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The feasibility of correcting for failure of constant luminance in a colour television system

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Research Department, Engineering Division
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RESEARCH DEPARTMENT

THE FEASIBILITY OF CORRECTING FOR FAILURE OF CONSTANT LUMINANCE IN A COLOUR TELEVISION SYSTEM

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(PH-89)

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Summary

In a colour television transmission system such as the PAL system a constant-luminance failure is caused because the red, green and blue separation signals used to form the chrominance and luminance signals are not linearly related to the light outputs required from the red, green and blue display picture-tube phosphors.

As a result, not all of the displayed luminance information travels via the luminance channel and the remainder, which travels via the chrominance channel, suffers a severe bandwidth restriction. This report shows that it is possible, by modifying the coding process, to retain the otherwise lost information concerning fine detail associated with saturated colours by redirecting it to the luminance channel. This results in a high-frequency boost of the luminance signal where there is fine detail associated with highly saturated colours in the picture. The resulting possibility of increased cross-colour, and the effect of the high-frequency boost on the monochrome picture are briefly discussed.

1. Theory

1.1. General

In a colour television camera or telecine the red, green and blue components of a scene produce linearly-related signal outputs R,G,B from the respective camera tubes or photomultipliers. These signals are then gamma-corrected before being fed to a coder, so that the signals applied to the coder are of the form:

$R_o^{1/\gamma_1}\ G_o^{1/\gamma_1}\ B_o^{1/\gamma_1}$ where $1/\gamma_1$ is the exponent of the power law correction applied at the signal source to offset the non-linear transfer function γ_2 of the receiver picture tube. Typical values are $\gamma_1 = 2{\cdot}2$, $\gamma_2 = 2{\cdot}8$.

If these signals were fed directly to a display picture tube, then the beam currents and hence display phosphor brightness would be of the form:

$$R_o^{\gamma_2/\gamma_1} \qquad G_o^{\gamma_2/\gamma_1} \qquad B_o^{\gamma_2/\gamma_1}$$

and would apply for all video frequencies and the distortion to be discussed in this report would not occur.

When the signal is coded, however, the three coder input signals are formed into a wide-band luminance signal Y' and two colour-difference signals $(R_o^{1/\gamma_1} - Y')_{lf}$ and $(B_o^{1/\gamma_1} - Y')_{lf}$ of restricted bandwidth where

$$Y' = lR_o^{1/\gamma_1} + mG_o^{1/\gamma_1} + nB_o^{1/\gamma_1} \qquad (1)$$

$$(R_o^{1/\gamma_1} - Y')_{lf} = (1-l)R_o^{1/\gamma_1} - mG_o^{1/\gamma_1} - nB_o^{1/\gamma_1} \qquad (2)$$

$$(B_o^{1/\gamma_1} - Y')_{lf} = -lR_o^{1/\gamma_1} - mG_o^{1/\gamma_1} + (1-n)B_o^{1/\gamma_1} \qquad (3)$$

l, m and n are the coding coefficients which sum to unity. They are basically arranged to give the luminance signal a photopic response so that the system is compatible with the monochrome system. In practice this is not possible because the signals are not linearly related to the light output from the display picture tube. (For the NTSC or PAL system, l = 0·299, m = 0·587, n = 0·114.)

The suffix (lf) denotes that the signal is of restricted bandwidth.

In a colour receiver, a third colour-difference signal $(G_o^{1/\gamma_1} - Y')_{lf}$ is formed from the two that are transmitted; this is also a narrow-band signal defined by:

$$(G_o^{1/\gamma_1} - Y')_{lf} = -\frac{l}{m}(R_o^{1/\gamma_1} - Y')_{lf} - \frac{n}{m}(B_o^{1/\gamma_1} - Y')_{lf} =$$

$$= -lR_o^{1/\gamma_1} + (1-m)G_o^{1/\gamma_1} - nB_o^{1/\gamma_1} \qquad (4)$$

The three colour signals are then re-formed by adding the wide-band luminance signal to each colour-difference signal.

$$R^{1/\gamma_1} = (R_o^{1/\gamma_1} - Y')_{lf} + Y' \qquad (5)$$

$$G^{1/\gamma_1} = (G_o^{1/\gamma_1} - Y')_{lf} + Y' \qquad (6)$$

$$B^{1/\gamma_1} = (B_o^{1/\gamma_1} - Y')_{lf} + Y' \qquad (7)$$

Since the colour-difference signals contain only low-frequency components, the distortions which occur to the low-frequency and high-frequency video signals between the source and display must be considered separately.

1.2. Low-frequency signals

At low video frequencies no information is lost, and the addition of the luminance signal to the colour-difference

signals results in separation signals of the same form as those at the input to the coder.

$$R_{\rm lf}^{1/\gamma_1} = R_{\rm o}^{1/\gamma_1} \quad (8)$$

$$G_{\rm lf}^{1/\gamma_1} = R_{\rm o}^{1/\gamma_1} \quad (9)$$

$$B_{\rm lf}^{1/\gamma_1} = B_{\rm o}^{1/\gamma_1} \quad (10)$$

The relative display phosphor brightnesses in large picture areas are therefore the same as those which would be displayed by a directly-fed monitor and the displayed luminance is given by:

$$l_1 R_{\rm o}^{\gamma_2/\gamma_1} + m_1 G_{\rm o}^{\gamma_2/\gamma_1} + n_1 B_{\rm o}^{\gamma_2/\gamma_1} \quad (11)$$

l_1, m_1 and n_1 sum to unity and are the relative proportions of the red, green and blue phosphor primary-colours which add to give the reference illuminant white point. For PAL System I phosphors and Illuminant D_{65} white point $l_1 = 0{\cdot}2215$, $m_1 = 0{\cdot}7074$, $n_1 = 0{\cdot}0711$.

1.3. High-frequency signals

At high frequencies, when the colour-difference signals are not present, the three colour signals each become equal to the luminance signal

$$R_{\rm hf}^{1/\gamma_1} = G_{\rm hf}^{1/\gamma_1} = B_{\rm hf}^{1/\gamma_1} = Y'_{\rm hf} \quad (12)$$

Then each of the beam currents and hence the phosphor brightnesses will be of the form

$$Y'^{\gamma_2}_{\rm hf}$$

and since l_1, m_1 and n_1 sum to unity, the displayed luminance at high frequencies is also $Y'^{\gamma_2}_{\rm hf}$. In other words, at high frequencies the receiver behaves as if it were a monochrome receiver.

1.4. Constant-luminance index

This is defined as the ratio of the displayed luminance, resulting from the signal which has travelled only via the luminance channel, to the ideal value. In the above context, it is equal to the ratio of the displayed luminance for high-frequency signals to the displayed luminance for low-frequency signals; hence the constant-luminance index

$$k = \frac{Y'^{\gamma_2}}{l_1 R_{\rm o}^{\gamma_2/\gamma_1} + m_1 G_{\rm o}^{\gamma_2/\gamma_1} + n_1 B_{\rm o}^{\gamma_2/\gamma_1}} \quad (13)$$

$$= \frac{(lR_{\rm o}^{1/\gamma_1} + mG_{\rm o}^{1/\gamma_1} + nB_{\rm o}^{1/\gamma_1})^{\gamma_2}}{(l_1 R_{\rm o}^{\gamma_2/\gamma_1} + m_1 G_{\rm o}^{\gamma_2/\gamma_1} + n_1 B_{\rm o}^{\gamma_2/\gamma_1})} \quad (14)$$

1.5. Failure of constant luminance

Ideally the constant-luminance index k should be unity for all colours within the synthesis triangle and for all permissible luminance levels. If k departs from unity a failure of constant luminance is said to occur. When this happens the picture will appear different from that displayed by a directly fed monitor, since some of the luminance information will have travelled via the chrominance channel and suffered a reduction of bandwidth. Also, because the chrominance channel is liable to have an inferior noise performance, it is likely that additional noise will have been added.

When k is significantly less than unity the displayed picture will lack definition where there are highly saturated colours, and it may also appear more noisy in these areas.

With PAL System I transmissions k is greater than unity (maximum value = 1·1) over a small area of the synthesis triangle. This condition can be considered as if a negative quantity of luminance information has travelled via the chrominance channel. Definition will be increased more than necessary and any extra noise of the chrominance channel will of course still be added to the overall picture in the same way as for k less than unity.

Fig. 1 shows a contour diagram of the constant luminance index within the synthesis triangle for PAL System I transmissions with $\gamma_1 = 2{\cdot}2$ and $\gamma_2 = 2{\cdot}8$.

2. Correction methods

2.1. Correction signal

Correction for a failure of constant luminance in terms of its effect upon bandwidth may be achieved by adding a correction signal to the transmitted luminance signal. This correction signal (H) must be added only at high frequencies (i.e. when the failure of constant luminance occurs) and this is denoted in the equations below by the suffix (hf). When the correction signal is added, the transmitted luminance signal becomes $(Y' + H_{\rm hf})$ and the displayed luminance will be $(Y' + H_{\rm hf})^{\gamma_2}$.

At high frequencies the displayed luminance will be $(Y' + H)^{\gamma_2}$ so that the constant luminance index previously given by Equation (13) now becomes

$$k = \frac{(Y' + H)^{\gamma_2}}{l_1 R_{\rm o}^{\gamma_2/\gamma_1} + m_1 G_{\rm o}^{\gamma_2/\gamma_1} + n_1 B_{\rm o}^{\gamma_2/\gamma_1}} \quad (15)$$

Then for no failure of constant luminance k = 1 so that

$$(Y' + H)^{\gamma_2} = l_1 R_{\rm o}^{\gamma_2/\gamma_1} + m_1 G_{\rm o}^{\gamma_2/\gamma_1} + n_1 B_{\rm o}^{\gamma_2/\gamma_1} \quad (16)$$

$$\therefore\ Y' + H = (l_1 R_{\rm o}^{\gamma_2/\gamma_1} + m_1 G_{\rm o}^{\gamma_2/\gamma_1} + n_1 B_{\rm o}^{\gamma_2/\gamma_1})^{1/\gamma_2} \quad (17)$$

for convenience, let the right-hand side of the above equation be represented by P

$$P = (l_1 R_{\rm o}^{\gamma_2/\gamma_1} + m_1 G_{\rm o}^{\gamma_2/\gamma_1} + n_1 B_{\rm o}^{\gamma_2/\gamma_1})^{1/\gamma_2} \quad (18)$$

then

$$Y' + H = P \quad (19)$$

$$H = P - Y' \quad (20)$$

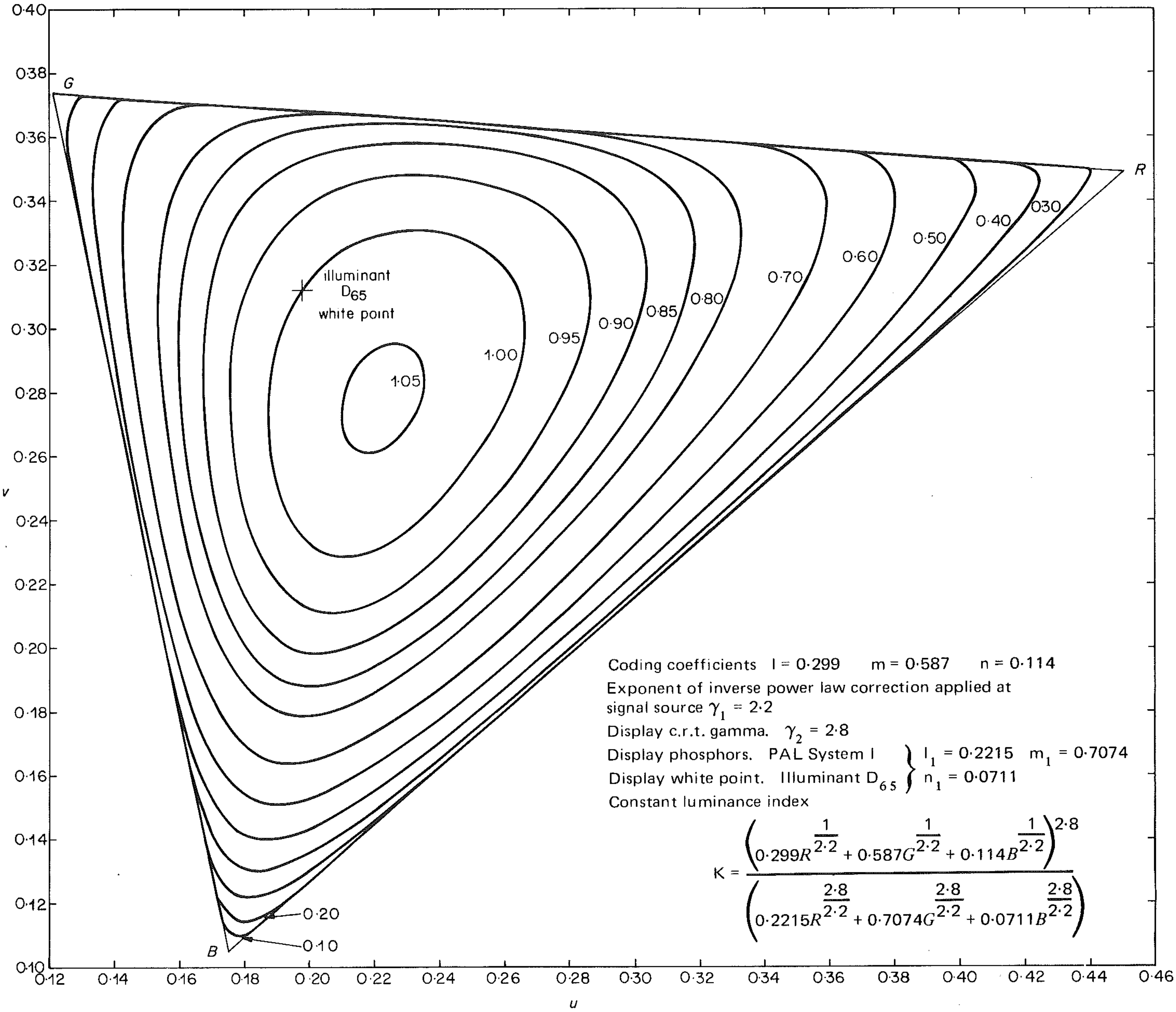

Fig. 1 - Contour diagram of constant luminance index within the synthesis triangle for PAL System I transmissions

But we must remember that the correction signal H is to be added only at high frequencies so that

$$H_{\mathrm{hf}} = (P - Y')_{\mathrm{hf}} \tag{21}$$

The required signal can be obtained by first forming a signal which represents $(P - Y')$ (using signals which have not been bandwidth restricted) and then high pass filtering the result to obtain the required high frequency correction signal, H_{hf}.

Fig. 2 shows graphically how the correction is achieved for a saturated green bar.

2.2. Corrected luminance signal

In practice it will probably be more convenient to form a corrected version of the transmitted luminance signal directly. As stated above, this luminance signal will be of the form

$$Y' + H_{\mathrm{hf}}$$

substituting from Equation (21),

corrected luminance signal

$$Y' + H_{\mathrm{hf}} = Y' + (P - Y')_{\mathrm{hf}} \tag{22}$$

$$= Y' - Y'_{\mathrm{hf}} + P_{\mathrm{hf}} \tag{23}$$

$$= Y'_{\mathrm{lf}} + P_{\mathrm{hf}} \tag{24}$$

In other words at low frequencies the luminance signal should be equal to Y' (given by Equation (1)) and at high

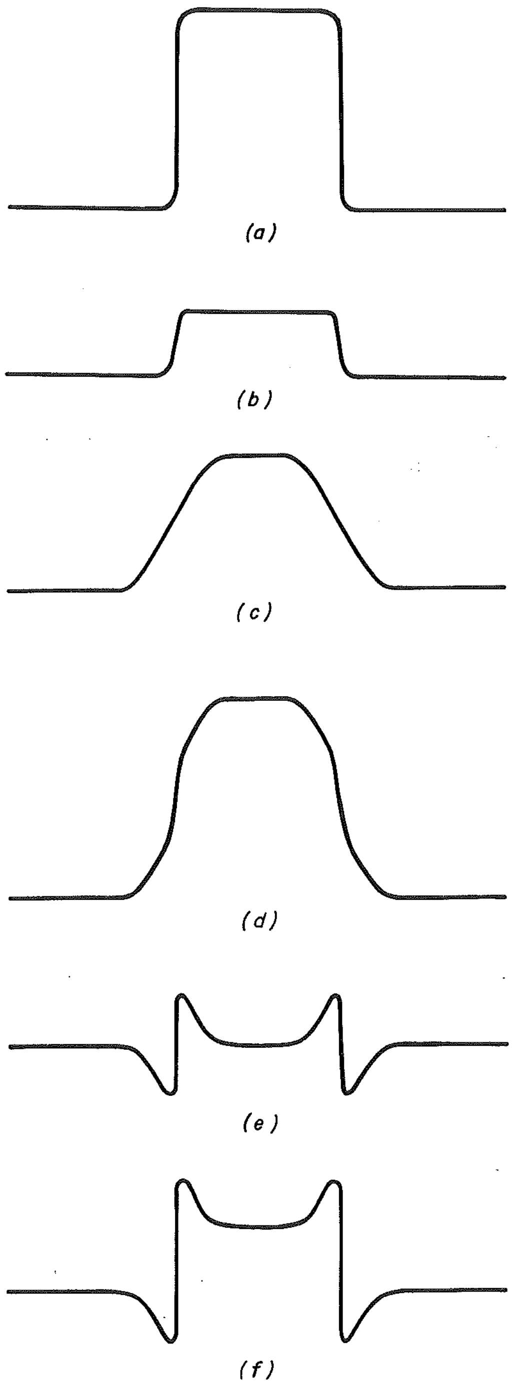

Fig. 2 - Waveforms representing the correction process for a saturated green bar using PAL System I phosphors. Constant luminance indes k = 0·318

(*a*) Ideal spatial response of displayed luminance of a bar (luminance value = 0·71)

(*b*) Component of displayed luminance which has travelled via the luminance channel (luminance value = 0·23)

(*c*) Component of displayed luminance which has travelled via the chrominance channel (luminance value = 0·48)

(*d*) Actual spatial response of displayed luminance (sum of (*b*) and (*c*))

(*e*) Correction signal which is added to the luminance signal

(*f*) Component of displayed luminance which travels via the luminance channel when a corrected luminance signal is used. This is the sum of (*b*) and (*e*) and when added to (*c*) produces the ideal luminance response as in (*a*).

frequencies it should be equal to signal P (given by Equation (18)). This arrangement requires both a low pass and a high pass filter to produce the required signal. A more convenient solution can be obtained:—

from (24)
$$Y' + H_{\mathrm{hf}} = Y'_{\mathrm{lf}} + P - P_{\mathrm{lf}}$$
$$= P - (P - Y')_{\mathrm{lf}}$$

Only a single low pass filter is required to form this signal and the required response is identical to that used to band limit the colour difference signals in a colour coder.

3. Practical instrumentation

3.1. Basic design

Bearing in mind that the coder input signals are R_0^{1/γ_1} G_0^{1/γ_1} and B_0^{1/γ_1} the block diagram in Fig. 3 shows how a corrected luminance signal may be produced using four suitable non-linear circuits and a low-pass filter.

Three of the non-linear circuits are identical and the fourth, which is connected in the feedback loop of an amplifier in order to obtain the inverse characteristic, is similar to the other three, except that the non-linearity is applied to signals of opposite polarity.

Since various propagation delays are involved, particularly in the low-pass filter, it is necessary to add delay to the signal path containing no filter in order to maintain signal time-coincidence in the two paths of the system.

The corrected luminance signal is substituted for the original luminance signal derived in the coder, but since the corrected luminance signal is delayed with respect to the colour-separation signals, the colour-separation signals fed to the coder must also be delayed to make them time coincident with the corrected luminance signal at the coder input (see Fig. 4).

In an integrated system this problem would not arise since in present coders the luminance signal is delayed to offset the effect of filtering the colour difference signals. The delayed luminance signal which results could be replaced by the corrected luminance signal, which is inherently delayed by a similar amount, and the total propagation delay of the coder would be virtually unaltered.

It will be noted that the correction process involves only γ_2, the picture tube power law, and not $1/\gamma_1$, the inverse power law correction applied at the picture source. This is because the object of the correction is to make the picture on a receiver after coding and decoding look the same, in terms of frequency response, as a directly-fed monitor.

3.2. Instrumental problems

The only significant problem in the instrumentation was found to be that of producing function generators

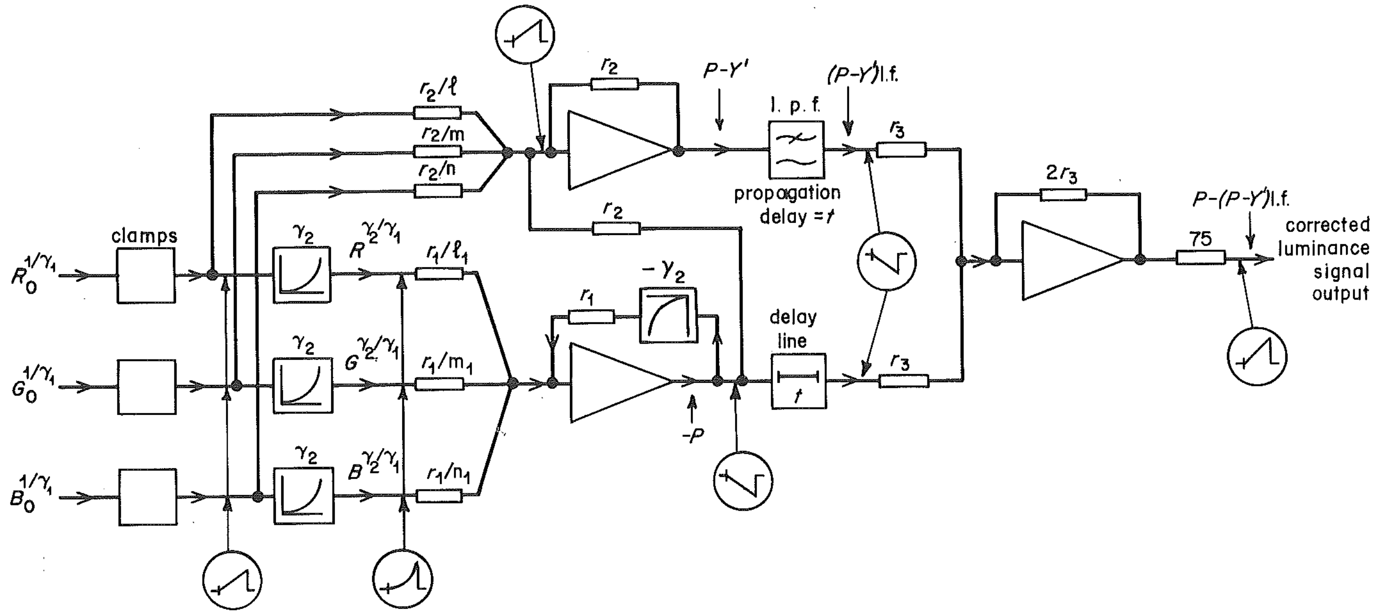

Fig. 3 - Basic arrangement used to derive a corrected luminance signal

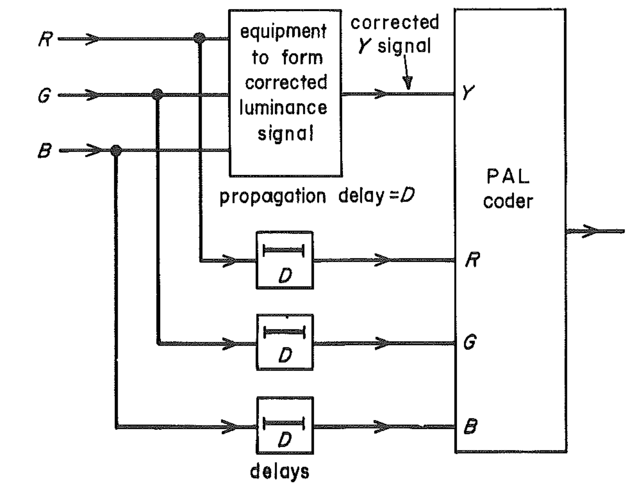

Fig. 4 - Timing arrangement when correction equipment is added externally to a colour coder

which would operate reliably at the upper video frequencies. To avoid using low-level video signals it was decided to use a multiple diode rather than a single diode technique.

In the first instance emitter followers were used instead of diodes to relieve the requirement for low-source-impedance bias-supply chains. The circuit used was as shown in Fig. 5. For the negative polarity version p.n.p. transistors and a negative bias supply were used; the circuit was otherwise similar.

It soon became apparent that the junction capacitance of the non-conducting transistors was affecting the frequency response, and that the effect was dependent upon signal level. Improved transistors were tried and diodes were added in series with the emitter leads. The latter modification was in effect using the diodes as switches to create the function and the emitter followers to supply a low impedance reference potential to the diodes. This improved the function generators in terms of the frequency response within the video bandwidth but the negative polarity circuit connected in a feedback path gave rise to high-frequency instability which could not be removed without affecting the video bandwidth.

4. Simulation of probable effects of correction

4.1. Procedure

It was decided in the interests of time to abandon attempts to build the ideal correction system described

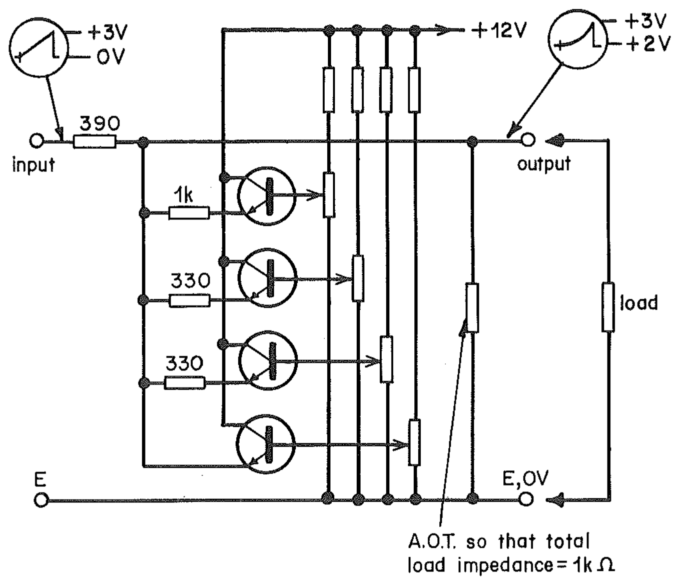

Fig. 5 - Multiple diode function generator

above and to concentrate on simulating the effect of adding a high-frequency correction to the luminance signal. The required degree of correction for various colours was calculated and pre-set, and various colour slide pictures were subjectively assessed using the correction applicable to different colours. From this an estimate was made of the effect the ideal correction would have upon the cross-colour performance of the colour system and upon the transient response of the monochrome system, in relation to the improved definition of the colour system which could be obtained by the addition of the correction.

4.2. Effect on cross-colour

The most serious effect of adding the correction signal was that the amount of coloured noise on the displayed picture was increased. This effect was caused largely by the method used for simulating the correction. All three colour signals were allowed to contribute to the correction signal and since (for a saturated colour) two of the signals were near black, gamma correction enhanced the effect of noise. In a practical correction device the function generators would considerably diminish this noise at black from the inactive channels, effectively removing the noise enhancement caused by gamma correction.

Apart from the noise, the cross-colour effect was not serious. The effect may be more noticeable on commercial television receivers where non-balanced colour demodulators are often used; this was not investigated. It would be possible to mitigate any additional cross-colour effects by adding a colour subcarrier notch filter to the correction signal path to reduce the amplitude of the offending frequency components. This would, of course, slightly reduce the effectiveness of the correction.

4.3. Effect upon a monochrome display

The high-frequency information added to the luminance signal will appear as overshoots in the monochrome receiver picture. With the correction added, the high frequency components of the luminance are displayed at the ideal photopic value, whereas at low frequencies the luminance of the display is at a lower value. For a saturated blue the overshoot can theoretically be as much as 31 times the amplitude of the low-frequency component of the signal. However, the rectification of subcarrier in the receiver cathode ray tube will significantly raise the displayed luminance level of saturated colours at low frequencies and this masks the effect. In a practical test the boost produced an effect similar to the application of moderate aperture correction.

The maximum amplitude of overshoot as a percentage of peak white can be up to about 35%. This occurs for a saturated primary colour at maximum brightness; the exact value of the maximum overshoot and the saturated primary colour for which it occurs depends upon the display tube phosphors for which the correction is designed. (For System I phosphors the maximum overshoot is 30% and this occurs for the green primary).

4.4. Improvement in definition

The tests showed that the addition of the correction can produce a worthwhile improvement in definition in parts of the picture containing saturated reds or blues. These are the colours in the synthesis triangle for which the constant luminance index is significantly less than unity. For green colours the effect of the correction is not so obvious and it diminishes still further as colours become less saturated (i.e. as the value of k approaches unity). It is not possible to produce an assessment of the improvement in definition of the picture as a whole without constructing the complete correction system with function generators; the simulation procedure allows assessment of the picture only on a colour by colour basis. It is thus not possible to draw any conclusion other than that the unwanted effects of cross-colour on the colour system and overshoots on the monochrome display are likely to be a tolerable exchange for the improved definition which should result on the colour display.

5. Conclusions and recommendations

It has been shown theoretically that with function generators having a flat frequency response over the full video bandwidth, it should be possible to correct for the bandwidth reduction effect of a failure of constant luminance. The effect on cross-colour is not likely to be serious compared with the improved definition which should result in and around areas of saturated colours.

The monochrome picture, however, would have overshoots on the edges of highly-saturated coloured areas. The effect of these overshoots would be greatly diminished by the rectification of subcarrier which occurs in the picture tube, and in practice the overall effect would be similar to the application of aperture correction. As far as the monochrome viewer is concerned it can be concluded that 'colour compatibility' could be slightly degraded by the addition of constant luminance correction.

The instrumental difficulties encountered in this feasibility study suggests that this type of device would be costly to install as an addition to existing colour coders when related to the expected improvement in quality. This cost would arise mainly from the alignment required for the function generators, the equalisation of the various propagation delays and the problem of creating space alongside existing coders. Most of these problems could however be overcome if the correction system were made integral with the colour coder, and if the 'latest state of the art' components were used. The system might therefore usefully be incorporated into the design of a new generation of colour coders.

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