ENCODING PARAMETERS FOR DIGITAL TELEVISION STUDIOS

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Summary

This paper looks at sampling frequencies which can be used to code the luminance and colour difference signals of the PAL, NTSC and SECAM colour television systems and recommends a suitable sampling standard for use in the digital television studio.

The sampling standard is derived from the characteristics of the widely used 625-line PAL and the 525-line NTSC systems and deductions made about the SECAM system.

1. INTRODUCTION

The PAL (Phase Alternating Line), NTSC (National Television System Committee) and SECAM (Sequential Couleur a Memoire) colour television systems are identified by the method used to transmit the colour information. In addition, colour standards identified by certain letters [1] have been recommended by the CCIR (International Radio Consultative Committee).

A number of organizations in several countries have investigated the possibilities for a worldwide component digital television coding format. In February 1982 the CCIR approved recommendations covering the basic characteristics of a digital video coding standard. It envisages a studio code based on a luminance sampling frequency of 13.5 MHz and a chrominance sampling frequency of 6.75 MHz. If these represent optimum coding parameters, then the television broadcaster has the opportunity of removing the limitations of the PAL, NTSC and SECAM standards as presently exist using analogue technology and to put in its place a compatible standard which achieves commonality of equipment, operation practices and an improvement in the quality of the television picture.

The SECAM system does not place any serious constraint on the choice of a component coded sampling standard because of the almost exclusive use of its components in the analogue studio. Traditionally almost all the signal processing requirements of composite PAL and NTSC, with their amplitude modulated colour difference signals have been met in the studio without resorting to their components. Hence the need to investigate the coding parameters for the PAL and NTSC systems only.

2. COMPONENT CODING CONSIDERATIONS

2.1 Source Encoding Point

Fig. 1 shows the principal signal path of a colour television system from the output of the colour camera to the output of the channel coder. Possible points for digital source component encoding are the full bandwidth red, green and blue (RGB) signals comprising the non-physical camera primaries ($R_oG_oB_o$) and the display primaries ($R_1G_1B_1$ and R'G'B'), or the luminance (Y) and colour difference (C_1C_2) transmission primaries, commonly called the YC_1C_2 components. It is unnecessary to distinguish between points along the RGB signal path for digitization purposes because no frequency translation or bandwidth truncation occurs along this path.

Limb et al. [2] have reviewed experimental and theoretical results which seek to quantify the relative merits of coding the RGB or YC_1C_2 signals. It is clear that RGB coded signals will find applications in areas where full bandwidth resolution is required. The efficiency with which the YC_1C_2 components trade bandwidth for signal quality makes them suitable as coding signals in restricted bandwidth environments.

To satisfy these requirements proposals have been made for a family of extensible codes [3] in which the

YC_1C_2 coded format is standardized with allowance made to accommodate other formats such as the RGB.

2.2 Quantization

The number of bits chosen to code the YC_1C_2 components determine the extent to which contouring effects o the quantization noise and other impairments associated with quantization are minimized.

Tests carried out by Moore [4] based on both a statistical criterion and another which sought to exploit the psychovisual characteristics of the human observer indicated that between 8 and 8.4 bits are adequate to code the luminance signal and between 7 and 7.4 bits for the colour difference signals. In practise all three components are coded at 8 bits per sample.

2.3 Sampling Structure

When the three-dimensional function representing a television image is sampled, the resulting three coordinate sampling points which indicate the relative position of the samples in space and time define the sampling structure. Vertical and temporal sampling rates as determined by the number of lines per frame and the frame rate are specified by the CCIR [1] and are unique to a particular colour standard. The horizontal sampling frequency determines the horizontal spacing between samples and the relative position of each sample on adjacent lines and fields.

The three fundamental fixed sampling structures that have been postulated [5] are shown in Fig. 2. They are derived from line-related sampling frequencies and are suitable for component coded signals. The samples of the orthogonal (0) structure are aligned vertically. Those of the line quincunx (QL) are offset by half a sampling period between one line and the next in the same field. In the field quincunx (QT) structure the offset is between even and odd fields and the samples are orthogonal in each field. Sampling frequencies which are integer multiples of the line frequency generate 0 structures. The QL and QT structures result from sampling frequencies which are odd multiples of half the line frequency and phase shifted by π radians at the start of even-numbered frames and even-numbered lines respectively.

Subjective tests on the luminance signal [5] indicate that all three structures produce comparable quality pictures for super Nyquist sampling rates.

Digital video processing is simplified if samples are vertically aligned and repeat exactly from frame to frame. The principle of separability of filters can also be applied, enabling the design of multi dimensional filters as combinations of one dimensional filters. Orthogonal structures satisfy these requirements exactly, while the QL and QT structures can be modified to satisfy them. Therefore the YC_1C_2 components should be sampled by super Nyquist line-locked sampling frequencies.

3. COMPOSITE CODING CONSIDERATIONS

Although the sampling standard is based on component coding, it is apparent that the composite PAL and NTSC signals will have to co-exist with the components over a protracted period in what is envisaged as a hybrid television studio (Fig. 3). Hence the need to digitally decode the composite signal to take advantage of the benefits of component signal processing.

To exploit the quadrature phase relationship between the chrominance subcarriers, synchronous digital demodulation is used to separate the chrominance components of the composite signal by:

(i) Selecting a subcarrier related sampling frequency which leads to automatic separation without the need for a subcarrier reference.

(ii) Conventional decoding, in which samples of the composite signal are multiplied by samples of an appropriately phased subcarrier sine wave.

Hashimoto et al. [6] have derived and Lucas [7] has stated the necessary conditions to accomplish (i) for the NTSC/M and PAL/I systems respectively. Conventional decoding is quite straightforward if the composite signal is sampled by a subcarrier-locked frequency, as the subcarrier phase appropriate to any composite sample is predetermined. However, if the sampling frequency is asynchronous, the subcarrier phase for any sample of the signal is initially unknown and must be derived from the colour burst [7] or from the sampling frequency [8]. This significantly increases the complexity of the hardware required to implement the decoding process, and adversely affects the extent to which the components are separated from the composite signal. Therefore the composite signal should be sampled by a subcarrier-locked frequency.

4. COMPATIBLE SAMPLING FREQUENCIES

4.1 For the PAL System

A sampling frequency is compatible if it satisfies the coding requirements of the component signals (being line-locked) and the composite signal (being subcarrier-locked) simultaneously. The subcarrier frequency f_{sc} and line frequency f_ℓ of the 625-line PAL/I system are related by the equation

$$f_{sc} = \left(\frac{1135}{4} + \frac{4}{625}\right) f_\ell \qquad \text{..... (1)}$$

where f_{sc} = 4.4336187 MHz and f_ℓ = 15625 Hz. The effect of the term $4f_\ell/625$ is insignificant and can be eliminated from (1).

Rearranging (1) yields

$$\frac{227}{4} nf_\ell \approx \frac{n}{5} f_{sc} \qquad \text{..... (2)}$$

where n is an integer. Sampling frequencies corresponding to the left hand side and right hand side of (2) are suitable for component and composite coding respectively. Hence these frequencies are compatible. If n is divisible by 4, an orthogonal structure is generated. If it is divisible by 2 but not by 4, a quasi-QL structure which repeats every two frames is formed.

Listed in Table 1 are compatible sampling frequencies for the PAL system derived from (2). Only super Nyquist frequencies limited to $4f_{sc}$ are considered. The upper frequency limit seeks to satisfy digital signal processing, storage and transmission requirements.

4.2 For the NTSC System

The subcarrier and line frequencies of the 525-line NTSC/M system are related by the equation

$$f_{sc} = \frac{455}{2} f_\ell \qquad \text{..... (3)}$$

where f_{sc} = 3.579545 MHz and f_ℓ = 15734.263 Hz. Equation (3) can be rearranged to yield

$$\frac{91}{2} n\ f_\ell = \frac{n}{5} f_{sc} \qquad \text{..... (4a)}$$

and

$$\frac{65}{2} n\ f_\ell = \frac{n}{7} f_{sc} \qquad \text{...... (4b)}$$

where n is an integer. Frequencies generated by (4a) and (4b) are clearly compatible as discussed previously. If n is even an orthogonal structure is formed, otherwise a quasi-QL structure results.

The compatible sampling frequencies for the NTSC system generated by equations (4) are listed in Table 2. These are all super Nyquist frequencies limited to $4f_{sc}$.

4.3 For the PAL and NTSC Systems

4.3.1 Line Period Considerations

In addition to satisfying the compatibility requirements of each colour system the sampling frequency should present a transparent interface between the systems. In terms of line period considerations this requires that essentially the same sampling frequency should produce for both systems:

(i) The same number of samples per line.
(ii) The same data rate.

It is not possible to satisfy both conditions because of the different line frequencies of the colour standards. However, disparities in data rates are small enough to be ignored or compensated for, while concentrating on satisfying (i).

From Tables 1 and 2 it can be seen that only frequencies 14.187500 MHz and 14.318180 MHz virtually satisfy the above conditions. Their characteristics are listed in Table 3.

4.3.2 Active Line Period Considerations

Line period considerations limit the number of sampling frequencies available for satisfying inter-system compatibility. Another approach is to specify that the same sampling frequency generate the same number of samples per active line period for both systems. This is facilitated by adjusting the line blanking interval. The development of this strategy follows.

The number of samples per active line period is given by

$$m_a = n\, f_\ell t_a \qquad \ldots\ldots (5)$$

where n is the number of samples per line, f_ℓ is the line frequency and t_a the active line period. If m_a is the same for both systems then

$$n_1 f_{\ell 1}\, t_{a1} = n_2\, f_{\ell 2}\, t_{a2} \qquad \ldots\ldots (6)$$

where subscript 1 and 2 refers to the PAL/I and NTSC/M systems respectively. From CCIR specifications [1], the active line period from 52.1 µs to 52.2 µs is common to both systems. If the active line periods are equal and constrained to lie in the above range then from (6)

$$n_1 = 1.006993 n_2 \qquad \ldots\ldots (7)$$

If n_1 and n_2 are limited to integer values only (hence producing orthogonal sampling structures) then n_2 must be multiples of 143. For the range of frequencies being considered, n_2 is limited to 715 and 858 with corresponding values of 720 and 864 for n_1. These generate sampling frequencies of 11.25 MHz and 13.5 MHz whose characteristics are listed in Table 3.

5. PROPOSED SAMPLING STANDARD

5.1 For the Luminance Component

The relative merits of the three sets of frequencies in Table 3 which may be standardized to sample the luminance component are evaluated below.

(i) 14.187500/14.318180 MHz: These frequencies generate an almost exact number of samples per line period (the difference of two samples can be ignored, dropped or eliminated by interpolation). They facilitate straightforward decomposition of the composite signal using either of the synchronous demodulation techniques. Because of the wide Nyquist margin, relatively cheap and simply designed filters are required. The major disadvantages are the relatively high data rates produced, the time constraint on data manipulation and the 130680 Hz difference in system frequencies. This difference cannot be ignored hence the need to switch between clock frequencies when processing signals derived from PAL and NTSC systems.

(ii) 13.5 MHz: This frequency produces an exact number of samples per active line period for both systems. It is easily instrumented, provides an adequate Nyquist margin and reduces the data rate by 6% compared with (i). Although it assumes a standard based on active line period considerations, it can also be based on line period considerations and the difference of six samples handled as in (i). It also ensures a common format in a number of digital studio equipment. Digital decoding of the composite signal will be more difficult because of its complex relationship to the subcarrier frequency. No doubt this will adversely affect the quality of the components derived from this process. However the continued improvement of the hardware required to obtain subcarrier phase information from line-locked sampling frequencies will help to overcome this problem.

(iii) 11.25 MHz: The characteristics of this frequency are similar to those in (ii). Significant differences are the 20% reduction in data rate and the unsatisfactory reduction of the Nyquist margin to 2% for the PAL signal. Resulting from the latter would be the need for more complex and expensive digital filters for signal processing. In addition, aliased components could become significant enough to impair signal quality.

The unsatisfactory Nyquist margin of the 11.25 MHz sampling frequency eliminates it from further consideration. The two frequency format in (i) seeks to satisfy the short term requirements of the hybrid studio while compromising on the single frequency requirement of inter system operations. The converse is true for 13.5 MHz. As the requirements of the hybrid studio will disappear in the long run, 13.5 MHz should be chosen to code the luminance component of the PAL and NTSC signals.

5.2 For the Colour Difference Components

The nominal bandwidth of the chrominance components of the PAL signal is 1.3 MHz. The chrominance components of the NTSC signals are nominally 1.3 MHz and 0.5 MHz wide. If the same frequency is chosen to sample both components and the Nyquist margin is maintained at the same percentage as that for the luminance components of the PAL and NTSC signals, then a sampling frequency of 3.19 MHz and 4.178 MHz would be adequate to code the chrominance components of the PAL and NTSC signals respectively. However in order to allow satisfactory operation of video processing equipment especially the chroma-keyer, experimental results [9] indicate that a sampling frequency of the order of at least 6 MHz is required for the PAL chrominance components. In addition, the chrominance sampling frequency should be uniquely related to the luminance sampling frequency in order to maintain an orthogonal structure, simplify its generation and produce cosited chrominance and luminance samples. These considerations suggest that the colour difference components of the PAL and NTSC systems should be sampled at 6.75 MHz.

6. CONCLUSION

Compatibility of the sampling frequency is desirable to ensure a simple decoding algorithm for the composite PAL and NTSC signals while at the same time satisfying the video processing requirements of the components. This severely restricts the range of frequencies from which a sampling standard can be chosen, especially for the PAL system because of the complex relationship between line and subcarrier frequencies. None of the frequencies under consideration fully met the compatibility requirements. Hence the decision to select a studio code which meets the long term requirements of a component coding format and which involves more complex composite decoding algorithms.

The studio code should therefore be based on a sampling frequency of 13.5 MHz for the luminance component and 6.75 MHz for the colour difference components of the PAL, NTSC and SECAM systems. This code should be extended into a family of extensible codes to satisfy other requirements.

REFERENCES

1. CCIR XIIIth Plenary Assembly, Geneva, 1974, Volume XI, Broadcasting Service (Television).
2. LIMB, J.O., RUBINSTEIN, C.B. and THOMPSON, J.E., "Digital Coding of Colour Video Signals — A Review", IEEE Trans. COM., Vol. COM-25, No. 11, November 1977.
3. DAVIDOFF, F., "The All-Digital Television Studio", Journal of the SMPTE. Vol. 89. No. 6. June 1980.
4. MOORE, T.A., "Digital Video: Number of bits per sample required for reference coding of the luminance and colour difference signals", BBC Research Department Report, RD 19774/42.
5. SABATIER, J. and KRETZ, F., "Sampling the components of 625-line colour television signals", EBU Review, No. 171, October 1978.
6. HASHIMOTO, H. and MATSUOKA, T., "Digital Separation and Reconstruction of NTSC Signals", IEEE Trans. Com., Vol. COM-28, No. 7, July 1980, pp 1085-1088.
7. LUCAS, K., "Sampling Frequencies for Digital PAL Decoding", IBA Experimental and Development Report 104/79.

8. CLARKE, C.K.P., "Digital PAL Decoding using Line-Locked Sampling", International Broadcasting Convention, Sept. 1980, pp. 199-202.
9. LUCAS, K. and NASSE, D., "Case Studies in the Implementation of Chromakey", (to be published).

TABLE 1

Compatible Sampling Frequencies for
Component and Composite Digital Coding of the PAL Signal

n	Number of Samples per Line	Sampling Frequencies for Component Goding (MHz)	Number of Samples per Cycle of Subcarrier	Sampling Frequencies for Composite Coding (MHz)
	$\frac{227n}{4}$	$\frac{227nf_{\ell}}{4}$	$\frac{n}{5}$	$\frac{n}{5} f_{sc}$
14	794½	12.414062	2.8	12.414132
16	908	14.187500	3.2	14.187580
18	1021½	15.960937	3.6	15.961027
20	1135	17.734375	4.0	17.734474

TABLE 2

Compatible Sampling Frequencies For
Component and Composite Digital Coding of the NTSC Signal

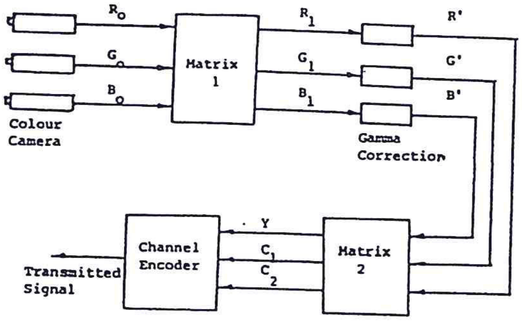
n	Number of Samples Per Line	Sampling Frequencies for Composite/Component Coding (MHz)	Number of Samples per Cycle of Subcarrier
	$\left(\frac{91n}{2}\right)$	$\left(\frac{91n}{2} f_\ell : \frac{n}{5} f_{sc}\right)$	$\left(\frac{n}{5}\right)$
13	591½	9.306817	2.6
14	637	10.022726	2.8
15	682½	10.738635	3.0
16	728	11.454544	3.2
17	773½	12.170453	3.4
18	819	12.886362	3.6
19	864½	13.602271	3.8
20	910	14.318180	4.0
	$\left(\frac{65n}{2}\right)$	$\left(\frac{65n}{2} f_\ell : \frac{n}{7} f_{sc}\right)$	$\left(\frac{n}{7}\right)$
17	552½	8.693181	17/7
18	585	9.204544	18/7
19	617½	9.715908	19/7
20	650	10.227272	20/7
21	682½	10.738635	3
22	715	11.249999	22/7
23	747½	11.761362	23/7
24	780	12.272726	24/7
25	812½	12.784089	25/7
26	845	13.295453	26/7
27	877½	13.806816	27/7
28	910	14.318180	4

TABLE 3

Compatible Sampling Frequencies for the PAL and NTSC Systems

System	Sampling Frequency (MHz)	Number of Samples per Line	Relationship with Subcarrier	Type of Digital Decoder Possible
PAL	14.187500	908	3.2 f_{sc}	either*
NTSC	14.318180	910	4 f_{sc}	either*
PAL	13.5	864	complex	conventional
NTSC	13.5	858	complex	conventional
PAL	11.25	720	complex	conventional
NTSC	11.25	715	complex	conventional

*Automatic Separation or Conventional



$R_oG_oB_o$: Non-physical camera primaries

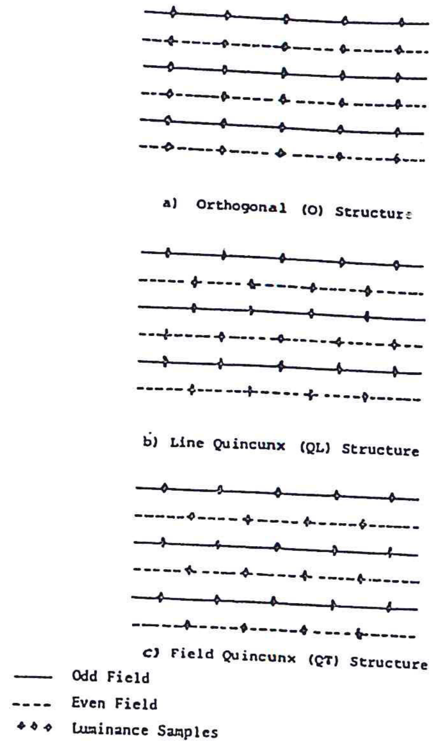
$R_1G_1B_1$: Display primaries (not gamma corrected)

$R'G'B'$: Display primaries (gamma corrected)

YC_1C_2 : Transmission primaries

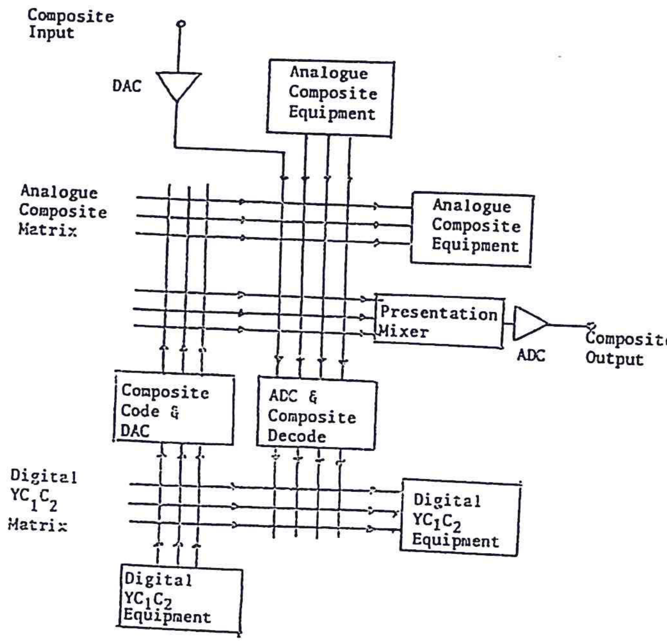
Block Diagram of the signal path of a colour television system

FIGURE 1



The three fundamental sampling structures

FIGURE 2



ADC: Analogue to Digital Converter

DAC: Digital to Analogue Converter

Hybrid Studio

FIGURE 3