interference, whilst not wasting spectrum. The optimum compromise between simplicity of modulation system, complexity of error correction system and system bandwidth should be found.

In principle, both analogue and digital modulation techniques can be used. Current studies indicate that digital techniques are preferable.

7.2 Analogue modulation techniques

Analogue techniques which have been considered for HDTV broadcasting use sub-sampling for baseband bandwidth reduction and frequency modulation for transmission.

Narrow RF-band HDTV signals such as MUSE, HD-BMAC and HD-MAC are valid candidates for the first HDTV broadcasting services by satellite in the 12 GHz band.

Without changing the baseband occupancy, the noise performance can be improved by increasing the deviation of the modulated carrier, resulting in a wider RF channel. In this case, the modulation parameters are optimized in order to obtain a good picture quality just above the FM threshold. However, it is expected that these systems do not provide sufficient basic quality for future wideband HDTV systems which should approach the quality potentially inherent in the studio standard. In addition, the noise performance and spectrum efficiency will be reduced and will probably be inferior to those of digital systems.

Towards this end, the basic quality could be improved by extending the baseband bandwidth. Extended versions of MUSE and HD-MAC are described below:

- Extended HD-MAC 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 which would be compatible with HD-MAC receivers and one based on 72 MHz sampling which would provide higher performance with much greater use of DATV, but is not completely compatible.
- Extended MUSE 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.

The best estimates for analogue systems indicate a preferred bandwidth of the order of 50 MHz, carrier-to-noise ratios of 17 to 22 dB are considered desirable, and protection ratios of the order of 25 to 30 dB are expected to be necessary, but there is very little experimental evidence to support this hypothesis.

The high protection ratios lead to less efficient frequency re-use, thus lowering spectrum efficiency.

It is the view of the ITU-R that wide RF-band HDTV is therefore likely to be implemented in digital form.

7.3 Digital modulation and channel coding techniques

A wide RF-band HDTV emission system should provide an overall quality virtually transparent to the HDTV studio quality.

The intrinsic HDTV picture quality depends first of all on the bit rate allocated to the picture coding and on the performance of the picture coding algorithm. To cope with interference and propagation effects, powerful error protection is required. The objective to bring to the home the full HDTV studio quality can be reached at a total bit rate of 140 Mbit/s, but lower bit rates, e.g. 70 Mbit/s for the source coding are also considered in order to improve the overall RF system performance by allocating a larger part of the bit rate to channel coding. The lower bound of the bit rate has not been identified and, of course, this is likely to change as bit reduction techniques improve (see § 5 of Part 2 of the present Report).

Present implementations of digital HDTV systems based on hybrid DCT require a bit-error ratio of 10^{-8} or better after error correction for an acceptable picture. For critical pictures a bit-error ratio in the vicinity of 10^{-10} may be required. To achieve this low error rate with realistic satellite power, it is necessary to use powerful error correction techniques. In practice, error correction is likely to use a two-stage process with a combination of source and channel coding. The channel coding is engineered in conjunction with the modulation system.

In accordance with § 7.1 of Part 2 of the present Report, the service availability can be expressed in terms of bit-error ratio at the input of the HDTV decoder (before error correction by FEC 1, see Fig. 55) by, for example:

- Full quality : BER < 2.6 x 10^{-4} for 99% of the worst month;
- Service quality : BER > 2.0 x 10^{-3}.

The following modulation examples are based on these figures. Other examples of modulation techniques and/or source and channel coding could be used, in which case these figures of BER would have to be reconsidered.

7.3.1 Suitable modulation and channel coding techniques

Suitable traditional methods of modulation are QPSK, 8-PSK and constant envelope modulation systems such as analogue FM, continuous phase modulation (CPM) and digital phase modulation (DPM). These digital techniques offer bandwidth efficiencies of 1.5 to 2 (bit/s)/Hz. Higher order, multilevel systems such as 16-PSK and 16-QAM offer bandwidth efficiencies approaching 3 (bit/s)/Hz, but are very sensitive to channel non-linear distortions and to interference. Therefore, they require a quasi-linear TWT operation. This also reduces the power that may be available. Furthermore, they require better C/N and C/I values than for, for example, QPSK [Cominetti, 1990].

Recent tests carried out on a satellite simulator indicated that E_b/N_o performance of 16-QAM can be significantly improved (about 3.5 dB at BER = 10^{-4}) by using a linearizer for the satellite TWT [Morello et al., 1991].

However, uncoded 16-QAM requires a very high TWT nominal power, about 8 dB higher than QPSK at the same BER, even when using a linearizer.

Further studies by computer simulation [CCIR, 1990-94, Doc. 10-11S/46 (Italy)] on trellis-coded 16-QAM with Viterbi decoding seemed to indicate that a small power reduction can be achieved with respect to uncoded 8-PSK (about 1 dB) with the same spectral efficiency, but with a significantly higher receiver complexity and using a TWT linearizer.

On the other hand, QPSK, as well as constant-envelope modulation systems, can operate efficiently at TWT saturation and 8-PSK can operate at about 0.5 dB back-off.

Thus, it may be concluded that, currently, high-order, multi-level modulation methods are less appropriate for digital HDTV broadcasting by satellite.

Two systems of advanced modulation and channel coding techniques have been investigated [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-2 (EBU)] [Dosch, 1990] [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-29 (Germany)] [Cominetti and Morello, 1990] [CCIR, 1986-90, Doc. JIWP 10-11/3(90)-21 (Italy)]. They are as follows:

- System A - QPSK with concatenated codes, i.e. a block code associated with the source (FEC 1) and a convolutional code with rate 1/2 (System A1) or 3/4 (System A2) associated with the channel (FEC 2).
- System B - Trellis coded 8-PSK with rate 2/3 in combination with a block code associated with the source (FEC 1).

Both families of systems make use of soft-decision Viterbi decoding in the receiver.

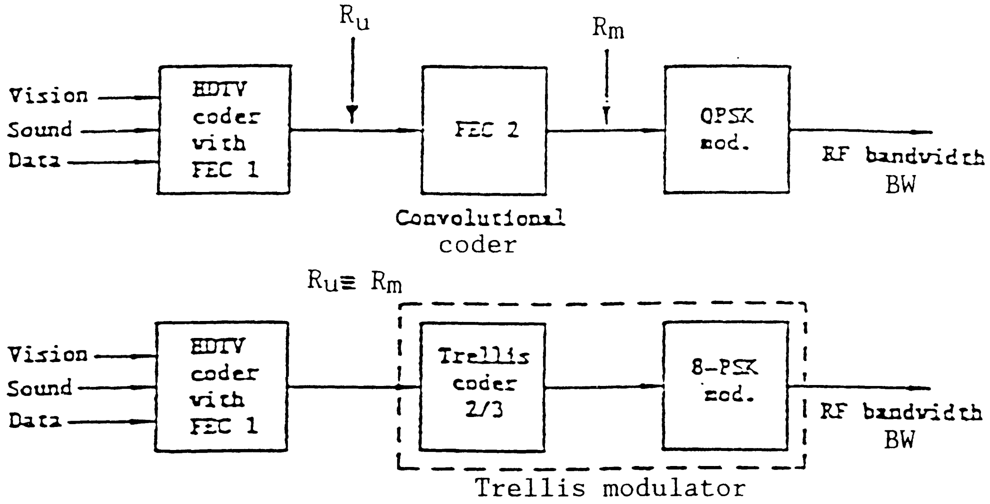
Figure 55 shows block diagrams of these advanced digital modulation system approaches. Table 19 compares the performance of six different modulation and coding schemes over a satellite channel with a saturated TWT under the assumption that the bit rate at the output of the HDTV coder, including FEC 1, is equal for all coding schemes. For systems 2-6 in Table 19, the RS(255,239) Reed-Solomon code (with interleaving depth between 2 and 4) is used as FEC 1 (outer code). This code allows high burst-error correcting capabilities, which is required in combination with a soft-decision decoder.

The Viterbi decoding of convolutional codes and Trellis-coded 8-PSK which do not include FEC 1 have the advantage of a relatively gradual failure characteristic with decreasing C/N [Dosch, 1990]. This is achieved at the expense of higher E_b/N_o requirements. According to computer simulations for the Trellis coded 8-PSK, there is about 3.5 dB variation of C/N between the points corresponding to a channel bit-error ratio of 10^{-5} (excellent picture quality) and 2.10^{-3} (system failure point). On the other hand, the coding gain of a system without FEC 1 is relatively small. If a concatenated coding scheme is used (with BCH or Reed-Solomon codes as FEC 1), a relatively steep overall failure characteristic is obtained at a BER in the region of a bit-error ratio of 10^{-3} at the output of the Viterbi decoder, but the coding gain increases substantially. Nevertheless, a FEC 1 with unequal protection of the various picture components can be designed to maintain a more gradual failure of the system, e.g., by an appropriate error correction of the most import bits of the picture information.

Experiments in the United States have measured the performance of concatenated codes for satellite television broadcasting and found that a moderate (but practical) increase in coding complexity over that associated with single-string codes results in a significant performance improvement. The trade-off between coding rates for a Reed-Solomon code and a convolutional code was carried out by trial-and-error, and it was found that the required E_b/N_o to maintain a given picture quality level was reduced by about 3 dB. The increased complexity in coding now requires two chips instead of the one chip required before. This scheme has been reduced to practice and will be used on the first United States broadcasting satellite system to operate in the 12.2-12.7 GHz band when it begins service in early 1994.

The coding method consists of concatenating a Reed-Solomon block code with a Viterbi convolutional code. For the high rate mode, the convolutional code would be rate 7/8 while a rate 2/3 would be used for the lower rate mode. The two convolutional codes used can be derived from a single rate 1/2 convolutional code. By omitting selected bits from the decoding process, the single rate 1/2 convolutional code can be modified, or "punctured", to operate at higher rates while retaining the simplicity of the rate 1/2 decoder and nearly the performance of the best higher rate codes. The ability to change convolutional code rates allows the aggregate code rate to change between approximately 0.77 and 0.58 (from 30 Mbit/s to 22.8 Mbit/s information).

The change in coding gain from 0.77 to 0.58 aggregate rate is approximately 1.3 dB. The change in data rate is approximately 1.2 dB. Therefore, the change in required E_b/N_o is 2.5 dB [ITU, October 1993, 10-11S/158 (United States)].



R_u : bit rate at the output of the HDTV coder
R_m : bit rate at the input of the modulator

FIGURE 55

Block diagram for two advanced digital HDTV modulation system approaches

TABLE 19

Performance of modulation and coding systems via satellite (same bit error ratio at the output of the HDTV coder)

System	Modulation/ coding system	Inner code (FEC 2)	E_{bu}/N_0* BER = 10^{-8}	Coding gain ref. to System 2	Relative RF channel bandwidth ref. to System 2	Spectrum efficiency
			(dB)	(dB)	%	(bits/s)/Hz
1	QPSK without FEC 1	-	12.8	-4.0	94	1.5
2	QPSK	-	8.8	0	100	1.4
3	QPSK	Convol.3/4**	5.2	+3.6	133.3	1.05
4	QPSK	Convol.1/2**	4.1	+4.7	200	0.7
5	8-PSK	-	14.0	-5.2	66.7	2.1
6	Trellis coded (2/3) 8-PSK	-	6.7	+2.1	100	1.4

* E_{bu}/N_o is the ratio of energy per useful bit and power spectrum density as follows: $E_{bu} = C/R_u$, where C = received carrier power at saturation and R_u = useful bit rate (excluding code redundancy). These figures refer to simulation results on a typical satellite channel with saturated TWT and Gaussian noise and include the implementation margins of 2 dB for the receiver.

** The convolutional codes used have the constraint length of 7. The 3/4 convolutional code is obtained by puncturing the 1/2 code.

7.3.2 System performance and capacity considerations

Various system approaches based on the coding principles of families A and B, operating with useful bit rates of 70 Mbit/s, 105 Mbit/s and 140 Mbit/s at the output of the baseband multiplexer (inclusive of video, audio and data, with FEC 1 by RS (255,239) are compared in Table 20, assuming the channel matrix of Fig. 56 [Cominetti, Morello (August 1990)].

The following parameters are considered:

- C/N ratios in 100 MHz required for a high-quality picture and for service continuity, as defined in § 7.3 of Part 2 of the present Report;
- useful bit rate (R_u);
- bit rate of modulator input (R_m);
- channel spacing (D_f);
- number of RF channels in 600 MHz of allocation; and
- required protection ratios (PR) for co-channel interference (CCI).

A system implementation margin of 2 dB has been considered. The values for protection ratios given in Table 20 correspond to an impairment of the C/N ratio of 1 dB at a channel BER of 2.6×10^{-4}, i.e., high-quality pictures.

Table 20 allows trade-offs between the main parameters involved in the system design, i.e., between picture quality, satellite power, the number of RF channels and protection ratios. The examples given in Table 20 do not take into account the provision of guardbands at band edges which are needed to protect adjacent bands from spurious emissions and vice versa. The determination of the guardband widths depends on the frequency allocation yet to be made and the systems eventually adopted.

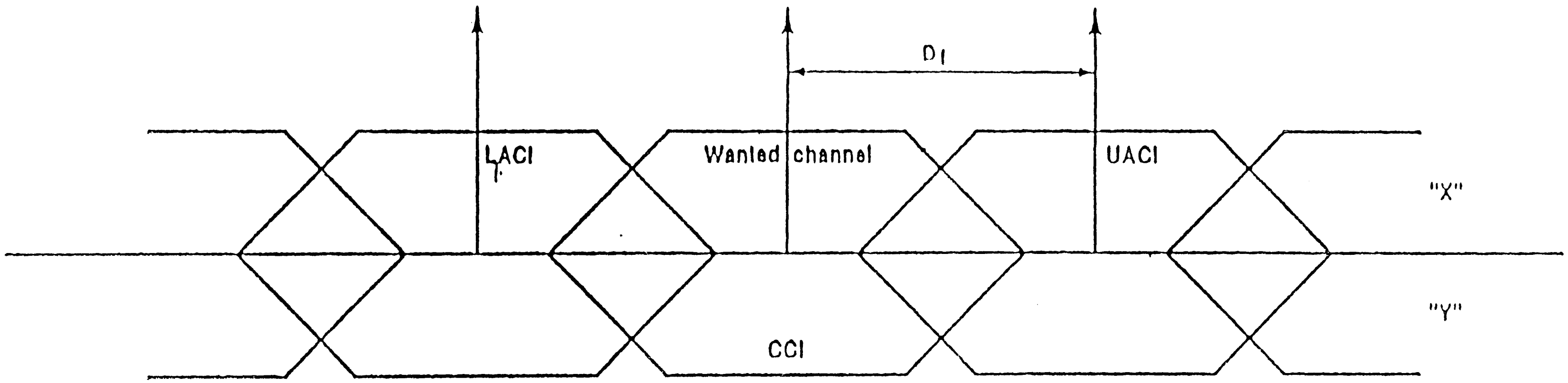
TABLE 20

Performance of different system approaches over a satellite channel

R_u (Mbit/s)	R_m (Mbit/s)	System	Df (MHz)	No. of channels per 600 MHz	PR (CCI) (dB)	Required C/N (dB) in 100 MHz (2 dB margin)	
						High quality	Outage
140	140	QPSK+RS	100	6	20.0	14.1	11.6
70	140	A1	100	6	11.1	5.6	4.6
	93	A2	66.7	9	15.3	6.6	5.7
	70	B	50	12	20.2	8.2	7.2
105	210	A1	150	4	11.1	7.4	6.4
	133	A2	100	6	15.3	8.4	7.5
	105	B	75	8	20.2	10.0	9.0
140	280	A1	200	3	11.1	8.6	7.6
	187	A2	133	4	15.3	9.7	8.8
	140	B	100	6	20.2	11.2	10.2

FIGURE 56

Digital transmission channel matrix



X: Polarization 1

Y: Polarization 2

LACI: Lower-adjacent interferer

UACI: Upper-adjacent interferer

CCI : Co-channel interferer

D$_I$: Channel spacing

System approach using 140 Mbit/s

In the case that a bit rate of 140 Mbit/s at the output of the baseband multiplexer is adopted, both systems A2 and B appear to achieve a picture quality potentially transparent to the studio quality. The main features of system A2 are the capability of operating with low protection ratios (15.3 dB against 20.2 dB of system B) and reduced satellite power (the necessary C/N is 1.5 dB lower).

The main feature of system B is the higher number of channels which may be available (6 compared with 4 for system A2).

System approach using 105 Mbit/s

In the case that a bit rate of 105 Mbit/s at the output of the baseband multiplexer is adopted, both systems A1 and A2 would make available a total of 4 and 6 channels in 600 MHz bandwidth with minimal requirements for satellite transmit power and CCI protection ratio.

A system of type B would allow up to 8 RF channels at the expense of somewhat higher satellite transmit power and CCI protection ratio requirements.

System approach using 70 Mbit/s

Provided that a bit rate of 70 Mbit/s fulfills the basic requirement for an HDTV broadcasting service in terms of picture quality, the satellite transmit power can be further reduced and the number of channels available increased.

According to the results achieved in [Cominetti, Morello, (August 1990)] for the especially adverse propagation conditions in Italy (rain climatic zone L) (Report 563) system A1 with 6 channels available appears to be suitable for operation with high service availability (99.6% of the worst month), acceptable satellite power (300 W) and receiving antenna diameter (90 cm).

Under less severe propagation conditions system A2 and system B in particular would allow a significant increase in the number of available channels (9 and 12 respectively).

As regards the number of channels available per service area, the indications given by [CCIR, 1986-1990, Doc. JIWP 10-11/3(90)-4 (EBU)] [Stott, 1990] and Table 20 suggest that all of the systems under consideration (A1, A2 and B) can operate on a common frequency plan on each of the two polarizations available.

Moreover, system A1, with PR (CCI) of about 11 dB, can operate with frequency reuse in the same service area using both polarizations even under severe propagation conditions with a large amount of depolarization. This allows the number of channels quoted in Table 20 to be doubled.

System A2, which has a PR of about 15 dB, also permits a doubling of channel capacity, but only if the propagation conditions are less severe.

Under the same propagation conditions, system B could also allow frequency reuse by operating with a CCI protection ratio of about 15 dB. This is achievable by increasing the channel spacing given in Table 20, in order to reduce the interference level from adjacent channels. However, in order not to increase the C/N impairment beyond 1 dB at a BER of 2.6×10^{-4}, as for the other systems, the satellite transmit power has to be increased by 0.8 dB.

7.3.3 Interference considerations of digital systems

The robustness against interference of modern digital modulation systems in conjunction with powerful error correction techniques allows efficient use of the allocated spectrum. In order to achieve a high level of frequency reuse, it is necessary to employ digital systems which can tolerate co-channel protection ratios of between 15 to 20 dB. Systems can be designed which can cope with co-channel carrier-to-interference ratios as low as 11 dB at the expense of increased channel bandwidth for the same useful bit rate (see § 7.3.2). Figure 57 shows as one example, the improved ruggedness of convolutionally coded QPSK (rate ½), associated with soft decision Viterbi decoding) [Stott, 1990] [CCIR, 1986-1990, Doc. JIWP 10-11/3(90)-18 (United Kingdom)].

Generally there is a trade-off between the channel spacing and the co-channel interference requirements. All systems can operate at 0 dB of adjacent channel interference. Note however that there may be problems if significant spectral regeneration occurs in a non-linear TWT channel. This question has been taken into account for the examples cited above.

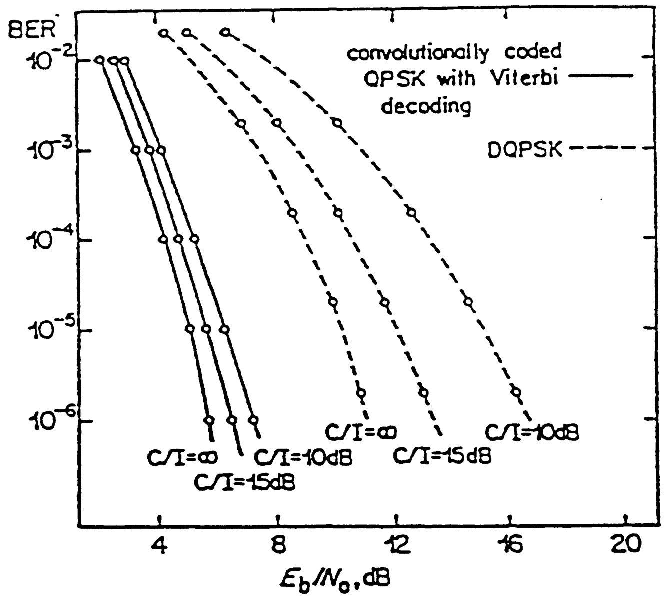


FIGURE 57

Error performance of convolutionally-coded QPSK with Viterbi decoding and conventional DQPSK in the presence of co-channel interference and random noise

7.3.4 Power efficiency of digital systems

An important feature of any system is the power requirement of the satellite.

An example power budget is given in § 8 of Part 2 of the present Report for a 1° beam at 22 GHz [Doc. JIWP 10-11/3(90)-18 (United Kingdom)]. This feature, associated with the use of directional antennas ensuring efficient orbital discrimination, makes it possible to allocate the whole of the band to each country (see § 10 of Part 2 of the present Report). It shows that a TWT power of about 300 W is necessary to achieve adequate performance.

Satellite power and RF-bandwidth requirements for the different digital HDTV modulation systems given in Table 19, assuming a bit rate of 140 Mbit/s at the output of the HDTV coder, including FEC 1, and a 2 dB additional implementation margin, are given in Table 21.

Studies on HDTV satellite broadcasting have led to the general conclusion that wide RF-band HDTV will probably be implemented in digital form.

Advanced digital modulation and channel coding techniques can be employed to reduce the required satellite power, to increase the ruggedness against interference and to optimize the spectral efficiency. Examples of digital modulation techniques are given which can be operated in the non-linear satellite channel, and which help to overcome the adverse propagation conditions in the frequency range under consideration. They also permit a significantly better reuse of frequencies than was previously the case.

These features are fundamental for a practical and flexible introduction of wide RF-band HDTV.

TABLE 21

Satellite power and RF bandwidth requirements for the digital HDTV modulation systems of Table 19, assuming a bit rate of 140 Mbit/s at the output of the HDTV coder, roll-off factor of 0.5, and a 2 dB implementation margin; the RF frequency is assumed to be 22 GHz

System	E_b/N_0 required (dB)	C/N in 100 MHz (dB)	Bandwidth (MHz)	Satellite power (dBW)	(W)
1	14.8	16.3	100	28.8	758
2	10.8	12.3	105	24.8	300
3	7.2	8.7	140	21.2	132
4	6.1	7.6	210	20.1	102
5	16.0	17.5	70	30	1000
6	8.7	10.2	105	22.7	186

8. System examples

For wide RF-band HDTV satellite broadcasting, both analogue and digital systems are considered. In the past, analogue wide RF-band HDTV systems have been investigated. In recent years efforts have been concentrated in the development of digital systems. As described in § 7 above, digital systems have become more attractive than analogue systems in terms of trade-off between quality and satellite power and robustness against interference and frequency reuse. thanks to the recent rapid progress in digital techniques such as source coding, channel coding, error correction, VLSI implementation, etc.

Table 22 gives the principal characteristics of a digital system example.

TABLE 22

Characteristics of a high-quality digital transmission format (example)

Parameter	
Aspect ratio	16:9
Picture rate (Hz)	25 (Note)
Active lines/picture	1152
Basic sampling frequency (MHz)	72
Active samples/line:	
luminance	1920
colour difference	960
Compression method	adaptive predictive DCT, block variable length coding, motion compensation
Maximum luminance bandwidth (MHz)	30
Maximum colour difference bandwidth (MHz)	15
Digital assistance (Mbit/s)	included in video bit rate
Coded video bit rate (Mbit/s)	125
Digital sound/data multiplex (Mbit/s)	3 to 5
Sound signal bandwidth (kHz)	20
Sound sampling frequency (kHz)	48
Sound coding/modulation method	ISO/IEC
Error Protection coding (Mbit/s)	10
Bit rate of the modulating signal (Mbit/s)	140
Type of modulation	Digital a) 4PSK + ½ conv. code b) 4PSK + ¾ conv. code c) TC-8PSK (rate 2/3)
Required RF bandwidth (MHz)	a) 210 b) 140 c) 105

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

8.1 Link budget

Examples of the link budget are shown in Table 23. In this table the following parameter values are assumed:

Receiving antenna size	:	75 cm (Efficiency 70%)
Satellite antenna beam size	:	1°
Down-link frequency	:	22 GHz
Rain climatic zone	:	K
Elevation angle	:	30°
Latitude	:	45°

For the example shown in Table 23, satellite transmitter powers of 330 W and 170 W per channel are required for Example 1 and Example 2 respectively to achieve adequate performance for digital wide RF-band HDTV satellite broadcasting. The higher satellite transmitter power is expected to be available as described in § 13. Thus it can be concluded that wide RF-band HDTV BSS which will achieve the service quality objective described in § 2.1 of Part 2 of the present Report will be technically feasible in the near future.

TABLE 23

An example link budget at 22 GHz for wide RF-band HDTV satellite broadcasting systems

	Example 1	Example 2	Example 3
System parameters			
Modulation	QPSK + ¾ conv.	QPSK +¾ conv.	Analogue
Frequency (GHz)	22	22	22
Usable bit rate (excluding FEC 2) (Mbit/s)	140	70	
Required bandwidth (MHz)	133	67	54
Satellite parameters			
Transmitter power (dBW)	25.3	22.3	30.0
Transmitter power (W)	339	170	1000
Feeder loss (dB)	2.5	2.5	2.5
Antenna gain (dB)	41.4	41.4	41.4
e.i.r.p. (dBW)	64.2	61.2	68.9
Propagation			
Free-space loss (dB)	211.0	211.0	211.0
Atmospheric losses (dB)	7.2	7.2	7.2
Received pfd (dB(W/m^2))	-105.7	-108.7	-101.0
Receiving system			
Antenna gain (dB)	43.2	43.2	43.2
Pointing loss (dB)	0.9	0.9	0.9
Noise figure (dB)	2.5	2.5	2.5
Figure of merit (dB(K^{-1}))	15.5	15.5	15.5
Noise (Nyquist) bandwidth (MHz)	93.0	46.0	54.0
System margin			
C/N degradation (dB) due to up link	0.5	0.5	0.5
Overall C/N (dB)	10.0	10.0	17.0
Necessary C/N (dB)*	10.0	10.0	17.0
Protection ratio			
Co-channel (dB)	15.3	15.3	25 - 30

* Including 2 dB implementation margin and 1 dB degradation due to interference.

Figure 58 shows the variations of satellite transmission power as a function of frequency for a number of elevation angles using as the reference the power values of Table 23.

For analogue wide RF-band HDTV satellite broadcasting, a satellite transmitter power of around 1000 W would be required. This power is much larger than that required for the digital systems and, in addition, the necessary co-channel protection ratios are higher compared to those for the digital systems. These factors lead to the conclusion that digital systems are more promising than analogue systems.

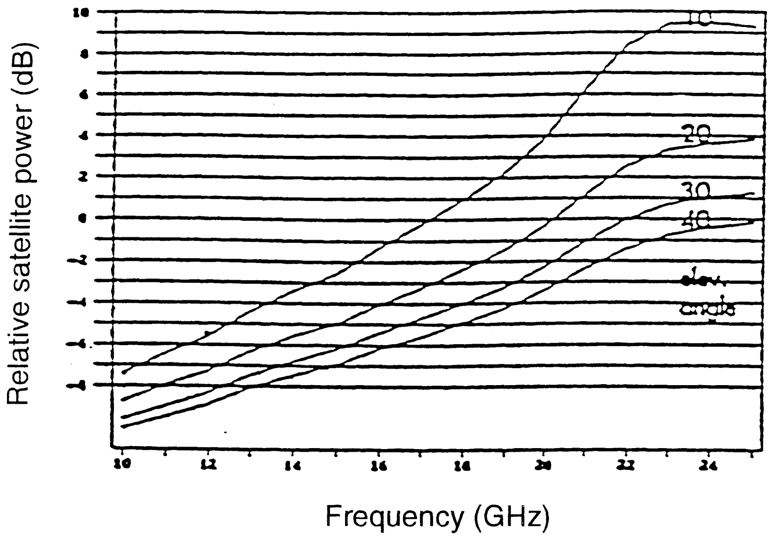


FIGURE 58

Satellite transmitter output as a function of frequency relative to the required power at 22 GHz

9. Frequency bands

WARC ORB-88, 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 the 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.

9.1 Suitable frequency bands

Existing BSS available frequency bands

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

- 12 GHz band (11.7 to 12.7 GHz) : (see § 12 of Part 2 of the present Report)
- 23 GHz band (22.5 to 23.0 GHz) : (not allocated in Region 1, see below).

The following allocated bands are not suitable at this time from the point of view of propagation and technology:

- 42 GHz band (40.5 to 42.5 GHz) and 85 GHz band (84.0 to 86.0 GHz).

Other suitable frequency bands (for sharing see § 11)

The following frequency bands have been considered for wide RF-band HDTV:

17.3 to 17.8 GHz, 19.7 to 20.3 GHz, 21.4 to 22.0 GHz, 22.5 to 23.0 GHz and 24.25 to 25.25 GHz.

The lower frequency bands have advantages from the point of view of link budgets, and the higher frequency bands may have advantages from the point of view of frequency reuse as a result of better receive antenna discrimination for a constant receiving antenna size. In particular:

17.3 to 17.8 GHz

This band is suitable from a propagation point of view. However, in this band reverse band working with the BSS 12 GHz feeder links is necessary. Sharing seems possible only if the feeder-link earth stations can be sited at a certain distance (see § 11.5) from HDTV home receivers and this could make the use of transportable earth stations difficult. Sharing in the upper 100 MHz could be very difficult since it is also shared with fixed, mobile and fixed-satellite services. If there is a requirement for 600 MHz of spectrum, an extension on the lower end of this band would be needed and this may prove to be even more difficult.

19.7 to 20.3 GHz

This band seems suitable from the propagation point of view, but would require sharing (space-to-Earth) with the mobile-satellite service and the fixed-satellite service. There are no pfd limits specified in this band and hence sharing is very difficult.

21.4 to 22.0 GHz

This band is allocated only to the fixed and mobile services. Studies have shown that the coordination distance with a certain type of the fixed service used in this band will be in the range of 120 km (main-lobe of fixed service transmitting antenna) and 2 to 6 km (backlobe of fixed service transmitting antenna).

This band represents a compromise between propagation and sharing difficulties, from a technical point of view (see § 11).

22.5 to 23.0 GHz

This band is already allocated in Regions 2 and 3 and its use is subject to agreement under Article 14 of the Radio Regulations. It is not allocated to the broadcasting satellite service in Region 1. While this band is a possible worldwide band for HDTV broadcasting by satellite, it is shared with fixed, mobile and intersatellite services.

In addition, protection of critical radio astronomy observations in the band 22.81 to 22.86 GHz would restrict the capacity of the band. Also, the propagation effects in this band are relatively severe.

Frequencies above 23 GHz

The band 24.25 to 25.25 GHz is slightly above the range mentioned in Resolution 521. Propagation characteristics are only marginally inferior to the 22.5 to 23.0 GHz band, but a full 1 GHz of spectrum may be available if the radionavigation service is not implemented in this band.

Propagation factors affecting the use of these bands

Propagation effects (rain attenuation and depolarization) generally become worse with increasing frequencies, resulting in higher satellite power and/or less service availability. The various measurements of rain attenuation show that if the attenuation at 12 GHz is A dB, then at 20 GHz it is approximately 3.5 x A dB, at 30 GHz about 6 x A dB and at 42 GHz about 8 x A dB. In addition, attenuation is particularly large near the absorption frequencies due to certain atmospheric gases (near 22, 60 and 120 GHz).

10. Total bandwidth required by the service

A rigid a priori plan will result in an inflexible allocation which will be difficult to exploit, and which will not be adaptable as new ideas and requirements are developed. Studies are nonetheless useful in order to determine how much use can be obtained from each megahert of spectrum allocated to the BSS. By combining this result with the demand for the number of programmes one can determine the bandwidth needed for a new allocation.

The total bandwidth required for a satellite broadcasting service depends on a number of parameters, such as the definition of the service areas, the channel bandwidth, the performance of the satellite and the receiving antennas, the necessary protection ratios and the number of programmes required for each country or service area.

With a set of assumptions for these parameters, it is possible to determine by computer studies the number of channels necessary to broadcast one programme to each service area and, given the number of programmes, to obtain the total bandwidth required. Alternatively, for a given allocated band, it is possible to determine its capacity in terms of the number of HDTV programmes per service area. The studies can be made manually or with the aid of a suitable computer program to produce results in which one must evaluate the equivalent protection margins, which should, if successful, all be positive.

Such computer studies have been carried out within the EBU for wide RF-band HDTV for systems allowing picture quality virtually transparent to studio quality, with a specially developed computer program. The fundamental assumption was national coverage in Europe and North Africa, and in some cases for the whole of Africa.

The following parameters were considered in the case of a digital wide RF-band HDTV system*:

- frequency around 20 GHz;
- channel spacing (D_f) between 100 MHz and 200 MHz according to the coding and modulation system;
- co-channel protection ratio: 20, 15 or 11 dB according to the system; these protection ratios are compatible with the new digital modulation systems being considered now. The planning techniques reported here are not suitable for analogue systems which require more protection;
- adjacent channel protection ratio: 0 dB, or alternatively the adjacent channel is neglected if its effect (which is noise-like) is included in the computation of the co-channel protection ratio for a given channel spacing;

* An analogue wide RF-band HDTV system will require a protection ratio at least 10 dB higher than that of a digital system. Thus, although the channel bandwidth may be reduced, the reuse of frequencies will be less favourable and so the analogue system is less spectrum-efficient.

- atmospheric attenuation: none, because in most cases the interfering signal suffers similar attenuation to that of the wanted signal;
- atmospheric depolarization: 20 dB (this XPD value is not lower in Europe for 99% of the worst month below 23 GHz).

In addition the following values were adopted for the exercises:

- satellite spacing: 3° or 2°;
- satellite transmitting antena diagrams (co- and cross-polar) of WARC BS-77;
- receiving antenna: reference diagrams (co- and cross-polar) of WARC BS-77 or an antenna with higher performance*;
- uniform values of e.i.r.p.s;
- test-point: the most critical test-point in the coverage area, situated at the edge of the wanted beam in the direction of the centre of the interfering beam**.

In a first series of exercises [CCIR, 1986-1990, Doc. JIWP 10-11/1-013 (EBU) and Doc. JIWP 10-11/1-21(United Kingdom)], the beams and the orbit positions were selected carefully within an orbital arc running from -40° to 25° for Europe and Africa. The co-channel protection ratio was 20 dB. The satellite spacing was 3° and it was shown that a given orbit position could be shared by two or three countries, even within Europe. With the WARC BS-77 receiving antenna template (with a beamwidth of 1°) results using only one channel, but still the two polarizations were obtained with only a few negative protection margins for 33 countries in Europe and North Africa and also for 71 countries in Europe and the whole of Africa. With the improved receiving antenna, the results were significantly better. It is therefore possible to use all channels in every country but different countries would still have different polarizations.

---

* The following performance was assumed for this antenna. It is still theoretical, but an antenna of this type is being studied in Germany. The values are:

D (degrees)	R (dB)	R_x (dB)	Where:
0	0	-35	D : spacing between wanted and unwanted satellites
2	-25	-35	
3	-25	-35	R : relative co-polar gain
4	-30	-35	
6	-30	-35	R_x: relative cross-polar gain
8	-33	-35	
>9	-35	-35	

** In the case of multiple interference, the test point is different for different interferers. However, the interferences were added in power and this simplified assumption is therefore pessimistic.

If the channel bandwidth is 100 MHz, then the total bandwidth is simply 100 MHz multiplied by the number of HDTV programmes. For example, a band of 600 MHz will have a capacity of six HDTV programmes per country, without making an allowance for the guard bands. Each country could, however, make its own trade-off of bit rate per programme against the number of programmes available. The technique becomes more powerful as the receiving antenna increases in discrimination. This tends to increase as the frequency of operation increases, and this indicates that there would be some improvement in spectrum efficiency when operating at frequencies from 17 GHz. Provided that the e.i.r.p. per unit of bandwidth remains below a predetermined value, any option can be exercised.

In a second series of exercises, an attempt was made to double the capacity by allocating to each country not only all channels, but also the two polarizations. In this case, the conditions to avoid negative margins for 33 countries in Europe and North Africa or for 71 countries in Europe and the whole of Africa were:

- In order to limit the orbital arc to about 65°, the satellite spacing must be reduced to about 2° because it is no longer possible to use the same orbit position for more than one country in Europe.
- The co-channel protection ratio must be reduced to about 15 dB, and the adjacent channel interference should be negligible; with the appropriate filtering and channel spacing this should be possible with some of the digital systems under study*. If, then, for example the co-channel protection ratio is 15 dB and the channel spacing is 133 MHz, the capacity of a 600 MHz allocation will be eight programmes per country, using both senses of polarization, sufficient additional spectrum for the necessary guardbands.

11. Sharing with other services

Sharing with other services is detailed in Reports ITU-R BO.631, ITU-R BO.807, ITU-R BO.951 and in the ex-CCIR report to WARC ORB-88.

The range of frequencies to be considered is specified in Resolution 521 of WARC ORB-88 as 12.7 to 23 GHz.

The studies of sharing in this range are not yet complete, and there are many bands of frequencies for which the ITU-R has little information. The text below is a summary of the current position.

11.1 Interference to the fixed service from the BSS

FS systems above 17 GHz are principally digital systems designed to meet the performance and availability objectives given by Recommendations ITU-R F.594 and ITU-R SA.577 respectively. Sharing with the BSS in the frequency bands above about 20 GHz can be facilitated on the same basis as sharing with the FSS in the bands near to 20 GHz, namely by establishing appropriate pfd limits for the band.

Report ITU-R F.1189 has determined, based on single entry criteria given in Recommendations ITU-R F.594 and ITU-R SA.557, that the pfd limits at low angles of arrival should be:

$$PF_0 \; -109 - \delta F \quad \text{dBW/(m}^2 \cdot \text{MHz)}$$

---

* If the co-channel protection ratio is reduced to 11 dB, a satisfactory result is obtained with the WARC BS-77 receiving template (but with a beamwidth of 1°). A system of this kind would probably need a larger channel bandwidth.

where δF is the value of the fade differential between nearly coincidental paths at low angles of arrival due to multipath propagation anomalies in clear air. [CCIR, 1986-1990, Doc. JIWP 10-11/1-19 (Canada)] has developed pfd limits for off axis angles using the assumption that:

- the δF factor diminishes rapidly as the elevation angle increases and can be assumed to be zero for angles of arrival greater than 3°;
- Recommendation ITU-R F.699 is used for the establishment of off-axis antenna discrimination pattern for the FS antenna.

With these assumptions, and allowing for a terrestrial radio path elevation angle of up to 0.4°, the following pfd limits were developed (all limits are in dBW/($m^2 \cdot$ MHz)):

PF_1	=	$-109 - \delta F(3 - \varepsilon)/3$	$0 < \varepsilon < 0.4°$
PF_2	=	$-109-\delta F(3-\varepsilon)/3+3.7(\varepsilon-0.4)^2$	$0.4° < \varepsilon < 2.32°$
PF_3	=	$-95.4 - \delta F(3 - \varepsilon)/3$	$2.32° < \varepsilon < 3°$
PF_4	=	$-106.1 + 25 \log(\varepsilon - 0.4)/3$	$3° < \varepsilon < 28.6°$
PF_5	=	$-69.8 \quad 28.6 < \varepsilon$	

Although the above pfd limits were developed explicitly for the 22.5 to 23 GHz band, they are only slightly changed (break point values) for application to the band 21.2 to 22.0 GHz and thus could be considered appropriate for the whole of the 21.2 to 23 GHz range.

Considering the impact of these pfd limits on wide RF-band HDTV BSS emissions, based on examples contained in [Tables I and III of Doc. JIWP 10-11/3(90)-39(Rev.2), CCIR, 1986-1990] for digital wide RF-band HDTV systems, the clear air values at the edge of the coverage area are given by:

System 1: pfd = -119.4 dBW/($m^2 \cdot$ MHz) System 2: pfd = -119.8 dBW/($m^2 \cdot$ MHz)

Based on a value of differential fading (δF) of 6 dB, which is suggested as an appropriate value in Report ITU-R F.1189 until further information is obtained on the phenomenon, the above pfd limits would not impose any constraints on the BSS digital system as proposed in [Tables I and III of Doc. JIWP 10-11/3(90)-39(Rev.2), CCIR, 1986-1990].

In the case of an analogue system as described in [Table III of Doc. JIWP 10-11/3(90)-39(Rev.2), CCIR, 1986-1990], no energy dispersal is assumed, hence the clear air pfd at the edge of coverage would be:

$$-101 + 5.5 = -95.5 \text{ dBW/(m}^2 \cdot \text{MHz)}$$

Allowing for atmospheric attenuation according to Report ITU-R PN.719 and assuming a moderately humid climate (ρ = 10 g/m^3) the following table indicates the net protection expected in the case of the above pfd limits.

Assuming a δF value of 6 dB, it can be seen that the net protection afforded the FS according to these pfd limits will be positive. Thus analogue wide RF-band HDTV systems based on the current proposals would experience no hardships in meeting these pfd limits. This compatibility is due in principle to the high values of atmospheric attenuation experienced on low angle slant paths, especially in the frequency range 21.2 to 23 GHz.

Elevation angle	Permissible pfd (dBW/M2 · MHz)	Discrimination (dB)	Atmospheric absorption (dB)	Net protection (dB)
0°	-109 - δF	13.5 + δF	39.5	26 - δF
0.4°	-109 - 0.87δF	13.5 + δF	30.2	16.7 - 0.87δF
2.37°	-95.4-0.23δF	-0.1 + 0.23δF	12.5	12.6 - 0.23δF
3°	-95.4	-0.1	10	10.1
28°	-70.0	-25.5	0.1	25.6
48°	-69.8	-25.7	-0.4	25.3

In consideration of reverse band sharing in the 17.3 - 17.8 GHz band, the portion of the band 17.7 - 17.8 GHz is shared, among other services, with the FS.

Article 28 of the Radio Regulations specifies the following pfd limits for this band:

-115	dBW/(m^2 · MHz)	$0 \leq \varepsilon < 5°$
-115 + 0.5 (ε - 5°)	dBW/(m^2 · MHz)	$5° \leq \varepsilon < 25°$
-105	dBW/(m^2 · MHz)	$\varepsilon \geq 25°$

Considering the analogue and digital wide RF-band HDTV system examples given in [Table III of Doc. JIWP 10-11/3(90)-39(Rev.2), CCIR, 1986-1990], the clear air pfds at the edge of coverage (EOC) are (assuming no energy dispersal for the analogue wide RF-band HDTV case):

Digital	wide RF-band HDTV (System 1)	:	-120.7 dBW/(m^2 · MHz)
Digital	wide RF-band HDTV (System 2)	:	-120.6 dBW/(m^2 · MHz)
Analogue	wide RF-band HDTV (System 3)	:	-96.3 dBW/(m^2 · MHz)

At a 5° elevation angle, the differential in atmospheric attenuation between the EOC and the 5° elevation contour is 1 dB (for ρ = 7 g/m^3) which is significantly less than for the 21.2 - 23.0 GHz band. Based on the above pfd limits, the excess isolations required by the satellite transmit antenna to the 5° elevation contour are:

Digital	wide RF-band HDTV	:	-120.6 - 1.0 - (-115.0) = -6.6 dB
Analogue	wide RF-band HDTV	:	-96.3 - 1.0 - (-115.0) = 17.7 dB

Negative values imply an excess of isolation and hence no restriction on the BSS service. Thus for digital W-HDTV systems the above pfd limits would place no restrictions due to sharing with the FS.

In the case of the analogue W-HDTV example there is a deficiency of 17.7 dB. This could be a major constraint on the location of the BSS service areas, particularly at the higher latitudes.

11.2 Interference to the mobile service from the BSS

In this portion of the spectrum, the mobile service typically operates in the transportable fixed mode. This means that stations will operate for periods of hours or days from the same location. For a mobile system having similar characteristics to those outlined in § 11.1 and having its antenna directed towards a BSS satellite, the interference levels would be of the same order and as objectionable as those found in § 11.1. No detailed information is available on the use of any of this spectrum by the mobile service.

11.3 Interference to the inter-satellite service from the BSS

The bands extending from 22.55 to 23.55 GHz are allocated to the inter-satellite service. There is potential for interference from the BSS into the ISS, either by direct coupling of side lobes for satellites closely spaced, or from antipodal coupling. This is discussed in Report ITU-R BO.951 and in the report of IWP 2/2 to the JIWP WARC-92.

A recent study by ESA has shown that improved sharing conditions can be expected if the ISS uses receiving antennas with a rapid roll-off as defined in Report ITU-R BO.810.

In cases where a relaxed antenna conforming to Report ITU-R S.558 is used, the BSS may be located in between pairs of satellites, provided that the spacing of the ISS is greater than 5°. When BSS satellites cannot be placed between pairs of ISS satellites, then they must be accommodated at approximately 1° to 2° beyond the arc bounded by the two satellites. With the tighter antenna specification of Report ITU-R BO.810, then the separation from the ISS reduces to 1°.

If there is a need to space an HDTV satellite within 2° of an ISS station this may mean that the ISS and the BSS may be incompatible in this case.

The main problem might be expected from a BSS satellite feeding an equatorial region. As it is likely that such satellites will not provide services to areas on or near the rim of the Earth, interference from this source is reduced significantly.

11.4 Interference to the radio astronomy service from the BSS

The radio astronomy service is protected in the bands 22.01 to 22.21 GHz, 22.21 to 22.5 GHz, 22.81 to 22.86 GHz and 23.07 to 23.12 GHz by footnotes in the Radio Regulations.

The BSS satellite is likely to generate interference, not only from the in-band signal but also from out-of-band components or spurious emissions. An ESA study has shown that the use of the spectrum in this region is highly inefficient if guard bands are included to protect the radio astronomy service.

As a consequence, any use of the frequency bands in the region 22.01 through to 23.12 GHz would be severely compromised.

11.5 Interference between the FSS and the BSS

If an HDTV service is to be introduced into the band 17.3 to 17.8 GHz then a reverse band operating situation will exist in part of this band with the existing 17 GHz feeder-link service to the existing 12 GHz BSS.

The two sharing situations that arise are:

- HDTV satellite transmission interfering with a feeder-link receiver, and
- feeder-link transmissions interfering with an HDTV receiver.

HDTV satellite transmissions interfering with a feeder-link receiver

There are two cases to consider: nearby satellites and near-antipodal satellites.

For nearby satellites, the distance between the transmitting and the receiving satellites must be such that interference is at an acceptable level. Hence the separation distance will depend on the assumptions made on certain critical parameters such as the C/I requirement, the fade margin and the antenna side lobe performance.

A study carried out by the United Kingdom [CCIR, 1986-1990, Doc. JIWP 10-11/1-17] indicated that the separation of about 0.1° would be adequate. Another study by Canada [CCIR, 1986-1990, Doc. JIWP 10-11/1-45] using different assumptions concludes that a separation of about 1.5° for the case of a digital system, and 2° for the case of an analogue system would be adequate.

There is a small arc of the GSO near the equatorial rim of the Earth where it is possible for near-antipodal satellites to cause interference.

In studying the antipodal case for FSS, it has been customary to assume the edge of service area is near the horizon, and thus only 3 dB of discrimination has been assumed in the direction of the feeder-link antenna.

However, if one assumes that the minimum elevation angle within the service area should be at least 10° for propagation reasons, especially for equatorial countries, the horizon of the satellite would be far away from the 3 dB contour. Therefore the satellite transmitting antenna isolation toward the feeder-link receive antenna should be better than 15 dB. With this assumption, a C/I of 40 dB can be met in the antipodal direction.

Feeder-link transmissions interfering with an HDTV receiver

There are two distinct mechanisms for interference:

- propagation in the troposphere by line-of-sight and great-circle paths, and
- propagation by scattering by hydrometeors.

Sharing between a potential allocation of 17.3 to 17.8 GHz for the use of BSS (HDTV) could give rise to the need for coordination with feeder-link earth stations in the WARC ORB-88 BSS Plans.

[CCIR, 1986-1990, Doc. JIWP 10-11/1-40 (Canada)] describes a method for developing coordination areas around BSS feeder-link earth stations so as to protect BSS (HDTV) receive earth stations service area boundaries. This method allows interference criteria for both analogue and digital HDTV to be calculated.

The long term criterion corresponds to a 0.5 dB degradation of the protection margin. The distance required to keep the interfering signal below this interference criterion is then found on the basis that long term interference generally occurs only within line-of-sight plus a small distance for refraction cases.

The short term interference criterion is calculated assuming that the interfering signal is enhanced for 0.029% of the time. It is obtained by allowing the short term interference within 10 dB of the clear air protection margin in the analogue case, and within the desired C/N in the digital case. The required distance is found using Report ITU-R SF.382. The analysis is based on worst case antenna discrimination.

Coordination distances are relatively small, ranging from 40 to 185 km. These separations can be reduced by considering site shielding techniques, and detailed coordination at implementation. Coordination areas are smaller for digital systems than for analogue.

In practice the coordination distances around a feeder-link station are very dependent on the terrain. Local site shielding can often be a significant factor. To illustrate this Fig. 59 represents the coordination contour in the case of digital HDTV with no site shielding. Figure 60 shows the same case with 25 dB of site shielding assumed.

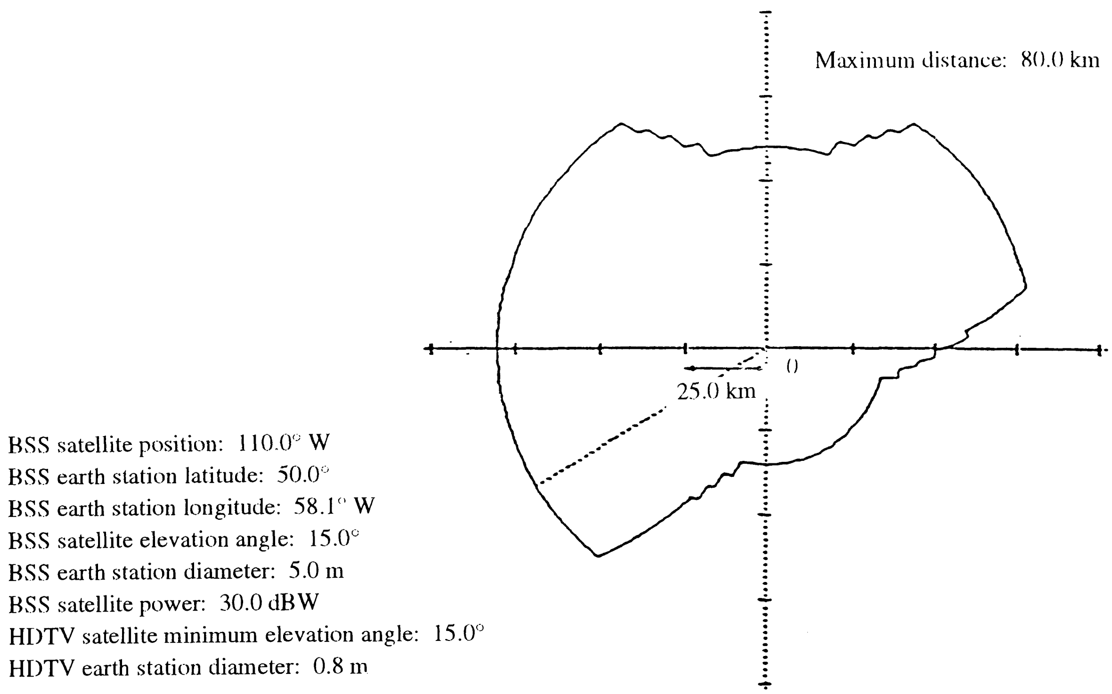


FIGURE 59

Digital wide RF-band HDTV (no site shielding)

The effect of bi-directional rain scatter is to define an interference area around the feeder-link earth station.

For rainfall rates that are exceeded for 1% of the worst month the interference criterion is exceeded for distances of less than 12 km.

Hence it can be seen that the rain scatter distances are of the same order as for the direct path.

In consideration of reverse band sharing of the 17.3 to 17.8/18.1 GHz Plans and BSS wide RF-band HDTV, it is noted that the band 17.7 to 17.8 GHz is also allocated to the FSS (space-to-Earth). Thus to assess the feasibility of reverse band working in this range of frequencies it will be necessary to assess the feasibility of sharing between the BSS wide RF-band HDTV and the FSS.

[CCIR, 1986-1990, Doc. JIWP 10-11/1-39 (Canada)] addresses the required satellite spacing between co-coverage FSS and BSS satellites as a function of C/I. Only video traffic is considered in the FSS at these frequencies.

The pertinent assumptions used in the examples are given below.

Fixed-satellite service system

Saturated e.i.r.p. (edge of coverage)	:	47 dBW and 50 dBW
RF bandwidth (TV) only	:	27 MHz (FM modulation)
C/I (single entry)		
Analogue wide RF-band HDTV system	:	33 dB
Digital wide RF-band HDTV system	:	28 dB

Also two design values were assumed for the earth station FM receiver threshold (8 and 10 dB), corresponding to reception at the edge of the coverage area for 99% of the worst month.

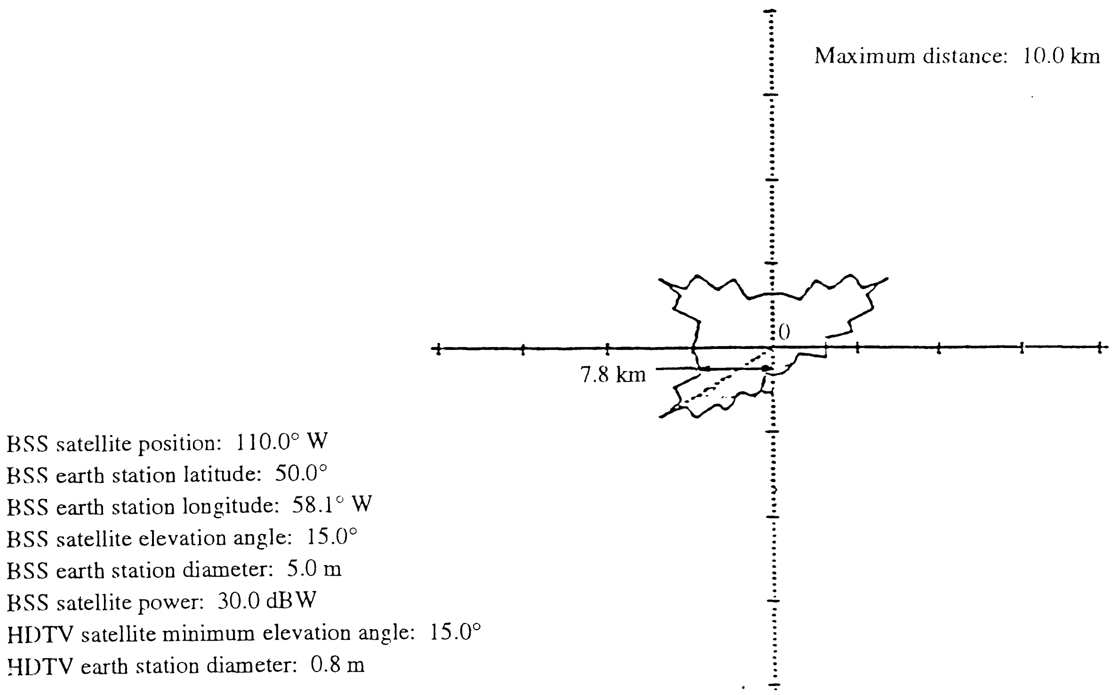


FIGURE 60

Digital wide RF-band HDTV (site shielding = 25 dB)

Also in the case of interference from the wide RF-band BSS system into the FSS channel, uniform energy distribution is assumed, hence only part of the interference power was assumed to fall within the FSS channel (in the ratio 24/70 in this example).

In summary, the analysis shows that the separation required between co-coverage wide RF-band HDTV BSS and FSS TV satellites would be dominated by interference from the wide RF-band BSS satellites. For an analogue HDTV interferer, a separation angle of approximately 21° would be required, corresponding to the 8 dB FSS receiver threshold. The separation reduces to 14° when the FSS receiver threshold is increased to 10 dB.

Wide RF-band HDTV BSS systems

	Analogue system	Digital system
RF bandwidth (MHz)	54	70
e.i.r.p. (EOC) (dBW)	63.4	64.7
Receive antenna diameter (m)	0.9	0.9
C/N_{down} (dB)	22.5	22.5
C/N_{total} (dB)	22.0	22.0
$C/I_{single\ entry}$	40.0	35.0

For the case of interference from digital wide RF-band HDTV into FSS TV, these separation angles are approximately 10° and 6° respectively.

The separation requirements in terms of interference from FSS into the wide RF-band HDTV BSS were considerably less, ranging from approximately 2° for the case of interference into digital wide RF-band HDTV up to 4.3° for interference into analogue systems.

As noted, the study only addressed interference into FSS/TV traffic. The case of interference into SCPC would be more complex. However, noting that the BSS emissions should comply with the pfd limits for that band, the analogue wide RF-band HDTV would need to incorporate about 7.2 MHz (p-p) of energy dispersal for elevation angles greater than 23°. Preliminary analysis shows that, using the above energy dispersal bandwidth, over 13 MHz of guardband would be needed to minimize FSS intra-system interference effects. A large portion of the 27 MHz transponder bandwidth (>50%) could not be used. The use of digital HDTV may ease the situation.

11.6 Interference to the mobile-satellite service from the BSS

In this portion of the spectrum, the mobile-satellite service typically operates in the transportable fixed mode. This means that stations will operate for periods of hours or days from the same location. For a mobile system having similar characteristics to those outlined in § 11.5 and having its antenna directed towards a BSS satellite, the interference levels would be of the same order as those found in § 11.5.

No detailed information is available on the use of any of this spectrum by the mobile-satellite service.

11.7 Interference to the radiolocation service from the BSS

The radiolocation service occupies a number of bands between 15.7 and 17.3 GHz. Many systems are deployed in these bands, including airborne radar systems.

It is typical of these systems that they transmit high power levels, but receive weak signals. The relatively high powers used by the BSS is likely to cause unacceptable interference to the radiolocation service.

It is believed that the radiolocation service cannot share with the BSS, however, there is little information available on the subject.

11.8 Interference to the radionavigation service from the BSS

This service (including the aeronautical radionavigation service) operates in the bands 13.25 to 13.4 GHz, 14 to 14.3 and 15.4 to 15.7 GHz.

In some instances, this is a safety-of-life service. However, little detailed information is available on these bands.

11.9 Interference to the BSS from the fixed service

In Article 8 of the Radio Regulations, a number of frequency bands are allocated to the FS on a primary basis, as indicated in Table 24.

TABLE 24

Frequency allocations to the fixed service above 11.7 GHz on a primary basis

Frequency band (GHz)	Region 1	Region 2	Region 3
11.7 to 12.1	x	x	x
12.1 to 12.2	x		x
12.2 to 12.5	x	x	x
12.5 to 12.75		x	x
12.75 to 13.25	x	x	x
14.3 to 14.4	x		x
14.4 to 15.35	x	x	x
17.7 to 19.7	x	x	x
21.2 to 23.6	x	x	x
25.25 to 29.25	x	x	x

The frequency bands 11.7 to 12.5, 12.2 to 12.7 and 11.7 to 12.2 GHz are allocated to Regions 1, 2 and 3 respectively. The sharing between the BSS and the FS in these bands is regulated by Appendix 30 of the Radio Regulations.

The interference from digital radio relay systems to the BSS is given in [CCIR, 1986-1990, Doc. 10-11/1-5 (Japan)] for the 21.2 to 23 GHz band. In this study, two examples of interference calculation are introduced.

Example

1) Desired service : BSS, -80 dBm of received signal level (75 cm antenna).

Interfering service : FS (local distribution radio system, using binary FSK 4 km link, (60 cm antenna, 20 dBm transmit power)).

2) Desired service : The same as in Example 1.

Interfering service : Digital radio relay system as specified in Report ITU-R F.1189 64 QAM, (46 cm antenna, 23 dBm of transmit power).

Calculated C/I : 17 dB.

The calculation results show that it is very difficult to share the same frequency band between digital radio relay systems and the BSS for HDTV reception. There is considerable interference to the HDTV BSS in the vicinity of the service areas of the digital radio relay system.

The frequency band 22.5 to 23 GHz is also allocated to the BSS in Regions 2 and 3. The sharing considerations between transmitting fixed stations and receiving BSS stations are discussed in [CCIR, 1986-1990, Doc. JIWP 10-11/1-20 (Canada)].

The results of the study are summarized in Table 25.

For a discussion of short-term and long-term criteria see § 11.5.

From this the following conclusions can be drawn:

- In the main lobe of the FS transmitter, the coordination distance would be 120 km to protect analogue and 74 km to protect digital wide RF-band HDTV, but the arc affected would be narrow.

TABLE 25

Summary of separation distance for analogue and digital HDTV

Wanted HDTV signal type	Analogue		Digital
Interfering FS signal	Coherent	Non-coherent	Non-coherent
Long-term criteria (dBW)	-144.3	-133.3	-132.1
Short-term criteria (dBW)	-139.3	-120.0	-118.8
Long-term pfd at edge (dBW/m^2)	-100.1	-89.1	-87.9
Short-term pfd at edge (dBW/m^2)	-95.1	-75.8	-74.6
Maximum distance (km)	120	70	74
Minimum distance (km)	6	1.8	2.1
Angular width of minimum distance	264°	265°	266°

Off the main lobe, the coordination distances fall rapidly.

The separation distances are very small in the back lobe of the transmitter antenna.

As a conclusion, sharing between the fixed service and the BSS (HDTV) within the same service area would be difficult. However, sharing between BSS service areas and fixed-service transmitting stations may be possible given the relatively small coordination distances.

11.10 Interference to the BSS from the mobile service

In this portion of the spectrum, the mobile service typically operates in the transportable fixed mode. This means that stations will operate for periods of hours or days from the same location. For a mobile system having similar characteristics to those outlined in § 11.9 and having its antenna directed towards a BSS receiver, the interference levels would be of the same order, and as objectionable as those found in § 11.9.

11.11 Interference to the BSS from the inter-satellite service

The ISS operates at lower power levels than those foreseen to be in use for the BSS and it usually operates by pointing in a direction away from the Earth. As a consequence, the interference to the BSS from this source is minimal.

The conclusions of Report ITU-R BO.951 are that for short ISS links, interference to the HDTV BSS service should not be a problem. For long ISS links, Report ITU-R BO.951 indicates that C/I levels worse than 40 dB may be encountered. Given that current thinking indicates that a digital system may be adopted for the HDTV service, then this level of interference should not cause a major problem.

11.12 Interference to the BSS from the mobile-satellite service

The mobile-satellite service allocation is 20.2 to 21.2 GHz. There are many satellites, both operational and planned which use this band. There is, however, little information available on sharing in this band.

11.13 Interference to the BSS from the radiolocation service

As noted in § 11.7, the radiolocation service occupies a number of bands between 15.7 and 17.3 GHz. Many systems are deployed in these bands, including airborne radar systems.

It is typical of these systems that they transmit high power levels, but receive weak signals. The high powers used by the radiolocation service would lead to significantly greater pfds in the immediate vicinity of the BSS receiver than would be available from the BSS. This would cause unacceptable interference to the BSS.

It is expected that the two services cannot share spectrum. There is however little detailed information available.

11.14 Interference to the BSS from the radionavigation service

There is no information available on this subject.

11.15 Other situations

The agenda of WARC-92 includes consideration of new space services above 20 GHz. It is noted that these might include links between:

a) Geostationary-orbit satellites and Earth

transmissions would be similar to those for existing geostationary-orbit satellites. In bands shared with the FS, they could be accommodated under the same sharing conditions as currently used between the FSS and the FS;

b) Geostationary-orbit satellites and geostationary-orbit satellites

this is discussed in Report ITU-R SF.791;

c) Geostationary-orbit satellites and low-Earth-orbiting satellites

uses the ISS bands 22.55 to 23.55 and 25.25 to 27.5 GHz. Sharing with the lower ISS band is discussed in § 11.3 and § 11.11. The upper band is not considered for HDTV down links;

d) Low-Earth-orbiting satellites and low-Earth-orbiting satellites

is planned for the 25.25 to 25.55 GHz Earth exploration satellite band. This is outside the range of frequencies of interest;

e) Geostationary-orbit satellites and lunar or extra-orbital stations

is similar to c), but there is added compatibility because the geostationary-orbit satellite antenna is expected to point away from the Earth.

This is discussed in the report of IWP 2/2 to JIWP WARC-92.

12. Long-range future suitability of the 11.7 - 12.7 GHz band for wide RF-band HDTV

Resolves 3 of Resolution 521 (WARC ORB-88), states: "While the 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 stability of these bands for (wide RF-band) HDTV without prejudice to the existing Plans in this band."

The term "Wide RF-band HDTV" was developed at WARC ORB-88 to distinguish between HDTV systems which, as a result of accepting a degree of degradation compared to studio HDTV quality, could be fitted within the 24/27 MHz channels of existing BSS plans; and HDTV systems which would be able to transmit a quality virtually transparent to studio HDTV, and which at that time were expected to require a significantly wider RF bandwidth. At this time it has not been demonstrated that near studio quality HDTV can be accommodated in the 12 GHz BSS channels.

Some administrations see advantages in being able to use the 11.7 - 12.7 GHz band for high quality HDTV. They have noted the rapid development of digital TV and are of the opinion that, in the near future, it will be possible to transmit sufficient data in an existing BSS channel to carry an HDTV signal of adequate quality.

Some administrations consider that an RF channel bandwidth greater than 24 - 27 MHz will remain necessary to achieve the objective of virtual transparency, bearing in mind that the expectations of the public will rise, and that improvements in the studio standard and the display technology will increase still further the amount of information to be transmitted. They also see difficulties in achieving compatibility between digital HDTV systems and existing analogue BSS systems.

At this time it is not clear how much information will need to be transmitted for the near studio quality HDTV systems, and how efficient the coding and modulation systems will become. Therefore it is not possible at this stage to determine whether the near studio quality HDTV systems can be accommodated in the 12 GHz band without prejudice to the existing Plans. More studies should be made in the future to determine if wide RF-band HDTV could be accommodated in this band taking into account technological developments allowing more efficient use of spectrum and orbit resources.

13. Feeder links for wide RF-band HDTV systems

13.1 System characteristics

According to the Radio Regulations, the feeder links to the BSS are part of the FSS and thus will operate in FSS frequency bands in the Earth-to-space direction. It may be possible to accommodate the feeder links for wide RF band HDTV within these existing frequency bands allocated to feed the BSS satellites.

Up-link earth stations for the BSS are already operating satisfactorily in the 14 GHz and 17 GHz bands, and TWTs of up to 750 W have now been developed for the 27.5 to 30.0 GHz band. Therefore, the technology is available for the operation of up links up to 30 GHz, and other factors, including sharing and economic considerations, will determine which band or bands should be used.

The lower the frequency band which can be used for the feeder links, the higher the availability of the feeder links, and the easier it will be to achieve a satisfactory overall performance for the service. If it is necessary to use new bands, such as 30 GHz for the feeder links, very high rain margins will be required. Depending on the climate, the required margin will range from 10 dB to 20 dB at 17 GHz to up to 30 dB at 30 GHz. Up link power control may be expected to restore about 10 dB of this margin, but where higher values are required, other mitigation techniques, such as site diversity, will be needed. Further increase in power capacity of TWT is necessary.

For digital transmission, as proposed for wide RF-band HDTV, it is important that amplifiers should be as linear as possible. Techniques have been developed for linearizing TWT amplifiers. These have been used for several years in some up-link earth stations and are now being applied to satellite transponders. This technology should be considered for wide RF-band HDTV.

13.2 Sharing and suitable frequencies

Present situation of available frequency bands for BSS feeder links according to the Radio Regulations (RR)

13.2.1 Introduction

The frequency bands allocated to the fixed-satellite service (FSS) in the Earth-to-space direction by the RR are summarized in Table 26.

TABLE 26

Frequency bands allocated to the FSS (E-S)

10.7 - 11.7 GHz	(only in Region 1)
14.0 - 14.5 GHz	(in the three Regions)
14.5 - 14.8 GHz	(limited to feeder links for the BSS to countries outside Europe)
17.3 - 18.1 GHz	(in the three Regions)
27.0 - 27.5 GHz	(only in Regions 2 and 3)
27.5 - 31.0 GHz	(in the three Regions)

Technical considerations on the choice of a proper band for the feeder links for wide RF-band HDTV BSS

13.2.2 Constraints due to domestic reception

The down-link budget of the wide RF-band HDTV BSS is more severe than that of the BSS in the 12 GHz band. This will probably result in an increase of the G/T required for domestic receiving stations when planning wide RF-band HDTV BSS down links.

13.2.2.1 With the aim to limit the cost of wide RF-band HDTV domestic receiving stations, it would be highly advisable that, (for the wide RF-band HDTV BSS) the up link does not impair the total C/N by more than 0.5 dB. With this assumption, up- and down-link budgets could be defined.

Preferably, up and down links should be engineered together with the aim of balancing the margins of the up and down C/N ratios so as to obtain an acceptable total C/N ratio at the domestic receiver.

13.2.2.2 Constraints due to the link budget and atmospheric depolarization

Moreover, in choosing a frequency band for the feeder link, the XPD effects of the atmosphere should be taken into account.

In Table 27, tentative values for atmospheric attenuation and XPD for the same percentage of the worst month are summarized for a particular geographical zone taken as an example.

Too low values for the XPD increase the danger of mutual interference between different feeder links, thus rendering impossible the use of polarization discrimination. As a consequence, the necessary up-link bandwidth could be up to twice as much as that required for the down link.

13.2.3 Considerations for the presently available feeder link frequency bands for the BSS

A lower frequency than for the down link should preferably be used to ensure better availability for the feeder links, but this may be difficult due to the heavy use of the lower frequency bands. Operating the feeder link band close to the down link band so that similar propagation conditions can be experienced is one alternative. However a too close proximity of the two bands could require complex requirements in the spacecraft to isolate the reception and the transmission. Site diversity can greatly improve the availability for feeder links in cases where higher frequencies are used.

10.7 - 11.7 GHz band

In order to allocate this band on a worldwide basis to the feeder links of the W-HDTV BSS, a modification of the RR would be needed.

Serious difficulties may arise with the sharing of the existing fixed terrestrial and satellite services.

14 - 14.8 GHz band

This band seems to show some advantages: relatively low frequency, good propagation conditions, consolidated technology. However, it is already heavily utilized.

17.3 - 18.1 GHz

A disadvantage of this band is the necessity to have two different orbital positions for each country using the two services (WARC BS-77 and the new W-HDTV) and in sharing with existing mobile, FSS and fixed terrestrial radio links operating in the band 17.7 - 18.1 GHz.

The propagation conditions still permit an up link power budget which will not impair the total (up and down) C/N ratio by more than 0.5 dB.

TABLE 27

Worst month values for rain attenuation (A_p) and depolarization (XPD)

Frequency (GHz)	A_p* (dB)		XPD** (dB)			
			Circular pol.		Linear pol.	
	99%	99.9%	99%	99.9%	99%	99.9%
11.7	1.1	3.3	29.8	23.2	42.9	37.2
14	1.6	5.0	29.0	22.0	42.2	36.0
18	2.8	8.7	26.5	17.9	39.6	31.9
27	5.7	18.8	24.9	15.7	38.0	29.7
30	6.8	21.8	24.5	15.6	37.7	29.6

* Rain attenuation A_p scaled from observed values listed in Report ITU-R BO.215-7 for 11.7 GHz, valid for Europe; scaling techniques as in Report ITU-R PN.564-4 (§ 2.2.1.2): circular polarization.

** XPD evaluated by using Report ITU-R PN.564-4 (§ 4.1.1) prediction model; elevation angle 32°, rain attenuation as listed.

27 - 27.5 GHz

In order to allocate this 500 MHz-wide band on a worldwide basis, a modification of the Radio Regulations would be needed.

27.5 - 31 GHz

Propagation characteristics in this frequency band lead to high values of rain attenuation and difficult link budgets. As a consequence, the concept of 0.5 dB impairment of the total C/N ratio due to the feeder link should be reconsidered, as this causes a consequent burden on the domestic receiving stations unless the down link power is increased to compensate.

Moreover, the atmospheric depolarization effects may lead to an increase of the required total bandwidth for the feeder links.

14. Satellite and earth station technology

14.1 High-power amplifiers and transponders for space use

High power travelling wave tubes of the coupled-cavity type with an output power of 230 W at the frequency range of 22 GHz have been developed [Hoshino et al., 1990]. Therefore, TWTs of more than 200 W output power are available for broadcasting satellites and more than 400 W output power can be achieved by parallel operation. A TWT with output power of 500 W, and efficiency more than 50% is an achievable target within a time scale of 10 to 15 years.

A bread board model of a high power transponder at 22 GHz for broadcasting satellite use has been developed, where a 100 W TWT is utilized. A bandwidth of 150 MHz and a satellite receiver noise figure of 4.4 dB have been obtained.

Solid state power amplifiers (SSPA) for the 12 GHz band with output powers of several tens of watts have been developed. For the 22 GHz band, 12 W SSPAs have been developed for space use. The power and efficiency of these FET amplifiers can be further improved with development in the device technology, and high efficiency SSPAs, having outputs of several tens of watts at 22 GHz, can be expected.

Linearizers for TWT amplifiers, as referred to in § 7.3.1 of Part 2 of the present Report, should be considered also for spacecraft.

14.2 Multiplexers

For the 22 GHz band, filters for output multiplexers with 0.4 dB insertion loss and 150 MHz bandwidth have been fabricated and tested with RF signals up to 100 W.

Studies indicate that single filters should not normally be operated beyond about 225 W RF power at around 20 GHz to avoid multipacting effects. However, there are methods of power splitting between several filters which allow this limitation to be overcome.

14.3 Antennas for broadcasting satellites

Simple elliptical beam antennas may be preferable for the coverage of small service areas. For large service areas, shaped beam technologies may be employed to cover the service area efficiently. For shaping the coverages, multiple beam antennas (MBA) and shaped reflector antennas are available. Shaping the coverage, however, tends to degrade cross polar and off-axis performances.

If beam shaping is to be implemented, the shaped-reflector approach is generally preferred over multifeed horns because of complexity. Shaped-reflector 22 GHz band contoured beam antennas have been developed [Shogen et al., 1990]. It has been shown that various requirements of antenna gain and beam shape can be satisfied by shaped reflector antenna. Where multiple coverages are required, MBA techniques, with multifeed horns, are necessary if only one reflector is to be used.

Beam-shaping techniques can also be applied to tailor the antenna pattern so as to provide increased e.i.r.p. to areas within the coverage zone, subject to higher propagation losses. In future, based on this technique, using variable power dividers and phase control, this adjustment of e.i.r.p. could even be made adaptive in order to compensate, at least to some extent, for high local rain fades. The latter technique is complicated and needs further development but can be useful for countries suffering from high rain attenuation, especially at higher frequencies.

14.4 Overall power requirements

The number of transponders which can be accommodated on board a satellite bus depends mainly on the prime power available and the thermal dissipation control. Assuming an efficiency of 50% for the TWT and 90% for the electronic power conditioner, five 200 W TWTs can be supported by a prime power of 2.5 - 3 kW (the EUROSTAR 200 class spacecraft like OLYMPUS). Thermal analyses must be performed in more depth to establish more accurately the spacecraft capabilities. Greater capacity can be expected in the future as further developments are made in spacecraft technology. It is predicted that the spacecraft bus can provide sufficient d.c. power to operate, say, six TWTs at 350 W RF output power.

14.5 TWTs and klystrons for earth stations

Microwave tubes (TWTs and klystrons) with more than 1 KW output power are already available for the range 14 to 17 GHz. High power microwave tubes up to 30 GHz with output power of 350 W to 750 W have been developed for satellite communication earth stations, which are also available for the feeder link of HDTV satellite broadcasting systems.

14.6 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 (Federal Republic of Germany) was launched in June 1989. Basically an operational telecommunication satellite it also carries a 30/20 GHz payload for test purposes (bandwidth 90 MHz, e.i.r.p. 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 communications and broadcasting engineering test satellite (COMETS).

15. Conclusions

Wide RF-band HDTV is defined to produce virtually transparent pictures to the HDTV studio production system. Two levels of service reliability are defined. First the percentage of time during which the above quality objective is achieved (usually 99% of the worst month) and second, the percentage of time when the system performance is totally inadequate.

Propagation effects represent the main cause of degradation to HDTV service performance and availability. Rain attenuation and rain depolarization are the dominant propagation factors in the frequency range 10 to 31 GHz. Except for atmospheric absorption, which has a local maximum at 22.3 GHz, all other propagation effects increase continuously with frequency.

In principle both analogue and digital systems are possible. Analogue systems require very high satellite powers (about 1000 W) and also higher protection ratios. Low-level digital modulation systems (e.g. QPSK or 8-PSK) are rugged in the presence of noise and interference and offer efficiencies up to about 2 (bit/s)/Hz. Higher-order digital systems, (e.g. 16-PSK, 16-QAM) with appropriate channel coding offer channel efficiencies up to 3 (bit/s)/Hz but are more vulnerable to interference and satellite non-linearities.

At present, some 110 Mbit/s would be required for coding of the vision signal and methods for getting lower figures are being studied. It is also necessary to add some 20 to 30 Mbit/s for sound, synchronization and other purposes.

As an example, at 22 GHz in rain zone K and 30° elevation angle some 170 - 350 W would be required in the satellite if receiving antennas of about 0.7 m diameter are going to be used.

After examination of existing BSS frequency bands in the range defined by the agenda of the conference, for their suitability for wide RF-band HDTV, some other possible frequency bands are identified and presented, within or in the vicinity of this range. Comments have also been introduced on the long-term suitability of the 11.7 - 12.7 GHz band for wide RF-band HDTV.

Various computer exercises have been presented in input contributions. They make it possible to give an estimate of the bandwidth to be considered by the conference, depending on the number of programmes and other technical assumptions. A figure of 600 MHz has been quoted in some of these exercises.

Possible frequency bands for the feeder links are discussed with general technical considerations to be taken into account.

As the possible frequency range covers a wide part of the spectrum, numerous sharing situations have to be examined. Some results existing in CCIR reports are summarized. They have been complemented by new information, especially on sharing between the fixed service and the broadcasting-satellite service for wide RF-band HDTV.

16. References

ARDITO, M., BARBERO, M. and IBAÑEZ [1990] - Performance of Codecs for Bit-rate reduction applied on Conventional TV and HDTV Signals, IBC 1990, Brighton (United Kingdom), 21-25 September 1990.

BARBERO, M., CUCCHI, S. and BAILON, J.L.H. [August 1989] - A flexible architecture for an HDTV codec based on DCT, 3rd International Workshop on HDTV, Turin (Italy).

BARBIERI, G.F. and COMINETTI, M. [October 1990] - Experiments of point-to-multipoint digital transmission of HDTV via satellite during the football World Cup 1990 in Italy, 132nd SMPTE Technical Conference, New York.

BARBIERI, G.F., MOLO, F. and TEJERINA, J.L. [1990] - Bit-rate reduction of HDTV based on Discrete Cosine Transform, Telettra Review No. 45.

BRYANT, D. and ALLNATT [1980] - Low elevation angle scintillations, Electr. Letters.

COMINETTI, M. [1990] - Perspectives and evolution of HDTV by satellite, ITU Telecommunications Journal Vol. 57, IX/1990.

COMINETTI, M. and MORO, F. [April 1990] - A codec for HDTV signal transmission through terrestrial and satellite digital links, NAB 1990, Atlanta (United States of America).

COMINETTI, M. and MORELLO, A. [August 1990] - Wide RF-band digital HDTV emission systems - Performance of advanced coding/modulation techniques, RAI Research Centre, Technical Report 90/4/E.

DIGICIPHER [June 1990] - Digicipher HDTV System, General Instrument Corporation, Videocipher Division.

DOSCH, C. [December 1990] - Direct satellite broadcasting of digital HDTV in the 20 GHz range, EBU Review, Technical No. 244.

GUICHARD, J. and NASSE, D. [1987] - Digital image coding, L'echo des Recherches.

HOSHINO, H. et al. [1990] - High power space TWTA development activities for new broadcasting satellites, AIAA 13th Communication Satellite Systems Conference, pp. 759-765.

IMAI and NAKAKITA [1989] - A 22 GHz band low-noise down converter for satellite broadcast receivers, 19th EuMC proc., pp. 549-555.

MORELLO, A. et al., [1991] - Performance of a 16 QAM modem at 70 Mbit/s over satellite simulator with TWTA linearizer, RAI Research Centre, ESTEC contract 9100/10/NL/PM.

SHIBATA et al. [1986] - 20 GHz band low-noise HEMT amplifiers, IEEE MTT-S International Microwave Symposium Digest, pp. 75-80.

SHOGEN, K. et al. [1990] - A study on highly-shaped contour beam antenna for Japanese DBS, AIAA 13th Communication Satellite Systems Conference, pp. 229-238.

STOTT, J.H. [1990] - Satellite broadcasting: A common-frequency approach to wideband HDTV with a hand-made example "plan", BBC Research Department Report 1990/7.

WOODS, J.W. and O'NEIL, S.D. [October 1986] - Sub-band Coding of Images, IEEE Trans. of ASSP Vol. 34, No. 5, pp. 1278-1288.