RECOMMENDATION ITU-R BT.1117-2

STUDIO FORMAT PARAMETERS FOR ENHANCED 16:9 ASPECT RATIO 625-LINE TELEVISION SYSTEMS (D- AND D2-MAC, PALplus, ENHANCED SECAM)

(Question ITU-R 42/11)

(1994-1995-1997)

The ITU Radiocommunication Assembly,

considering

a) that there are already broadcast services offering 16:9 programmes;

b) that there are proposals to introduce new systems of television broadcasting with improved quality of picture and sound, including a wider aspect ratio;

c) that most broadcasting organizations are committed to maintaining a service to their viewers with receiving installations equipped only for terrestrial reception;

d) that many broadcasting organizations will wish to enhance the quality of their existing services;

e) that enhancements of existing terrestrial standards must remain compatible with current channel allocations;

f) that enhancements of existing terrestrial standards must maintain a high degree of picture compatibility;

g) that the principal enhancements identified as means of delivering improved images and sound by enhanced television emission include:

picture – wider aspect ratio,

– reduced cross effects,

– ghost cancellation,

– enhanced resolution;

sound – digital, multi-channel sound;

h) that so far, completely satisfactory decoding of PAL and SECAM encoded signals has not been achieved;

j) that it is desirable that there be the maximum commonality of studio format parameters for different transmission/emission standards, for example, the MAC/packet and PALplus systems;

k) that changes to studio/production format and practices can improve the compatibility of an enhanced television signal and thus facilitate the introduction of enhanced systems;

l) that the provision of an improved studio format will assist the process of up-conversion to HDTV,

recommends

1 that organizations intending to produce programmes for enhanced television services should adopt component standards using some, or all, of the techniques given in Annex 1. A short analysis of when and where each option should be used is given in Annex 3,

invites

1 administrations to make contributions on this matter with a view to completion of this Recommendation.

ANNEX 1

Techniques and modules for programmes produced for enhanced 16:9 625-line systems

1 Use of conventional 625-line production systems

1.1 Video signal format

1.1.1 Digital systems

The question of whether 625-line, 16:9 broadcast systems, both present and planned, would require any change to digital standards used in production has been studied.

Recommendation ITU-R BT.601 encompasses both 13.5 MHz and 18 MHz sampling frequency for 16:9 aspect ratio. Part A covers 13.5 MHz and Part B 18 MHz.

Given the specifications of the D/D2-MAC and PALplus systems and the probable performance of an enhanced SECAM system, some administrations consider that Part A (13.5 MHz) of Recommendation ITU-R BT. 601 is adequate for 16:9, 625-line productions for these emission systems.

1.1.2 Analogue systems

Use of analogue component systems has proved to be perfectly appropriate provided that they are routed through equipments with a bandwidth which is greater or equal to that of the emission system that has to be fed (see Note 1).

NOTE 1 – In the interim some broadcasters may wish to use analogue composite systems before they can convert their facilities to digital component ones. If so, all reasonable steps shall be taken to use some form of improved, “clean” composite coding and decoding methods.

1.1.3 Modified analogue and digital composite format solutions

1.1.3.1 The Com^3 (composite compatible component) system

One option specified in Annex 2 is the Com^3 system which exploits the additional bandwidth provided by D2 and D3 digital composite videotape recording formats to provide a luminance bandwidth of 6.6 MHz for PAL equivalent to a bandwidth of about 5.0 MHz in a conventional 4:3 system. The method employs a novel form of colour coding that can permit freedom from cross effects while maintaining compatibility with existing PAL studio equipment, and employs Nyquist filtering to maintain picture quality through repeated transcoding to and from component formats.

1.1.3.2 The motion adaptive colour plus process

A second option is to use the motion adaptive colour plus (MACP) process (the improved method of colour coding used in the PALplus system. See Recommendation ITU-R BT.1197). This process has been designed to be suitable for use in composite PAL environments where the encoded signal bandwidth is restricted to about 5-6 MHz. Applications could include studio-to-studio linking.

1.2 Adjustments to conventional production equipment

1.2.1 Cameras

CCD cameras switchable between 16:9 and 4:3 formats are now commonly available. The new 16:9 sensors have the same image diagonal as the earlier 4:3 sensors. Lenses for the latter format can be used without any change in zoom range (or angle of view). When switching to the 4:3 format the image diagonal is reduced and consequently the angle of view.

Lenses for studio-type cameras compensating for this viewing angle reduction, are now available. These lenses have a range extender turret equipped with a unit for reduction of image size in the same ratio as the diagonal is reduced.

When switching between the two formats, the settings of the image enhancer unit must be changed accordingly to maintain optimum image quality.

The scanning of camera tubes can be modified to provide the new aspect ratio. In order to maintain the same lens performance with the 16:9 aspect ratio, the image diagonal must be kept unchanged. To maintain optimum picture quality with the 16:9 aspect ratio, it may be necessary to optimize the adjustments of a number of the camera functions. Some of these adjustments may be time consuming. If the same set of tubes are used for both aspect ratios, it is likely that scanning marks will be visible in the picture.

1.2.2 Telecine

For flying spot telecines, the methods of changing between 4:3 and 16:9 operation are simple. Either a change of gate is used (16 mm – Super 16 mm) or the telecine is re-scanned. Problems may arise with raster burning if the same scanning tube is used for both ratios.

Modern types of CCD telecines with a suitable line-array sensor provide an easy and reliable change-over between 4:3 and 16:9 formats. Separate optical blocks together with integrated sizing and zooming facilities can be used for the replay of any of the various current film formats.

1.2.3 Processing

Equipment such as vision mixers, digital video effect generators (DVEs), caption generators and graphic systems can be used with the 16:9 aspect ratio without any modification to the hardware. Only the software must be updated to accommodate the geometry of the new image format.

1.2.4 Videotape recorders

In the case of analogue component videotape recorders (VTRs) the bandwidth is about 5.5 MHz. Taking into account the change of aspect ratio, this becomes equivalent to a resolution of about 4 MHz in a conventional system with a 4:3 aspect ratio. This resolution is deemed to be sufficient for the enhanced emission systems considered here. Consequently existing analogue component VTRs can be used for this application.

In the case of digital component VTRs with 720 samples per active line, the resolution is the same as the one envisaged for the emission systems considered here. Consequently existing digital component VTRs are perfectly able to be used for this application in Europe.

The Asia-Pacific Broadcasting Union (ABU) is of the view that consideration should also be given to the adoption of 960 samples per active line.

In the case of digital D2 and D3 composite recorders, bandwidths in excess of 8.8 MHz for PAL are available for a single composite signal. The video bandwidth achievable using these formats depends on the nature of the modified composite signal described in § 1.1.3.

1.2.5 Monitoring

Picture monitors with 4:3 aspect ratio cathode ray tubes (CRTs) may possibly be adjusted to give a letter-box 16:9 aspect ratio picture. It is likely that the monitor must be completely realigned if such a scanning readjustment is implemented.

Picture monitors switchable between the two aspect ratios are now available. A requirement for these monitors must be that no realignment is necessary when switching between the formats.

Waveform monitoring equipment can be used for both aspect ratios without any modifications.

2 Down conversion from HDTV sources

The use of HDTV equipment gives a single source which can be used for all the 16:9 services currently envisaged, from enhanced to high definition.

Whilst for enhanced definition services this may have substantially more "headroom" than required, this approach has the advantage that only one step of re-equipment is likely to be needed. Thus the recorded programmes would have adequate quality for the near-term analogue and the long-term digital HDTV as well as for 35 mm film distribution and archival purposes.

The HDTV studio source would be down converted to match the input requirement of the enhanced TV system encoders. Such a method of production and down conversion has already been successfully implemented.

The advantages of using HDTV studio sources for enhanced services, compared with lower definition sources, depend on the time-scales for the establishment of the studio facilities and the implementation of HDTV services.

The choice may also be influenced by the range of services for which the programmes are likely to be used, i.e. solely for one particular enhanced service or for a number of services at various levels of definition.

3 Improved film production methods

Film offers a suitable recording and storage medium for future productions of wide screen programmes.

For the production of 625/50 programmes in the 16:9 aspect ratio on film, the most cost-effective solution would be to take the standard 16 mm camera aperture, with an aspect ratio of 1.37:1, and mask it down for a 16:9 presentation on a widescreen display. Should wide screen transmission for television be the predominant aim, the Super 16 mm format, with a nominal aspect ratio of 1.66:1, should preferably be used for image capture, as this format allows a larger image area to be recorded on the film. The standard 16 mm camera aperture would need to be modified to Super 16 mm aperture and the lens axis would need to be re-centred. Modern 16 mm film cameras enable a simple and quick change-over between standard and Super 16 mm mode of operation.

In order to be prepared for future broadcast of film programmes in higher quality television systems (e.g. HDTV), production on 35 mm film would be the better choice. A compromise approach, for the adaptation of the recorded image format for presentation both on 16:9 and 4:3 TV receivers, can be the "shoot and protect" concept. Two possibilities for such dual-purpose TV productions are currently used for film productions in European broadcasting organizations:

– the "Academy" camera aperture, with an aspect ratio of 1.37:1 (the areas above and below a 16:9 area are protected);

– or a camera aperture with an aspect ratio of 1.66:1 (the areas on either side of the central 4:3 area are protected).

The selection of the wanted image area for either 16:9 or 4:3 transmission can be done at the stage of film-to-tape transfer.

See also Recommendations ITU-R BR.782, ITU-R BR.783 and ITU-R BR.716.

ANNEX 2

The Com^3 system: a PAL-compatible digital component coding system

1 Introduction

This Annex describes a video coding system which conveys video component signals at near Recommendation ITU-R BT.601 (Part A) (13.5 MHz) quality, through existing digital or analogue composite PAL or NTSC infrastructures.

The key features of this system, known as Com^3, are:

– luminance bandwidth comparable with Recommendation ITU-R BT.601,

– isotropic chrominance resolution for 16:9 aspect ratio viewing,

– complete freedom from cross-colour and cross-luminance,

– coded signal is usable with the majority of composite PAL/NTSC equipment,

– luminance bandwidth of 5 MHz and freedom from cross effects are maintained after band limiting of the coded signal to normal PAL/NTSC bandwidths,

– the single wire component coded signal can be decoded by conventional PAL/NTSC decoders with a just perceptible reduction in quality,

– conventionally coded PAL/NTSC can be decoded by the single wire component decoder, with a slight improvement in quality.

The development and field testing of this system has now progressed to the stage where it is possible to define a full specification, as a precursor to the standardization process.

2 Basic form of signal

The coded signal (Fig. 1) conveys areas of the luminance and chrominance frequency spectrum shown in Fig. 2. The signal is formed by first processing an *RGB* signal to obtain band-limited luminance and chrominance signals using the arrangement shown in Fig. 3. The luminance and chrominance signals are then processed to form the coded signal using the arrangement shown in Fig. 4; this incorporates a *Weston PAL assembler* that forms the PAL-like part of the signal, together with additional circuitry concerned with the high-frequency luminance signal. In a decoder, the signal is separated into sampled luminance and chrominance by the circuitry shown in Fig. 5. These signals are then post-filtered and converted back to *RGB* as shown in Fig. 6.

FIGURE 1

Spectrum of Com^3 signal

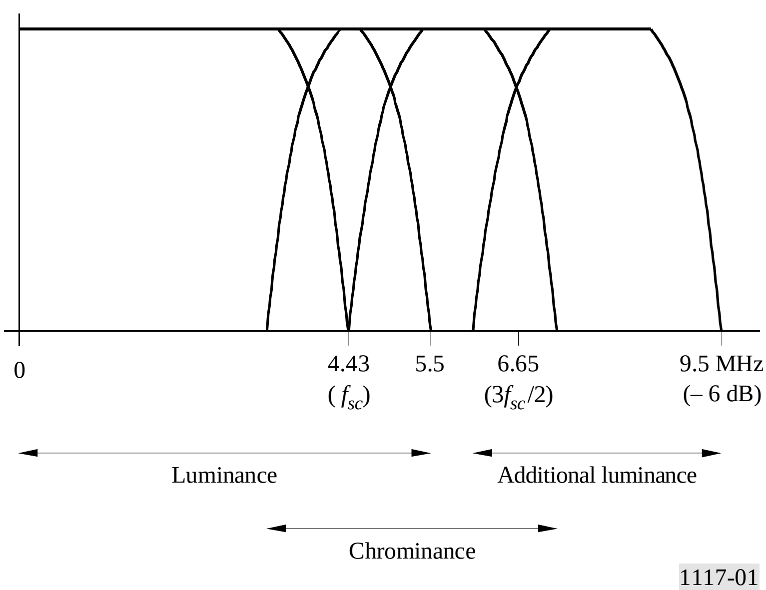


FIGURE 2

The two-dimensional spectra of the luminance and chrominance signals that may be conveyed by the coded signal, drawn for a 16:9 aspect ratio

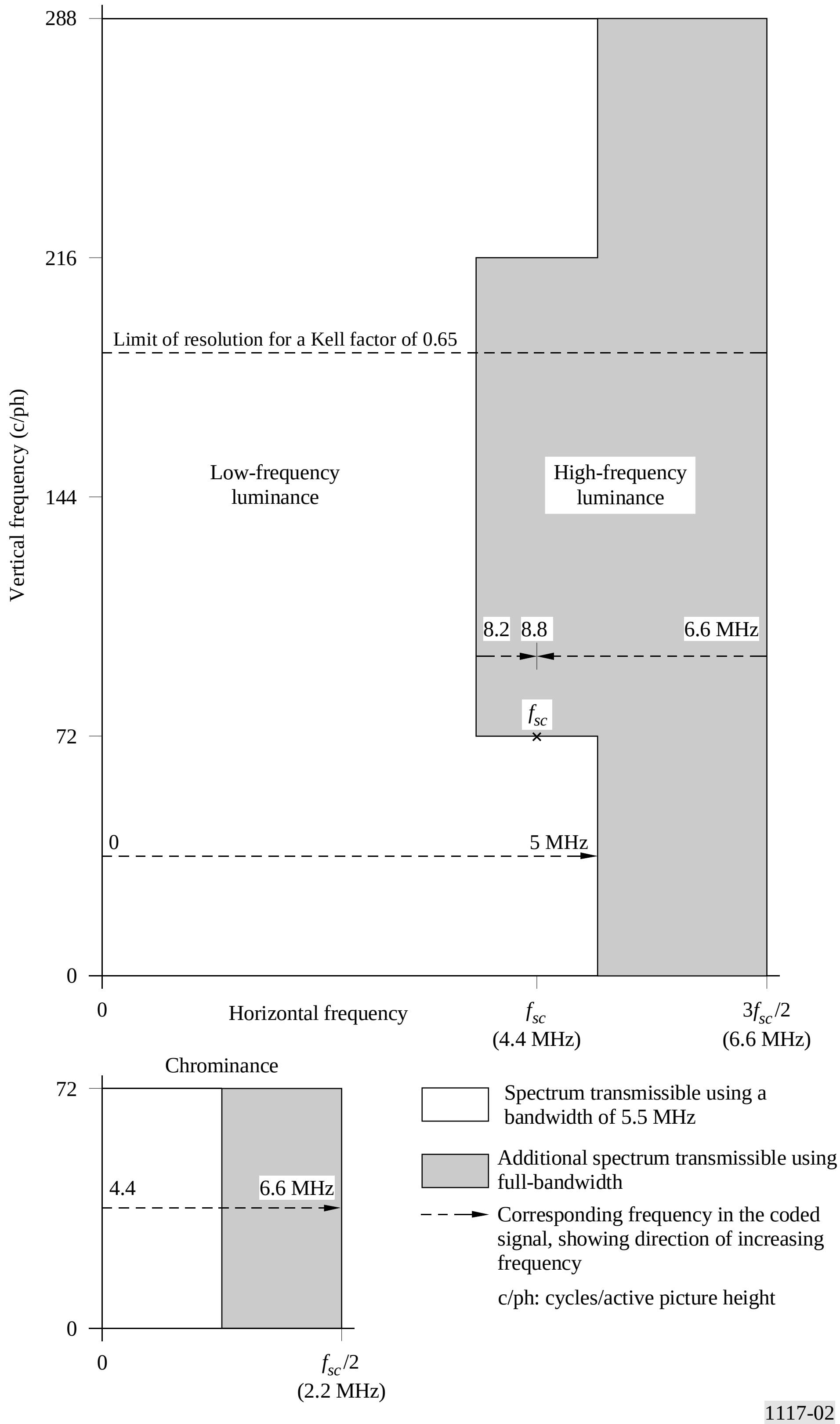


FIGURE 3

Pre-filters and vertical chrominance sampler in a coder

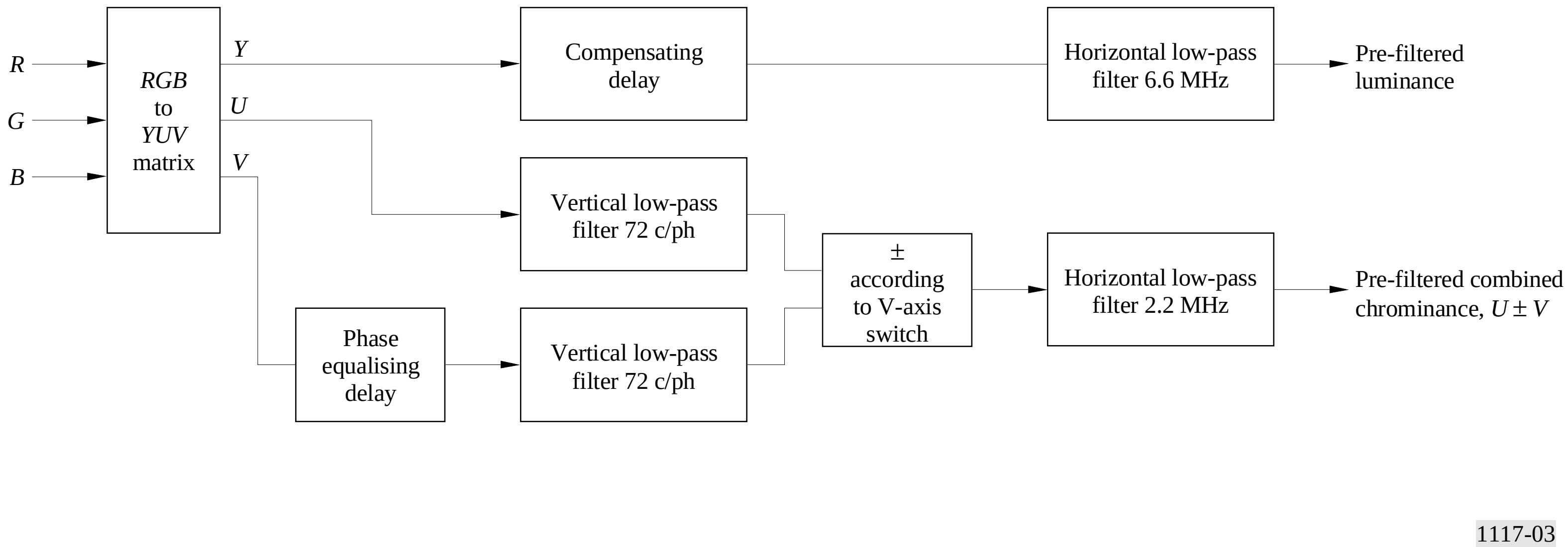


FIGURE 4

Block diagram of circuitry for forming a coded signal from the pre-filtered luminance and combined chrominance signals

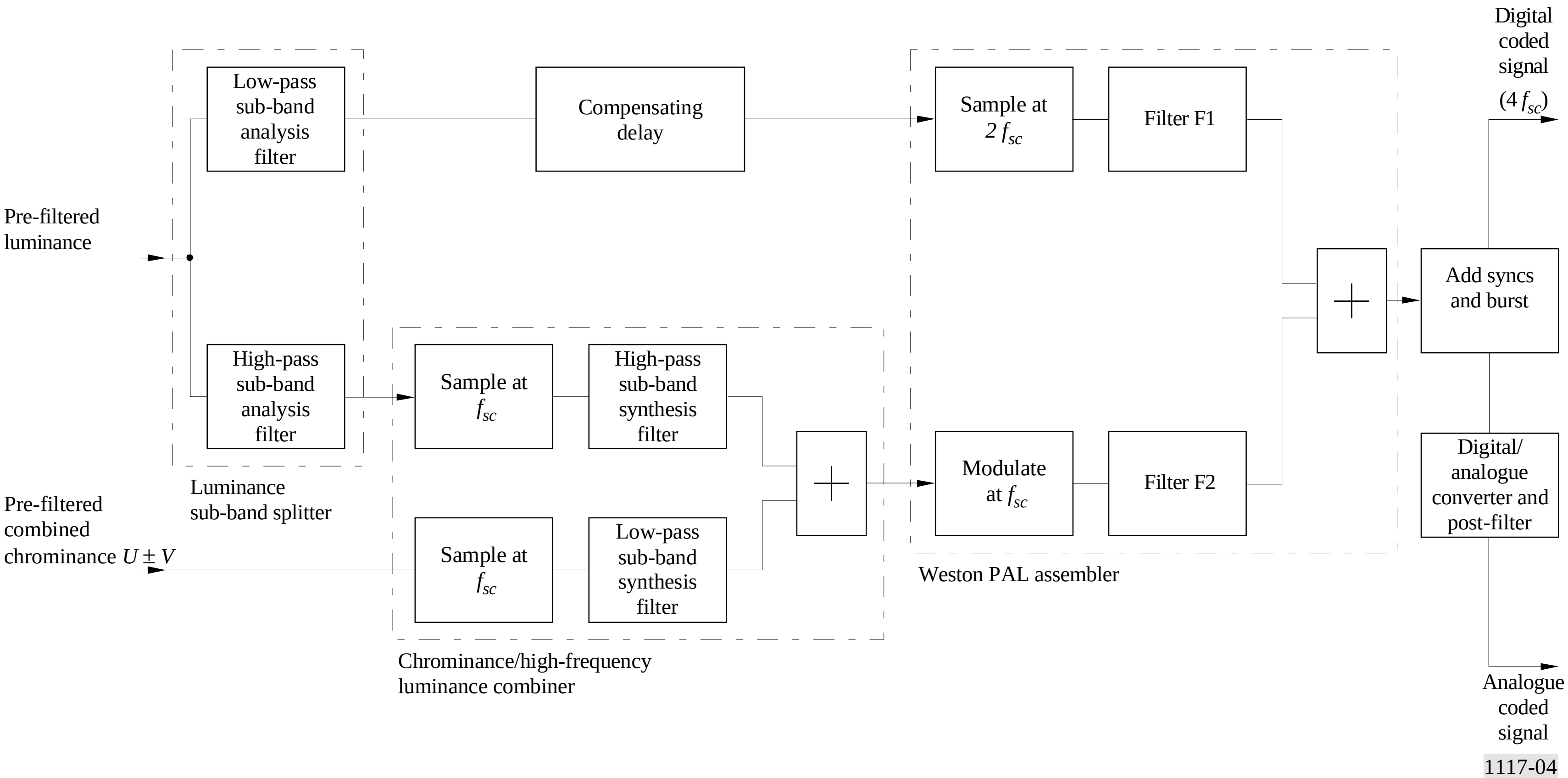


FIGURE 5

Block diagram of circuitry for splitting the coded signal into sampled luminance and combined chrominance signals

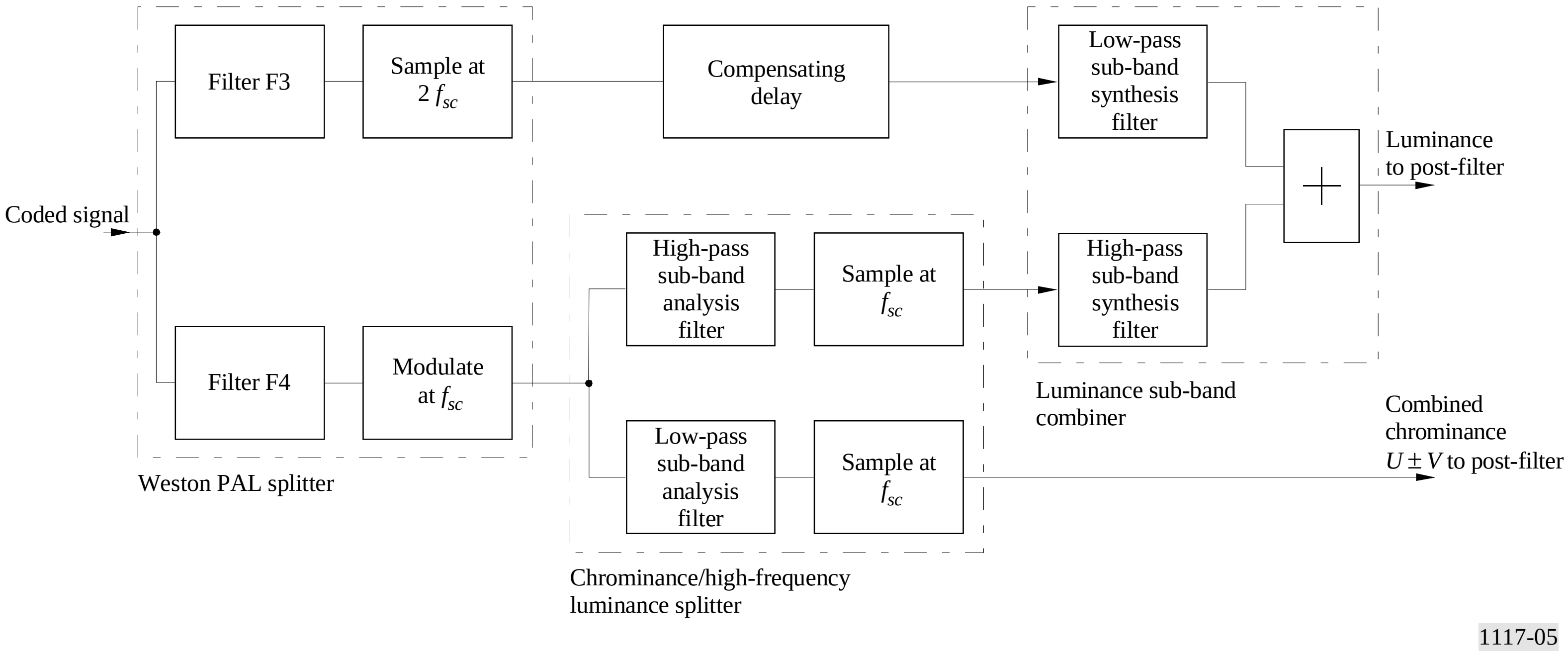
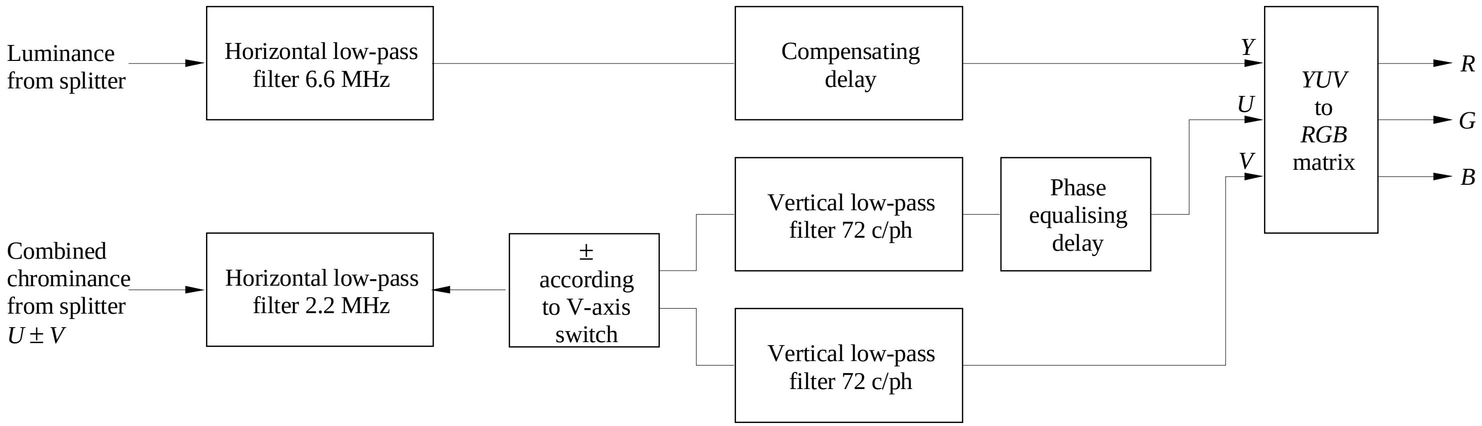


FIGURE 6

Post filters in a decoder



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The basic format of the signal is exactly like normal PAL. Indeed, in plain areas (where only very low frequency luminance and chrominance signals are present and there is no variation of chrominance from line-to-line), the signal is identical to a normal PAL signal. This specification therefore does not discuss aspects such as signal levels, timing of sync pulses or subcarrier phase.

The coded signal will be specified by defining the filter responses and sampling lattices used in Figs. 3 and 4. The responses of the filters of Fig. 4 are more critical than those of Fig. 3, since they determine the details of the spectrum of Fig. 1 and thus the degree to which the various parts of the coded signal may be separated from each other in a decoder. There are many sets of filters that could be used which would allow (near) perfect separation of the component signals in a decoder using a corresponding set of filters; however, it is necessary to specify one unique set of filters in order to define precisely a signal format that can be coded and decoded using equipment produced by many manufacturers.

3 Pre- and post-filters for luminance and chrominance

A suitable template for the 6.6 MHz low-pass luminance pre-filter is given in Fig. 7. The low-pass post-filter in the decoder (Fig. 6) may have the same response. The template shows that the filter is approximately 3 dB down at 6.6 MHz ($3f_{sc}/2$), the notional frequency at which the luminance signal is sampled. This allows the pre-post filter product to be a Nyquist filter (skew-symmetric about a gain of 0.5 at $3f_{sc}/2$), to prevent loss of quality in applications in which an extended studio PAL signal is to be decoded to component form and subsequently re-coded in the same sampling phase.

A suitable template for the 2.2 MHz low-pass chrominance pre-filter is given in Fig. 8. The low-pass post-filter in the decoder (Fig. 6) may have the same response, although it may be preferable to include a view filter that has a more gentle roll-off, to reduce the visibility of horizontal ringing. The template shows that the filter response is approximately 3 dB down at $f_{sc}/2$ to allow the product of the pre- and post-filter response to be Nyquist, as discussed above for the luminance.

The chrominance vertical pre- and post-filters should have unity gain at 0 c/ph, a notional cut-off point at 72 c/ph, and should have a null at 144 c/ph (c/ph is used as an abbreviation for cycles per active picture height, so for example, 144 c/ph is the highest vertical frequency that may be represented in a single field). A template for these filters is not given, since the detailed response achievable in practice will be determined by the chosen implementation. The filter should have a group delay of an odd number of half-lines; this is necessary to ensure that chrominance and luminance may be vertically co-timed at the coder output.

A "combined chrominance" signal is formed from the vertically-filtered chrominance signals, consisting of $U + V$ and $U – V$ on alternate lines, determined by the polarity of the V-axis switch.

4 Luminance sub-band splitter filters

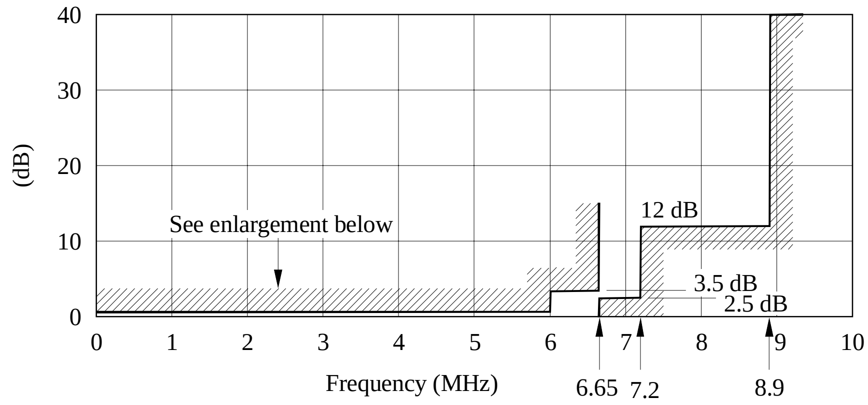
The filters used to split the luminance signal into low-frequency and high-frequency parts in the coder and to recombine these parts in the decoder are two-dimensional sub-band analysis and synthesis filters. Each filter has a vertical aperture of two lines.

The filters can be expressed in terms of four one-dimensional filters: $L1_y$, $L2_y$, $H1_y$ and $H2_y$.

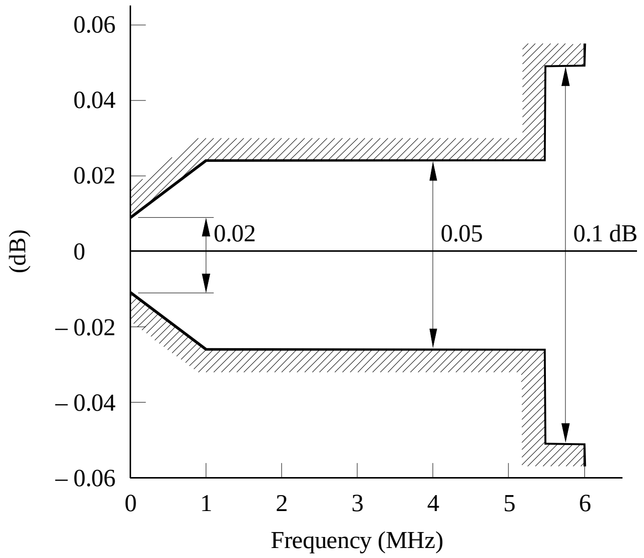
Templates for the filters $L1_y$ and $L2_y$ are shown in Figs. 9 and 10. Group delay templates are included largely for completeness; it is expected that these filters would be implemented as symmetrical digital FIR filters and would thus have exactly zero group delay. In order to ensure the minimum degradation of the luminance signal by a codec, $L1_y$ should be such that $L1_y^2$ is antisymmetric about a response of 1/2 at $0.875f_{sc}$. Similarly, $L2_y$ should be such that $L2_y^2$ is antisymmetric about a response of 1/2 at $1.125f_{sc}$.

FIGURE 7

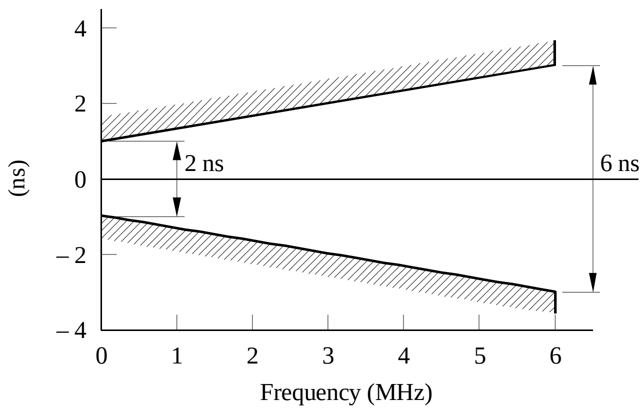
Frequency response of luminance pre-and post-filter



a) Frequency response



b) Pass-band ripple



c) Pass-band group delay

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FIGURE 8

Frequency response of chrominance horizontal pre-and post-filter

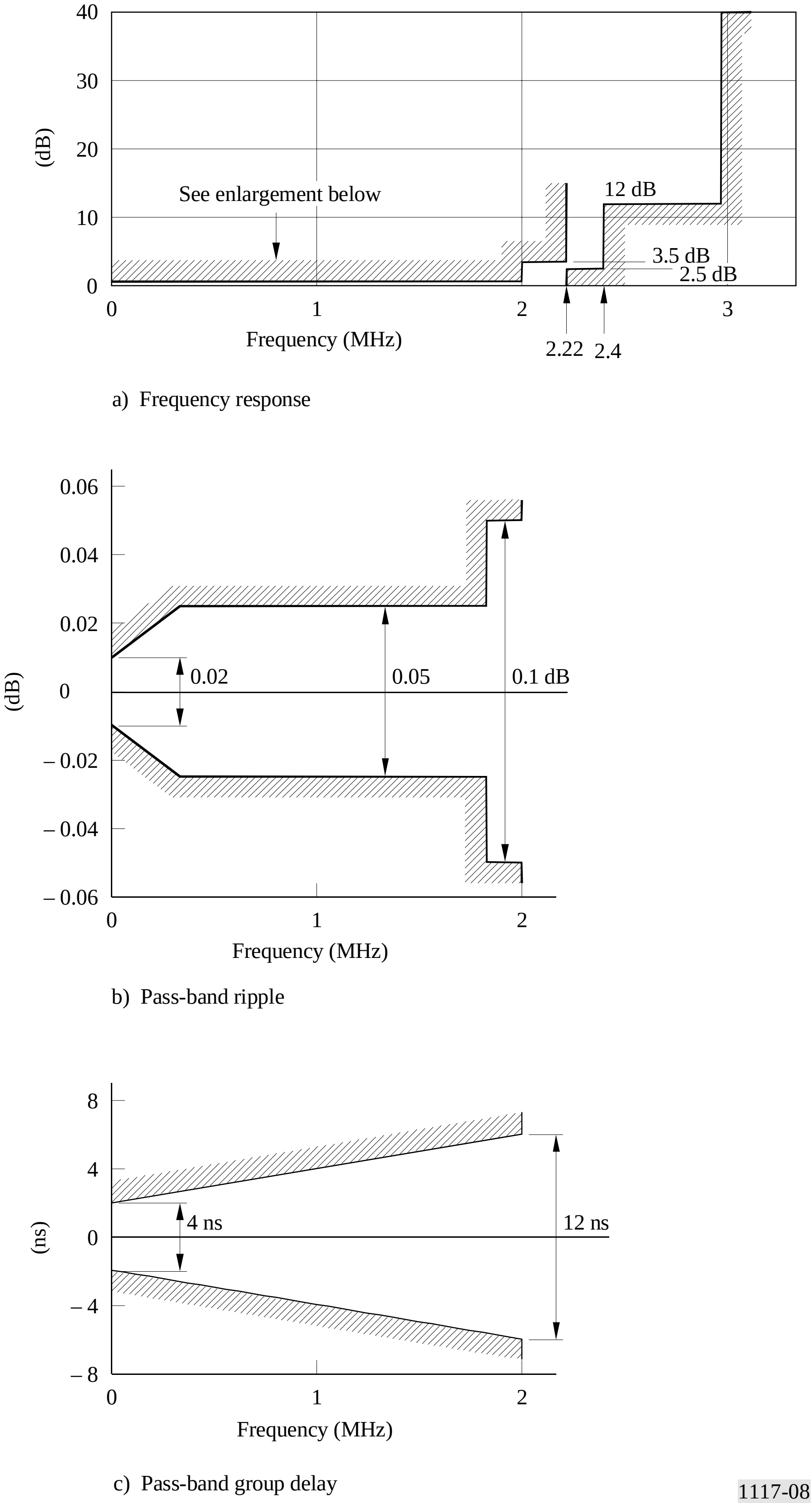


FIGURE 9

Frequency response of filter $L1_y$ used to make luminance sub-band splitter

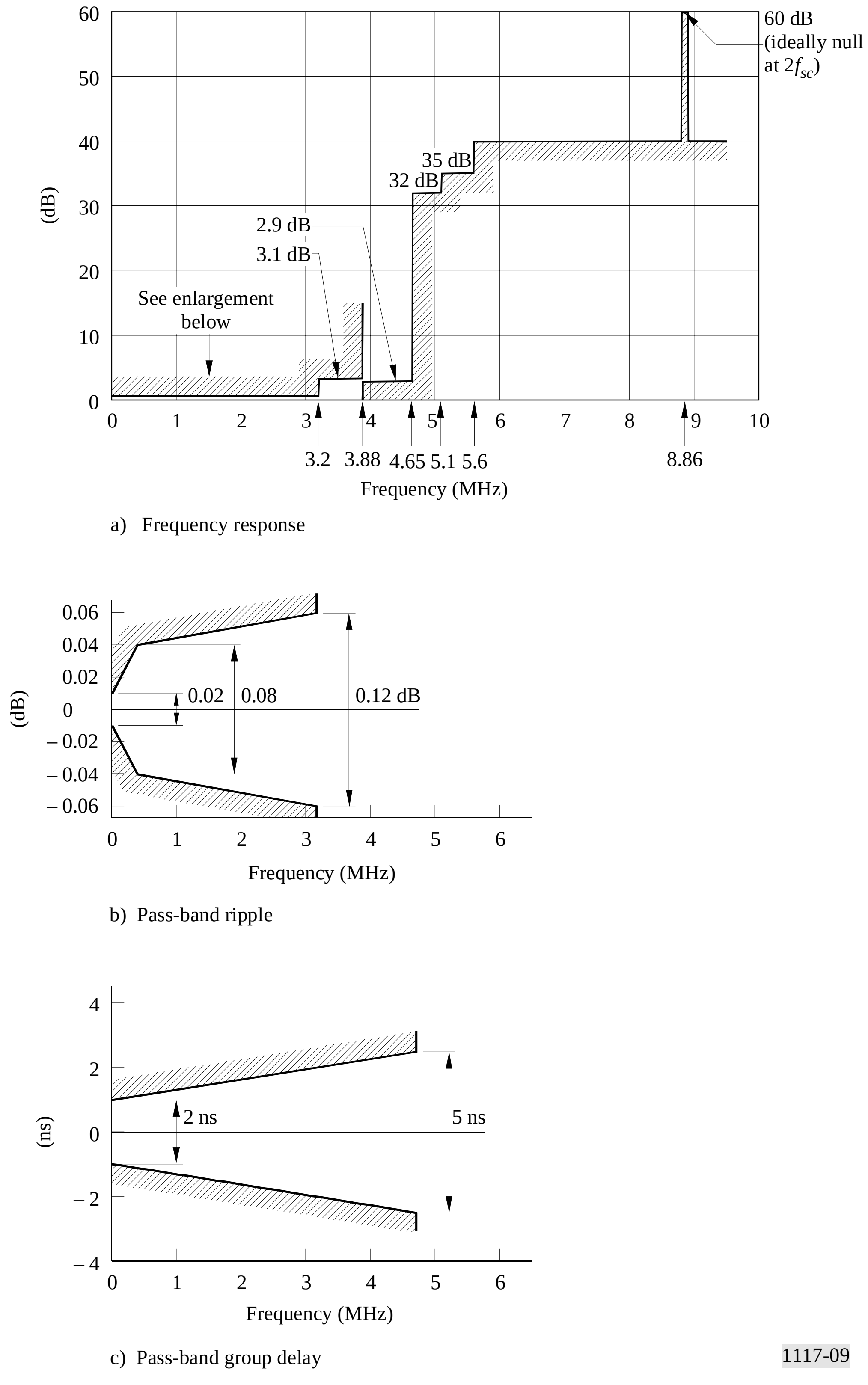
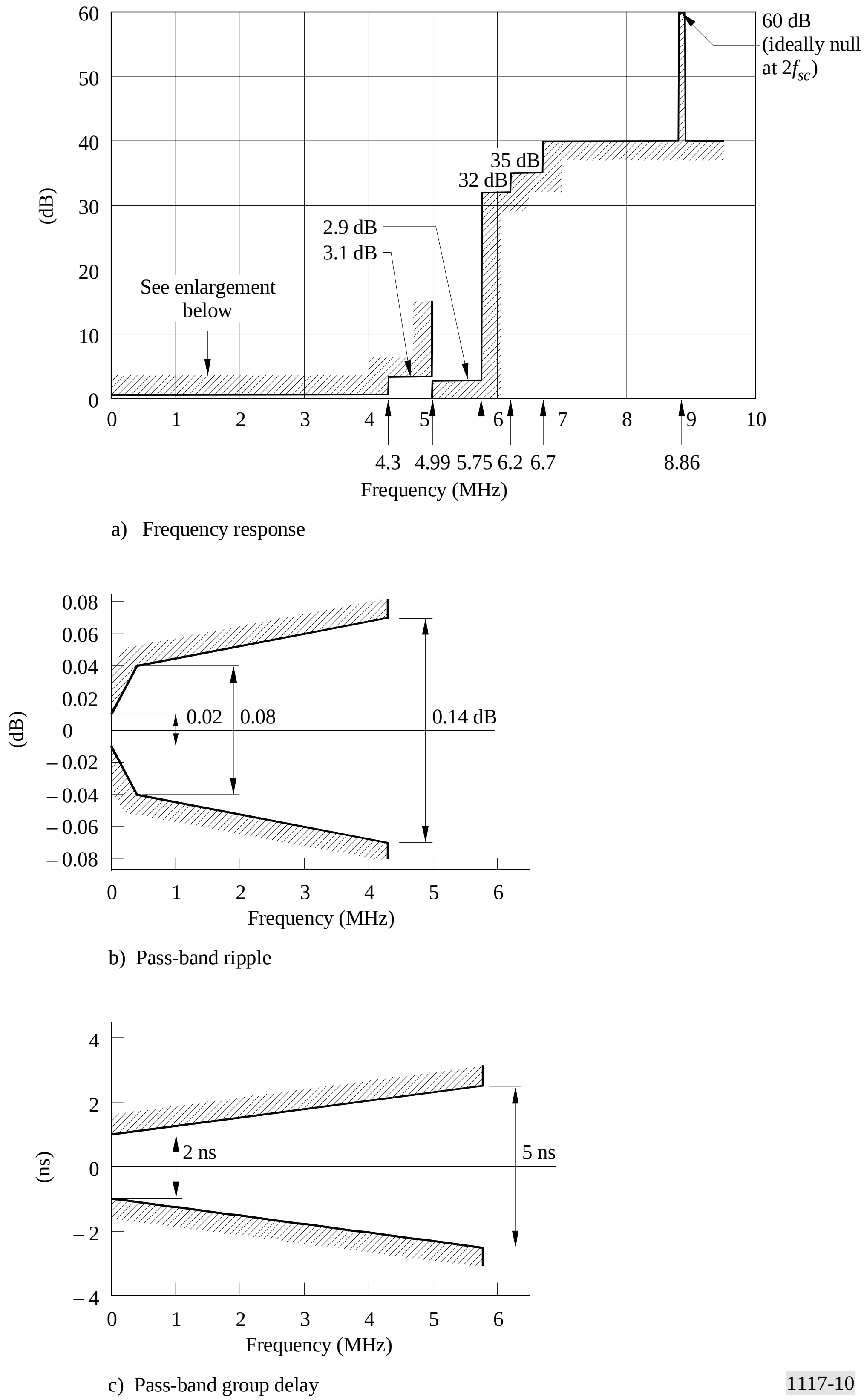


FIGURE 10

Frequency response of filter L2$_y$ used to make luminance sub-band splitter



The filters $H1_y$ and $H2_y$ have responses that are the reflection about f_{sc} of the responses of $L2_y$ and $L1_y$ respectively. For example, if the central coefficients of a digital filter operating at $4f_{sc}$ representing $L1_y$ are:

.. .. .. c3 c2 c1 c0 c1 c2 c3 .. .. ..,

then the corresponding coefficients of $H2_y$ are:

.. .. .. – c3 c2 – c1 c0 – c1 c2 – c3 .. .. ..

The analysis filters in the luminance sub-band splitter in the coder (Fig. 4) and the synthesis filters in the luminance sub-band combiner in the decoder (Fig. 5) are constructed from the four filters $L1_y$, $L2_y$, $H1_y$ and $H2_y$ according to Table 1.

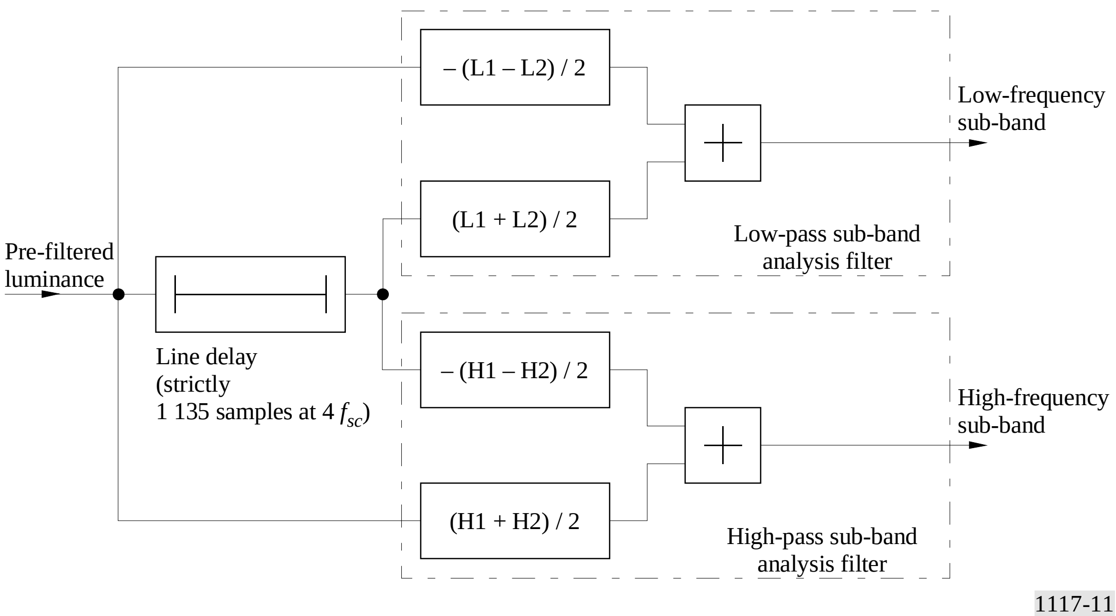
TABLE 1

	Non-delayed line	Delayed line
Analysis Low-pass High-pass	– (L1 – L2) / 2 (H1 + H2) / 2	(L1 + L2) / 2 – (H1 – H2) / 2
Synthesis Low-pass High-pass	(L1 + L2) / 2 – (H1 – H2) / 2	– (L1 – L2) / 2 (H1 + H2) / 2

Figure 11 shows a block diagram of the luminance sub-band splitter filters in the coder, which are in accordance with Table 1. From the positions of the low-frequency contributions it will be seen that the low-pass analysis filter introduces a delay of one line period at low frequencies whereas the corresponding synthesis filter passes low frequencies without introducing such a delay.

FIGURE 11

Block diagram of luminance sub-band splitter in the coder



5 Sub-band filters for combining chrominance and high-frequency luminance

These filters are one-dimensional sub-band synthesis filters. They determine the spectrum of the coded signal in the region around 6.6 MHz. The low-pass synthesis filter has an amplitude response which is maximally flat at DC and f_{sc} and is –3 dB at $f_{sc}/2$. It is not quite phaseless; this allows the combination of analysis and synthesis filters to give perfect reconstruction and to have a well-behaved amplitude response while having a relatively small horizontal aperture. The maximally-flat nature of the response ensures that virtually no high-frequency luminance information travels in the region interpreted as chrominance by a normal PAL decoder, by virtue of the high attenuation of the high-pass synthesis filter around DC. This prevents high-frequency luminance information giving rise to cross-colour when a normal PAL decoder is used.

Figure 12 shows a template for the response of the low-pass synthesis filter which acts as a low-pass filter in the coder after up-sampling the sampled chrominance signal from f_{sc} to $2f_{sc}$.

The high-pass synthesis filter is derived from the low-pass synthesis filter by inverting alternate coefficients and inserting a delay of one clock cycle at $2f_{sc}$, and then reversing the order of the resulting coefficients. This relationship is well-known in the field of sub-band analysis-synthesis.

The analysis filters used to separate chrominance and high-frequency luminance in the decoder are derived by reversing the order of the coefficients in the corresponding synthesis filters.

The f_{sc}-sampling operation at the input to the two synthesis filters consists of multiplying the signal by a delta function with a period of $1/f_{sc}$, co-phased with the colour subcarrier. If the coder is realized using circuitry clocked at $4f_{sc}$, this sampling operation reduces to forcing three samples out of four to zero.

6 Weston PAL assembler and splitter filters

These filters are specified in a similar way to the luminance sub-band analysis and synthesis filters, in terms of four one-dimensional filters: $L1_w$, $L2_w$, $H1_w$ and $H2_w$.

Templates for the filters $L1_w$ and $L2_w$ are shown in Figs. 13 and 14. Group delay templates are included largely for completeness; it is expected that these filters would be implemented as symmetrical digital FIR filters and would thus have exactly zero group delay. In order to ensure the minimum degradation of the luminance signal by a codec, $L1_w$ should be such that $L1_w^2$ is antisymmetric about a response of 1/2 at $0.8f_{sc}$. Similarly, $L2_w$ should be such that $L2_w^2$ is antisymmetric about a response of 1/2 at $1.2f_{sc}$. Note the tight constraints on filter responses at f_{sc}; this is to ensure good compatibility with normal PAL.

The filters $H1_w$ and $H2_w$ are derived from $L1_w$ and $L2_w$ in exactly the manner described for the luminance sub-band filters.

The filters F1-F4 are constructed from these four filters according to Table 2.

TABLE 2

	Non-delayed line	Delayed line
Assembler		
F1 (low-pass)	(L1 + L2) / 2	– (L1 – L2) / 2
F2 (high-pass)	– (H1 – H2) / 2	(H1 + H2) / 2
Splitter		
F3 (low-pass)	– (L1 – L2) / 2	(L1 + L2) / 2
F4 (high-pass)	(H1 + H2) / 2	– (H1 – H2) / 2

From the positions of the low-frequency contributions (L1 + L2) it will be seen that F3 introduces a delay of one line period to low luminance frequencies whereas F1 passes low frequencies without introducing such a delay. Filters F1 and F2 may be realized in a manner similar to that shown in Fig. 11.

FIGURE 12

Response of low-pass sub-band synthesis filter used to combine chrominance and high-frequency luminance signals

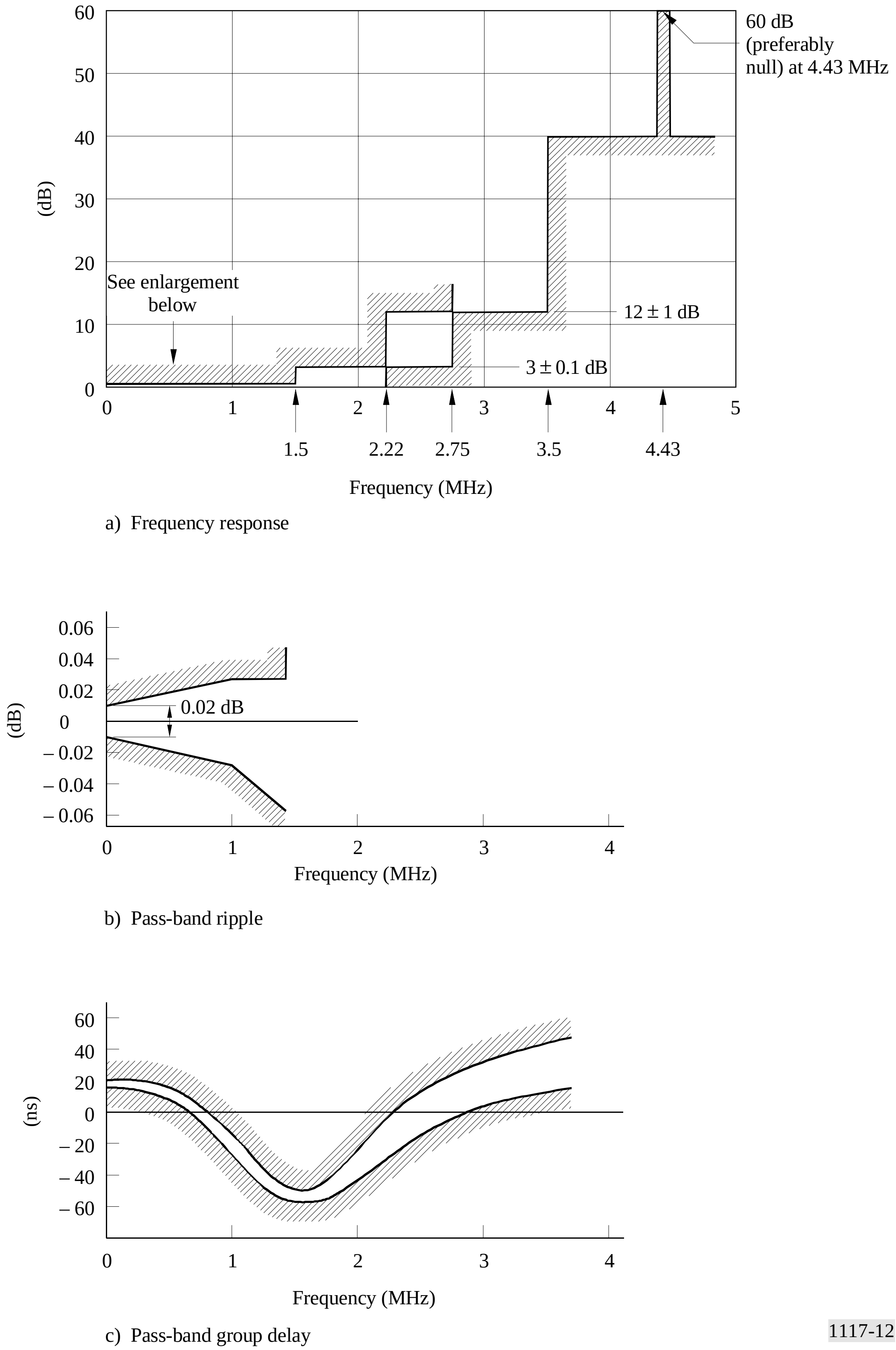


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FIGURE 13

Frequency response of filter $L1_w$ used to make Weston PAL assembler

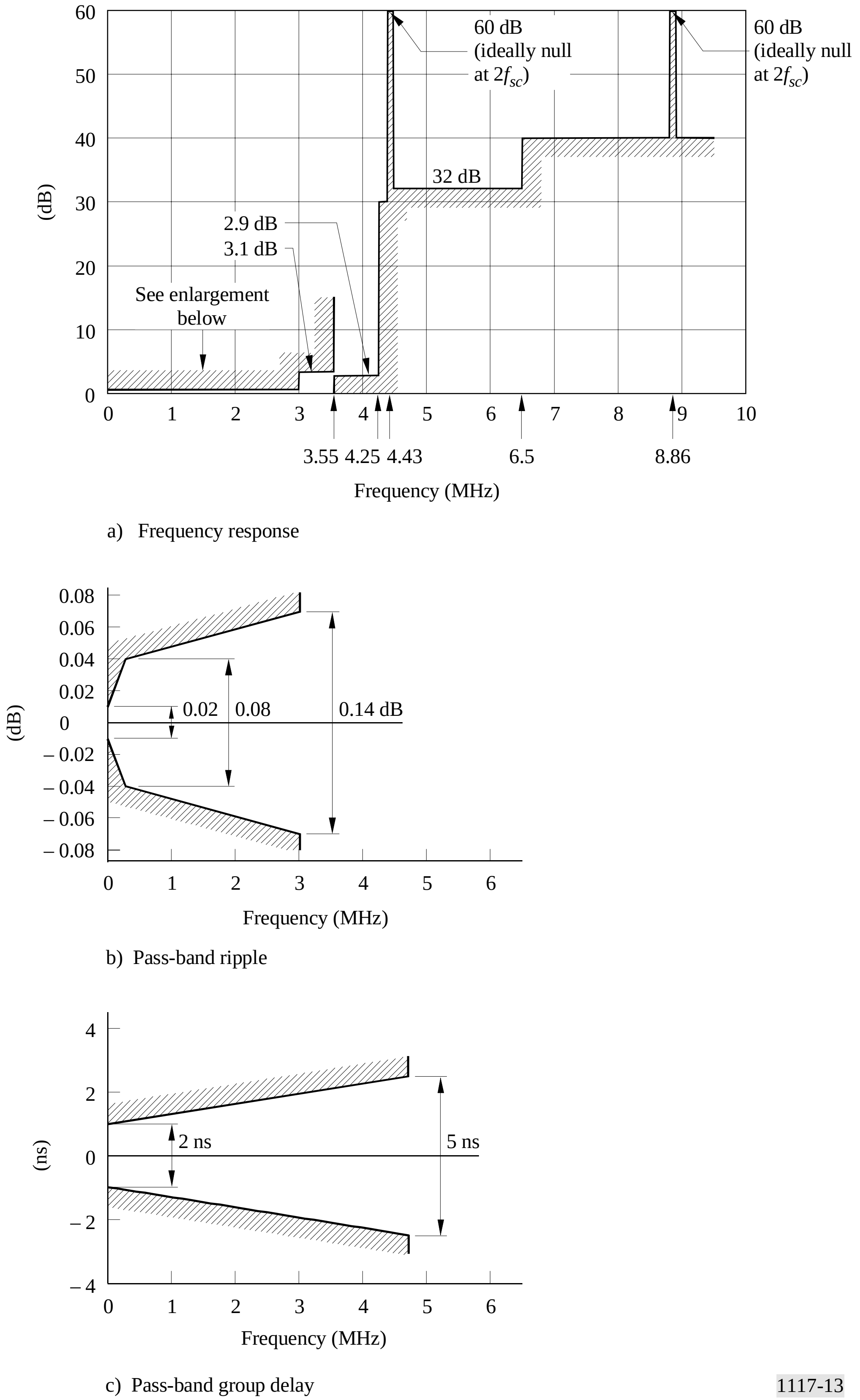

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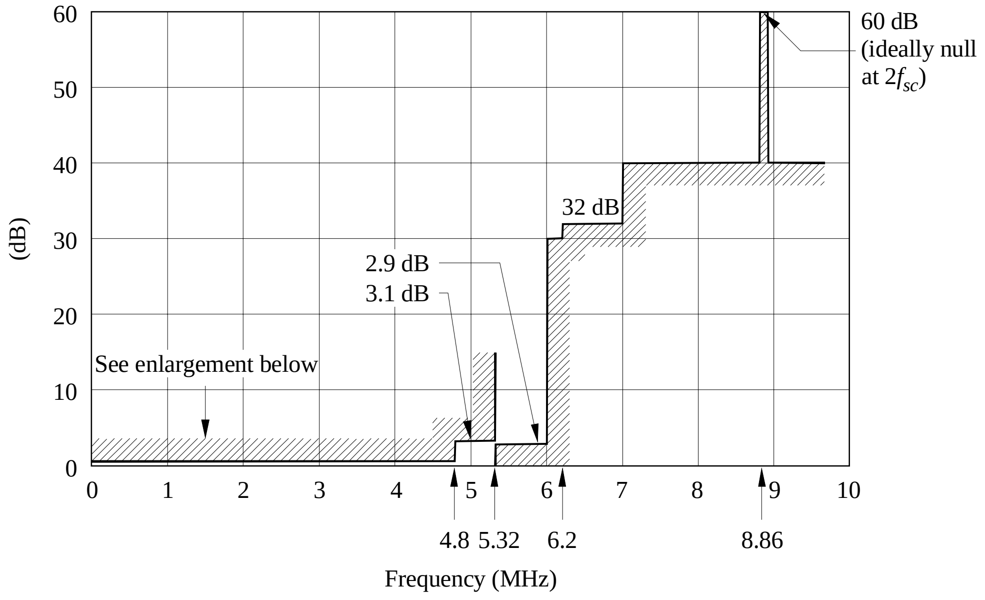
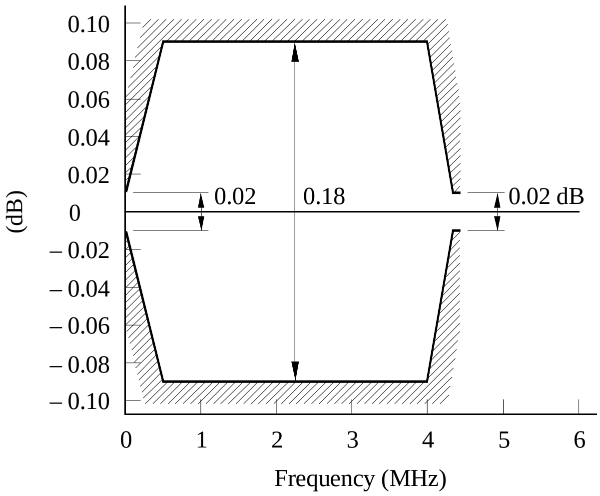
FIGURE 14

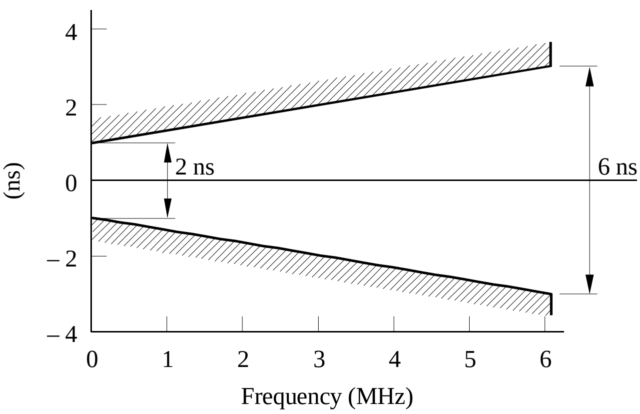
Frequency response of filter $L2_w$ used to make Weston PAL assembler



a) Frequency response



b) Pass-band ripple



c) Pass-band group delay

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7 Compensating delays

The delays through the luminance and chrominance paths of the coder clearly need to be equal to ensure that the coded picture appears correctly registered on both the decoder of Figs. 5 and 6 and a normal PAL decoder.

The luminance low-pass analysis filter introduces a delay of one line period, whilst F1 does not introduce such a delay, as explained earlier. Thus the circuitry of Fig. 4 introduces a total delay of one line period to the luminance signal. The filter F2 acts like a vertical filter having coefficients of –½, ½ at f_{sc} and thus introduces a delay to the chrominance signal of half a field line pitch.

Vertical alignment of luminance and chrominance can therefore be achieved by ensuring that the chrominance is vertically delayed by half a line pitch with respect to the luminance in the pre-filters of Fig. 3 and the post-filters of Fig. 6. A compensating delay will be required in the luminance path if the vertical chrominance pre-filter has a delay greater than half a line. Compensating delays for this purpose are shown in Figs. 3 and 6.

Correct horizontal alignment requires the addition of several delays:

– The luminance signal must be delayed by 2 samples at $4f_{sc}$ and the *V* chrominance signal by 4 samples (both relative to the *U* signal) in the pre-filters of Fig. 3. These delays are an approximate pre-correction for the differential delay introduced to *U* and *V* by the phase characteristic of the PAL assembler filter F2, and for the group delay characteristic of the low-pass sub-band synthesis filter used to combine chrominance and high-frequency luminance.

– To ensure correct positioning of the main luminance signal with the high-frequency luminance signal and the chrominance, a compensating delay is required in series with the signal passing through the filter F1 in Fig. 4 and F3 in Fig. 5. This delay compensates for the propagation delay through the sub-band filters used to join luminance and chrominance, and through the adder and modulator through which the combined signal passes. The value of the delay will depend on the exact design of the filters.

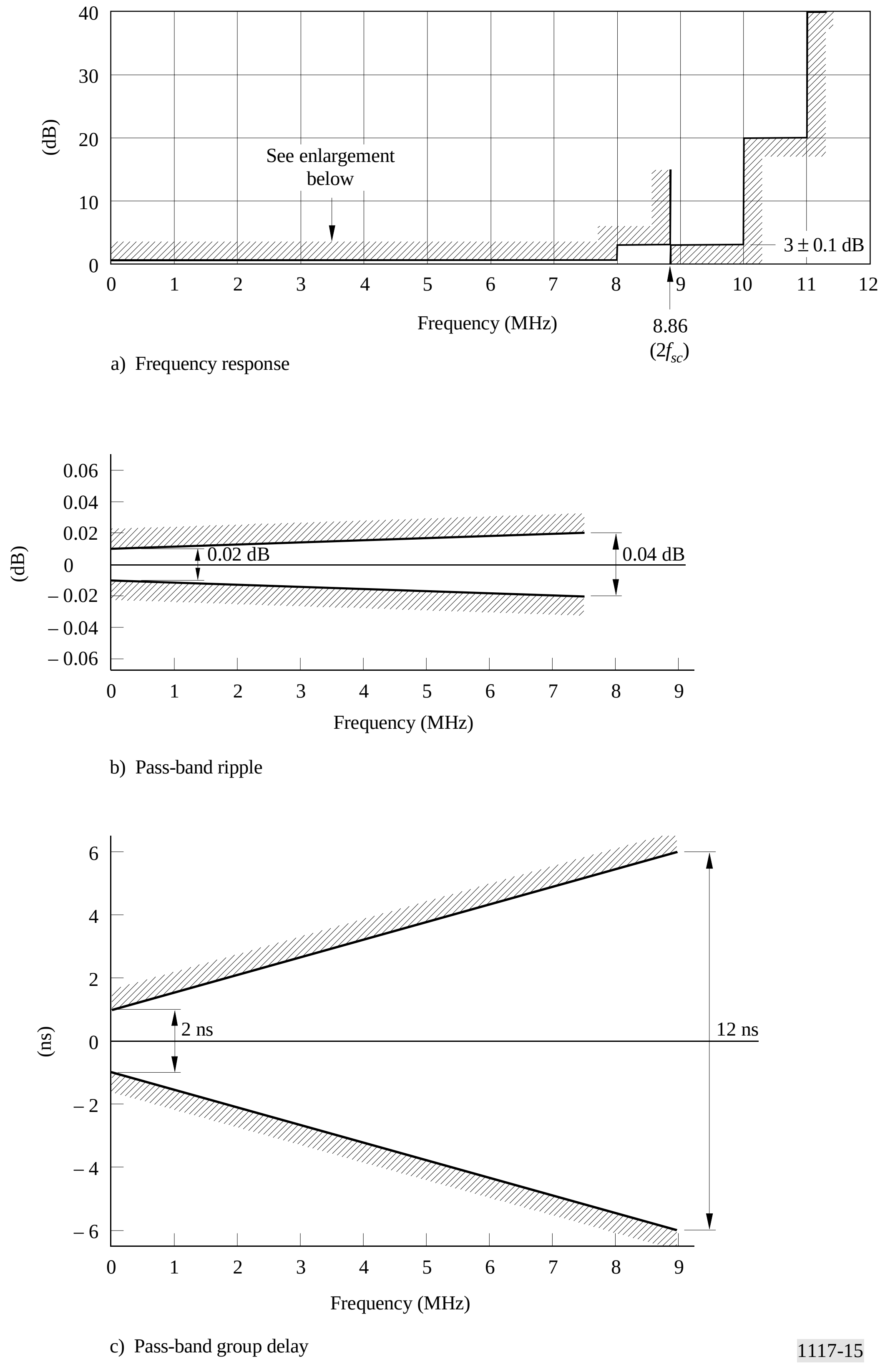
8 DAC post-filter

The frequency responses of the DAC post-filter at the output of the coder and the ADC pre-filter at the input to a decoder are chosen to have a product that is approximately Nyquist. The ideal response of the post-filter is shown in Fig. 15. The post-filter will of course include a sin $(x)/x$ equalizer, whose response is not included in the figure. Each filter, excluding the sin $(x)/x$ equalizer, is designed to be square-root Nyquist, and is 3 dB down at $2f_{SC}$. The ADC pre-filter in the decoder may have the same response.

Although the filter would normally be implemented as analogue circuitry, they may alternatively be implemented digitally by over-sampling the signal and using a DAC and ADC operating at a higher frequency. This will make it possible to achieve a pre-post product that is much closer to Nyquist, without problems associated with non-uniform group delay associated with analogue filters.

FIGURE 15

Frequency response of post-filter following the DAC
(discounting sin (*x*)/*x* equalizer)



APPENDIX 1

TO ANNEX 2

A European Broadcasting Union (EBU) evaluation of the Com^3 system

1 Introduction

Future broadcast distribution systems featuring improved quality and wide aspect ratio, such as digital, MAC and PALplus require source signals of “component” quality. The signal quality normally produced by composite equipment, although satisfactory for conventional delivery media, will not be good enough for the improved systems. Rapid introduction of new systems will, therefore, require an unacceptable level of capital investment by some broadcasters who have a large composite programme production infrastructure.

The composite compatible component (Com^3) system was developed by the British Broadcasting Corporation (BBC) to allow near component picture quality to be achieved over a wideband or digital composite infrastructure, as may be appropriate for a number of broadcasters. In this manner the capital investment burden will be reduced making a successful early introduction of new systems more likely.

2 The Com^3 system

The system specification makes the following claims:

– luminance resolution comparable with Recommendation ITU-R BT.601;

– isotropic chrominance resolution for 16:9 viewing;

– complete freedom from cross-colour and cross-luminance;

– coded signal is usable with the majority of composite PAL equipment;

– horizontal luminance bandwidth of 5 MHz and freedom from cross-effects are maintained after band limiting of the coded signal to normal PAL bandwidths;

– the coded signal can be decoded by conventional PAL decoders with a just perceptible reduction in quality;

– conventionally coded PAL/NTSC can be decoded by the Com^3 decoder, again with a slight improvement in quality.

Similar claims are made for NTSC although, after appropriate bandwidth limitation of the channel, the horizontal luminance bandwidth is correspondingly lower.

3 The experimental arrangement

The block diagram of the experimental arrangement is shown in Fig. 16.

A range of component sources was made available. These included luminance and chrominance frequency gratings, to explore the frequency responses of the system, and 16:9 aspect ratio video excerpts stored in component form on an Abekas disk drive and from D1 and Betacam videotape recorders. Down-converted HDTV sources in D1 format were also made available to provide high quality moving scenes. The members of the Expert Group were also invited to bring test material of their choice.

Means were provided for comparing the following coding paths:

– Com^3 encode – Com^3 decode,

– Conventional PAL encode – Conventional PAL decode,

– Com^3 encode – conventional PAL decode,

– Conventional PAL encode – Com^3 decode,

– Com^3 encode – field delay PAL decode,

– Conventional Pal encode – field delay decode.

The behaviour of Com^3 and PAL for limited bandwidth channels could be investigated by passing the signal through either a 5.5 MHz low-pass filter, a D3 recorder with standard filters or a remote VPR6 C format recorder. Two D3 videotape recorders were provided for recording and replay of Com^3 signals, one with standard input and output filters and one with modified filters (approximately half-Nyquist at 8.8 MHz – twice the PAL sub-carrier frequency).

Both 625-line and HDTV displays were provided. The 625-line display was an EV 1629 professional monitor and the HDTV display was a 38 in. SONY HDM 3830E fed by a Snell & Wilcox HD5100 up-converter. This arrangement allowed viewing of the source, the compatible picture and the decoded picture and the use of the SONY HDTV display ensured that the display tube was not a limiting factor.

3.1 Test sequences

The following test sequences were used in the evaluation along with a selection of longer natural sequences

3.1.1 Newpat

A highly critical test pattern which contains three different test signals:

– A two-dimensional luminance frequency sweep or zone-plate in which horizontal frequency increases vertically and vertical frequency increases horizontally. This part of the pattern allows luminance frequency response to be analysed and clearly reveals any alias patterns or spurious signal components such as cross-colour.

– Zone plates for the *U* and *V* chrominance components, holding the luminance constant; these again reveal aliasing and cross-luminance.

– A matrix of coloured squares which exercises every transition between the three primary and three complementary colours, black and white; this part of the pattern allows analysis of transient response and the level of *U*/*V* cross-talk.

3.1.2 Noël

A moving 16:9 sequence, originated in HDTV and down-converted to Recommendation ITU-R BT.601. This is a long excerpt from a light entertainment programme and contains several areas of highly detailed saturated colours. It was used for assessing subjective chrominance resolution and for detecting colour coding artefacts such as cross-luminance.

3.1.3 Cross-colour sequence

This is a moving sequence comprising a collection of patterned fabrics, chosen to excite both coarse and fine cross-colour, and some plain coloured fabrics which reveal the presence of cross-luminance. The camera pans and zooms over the scene.

3.1.4 Wimbledon

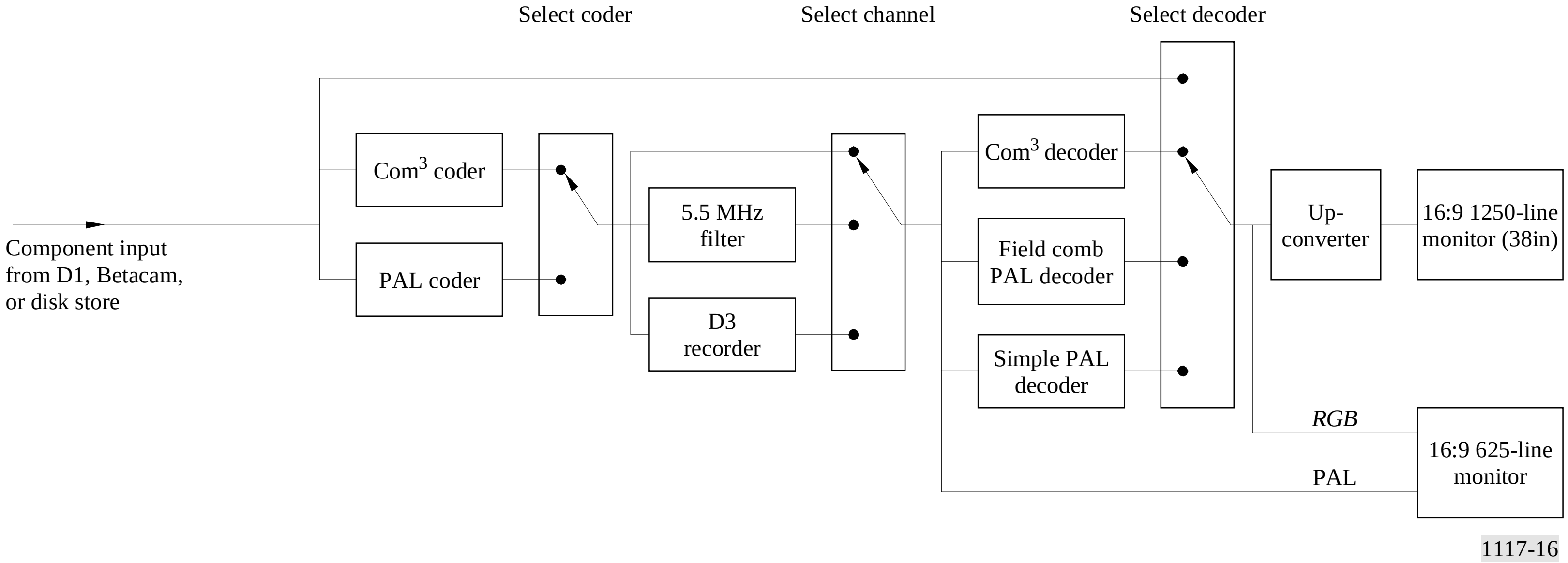
This is a palindromic sequence of a pan across a crowd of spectators at Wimbledon, and was originated at HDTV. As well as a high level of luminance detail, it contains numerous coloured areas, of varying size, hue and saturation, and chrominance transitions (in the spectator’s clothes). It was used for assessing luminance aliasing, small and large area cross-luminance, and chrominance bandwidth.

3.1.5 Gate

This is pan and zoom across a large and highly detailed, gilded wrought iron gate. It was used for assessing cross-effects and luminance aliasing.

FIGURE 16

Block diagram of equipment set-up for EBU evaluation of Com^3



4 The specialist evaluation

4.1 Behaviour of Com^3 with a flat channel (greater than 9 MHz)

4.1.1 Static luminance and chrominance resolution

Using the Newpat sequence the group concluded that the luminance bandwidth of the decoded Com^3 signal was comparable to that of the component source. There was, however, a barely perceptible moving high frequency alias appearing in the very high horizontal frequencies. This was later found not to be visible in natural pictures.

4.1.2 Chrominance resolution

Static chrominance resolution was assessed using the *U* and *V* zone-plate sections of the Newpat test pattern. The horizontal resolution of the decoded Com^3 signal, at 2.4 MHz was slightly lower than that of Recommendation ITU-R BT.601. It was observed that the vertical and horizontal resolutions of Com^3 were approximately equal. This means that the vertical resolution of Com^3 is approximately half that of Recommendation ITU-R BT.601.

This loss of chrominance resolution relative to Recommendation ITU-R BT.601 was also observed on critical natural pictures, e.g. Wimbledon.

Some ringing was observed on horizontal and vertical transitions of the coloured squares of the Newpat sequence but was not observed on natural pictures.

A comparison was also made between Com^3 and 4:2:0 processing. The two were found to be indistinguishable.

There was no perceptible cross-colour or cross-luminance.

4.1.3 Dynamic luminance and chrominance resolution

The dynamic luminance and chrominance resolutions of the system were investigated using a moving version of the Newpat test signal. No motion artefacts or modifications of the system performance could be observed.

4.1.4 Compatibility with conventional PAL

There are two compatibilities to be assessed, the ability of conventional decoders to decode the Com^3 signal and the ability of the Com^3 decoder to decode a conventionally PAL coded signal. These were again assessed using the Newpat test pattern and natural pictures.

4.1.5 Com^3 encoding followed by conventional PAL decoding

The Newpat test pattern and natural pictures, coded by the Com^3 coder were decoded by professional simple, line delay and field delay conventional PAL decoders.

Compared to PAL encoding-PAL decoding, there was a reduction in coarse cross-colour, similar levels of cross-luminance, a loss of vertical chrominance resolution and a slight horizontal chrominance mis-registration.

Overall, there was a barely perceptible loss of quality on natural pictures.

4.1.6 Conventional PAL coding followed by Com^3 decoding

The Newpat test pattern and natural pictures, coded by the conventional PAL encoder were viewed after decoding by the Com^3 decoder.

Compared to PAL encoding-PAL decoding, there was less large area cross-luminance. Edge cross-luminance was transferred from horizontal edges (as in normal colour bars) to vertical edges (as in horizontal colour bars). This behaviour is similar to that found with non-adaptive line or field comb PAL decoders. There was also an increase in coarse cross-colour.

On natural pictures, when cross-colour is not dominant, the overall picture quality was improved.

4.2 Behaviour of Com^3 with a non-flat channel

Since the Com^3 system uses the channel bandwidth between 4.4 and 8.8 MHz to increase the available luminance resolution, phase distortions over this band or reductions in channel bandwidth cause not only a reduction in available luminance bandwidth but also addition artefacts such as luminance aliasing and cross-effects. The visibility of these artefacts depends upon the magnitude of amplitude and phase distortions in the channel.

4.3 Behaviour of Com^3 with a 5.5 MHz channel bandwidth

A bandwidth limitation of 5.5 MHz was chosen as this is typical of internal limitations of some analogue and digital processing equipments. It also represents the nominal limit of many link systems.

With this filter in the channel, luminance resolution loss, luminance aliasing and cross-luminance were clearly visible in the Newpat test pattern. Luminance resolution loss, luminance aliasing and edge cross-luminance were visible on natural pictures.

The picture quality of Com^3 with a 5.5 MHz channel bandwidth is therefore less than Recommendation ITU-R BT.601 but remains better than PAL.

4.4 Behaviour of Com^3 with an intermediate channel bandwidth

A standard D3 recorder is supplied with an input filter of approximately 6 MHz bandwidth and an output filter with a slightly wider roll-off, which functions primarily as an anti-alias filter. In order to maintain sufficient bandwidth for Com^3 when using analogue inter-connection to and from the videotape machine it is necessary to install modified filters. These should each, ideally, have a half Nyquist response at twice sub-carrier frequency (~8.8 MHz). An analogue filter, however, can at best provide an approximation to this response.

With the modified filters installed, there was a just perceptible, low-level, luminance alias.

With the standard filters, the result was marginally better than for the 5.5 MHz bandwidth limitation.

4.5 Behaviour of Com^3 with phase distortions in the channel

Two types of phase distortion were investigated, a fixed phase error between the chrominance sub-carrier and the burst, such as might occur through mis-alignment of a mixer, and phase distortion over the critical 4.4 to 8.8 MHz band, such as might occur in a poorly aligned delay line or Proc-amp.

Cross-effects and luminance aliasing were just perceptible on the Newpat test sequence for a burst phase error of 5° of sub-carrier and became slightly annoying at 15°.

Cross-effects and luminance aliasing were just perceptible for a phase error of 25 ns between 4.4 and 8.8 MHz and clearly visible for a phase error of 60 ns.

Com^3 is therefore less tolerant to phase distortions than conventional PAL with delay line decoding. Phase distortions produce perceptible cross-effects and luminance aliasing for Com^3 where PAL would produce Hannover bars for simple decoding and saturation loss for delay line decoding.

4.6 Behaviour of Com^3 for multi-generation recording

The most significant effect of multi-generation recording occurs when the Com^3 signal is converted to Recommendation ITU-R BT.601 between generations. Under these conditions the reduction of vertical chrominance resolution is the dominant effect and increases with the number of generations as would be expected with repeated conversions between 4:2:2 and 4:2:0 coding.

The consequences of channel distortions arising from analogue inter-connection filters have been described and these would again be expected to be cumulative. A videotape of multiple generation recording with decoding to Recommendation ITU-R BT.601 between generations, and a known burst phase error of 1° per generation, was available. Two generations gave slight luminance aliasing and six generations gave rise to a low-level of cross-colour.

4.7 Mixing of Com^3 and conventional PAL

Mixing of Com^3 signals and PAL signals was demonstrated by showing a videotape of a Com^3 foreground keyed into a Com^3 background with an internally generated (conventional PAL) coloured border. The appearance of the coloured border was as expected from the assessment of Com^3 coding followed by PAL decoding.

5 Conclusions

For the flat channel, the claims made for the Com^3 system are met.

As the channel departs from the ideal, impairments are introduced and Com^3 was felt to be more critical than PAL in this respect.

ANNEX 3

1 Introduction

The present Recommendation contains two digital and two analogue approaches to the production of source material for 16:9 625-line enhanced television.

Guidance on the distance between these approaches is of value to organisations wishing to adopt enhanced programme production. This Annex briefly reviews the concepts for wide-screen production to clarify where and when each option might be used.

2 Wide-screen production concepts

Before discussing options for the studio video signal format it is necessary to understand the nature of 16:9 studio production.

2.1 Aspect ratio

The first concept concerns the basic difference between the 4:3 and 16:9 aspect ratios. The sole factor determining this difference is the spatial opto-electronic conversion in the source device (electronic camera, film camera, telecine) and the reverse electronic-opto spatial conversion in the display device (picture monitor, receiver). Aspect ratio is controlled by the shape of the source sensor and the shape of the display device. The intermediate video signal for the two aspect ratios is similar, and most importantly both signals use the full 576 frame lines for the active picture.

The difference between the two aspect ratios can be simply demonstrated by viewing a 16:9 source signal on a standard 4:3 display, vertically the picture has the same height but horizontally the image appears compressed or ‘squashed’. A 16:9 signal viewed in this manner is frequently referred to as ‘anamorphic’. The correct geometry is obtained when the 16:9 signal is viewed on a 16:9 display, or using the low-cost alternative of a 4:3 display with the vertical scan reduced by a factor of 3/4 (many 4:3 monitors now have a reduced scan 16:9 mode). This latter mode should not be confused with the compatible ‘letter-box’ wide-screen presentation on a 4:3 display comprising a central 430 line 16:9 panel with blank lines above and below. The letter-box format is reserved for compatible 4:3 transmission (as in PALplus), and the letter-box should not feature in the wide-screen production studio.

2.2 Resolution

The second concept concerns resolution. The 16:9 picture can be regarded as an increase in width on the standard 4:3 picture. Thus if cameras of each aspect ratio view the same scene and are framed for the same height, the 16:9 picture will contain additional horizontal information. It follows that if the corresponding video signals conform to the same standard 625-line timing specification, then the 16:9 signal must have enhanced analogue bandwidth or increased digital sampling frequency if the reproduced scene detail (spatial frequency) is to be similar. Bandwidth increases from 5(5.5) MHz to 6.67(7.33) MHz and the digital luminance sampling frequency from 13.5 MHz to 18 MHz. There are circumstances when enhanced resolution by increase of bandwidth is not justified, in particular when wide-screen transmission systems limit bandwidth to the current 5(5.5) MHz (MAC and PALplus). However for future transmission systems, possibly including up-conversion to HDTV, archived programme production with enhanced resolution will be advantageous. Similarly if 4:3 versions of standard specification are to be extracted as a sub-set from 16:9, the wide-screen original should have enhanced resolution.

2.3 Studio standard – component or composite

Current and projected future wide-screen transmission systems require a component input to the encoders, and thus the ideal production format is digital component. Many installed production environments are based on composite PAL, however this does not necessarily bar wide-screen production. Replacement of all standard PAL encoders and decoders with Clean PAL equivalents could allow use of existing PAL equipments while affording a final decode back to components with negligible levels of coding artefacts. The economics of this solution may not be warranted for studio production, and are probably best reserved for studio and inter-studio (network) communications. Standard PAL or wide-screen encoded transmission formats should not be used for wide-screen studio production.

2.4 Studio equipment

With similar video signal specifications for 4:3 and 16:9 aspect ratios, it would appear that much existing studio equipments can be used for wide-screen production. Assuming that final transmission will be band-limited, then the requirement for enhanced resolution could be disregarded, and existing equipments can be utilised. Inevitably new or modified cameras and picture monitors are required, and any equipments having spatial functions will require modification. For example, mixer wipe patterns will require geometry modification for 16:9 (an unmodified 4:3 circular pattern will appear elliptical for 16:9). Equipments with no spatial processing will not normally require modification, for example, distribution amplifiers, routing matrices, and several formats of video tape recorder.

3 Video signal format

Following the above review of wide-screen production concepts, the where and when for each of the option video signal formats should be clear.

3.1 Digital systems

It is envisaged that the digital systems under discussion are the digital component standards of Recommendation ITU-R BT.601.

3.1.1 Recommendation ITU-R BT.601 (Part A), 13.5 MHz luminance sampling

The digital component standard with a luminance sampling frequency of 13.5 MHz has been the mainstay of Recommendation ITU-R BT.601 since its conception in 1982 when aspect ratio was singular and fixed at 4:3. There is now a high level of installed equipments and a large choice of vendors for equipments conforming to the standard.

If the requirement for production is broadcasting 16:9 using one of the current or proposed bandwidth limited wide-screen transmission formats then Recommendation ITU-R BT.601 (Part A), 13.5 MHz is adequate for 16:9 production. Conversion between aspect ratios may have limitations and archived material may have insufficient resolution for use in future enhanced or high definition systems.

Existing installations will require modifications to handle the spatial differences between 4:3 and 16:9. The most significant changes are included in § 1.2 of Annex 1.

Equipments masquerading as component but operating with a core composite process with integral coding interfaces should not be used.

For new installations, equipments operating at both 13.5 MHz and higher sampling rates should be considered if future upgrades for enhanced resolution are required.

3.1.2 Recommendation ITU-R BT.601 (Part B), 18 MHz luminance sampling

Recommendation ITU-R BT.601 now contains a Part B fully specifying the enhanced studio digital standard using 18 MHz luminance sampling frequency for wide-screen 16:9 studio production. This then is the second option for a digital video signal format. Studio equipments are available for this standard, albeit the choice is limited at the present time, however it is possible to facilitate a complete studio installation. The newer 16:9 cameras have sufficient CCD pixel resolution for 18 MHz sampling.

The output from a 16:9 studio using 18 MHz sampling can be data-rate converted to interface with existing wide-screen transmission codecs. The source material can be archived at the higher rates and is thus future-proofed for extended and high definition applications. Standard 4:3 aspect ratio signals extracted from 16:9 originals will have the full specification of Recommendation ITU-R BT.601 (Part A), 13.5 MHz.

3.2 Analogue systems

It is of course perfectly feasible to use analogue component systems for wide-screen production provided that they are capable of providing a bandwidth at least equal to that of the transmission system and preferably greater. This will allow broadcasters to use such installations until such time as conversion to digital components is made.

Some broadcasters may wish to use existing analogue (or digital) composite PAL installations for wide-screen production as an interim measure before they can convert their facilities to digital component. This option is now feasible by reason of the development of Clean PAL systems which provide a composite signal compatible with existing standard PAL equipments yet can be decoded to recover a component signal with negligible coding artefacts. All existing PAL encoders and decoders within the main signal processing chain will be replaced by equivalent Clean PAL encoders and decoders. This includes those equipments which masquerade as composite but have a component core with integral interface decoders and encoders. Picture monitors with integral standard PAL decoders can be used with the exception of those required for quality monitoring. The cost of Clean PAL encoders and decoders is higher than that of standard PAL units and the economics of this solution must be examined carefully.

A more cost effective application of Clean PAL systems is for contribution and distribution of component quality signals over existing standard PAL communications or networks. The cost of the few codecs involved may compare favourably with the high cost of network replacement for digital component operation.

Currently two forms of Clean PAL system have been included as suitable for the above applications.

3.2.1 Com^3

This option if fully specified in Annex 2. The Com^3 Clean PAL system exploits the extended 8 MHz bandwidth provided by $4f_{sc}$ sampled D2 and D3 digital composite tape recorders. Using novel colour coding together with extended 9 MHz bandwidth Com^3 can provide a luminance bandwidth of 6.6 MHz for 16:9 production which is equivalent to about 5 MHz in conventional 4:3. A 9 MHz bandwidth can generally be maintained within a PAL studio environment for which Com^3 is well suited. For communication routes where links may be limited to 5 (5.5) MHz, the luminance and chrominance bandwidth of Com^3 is reduced, although the system remains free of cross-effects. Com^3 is a 4:2:0 system implying line-alternate colour difference signals, however, within a 9 MHz communication bandwidth, Com^3 has near Recommendation ITU-R BT.601 (Part A), 13.5 MHz component performance.

3.2.2 MACP

The second Clean PAL option is MACP which is the improved colour coding systems used for PALplus transmissions. The significant difference between Com^3 and MACP is that encoded MACP can be conveyed within the 5 (5.5) MHz of a standard PAL communication channel. It can therefore be used for both studio production and for communications. MACP has been described in Recommendation ITU-R BT.1197 – “Enhanced wide-screen PAL TV transmission system (the PALplus system)” – as part of the PALplus specification. MACP is a 4:1:1 system implying reduced colour difference bandwidth and there is a small loss of high frequency diagonal resolution for stationary areas, reducing to 3 MHz luminance in moving areas. Subjective tests have shown MACP to have near Recommendation ITU-R BT.601 (Part A), 13.5 MHz component quality. A variant of MACP could provide an enhanced luminance bandwidth with a correspondingly wider communication channel.