REPORT 1074-1

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

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

(1986-1990

## 1. Introduction

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

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

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

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

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

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

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

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

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

## 2. General characteristics of MAC systems

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

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

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

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

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

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

### 2.2 *The MAC signal*

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

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

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

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

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

### 2.2.1 Multiplexing aspects

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

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

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

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

### 2.2.2 Vision aspects

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

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

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

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

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

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

2.2.3 Summary

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

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

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

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

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

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

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

### 3.1 *Luminance and colour-difference bandwidths*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

### 3.4 *Choice of emphasis characteristic*

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

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

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

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

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

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

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

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

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

### 3.5 *Picture quality*

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

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

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

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

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

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

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

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

$A_0$: low frequency gain

$A_\infty$: high frequency gain

$f_z$: zero frequency

$f_p$: pole frequency

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

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

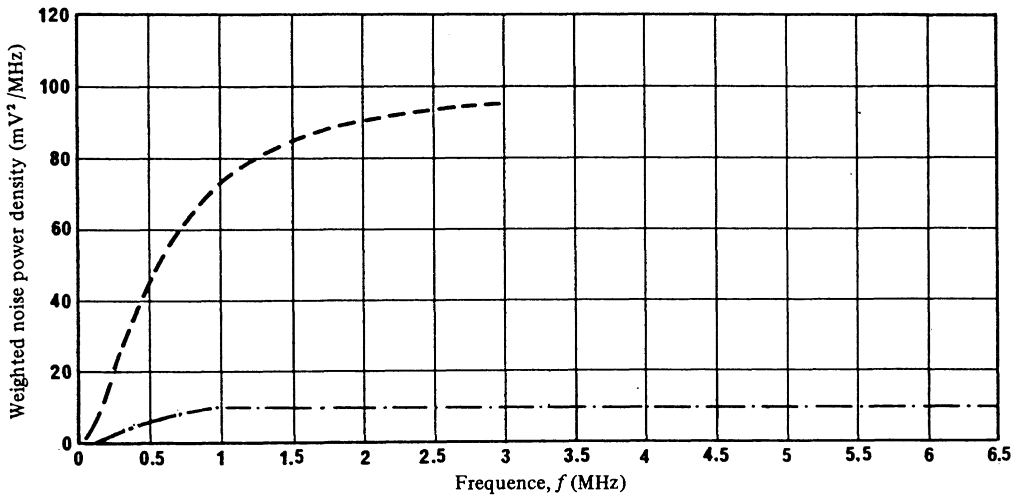


FIGURE 1 – *Colour-difference and luminance signals weighted noise power density*

Weighting filter : Recommendation 451

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

– – – – – – – Colour-difference signal

·—·—·—·— Luminance

The ordinate scale is such that the area below the curves, expressed in dB with respect to 1 $mV^2$, provides the weighted signal-to-noise ratios corresponding to $C/N = 14$ dB

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

### 3.6 *Future enhancements*

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

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

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

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

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

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

#### 3.6.2 Aspect ratio

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

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

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

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

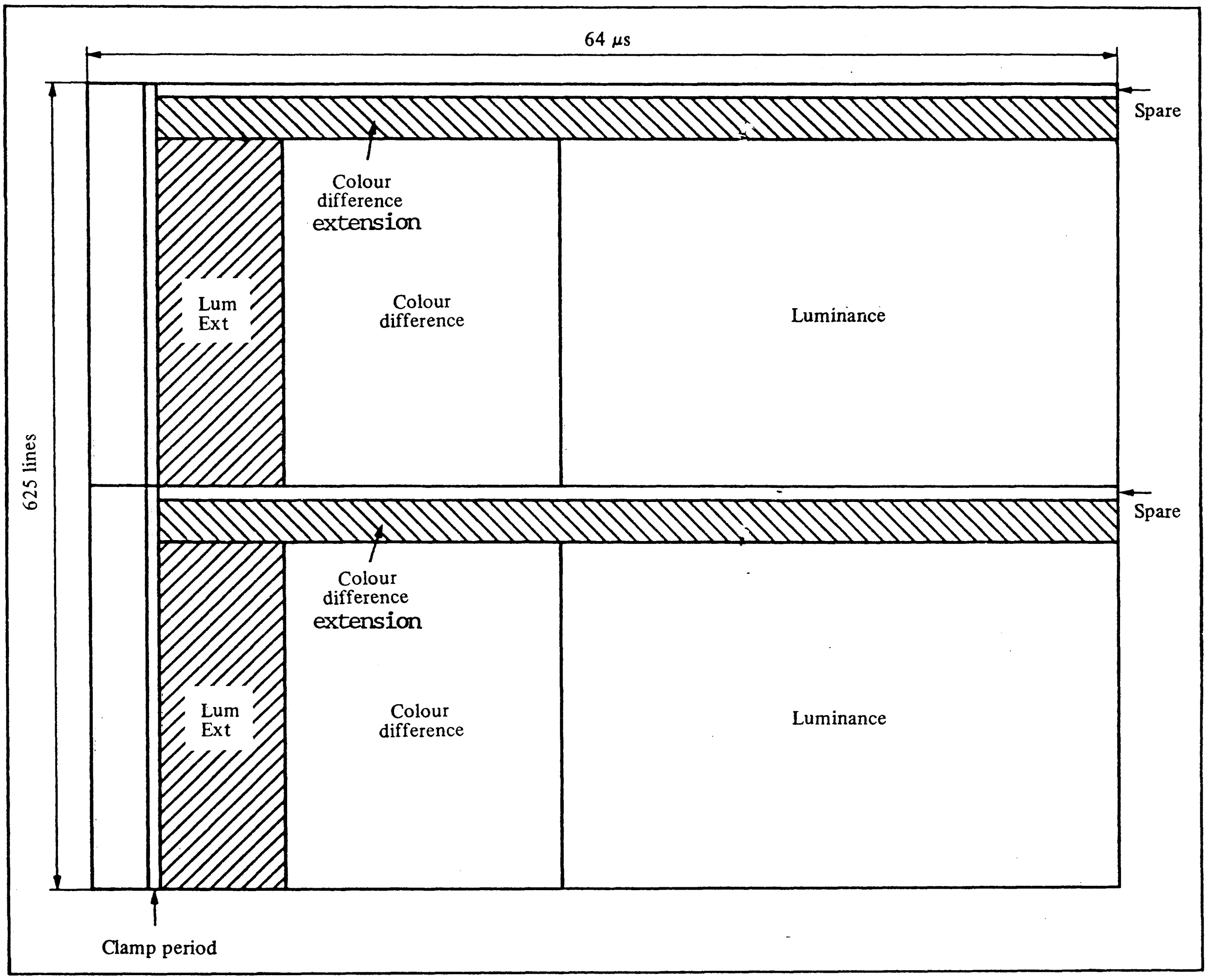


FIGURE 2 – *Proposed use of transmitted frame for extended MAC*

*Note.* – Shaded areas used for video extensions.

### 3.6.3 *Vision multiplexing at line and field rate*

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

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

#### 3.6.3.1 *Multiplexing at field rate*

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

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

3.6.3.2 *Multiplexing at line and field rate*

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

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

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

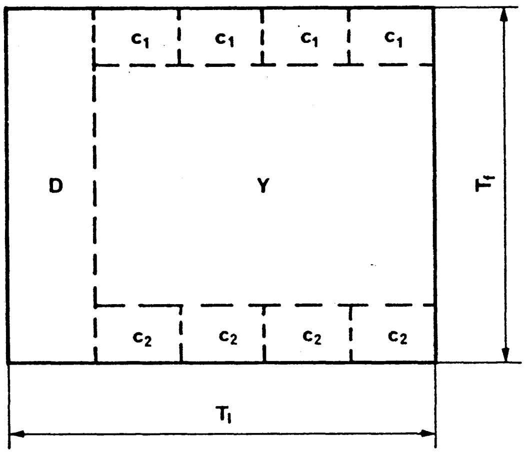


FIGURE 3a – *Multiplexing at field rate*

$T_f$: field period
$T_l$ : line period
$D$ : sound + data + sync.
$c_1$ : 1st colour-difference signal (e.g. $U$)
$c_2$ : 2nd colour-difference signal (e.g. $V$)
$Y$ : luminance signal

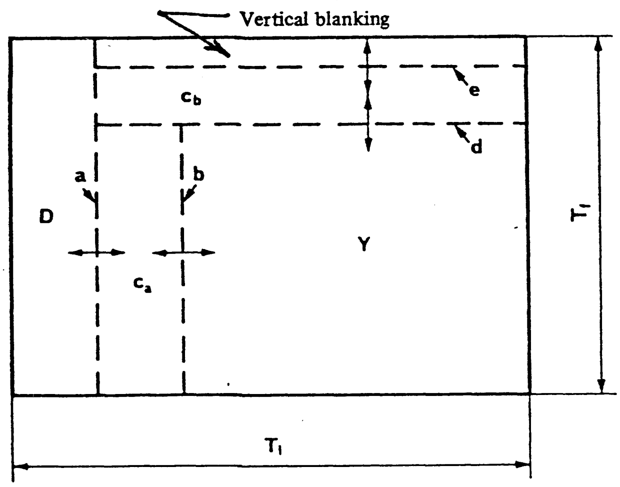


FIGURE 3b – *Multiplexing at field and line rate*

$T_f$: field period
$T_l$ : line period
$D$ : sound + data + sync.
$c_a$ : 1st colour-difference signal (e.g. $U$)
$c_b$ : 2nd colour-difference signal (e.g. $V$)
$Y$ : luminance signal

3.6.4 *HDTV* (see also Report 801)

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

3.6.5 *Stereoscopic television*

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

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

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

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

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

4.1 *B-MAC*

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

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

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

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

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

### 4.2 *Dual aspect-ratio B-MAC*

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

## 5. Scrambling for conditional access

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

### 5.1 *Scrambling algorithm*

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

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

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

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

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

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

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

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

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

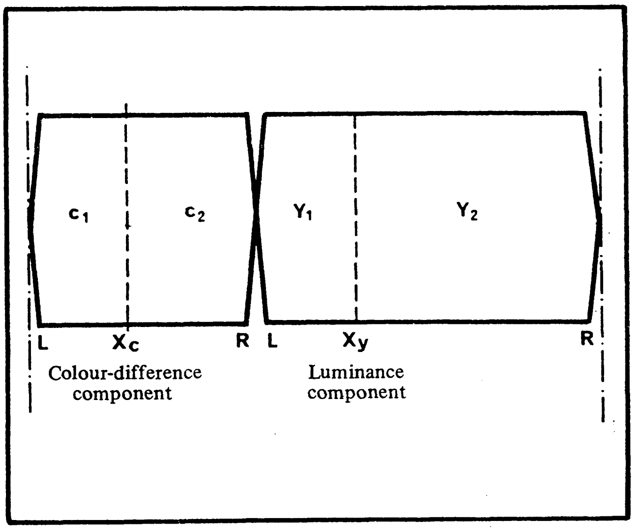


FIGURE 4a – *Normal MAC line*

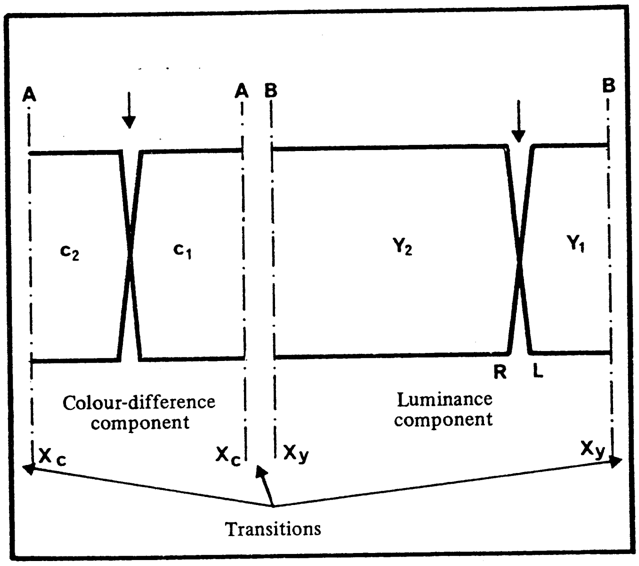


FIGURE 4b – *Double-cut component rotation scrambling*

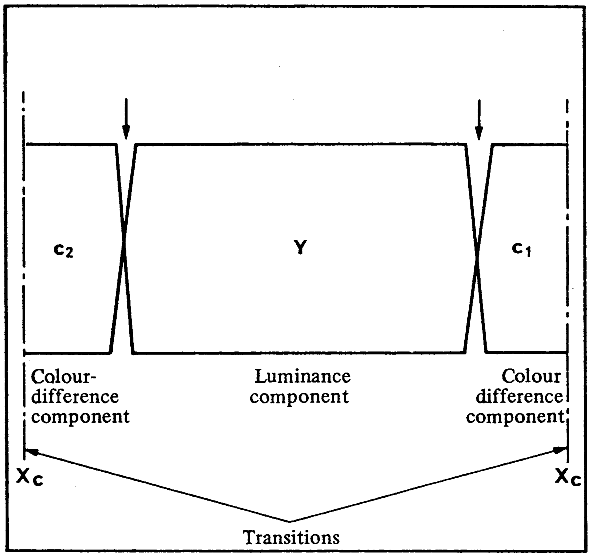


FIGURE 4c – *Single-cut line rotation scrambling*

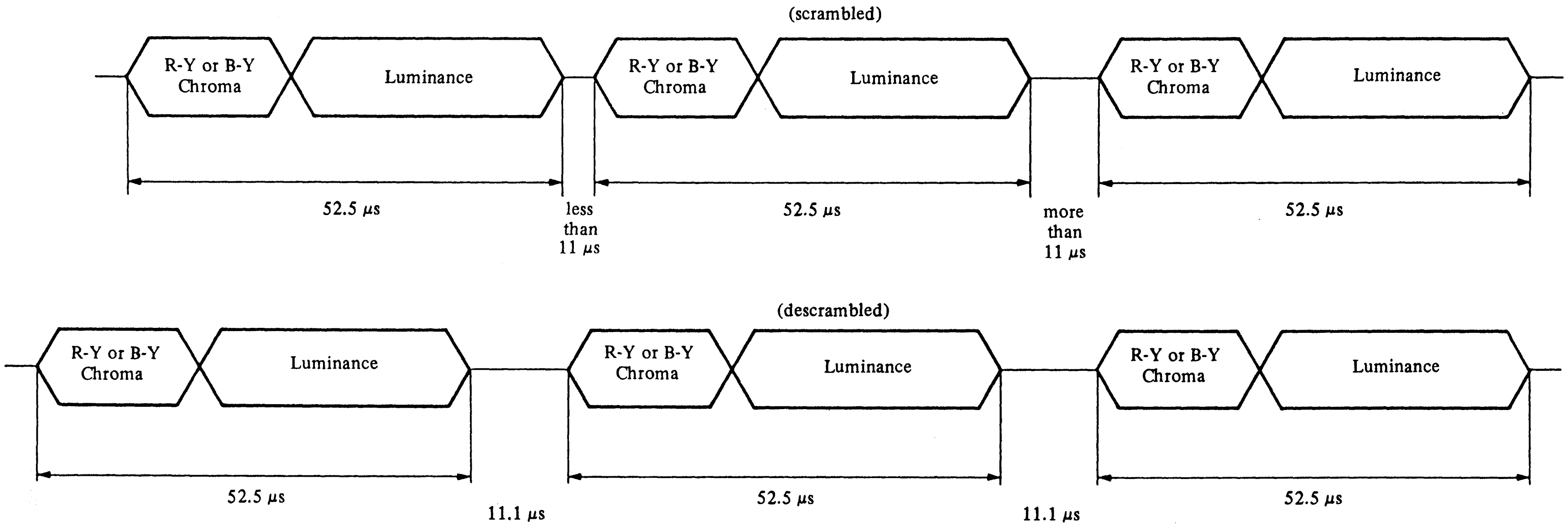


FIGURE 5 – *Line translational scrambling*

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

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*CCIR Documents*

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

# ANNEX I

## THE E7 PRE/DE-EMPHASIS CHARACTERISTICS*

### 1. E7 de-emphasis characteristic

#### 1.1 *Analogue E7*

Referring to the block diagram of Fig. 6:

*Delay element T*

T = 0

*Low-pass filter F*

The transfer function is given by

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

where $f$ = frequency
$f_o$ = 2.0 MHz

*Non-linear function $N^{-1}$*

This is illustrated in Fig. 7

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

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

A = 0.009
B = 19.80
C = 1.5642

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

*Post filter*

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

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

1.2 *Digital E7*

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

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

*Sampling rate*

20.25 MHz

*Delay element T*

T = 3 clock periods

*High pass filter $F_1$*

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

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

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

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

These are scaled for unity a.c. gain

*Non linear function $N_1$*

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

where $V_i$ = input
$V_o$ = output

then $N_1$ is described by

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

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

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

where A = 0.011
B = 19.80
C = 1.5225

## 2. Pre-emphasis characteristics

### 2.1 *Analogue pre-emphasis*

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

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

### 2.2 *Digital pre-emphasis*

The block diagram is shown in Fig. 11.

*High-pass filter* $F_1$

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

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

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

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

These are scaled for unity a.c. gain.

*Delay element T:*

3 clock periods

*Non-linear function* $N_1$

As for de-emphasis (§1.1).

*Non-linear function* $N_2$

This function is described by the following equation:

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

where A = 0.011
B = 19.80
C = 1.5225

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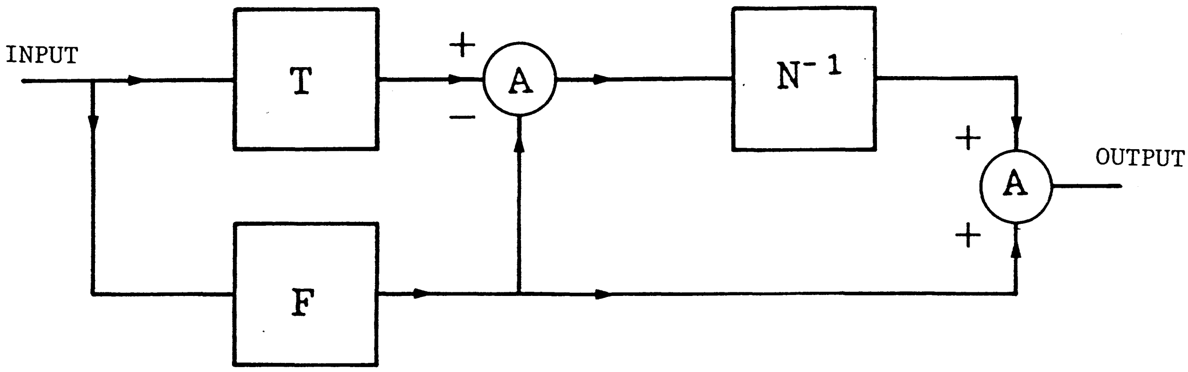
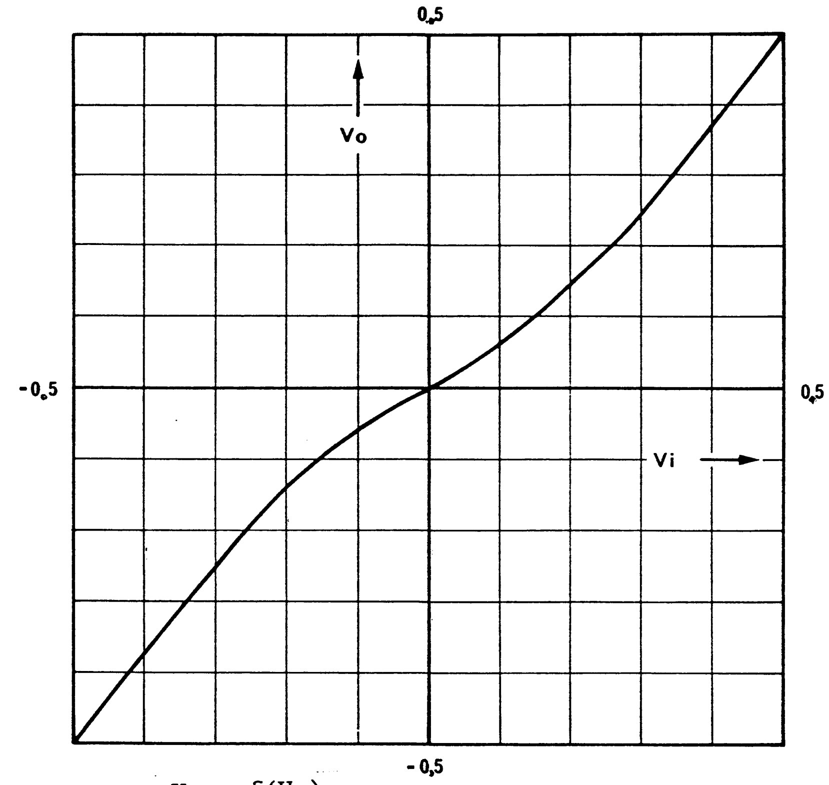


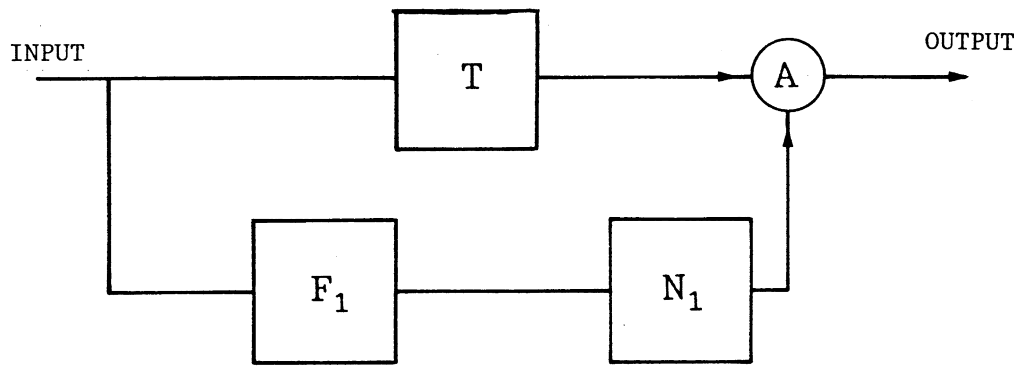

A : adder
T : delay element
F : low pass filter
$N^{-1}$ : non-linear function

Figure 6 - E7 de-emphasis block diagram




$V_o = f(V_i)$

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




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

Figure 8 - Recommended de-emphasis implementation (digital)

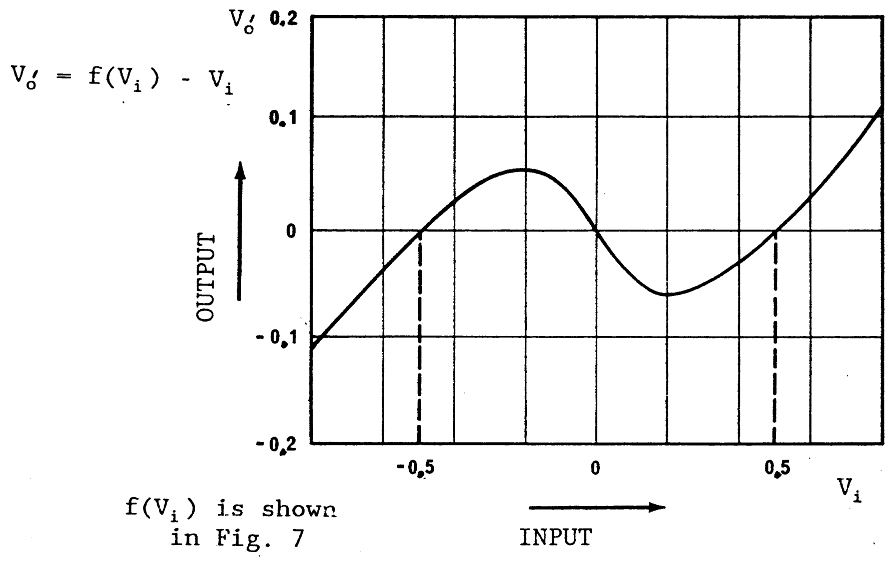
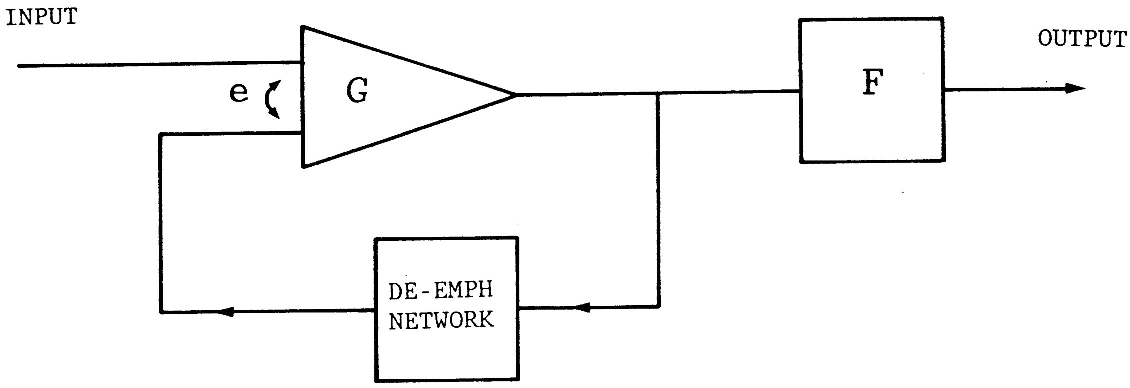



Figure 9 - $N_1$ non-linearity




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

Figure 10 - Analogue pre-emphasis configuration

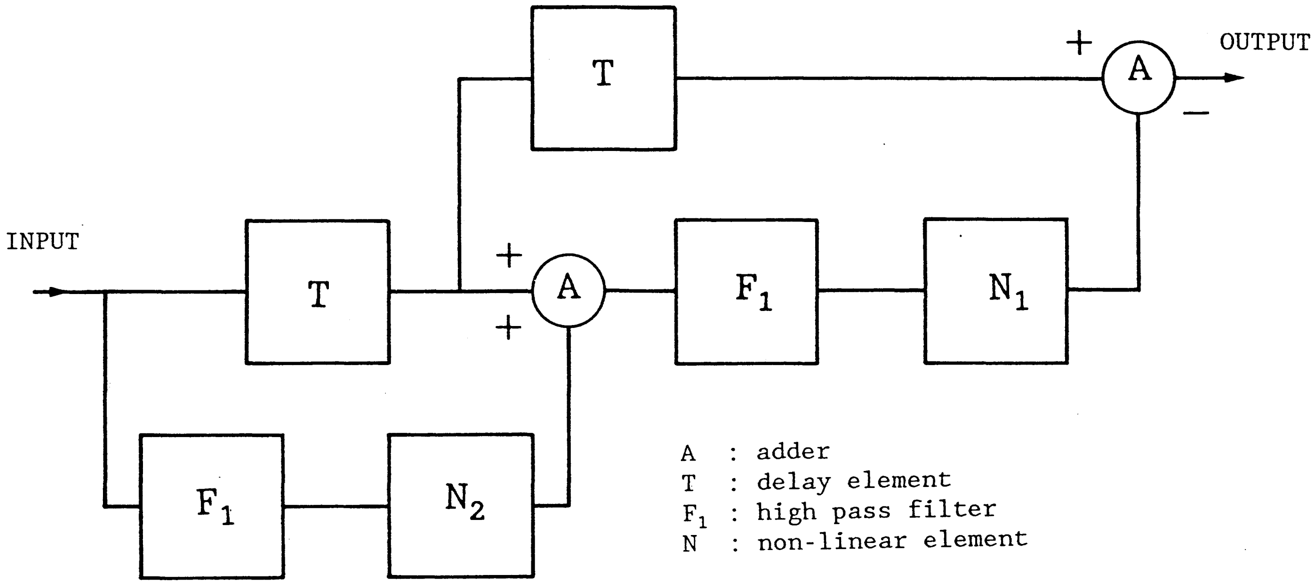



Figure 11 - Digital pre-emphasis configuration