SECTION 11B: DIGITAL TELEVISION

RECOMMENDATION ITU-R BT.601-4

ENCODING PARAMETERS OF DIGITAL TELEVISION FOR STUDIOS

(Questions ITU-R 25/11, ITU-R 60/11 and ITU-R 61/11)

(1982-1986-1990-1992-1994)

The ITU Radiocommunication Assembly,

considering

a) that there are clear advantages for television broadcasters and programme producers in digital studio standards which have the greatest number of significant parameter values common to 525-line and 625-line systems;

b) that a worldwide compatible digital approach will permit the development of equipment with many common features, permit operating economies and facilitate the international exchange of programmes;

c) that an extensible family of compatible digital coding standards is desirable. Members of such a family could correspond to different quality levels, facilitate additional processing required by present production techniques, and cater for future needs;

d) that a system based on the coding of components is able to meet some, and perhaps all, of these desirable objectives;

e) that the co-siting of samples representing luminance and colour-difference signals (or, if used, the red, green and blue signals) facilitates the processing of digital component signals, required by present production techniques,

recommends

that the following be used as a basis for digital coding standards for television studios in countries using the 525-line system as well as in those using the 625-line system:

1. Component coding

The digital coding should be based on the use of one luminance and two colour-difference signals (or, if used, the red, green and blue signals).

The spectral characteristics of the signals must be controlled to avoid aliasing whilst preserving the pass-band response. When using one luminance and two colour-difference signals as defined in Table 1 suitable filters are defined in Figs. 4 and 5. When using E'_R, E'_G, E'_B signals or luminance and colour-difference signals as defined in Table 2 a suitable filter characteristic is shown in Fig. 4.

2. Extensible family of compatible digital coding standards

The digital coding should allow the establishment and evolution of an extensible family of compatible digital coding standards. It should be possible to interface simply between any two members of the family.

The member of the family to be used for the standard digital interface between main digital studio equipment, and for international programme exchange (i.e. for the interface with video recording equipment and for the interface with the transmission system) should be that defined in § 4.

In a higher member of the family the sampling frequencies of the luminance and colour-difference signals (or, if used, the red, green and blue signals) are related by the ratio 4:4:4. The specifications for the 4:4:4 member are defined in § 5.

TABLE 1

4:2:2 member of the family

Parameters	525-line, 60 field/s systems	625-line, 50 field/s systems
1. Coded signals: Y, C_R, C_B	These signals are obtained from gamma pre-corrected signals, namely: E'_Y, $E'_R - E'_Y$, $E'_B - E'_Y$ (Annex 1, § 2 refers)	
2. Number of samples per total line: – luminance signal (Y) – each colour-difference signal (C_R, C_B)	 858 429	 864 432
3. Sampling structure	Orthogonal, line, field and frame repetitive. C_R and C_B samples co-sited with odd (1st, 3rd, 5th, etc.) Y samples in each line	
4. Sampling frequency: – luminance signal – each colour-difference signal	 13.5 MHz 6.75 MHz The tolerance for the sampling frequencies should coincide with the tolerance for the line frequency of the relevant colour television standard	
5. Form of coding	Uniformly quantized PCM, 8 (optionally 10) bits per sample, for the luminance signal and each colour-difference signal	
6. Number of samples per digital active line: – luminance signal – each colour-difference signal	 720 360	
7. Analogue-to-digital horizontal timing relationship: – from end of digital active line to O_H	16 luminance clock periods	12 luminance clock periods
8. Correspondence between video signal levels and quantization levels: – scale – luminance signal – each colour-difference signal	(See § 3.4) (Values are decimal) 0 to 255 220 quantization levels with the black level corresponding to level 16 and the peak white level corresponding to level 235. The signal level may occasionally excurse beyond level 235 225 quantization levels in the centre part of the quantization scale with zero signal corresponding to level 128	
9. Code-word usage	Code words corresponding to quantization levels 0 and 255 are used exclusively for synchronization. Levels 1 to 254 are available for video	

3. Specifications applicable to any member of the family

3.1 Sampling structures should be spatially static. This is the case, for example, for the orthogonal sampling structure specified in § 4 for the 4:2:2 member of the family and in § 5 for the 4:4:4 member.

3.2 If the samples represent luminance and two simultaneous colour-difference signals, each pair of colour-difference samples should be spatially co-sited. If samples representing red, green and blue signals are used they should be co-sited.

TABLE 2

4:4:4 member of the family

Parameters	525-line, 60 field/s systems	625-line, 50 field/s systems
1. Coded signals: Y, C_R, C_B or R, G, B	These signals are obtained from gamma pre-corrected signals, namely: E'_Y, $E'_R - E'_Y$, $E'_B - E'_Y$ or E'_R, E'_G, E'_B	
2. Number of samples per total line for each signal	858	864
3. Sampling structure	Orthogonal, line, field and frame repetitive. The three sampling structures to be coincident and coincident also with the luminance sampling structure of the 4:2:2 member	
4. Sampling frequency for each signal	13.5 MHz	
5. Form of coding	Uniformly quantized PCM, 8 (optionally 10) bits per sample	
6. Duration of the digital active line expressed in number of samples	720	
7. Correspondence between video signal levels and the 8 most significant bits (MSB) of the quantization level for each sample:	(See § 3.4) (Values are decimal)	
– scale	0 to 255	
– R, G, B or luminance signal(1)	220 quantization levels with the black level corresponding to level 16 and the peak white level corresponding to level 235. The signal level may occasionally excurse beyond level 235	
– each colour-difference signal(1)	225 quantization levels in the centre part of the quantization scale with zero signal corresponding to level 128	

(1) If used.

3.3 The digital standard adopted for each member of the family should permit worldwide acceptance and application in operation; one condition to achieve this goal is that, for each member of the family, the number of samples per line specified for 525-line and 625-line systems shall be compatible (preferably the same number of samples per line).

3.4 In applications of these specifications, the contents of digital words are expressed in both decimal and hexadecimal forms, denoted by the suffixes “d” and “h” respectively.

To avoid confusion between 8-bit and 10-bit representations, the eight most-significant bits are considered to be an integer part while the two additional bits, if present, are considered to be fractional parts.

For example, the bit pattern 10010001 would be expressed as 145_d or 91_h, whereas the pattern 1001000101 would be expressed as 145.25_d or 91.4_h.

Where no fractional part is shown, it should be assumed to have the binary value 00.

4. Encoding parameter values for the 4:2:2 member of the family

The specification (Table 1) applies to the 4:2:2 member of the family, to be used for the standard digital interface between main digital studio equipment and for international programme exchange.

5. Encoding parameter values for the 4:4:4 member of the family

The following specification given in Table 2 applies to the 4:4:4 member of the family suitable for television source equipment and high-quality video signal processing applications.

ANNEX 1

Definition of signals used in the digital coding standards

1. Relationship of digital active line to analogue sync reference

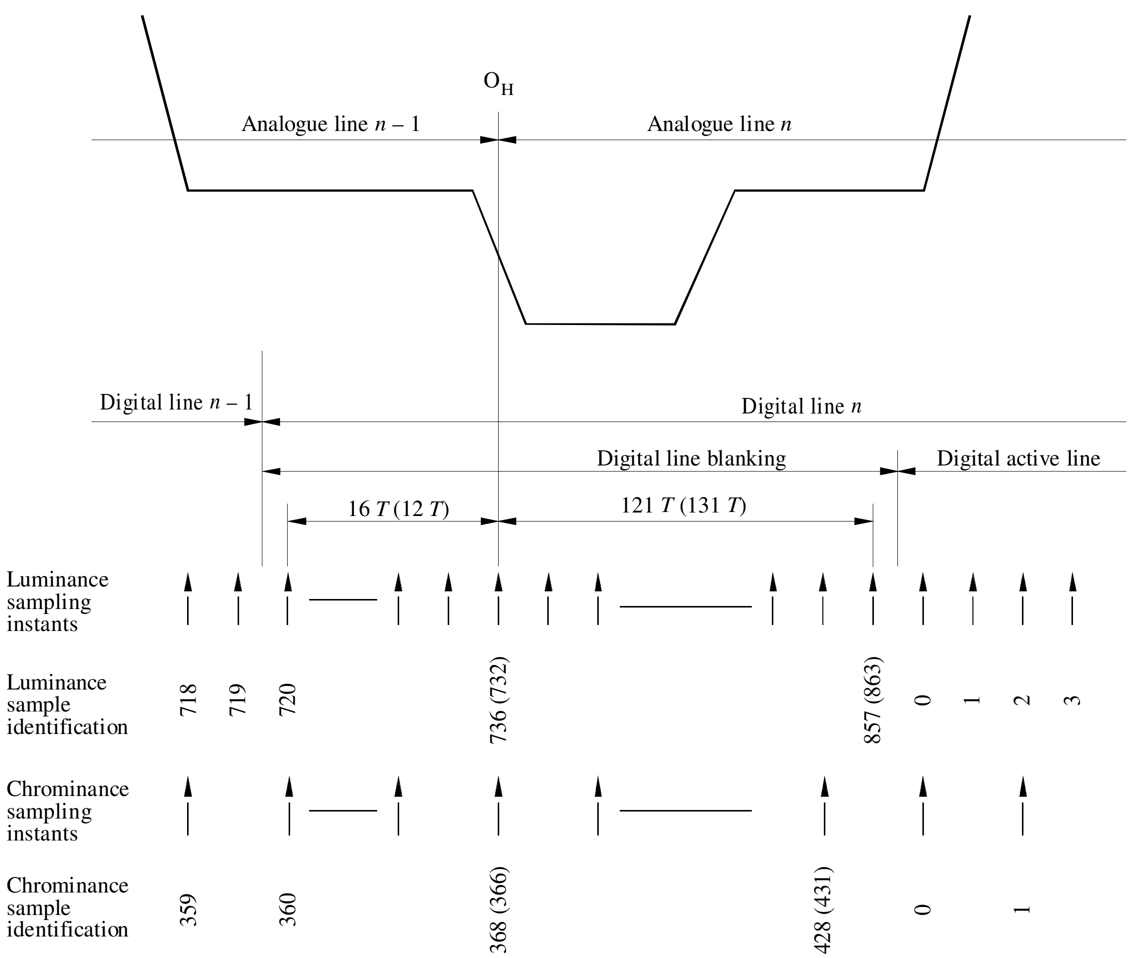
The relationship between 720 digital active line luminance samples and the analogue synchronizing references for 625-line and 525-line systems is shown in Fig. 1. A luminance sample is co-sited with the analogue line reference point O_H.

The identification numbers of the samples that make up the digital line, the digital line blanking and the digital active line are shown in Fig. 2. The respective numbers of colour-difference samples can be obtained by dividing the number of luminance samples by two. The (12, 132) and (16, 122) were chosen symmetrically to dispose the digital active line about the permitted variations. They do not form part of the digital line specification and relate only to the analogue interface.

The numbers of the digital lines that make up the digital fields and the digital field blanking intervals are shown in Fig. 3.

FIGURE 1

Relationship between video samples and the analogue line synchronization

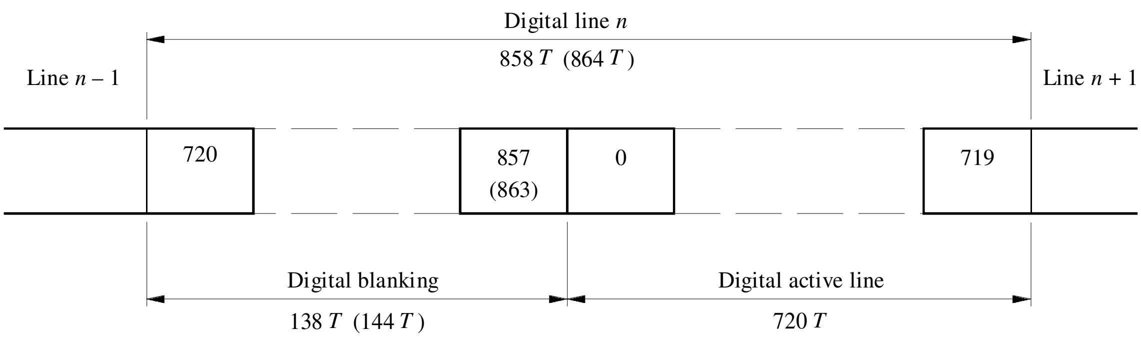


Note 1 – Sample identification numbers in parentheses are for 625-line systems where these differ from those of 525-line systems. *T* represents the luminance sampling period.

D01

FIGURE 2

Definitions of the digital line samples

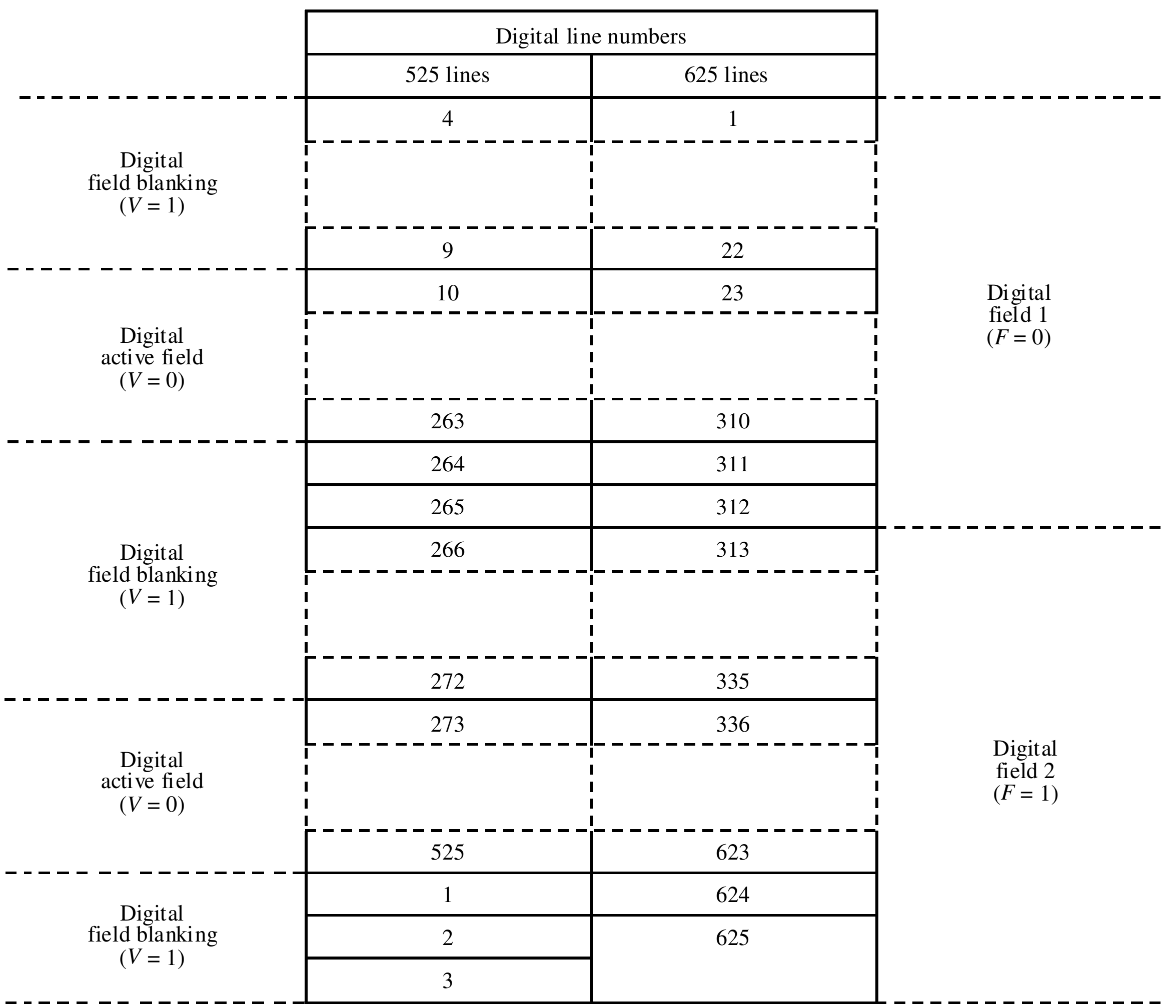


Note 1 – Sample identification numbers and sample periods in parentheses are for 625-line systems where these differ from those of 525-line systems.

D02

FIGURE 3

Line numbers in the digital picture (frame)



Note 1 – Digital line numbers correspond to the associated analogue line numbers defined in Recommendation ITU-R BT.470.

D03

2. Definition of the digital signals Y, C_R, C_B, from the primary (analogue) signals E'_R, E'_G and E'_B

This section describes, with a view to defining the signals Y, C_R, C_B, the rules for construction of these signals from the primary analogue signals E'_R, E'_G and E'_B. The signals are constructed by following the three stages described in § 2.1, 2.2 and 2.3 below. The method is given as an example, and in practice other methods of construction from these primary signals or other analogue or digital signals may produce identical results. An example is given in § 2.4.

2.1 Construction of luminance (E'_Y) and colour-difference ($E'_R - E'_Y$) and ($E'_B - E'_Y$) signals

The construction of luminance and colour-difference signals is as follows:

$$E'_Y = 0.299\,E'_R + 0.587\,E'_G + 0.114\,E'_B$$

whence:

$$\begin{aligned}(E'_R - E'_Y) &= E'_R - 0.299\,E'_R - 0.587\,E'_G - 0.114\,E'_B \\ &= 0.701\,E'_R - 0.587\,E'_G - 0.114\,E'_B\end{aligned}$$

and:

$$\begin{aligned}(E'_B - E'_Y) &= E'_B - 0.299\,E'_R - 0.587\,E'_G - 0.114\,E'_B \\ &= -0.299\,E'_R - 0.587\,E'_G + 0.886\,E'_B\end{aligned}$$

Taking the signal values as normalized to unity (e.g. 1.0 V maximum levels), the values obtained for white, black and the saturated primary and complementary colours are as follows:

TABLE 3

Normalized signal values

Condition	E'_R	E'_G	E'_B	E'_Y	$E'_R - E'_Y$	$E'_B - E'_Y$
White	1.0	1.0	1.0	1.0	0	0
Black	0	0	0	0	0	0
Red	1.0	0	0	0.299	0.701	–0.299
Green	0	1.0	0	0.587	–0.587	–0.587
Blue	0	0	1.0	0.114	–0.114	0.886
Yellow	1.0	1.0	0	0.886	0.114	–0.886
Cyan	0	1.0	1.0	0.701	–0.701	0.299
Magenta	1.0	0	1.0	0.413	0.587	0.587

2.2 Construction of re-normalized colour-difference signals (E'_{C_R} and E'_{C_B})

Whilst the values for E'_Y have a range of 1.0 to 0, those for $(E'_R - E'_Y)$ have a range of +0.701 to –0.701 and for $(E'_B - E'_Y)$ a range of +0.886 to –0.886. To restore the signal excursion of the colour-difference signals to unity (i.e. +0.5 to –0.5), coefficients can be calculated as follows:

$$K_R = \frac{0.5}{0.701} = 0.713; \qquad K_B = \frac{0.5}{0.886} = 0.564$$

Then:

$$E'_{C_R} = 0.713\,(E'_R - E'_Y) = 0.500\,E'_R - 0.419\,E'_G - 0.081\,E'_B$$

and:

$$E'_{C_B} = 0.564\,(E'_B - E'_Y) = -\,0.169\,E'_R - 0.331\,E'_G + 0.500\,E'_B$$

where E'_{C_R} and E'_{C_B} are the re-normalized red and blue colour-difference signals respectively (see Notes 1 and 2).

Note 1 – The symbols E'_{C_R} and E'_{C_B} will be used only to designate re-normalized colour-difference signals, i.e. having the same nominal peak-to-peak amplitude as the luminance signal E'_Y thus selected as the reference amplitude.

Note 2 – In the circumstances when the component signals are not normalized to a range of 1 to 0, for example, when converting from analogue component signals with unequal luminance and colour-difference amplitudes, an additional gain factor will be necessary and the gain factors K_R, K_B should be modified accordingly.

2.3 Quantization

In the case of a uniformly-quantized 8-bit binary encoding, 2^8, i.e. 256, equally spaced quantization levels are specified, so that the range of the binary numbers available is from 0000 0000 to 1111 1111 (00 to FF in hexadecimal notation), the equivalent decimal numbers being 0 to 255, inclusive.

In the case of the 4:2:2 system described in this Recommendation, levels 0 and 255 are reserved for synchronization data, while levels 1 to 254 are available for video.

Given that the luminance signal is to occupy only 220 levels, to provide working margins, and that black is to be at level 16, the decimal value of the luminance signal, $\overline{Y}$, prior to quantization, is:

$$\overline{Y} = 219\,(E'_Y) + 16$$

and the corresponding level number after quantization is the nearest integer value.

Similarly, given that the colour-difference signals are to occupy 225 levels and that the zero level is to be level 128, the decimal values of the colour-difference signals, $\overline{C}_R$ and $\overline{C}_B$, prior to quantization are:

$$\overline{C}_R = 224\,[0.713\,(E'_R - E'_Y)] + 128$$

and:

$$\overline{C}_B = 224\,[0.564\,(E'_B - E'_Y)] + 128$$

which simplify to the following:

$$\overline{C}_R = 160\,(E'_R - E'_Y) + 128$$

and:

$$\overline{C}_B = 126\,(E'_B - E'_Y) + 128$$

and the corresponding level number, after quantization, is the nearest integer value.

The digital equivalents are termed Y, C_R and C_B.

2.4 *Construction of Y, C_R, C_B via quantization of E'_R, E'_G, E'_B*

In the case where the components are derived directly from the gamma pre-corrected component signals E'_R, E'_G, E'_B, or directly generated in digital form, then the quantization and encoding shall be equivalent to:

$$E'_{R_D} \text{ (in digital form) } = \text{int}\,(219\,E'_R) + 16$$

$$E'_{G_D} \text{ (in digital form) } = \text{int}\,(219\,E'_G) + 16$$

$$E'_{B_D} \text{ (in digital form) } = \text{int}\,(219\,E'_B) + 16$$

Then:

$$Y = \frac{77}{256}E'_{R_D} + \frac{150}{256}E'_{G_D} + \frac{29}{256}E'_{B_D}$$

$$C_R = \frac{131}{256}E'_{R_D} - \frac{110}{256}E'_{G_D} - \frac{21}{256}E'_{B_D} + 128$$

$$C_B = -\frac{44}{256}E'_{R_D} - \frac{87}{256}E'_{G_D} + \frac{131}{256}E'_{B_D} + 128$$

taking the nearest integer coefficients, base 256. To obtain the 4:2:2 components Y, C_R, C_B, low-pass filtering and sub-sampling must be performed on the 4:4:4 C_R, C_B signals described above. Note should be taken that slight differences could exist between C_R, C_B components derived in this way and those derived by analogue filtering prior to sampling.

2.5 *Limiting of Y, C_R, C_B signals*

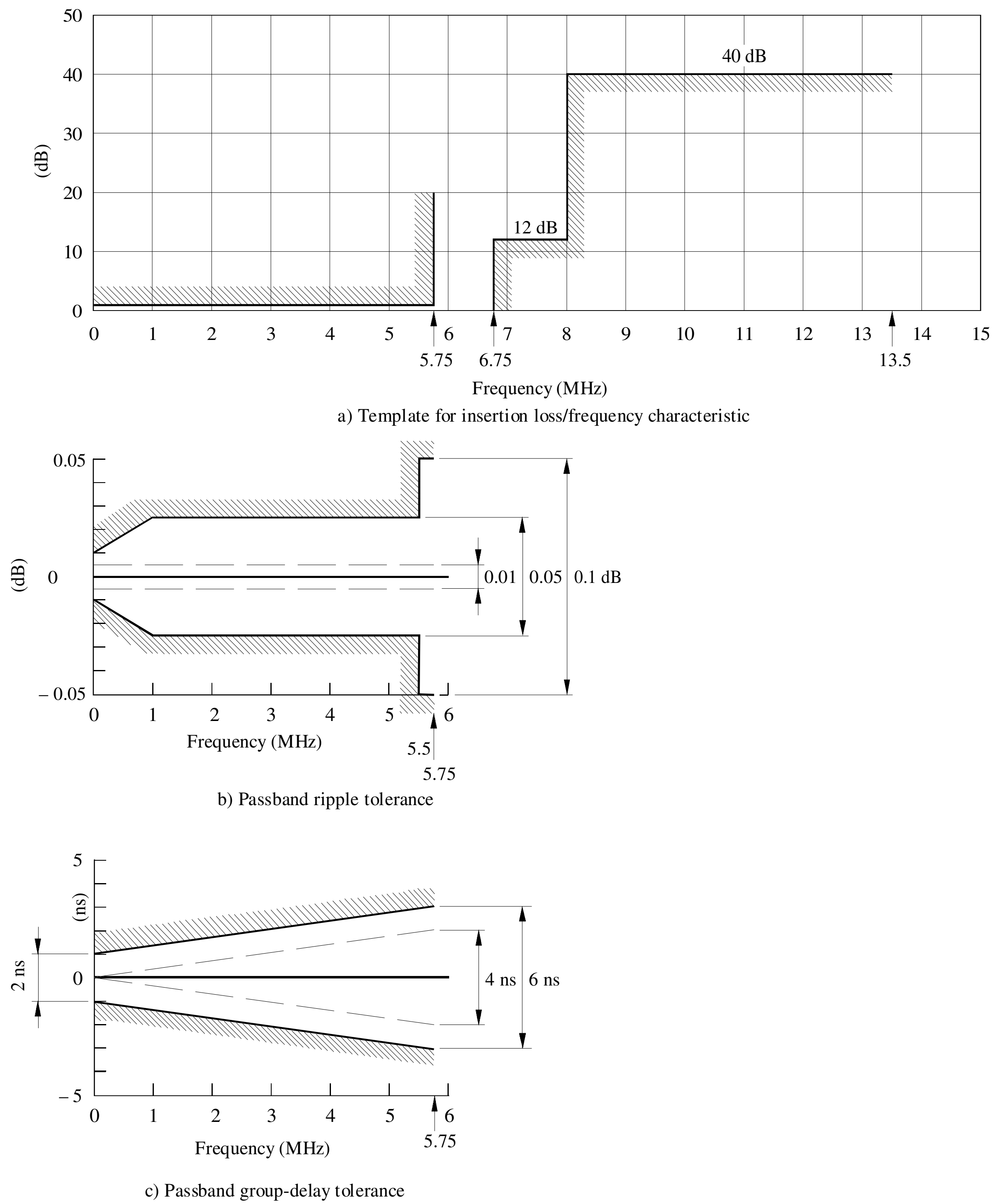
Digital coding in the form of Y, C_R, C_B signals can represent a substantially greater gamut of signal values than can be supported by the corresponding ranges of R, G, B signals. Because of this it is possible, as a result of electronic picture generation or signal processing, to produce Y, C_R, C_B signals which, although valid individually, would result in out-of-range values when converted to R, G, B. It is both more convenient and more effective to prevent this by applying limiting to the Y, C_R, C_B signals than to wait until the signals are in R, G, B form. Also, limiting can be applied in a way that maintains the luminance and hue values, minimizing the subjective impairment by sacrificing only saturation.

ANNEX 2

Filtering characteristics

FIGURE 4

Specification for a luminance or *RGB* signal filter used when sampling at 13.5 MHz

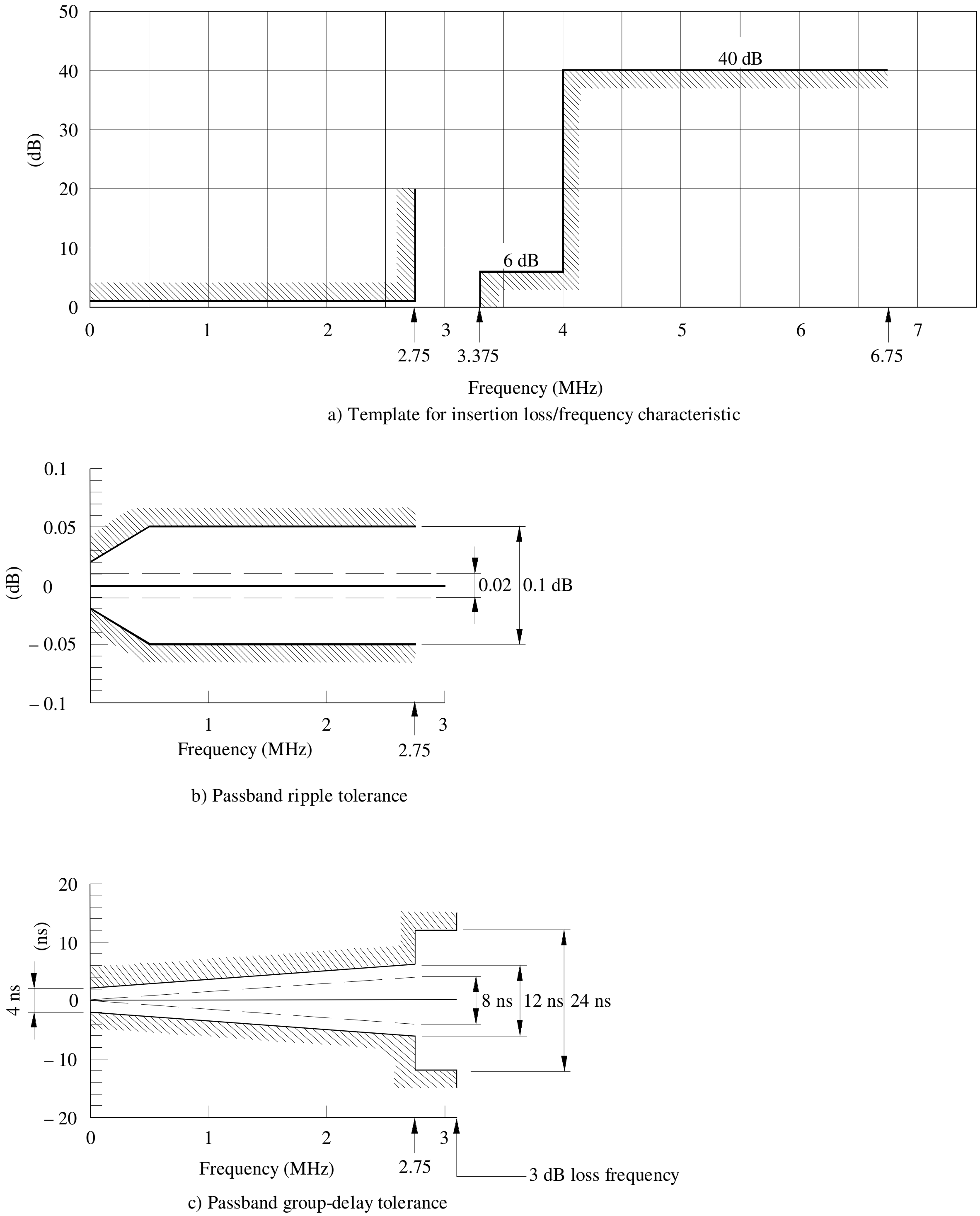


Note 1 – The lowest indicated values in b) and c) are for 1 kHz (instead of 0 MHz).

D04

FIGURE 5

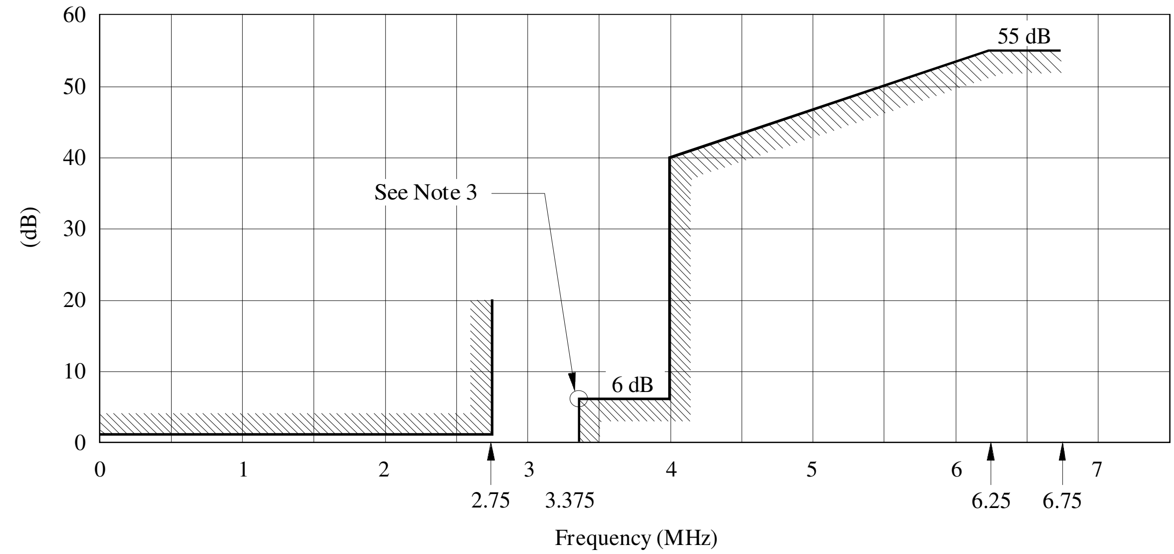
Specification for a colour-difference signal filter used when sampling at 6.75 MHz



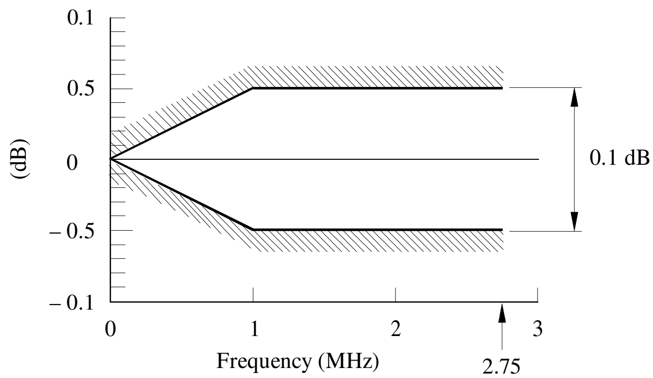
Note 1 – The lowest indicated values in b) and c) are for 1 kHz (instead of 0 MHz).

FIGURE 6

Specification for a digital filter for sampling-rate conversion from 4:4:4 to 4:2:2 colour-difference signals



a) Template for insertion loss/frequency characteristic



b) Passband ripple tolerance

Notes to Figs. 4, 5 and 6:

Note 1 – Ripple and group delay are specified relative to their values at 1 kHz. The fill lines are practical limits and the dashed lines give suggested limits for the theoretical design.

Note 2 – In the digital filter, the practical and design limits are the same. The delay distortion is zero, by design.

Note 3 – In the digital filter (Fig. 6), the amplitude/frequency characteristic (on linear scales) should be skew-symmetrical about the half-amplitude point, which is indicated on the figure.

Note 4 – In the proposals for the filters used in the encoding and decoding processes, it has been assumed that, in the post-filters which follow digital-to-analogue conversion, correction for the (sin *x*/*x*) characteristic of the sample-and-hold circuits is provided.

D06

ANNEX 3

Some guidance on the practical implementation of the filters recommended in Annex 2

In the proposals for the filters used in the encoding and decoding processes, it has been assumed that, in the post-filters which follow digital-to-analogue conversion, correction for the (sin x/x) characteristic is provided. The passband tolerances of the filter plus (sin x/x) corrector plus the theoretical (sin x/x) characteristic should be the same as given for the filters alone. This is most easily achieved if, in the design process, the filter, (sin x/x) corrector and delay equalizer are treated as a single unit.

The total delays due to filtering and encoding the luminance and colour-difference components should be the same. The delay in the colour-difference filter (Fig. 5) is double that of the luminance filter (Fig. 4). As it is difficult to equalize these delays using analogue delay networks without exceeding the passband tolerances, it is recommended that the bulk of the delay differences (in integral multiples of the sampling period) should be equalized in the digital domain. In correcting for any remainder, it should be noted that the sample-and-hold circuit in the decoder introduces a flat delay of one half a sampling period.

The passband tolerances for amplitude ripple and group delay are recognized to be very tight. Present studies indicate that it is necessary so that a significant number of coding and decoding operations in cascade may be carried out without sacrifice of the potentially high quality of the 4:2:2 coding standard. Due to limitations in the performance of currently available measuring equipment, manufacturers may have difficulty in economically verifying compliance with the tolerances of individual filters on a production basis. Nevertheless, it is possible to design filters so that the specified characteristics are met in practice, and manufacturers are required to make every effort in the production environment to align each filter to meet the given templates.

The specifications given in Annex 2 were devised to preserve as far as possible the spectral content of the Y, C_R, C_B signals throughout the component signal chain. It is recognized, however, that the colour-difference spectral characteristic must be shaped by a slow roll-off filter inserted at picture monitors, or at the end of the component signal chain.

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