VIDEO PROCESSING AND NOISE

1. Introduction

The Noise of a camera channel can be considered as one of the most important camera performance limitations. A performance figure in each channel of 48dB is typical; how is this figure obtained?

The noise measurement requires that the sensitivity of the camera is defined because the setting of gain control obviously affect the noise level of the camera. The conditions for setting sensitivity is shown below:

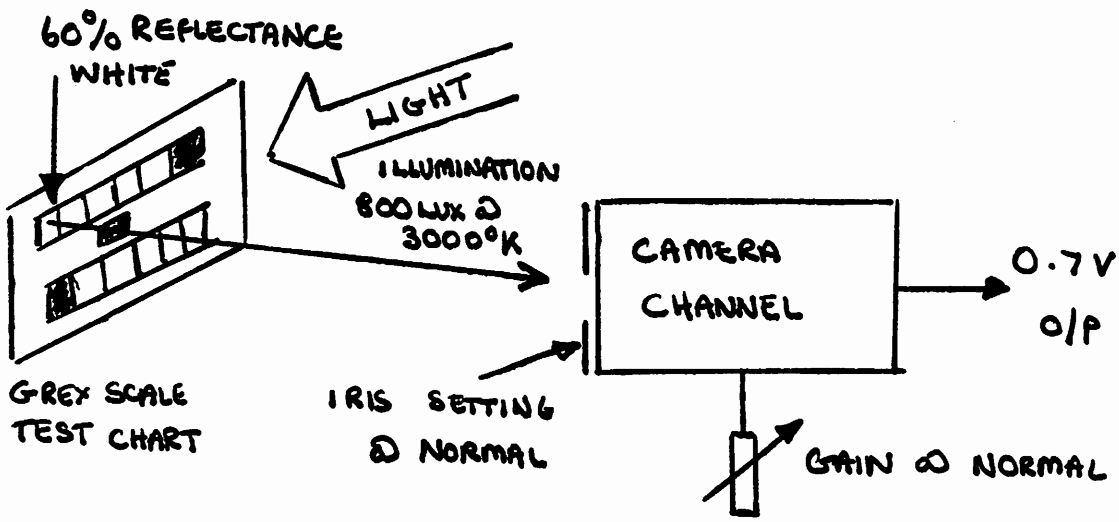

Figure 1

The light level onto the camera tube is defined by the test chart illumination (normal studio lighting level), and the IRIS setting which gives normal television depth of field (i.e. f = 2.8 for 25 mm tubes). The gain is then set to give normal signal output (0.7V video). The camera is now capped up and the noise measurement is made on a gated noise meter. But what about the setting of the other camera controls: The lift control obviously needs to bring the signal out of the black (and white) clippers. The gamma law needs to be set to linear to prevent the gamma law slope producing noise figures which vary with lift setting. Similarly contour (or Apperture) correction is switched out as the amount of correction will be dependent on the subjective effect required. Thus our signal to noise figure is higher than would be obtained in operation with gamma and contour correction in circuit. Also notice the relationship between sensitivity and signal to noise ratio.

The object of this handout is to look at the implications of noise performance within the camera channel.

1.1 Head Amplifier

The signal from a Plumbicon tube rarely exceeds 300nA. The output resistance of the tube is very high - several hundred megohms under normal working conditions and the output capacitance of the tube, depending on type, is between 5 and 15 pF.

From this input the head amplifier plus camera processing amplifier must produce a signal of 0.7 volt across 75R. The frequency response must either be flat to 5.5MHz or sufficiently noise free to enable correction to be carried out in a later stage. The Plumbicon camera tube can be considered as noise free and all the noise originated by the channel amplifiers. (See appendix 1).

The head amplifier noise performance will be further degraded by linear matrix correction, contour correction and gamma correction. Obtaining a low noise figure combined with flat frequency response leads to a number of design considerations:

Consideration 1.

Consider the camera channel as a number of amplifiers in cascade: Best overall signal to noise ratio is achieved when the gain of the first amplifier is high and successive amplification is low.

Consideration 2.

It is usual to use a Field Effect Transistor as the first gain device in the head amplifier. This is because junction transistors suffer from partition noise, thus FET's are inherently less noisy.

Any current intrinsically fluctuates due to the random motion of discrete electrons. Thus we may regard a current as comprising a perfectly quiet theoretical current PLUS a noise current:-

$$i_{real} = i_{theoretical} + i_{noise}$$

To a reasonable approximation we then get:-

i) Noise in junction transistor:-

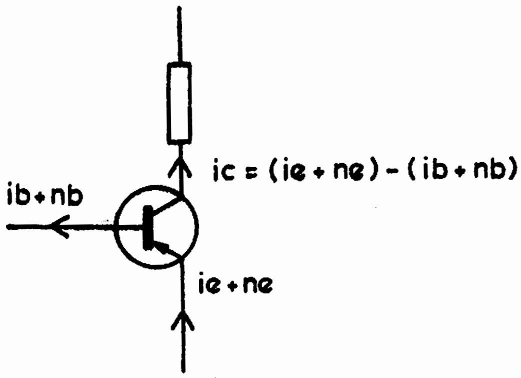

Figure 2a

Where n_b noise generated due to base current flow.

n_e noise generated due to emitter current flow.

$$i_c = i_e - i_b + \sqrt{n^2_e + n^2_b}$$

(This is the vectorial addition of noise).

ii) Noise in FET:-

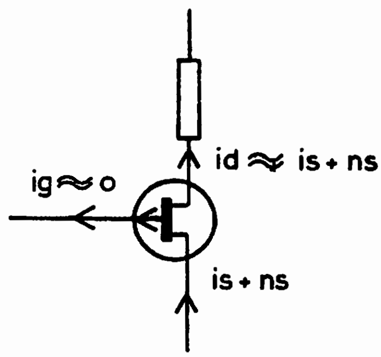

Figure 2b

$i_g \approx 0$ (very small)

$$i_d = i_s + n_s$$

Hence noise is less than a junction transistor.

Consideration 3

The tube output resistance is very high, consequently the tube output capacitance, and stray capacitance of the head amplifier and connecting wire is very important. Typically the required input resistance of the head amplifier is 1K to provide a flat frequency response. The input resistance is obtained by means of negative feedback.

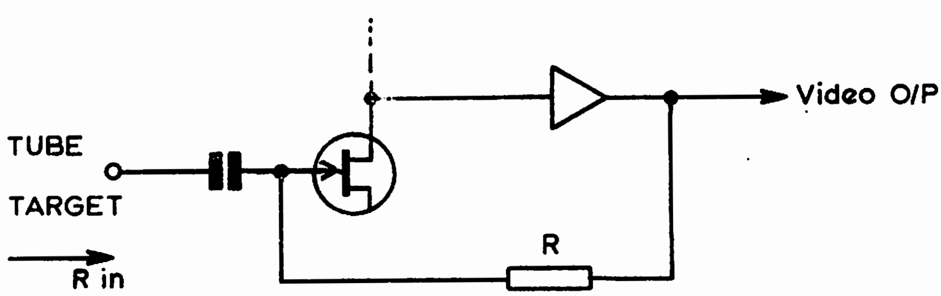

Figure 3

$Rin \approx \frac{R}{M + 1}$ Where M = Open loop gain

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Consideration 4

The lower input resistance reduces the voltage developed across the input and thus requires more gain from the head amplifier. Increasing the gain increases the noise as a consequence. If we reduce stray capacitance to a minimum, the head amplifier input resistance can be raised, and in consequence the noise at the output is reduced.

One method to reduce the stray capacitance is to reduce the Miller effect capacitance on the input FET.

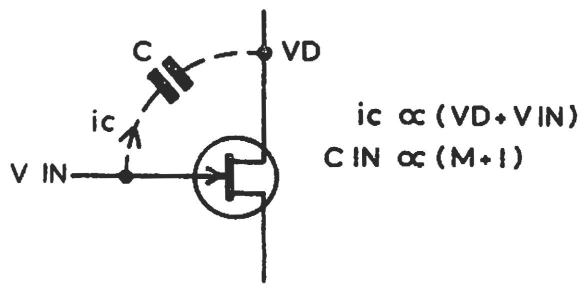

Figure 4

This capacitance can be reduced by feeding the output into a low impedance (i.e. current feed) making M approximately zero:-

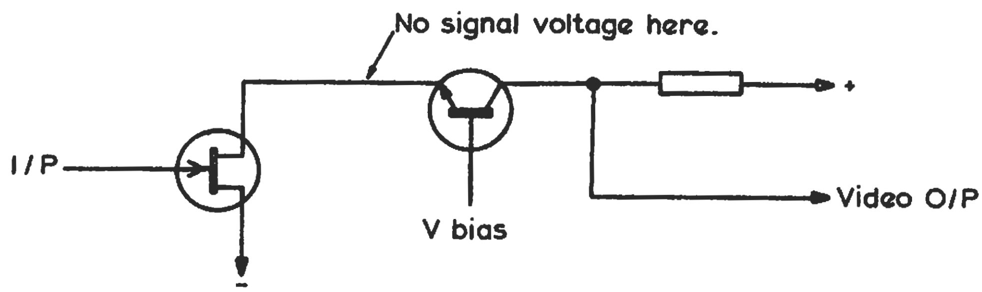

Figure 5

Another method is for the tube manufacturer to reduce the target ring to a point contact. LOCAP (low capacity) tubes also remove unwanted target area.

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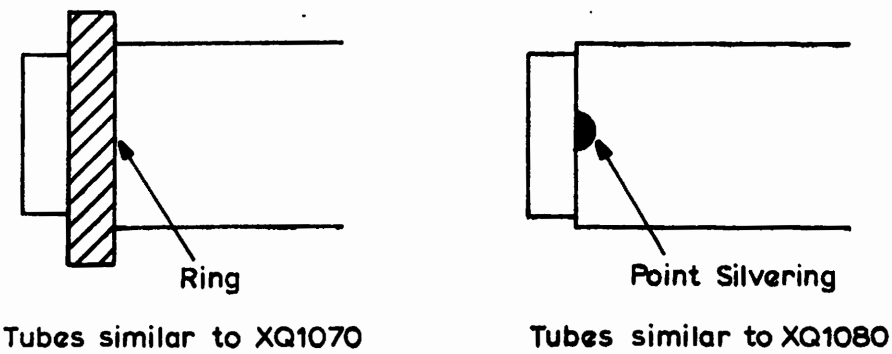

Figure 6

It is usual to reduce input lead stray capacitance to a minimum by mounting the head amp very close to the tube. It is now common for camera manufacturers to place the first amplifier FET inside the yoke assembly.

Consideration 5

To raise the input resistance still more and thus improve the S/N ratio further the stray capacitance could be 'cancelled' out by an inductor.

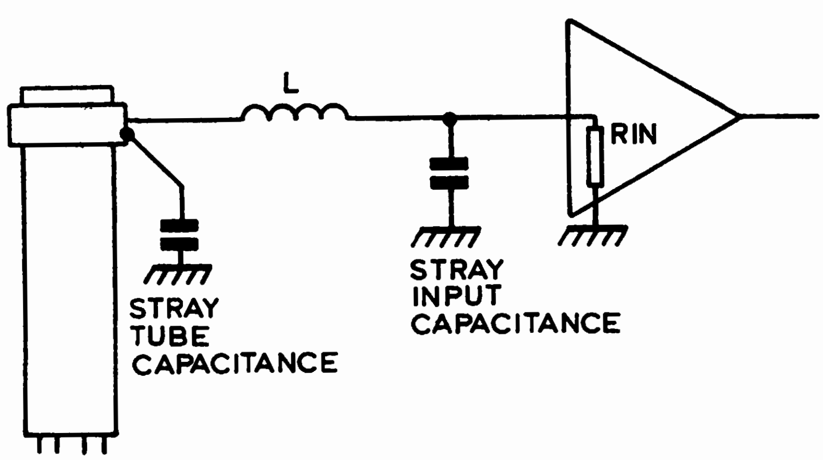

Figure 6

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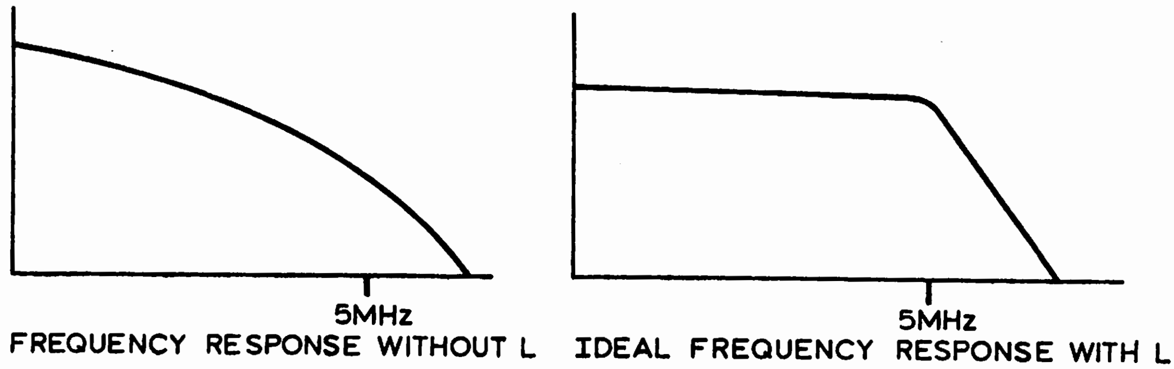

Figure 8

If the inductor value is chosen to overcompensate for the capacitance loss:

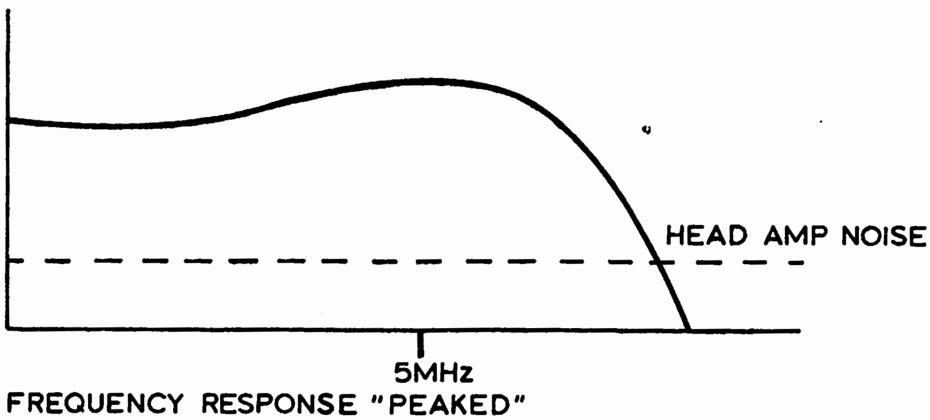

Figure 9

The peaking can be compensated after the head amplifier.

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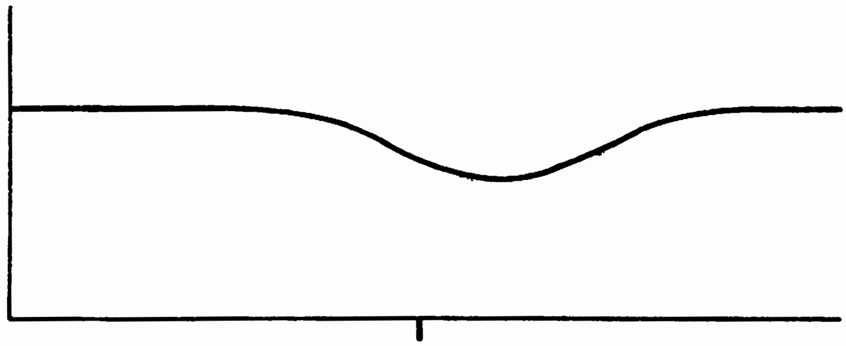

Figure 10

The output now has a flat frequency response with an improvement in H.F. noise

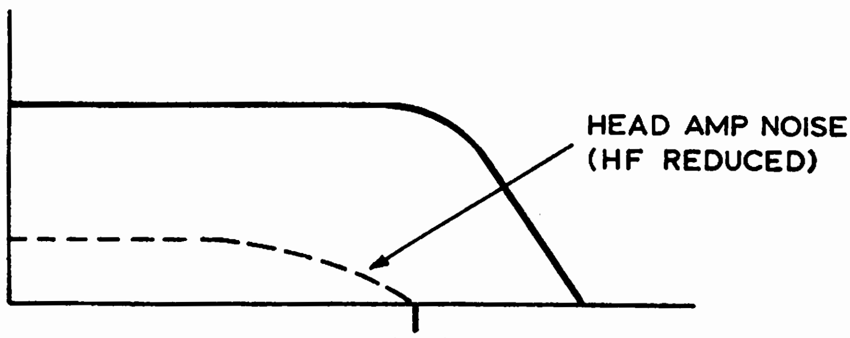

Figure 11

This technique is known as Percival peaking and a typical arrangement using it is given in Figure 12.

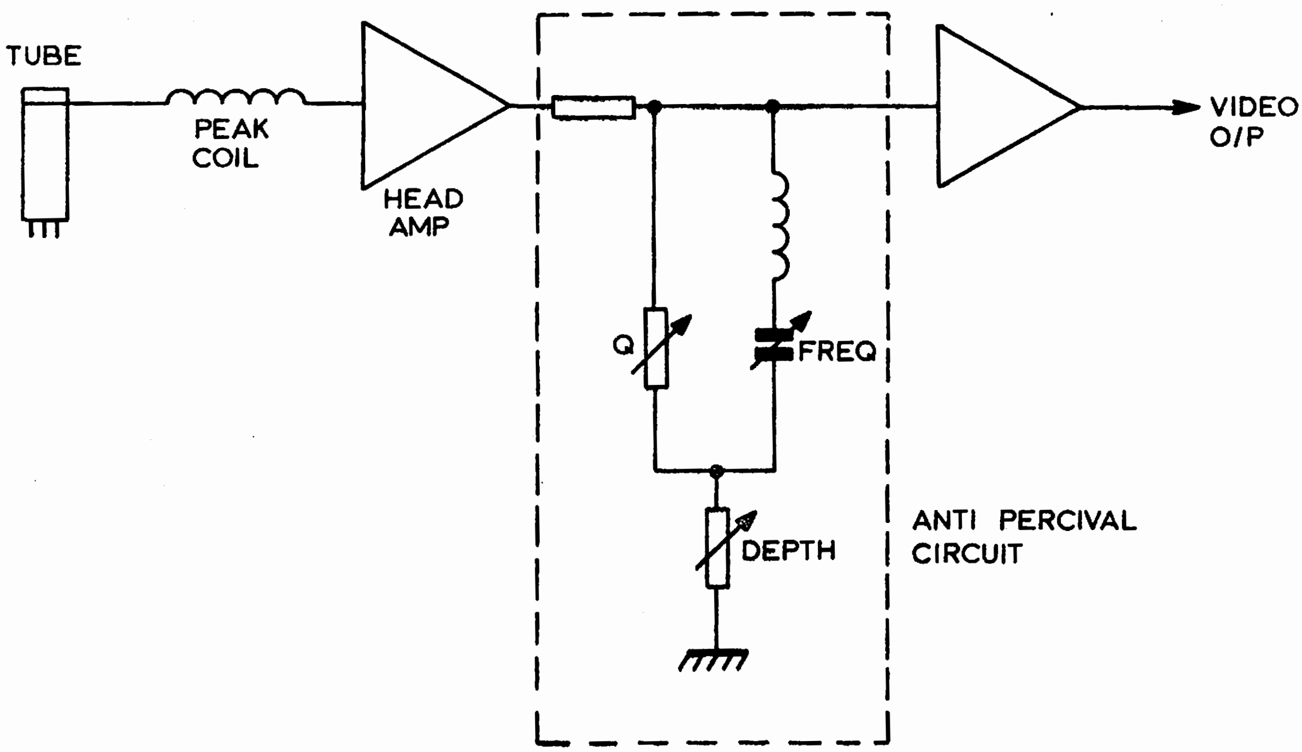

Figure 12

The anti Percival circuits must be carefully set up to obtain a flat frequency response. In practice this requires the use of a tube base signal injector to introduce a frequency sweep through the tube mesh to target capacitance. This has the advantages that the actual tube target to ground stray capacitance is corrected at the anti percival stage.

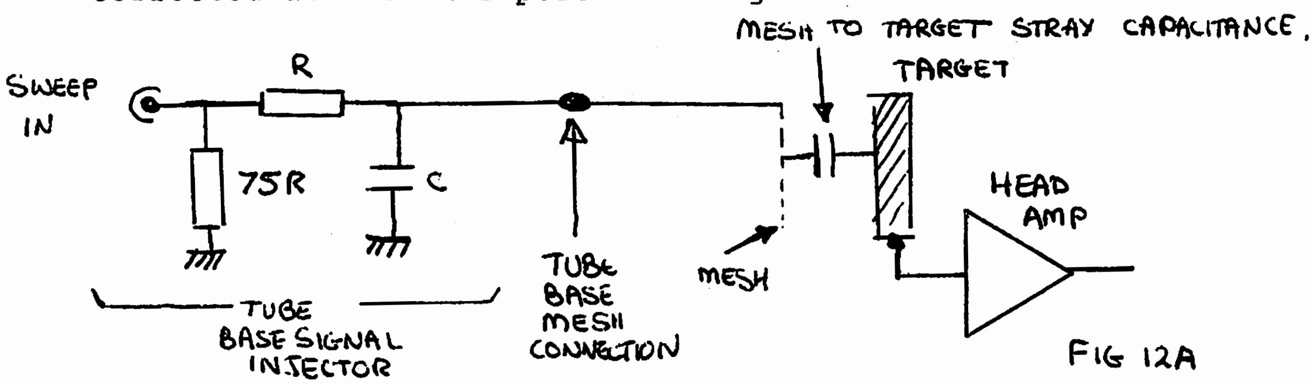

FIG 12A

NOTE: CAMERA MANUFACTURERS WILL CHOOSE VARIOUS COMBINATIONS OF THESE METHODS TO OBTAIN A FLAT FREQUENCY RESPONSE AND REQUIRED NOISE FIGURE.

1.2 Colour Correction and Linear Matrices

The colour fidelity of the colour camera requires linear matrixing. However matrixing requires addition and subtraction of video signals, however the noise associated with these signals will always add, and hence signal to noise ratio will reduce. So the colorimetry of the camera will also influence noise performance.

The Ideal Analysis characteristics

These indicate the proportions of R, G and B required to match a colour of any wavelength or band of wavelengths. For a given set of R, G and B primaries it is inevitable that very narrow band or monochromatic radiations will require negative amounts of one or more primaries to 'match' them. The 'ideal' analysis curves shown in figure 13 indicate the proportions of Red, Green and Blue required. (The radiation shown at 580 nm is discussed in the next paragraph). The negative lobes indicate the amounts of R, G and B which must be subtracted to give a perfect match.

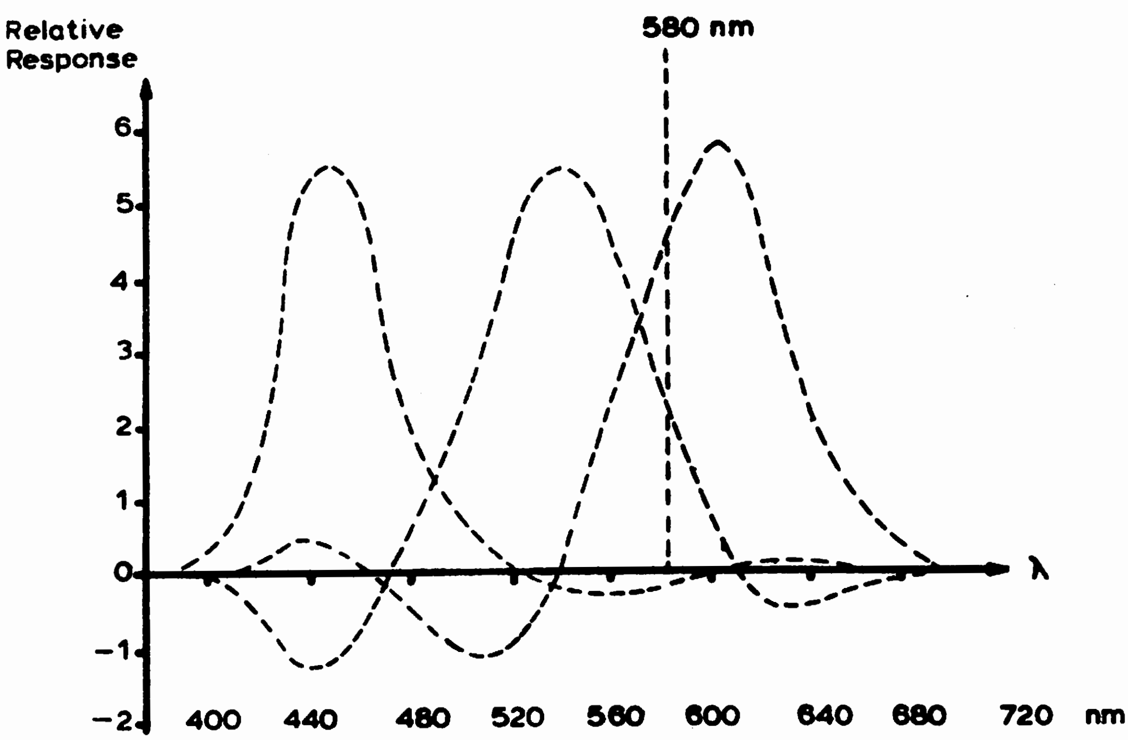

Figure 13: Ideal Analysis Curves

The Practical Importance of the Negative Lobes

A monochromatic radiation e.g. a yellow at 580 nm is seen from figure 13 to require light from the primaries in the proportions.

Match = 4.4 Red + 2.7 Green - 0.2 Blue.

Since a phosphor cannot produce a negative output this indicates that this yellow cannot be correctly reproduced on a monitor even if fed from a camera channel with ideal analysis characteristics. In terms of a chromaticity chart any colour lying outside the RGB triangle does contain negative quantities in its specification and cannot be correctly reproduced. This is not a serious limitation since very few surfaces, under normal illumination, do plot outside the triangle.

A far more serious problem is that of the more common wide band (less saturated) colours.

Figure 14 shows the energy distribution for a wide band range.

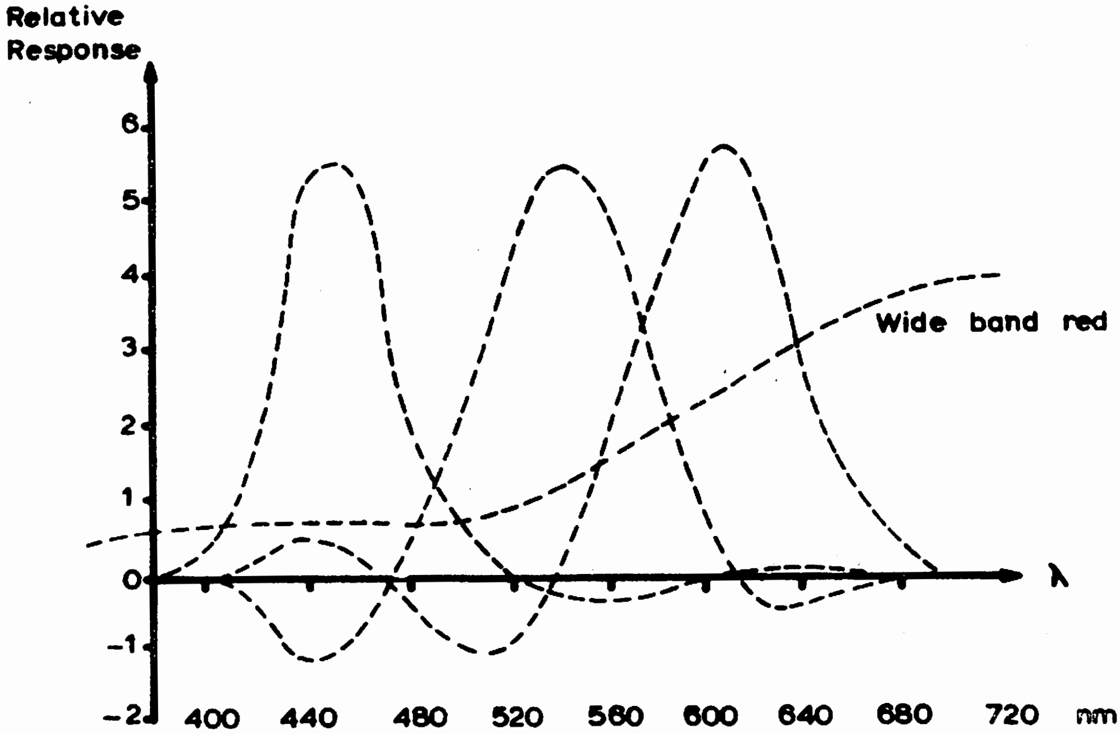

Figure 14: Matching a wide band red

To reproduce this red, calculations from the curves indicate that:

+0.5(R) - 2(R) + 74(R) [summing the product of the two responses at 10 nm steps]

and -1.5(G) + 34(G) - 4(G)

and +10(B) - 1.5(B) + 0.5(B) would

be required for correct reproduction.

i.e. 72.5(R) + 28.5(G) + 9.0(B)

If the analysis had, for any reason, not included the minor lobes - negative and positive - the description would have been:

74(R) + 34(G) + 10(B)

The omission of the negative lobes would thus have introduced errors into the reproduction.

Remember: Skin tones are wide band reds!

A Method of Obtaining the Negative Lobes by Matrixing

An optical analysis system employing camera tubes and filters cannot produce positive outputs over one band of frequencies and negative outputs over another. The negative lobes are obtained by matrixing the outputs of the three tubes in order to give an overall analysis approximating to the ideal analysis. Figure 15 shows a set of three possible analysis characteristics and indicates that a matrix providing a Red output proportional to +1.82 of the Red input, -0.53 of the Green input and -0.29 of the Blue input would produce an effective Red analysis as shown. A similar process would produce the required Green and Blue analysis.

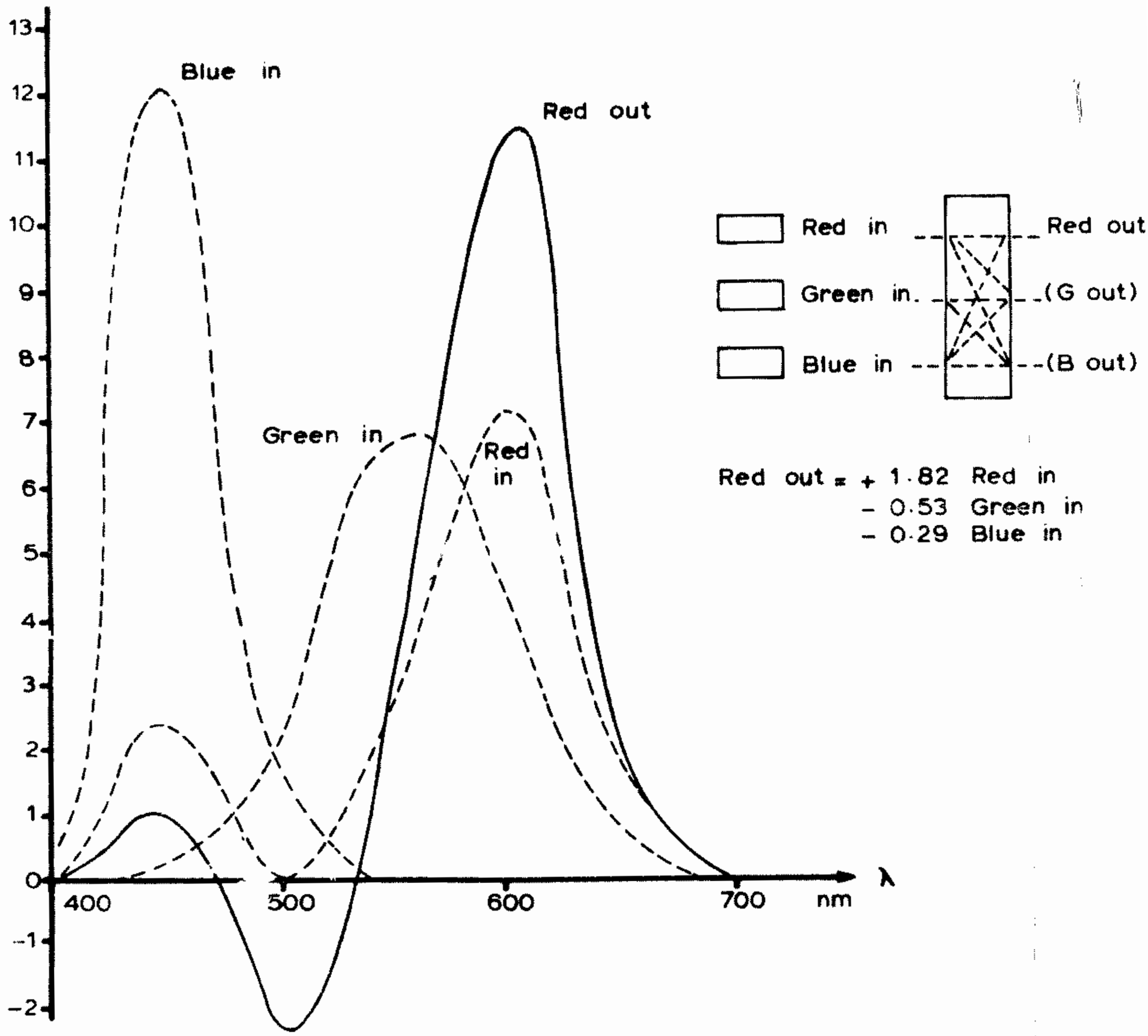

Figure 15: Negative Lobes by Matrixing

Practical Analysis Characteristics

In practice limitations are imposed by the optical splitting system sensitivity, camera tube response and noise considerations. A free choice of the positive lobes is thus not available. The matrix coefficients are chosen using 26 carefully selected test colours. Ideally all colours should be reproduced with correct hue and saturation. In practice a compromise is achieved with careful attention to skin tone colours.

Figure 16 below shows a practical set of camera analysis curves, the matrix and the overall channel response for the camera.

Figure 17 on page 15 shows the chromaticity of 5 reproduced colours both with and without the matrix.

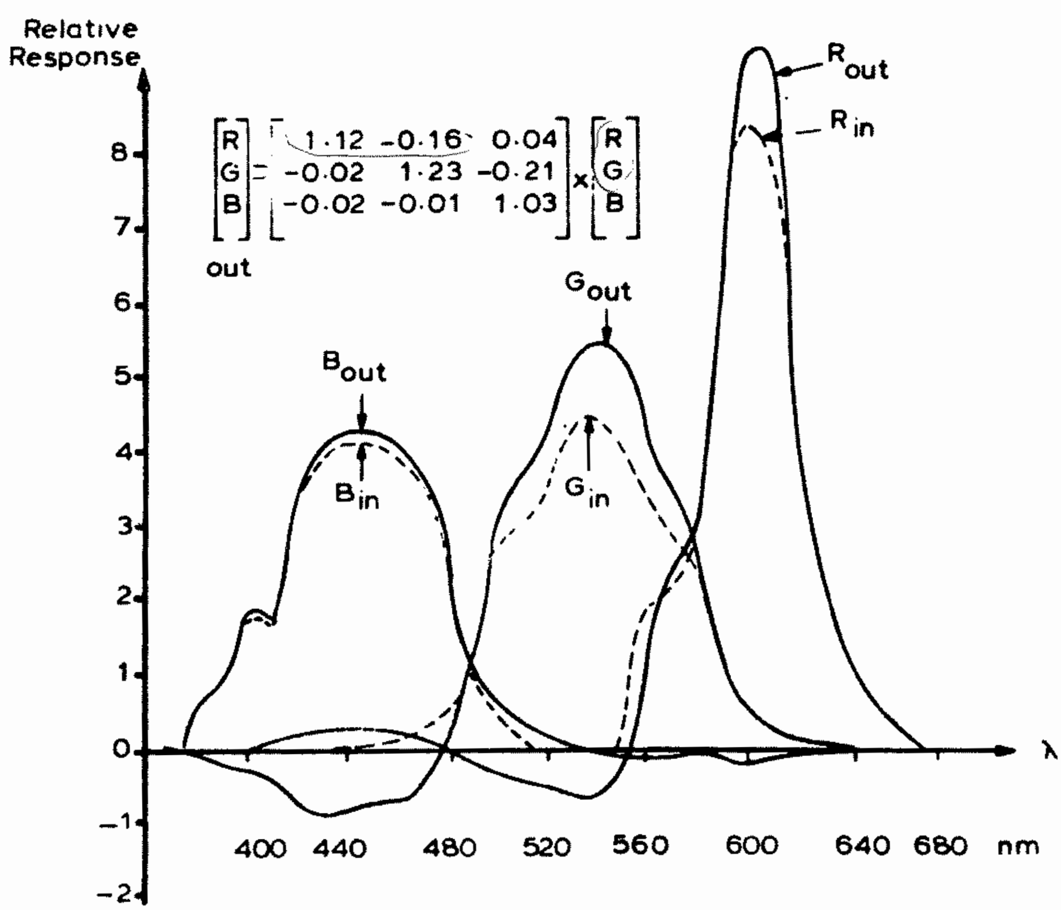

Figure 16

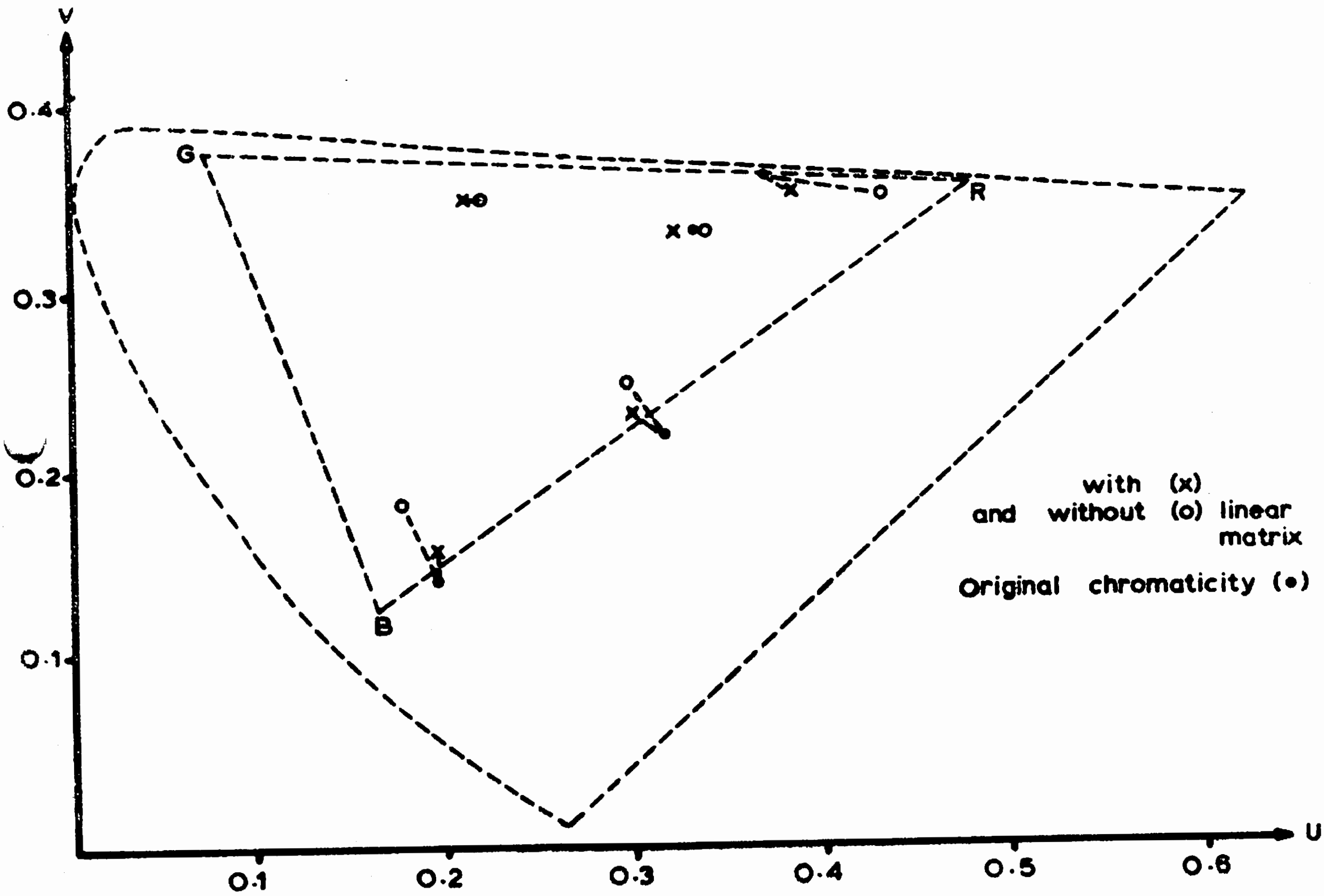

Figure 17

Noise Considerations

When an acromatic scene is viewed by the camera the signal level leaving the matrix is the same as that entering. However, the noise on the signal will be determined by the coefficient of the matrix. One of the principle design factors of an optical splitting component is that of obtaining positive lobe shapes such that the minimum matrix correction is required. A good rule-of-thumb is that no single coefficient should much exceed 1.3.

1.3 Contour Correction

(The basic princples were covered in handout 16F 'Three Tube Colour Camera Channels')

The contour correction signal derived may be described by:-

$$\text{Correction} = E_1 - (E_0 + E_2)/2$$

Where E_0 is the input signal

E_1 is the E_0 signal delayed by one time element

E_2 is the E_0 signal delayed by two time elements

However, when signal voltages are subtracted their associated noise voltages add obeying the 'square root of the sum of the squares' rule. Thus the derived 'correction' signal has a much worse S/N ratio than the original video. When this correction is added to the main video signal the channel S/N ratio is degraded.

(Note - improvement in the resolution of the camera tube will decrease the correction required and therefore improve the channel signal to noise ratio).

To reduce the effects of noise on the correction signal several electronic refinements may be introduced.

a) Low Pass Filter in the vertical rate correction signal. The vertical rate correction signal bandwidth extends to about 1MHz, filtering removes H.F. noise without affecting the correction signal thus improving the final signal to noise ratio.

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b) Core Noise

A typical correction signal is shown in figure 18.

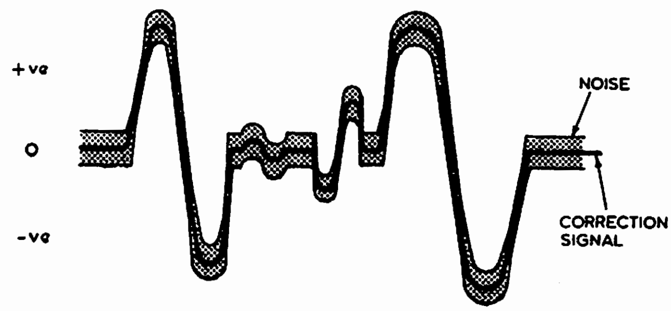

Figure 18

It can be seen that when this correction waveform is added to the video signal it adds noise with the 'edges'. By 'coring' the centre from the correction, the noise can be removed leaving the correction waveform virtually unaffected. This can be achived by a non linear circuit operating in a similar way to cross-over distortion in a class B amplifier.

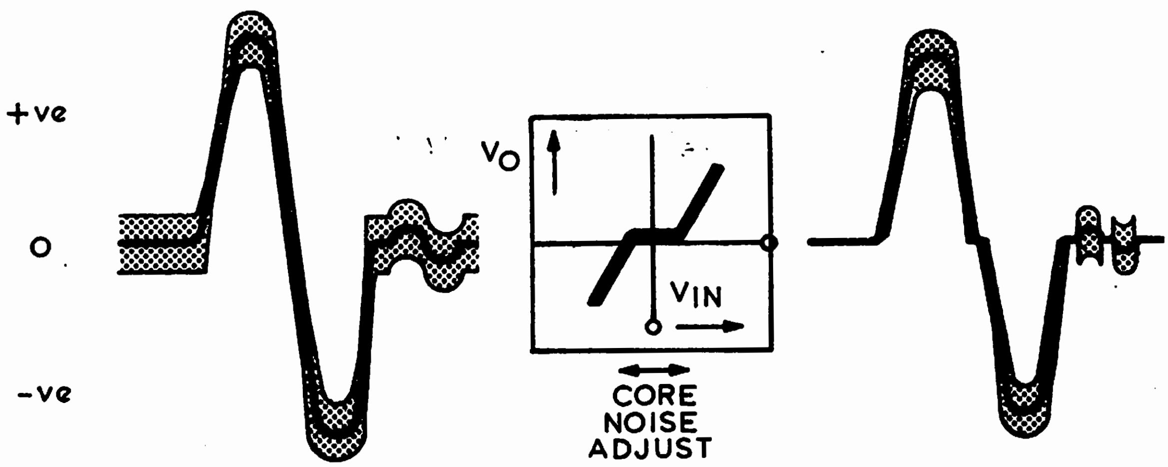

Figure 19

However fine detail is also removed by this process so caution must be shown in operating this control to prevent an unnatural picture.

c. Comb Filter

Consider the addition of three successive television lines E_0 , E_1 , E_2 :-

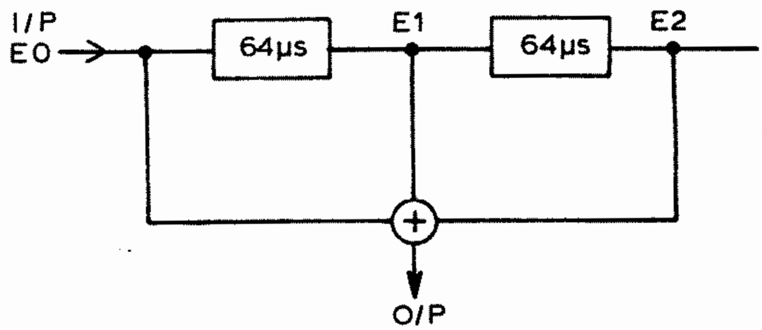

Figure 20

The O/P signal = $E_0 + E_1 + E_2$

$$+ \sqrt{E_{no}^2 + E_{n1}^2 + E_{n2}^2}$$

where E_{no} = noise on signal E_0 etc.

If $E_0 = E_1 = E_2$

O/P signal = $3\ E_0 + \sqrt{3}\ E_{no}$

which is an improvement of $\frac{3}{\sqrt{3}}$ (≈ 5dB)

in signal to noise ratio

This improvement cannot be obtained in practice on main video paths owing to the loss of vertical resolution. (i.e.: the picture is averaged over three lines!)

The input to the horizontal rate corrector could be 'comb filtered'. The horizontal rate correction signal produced would show a noise reduced video input. However some loss of diagonal resolution is produced:

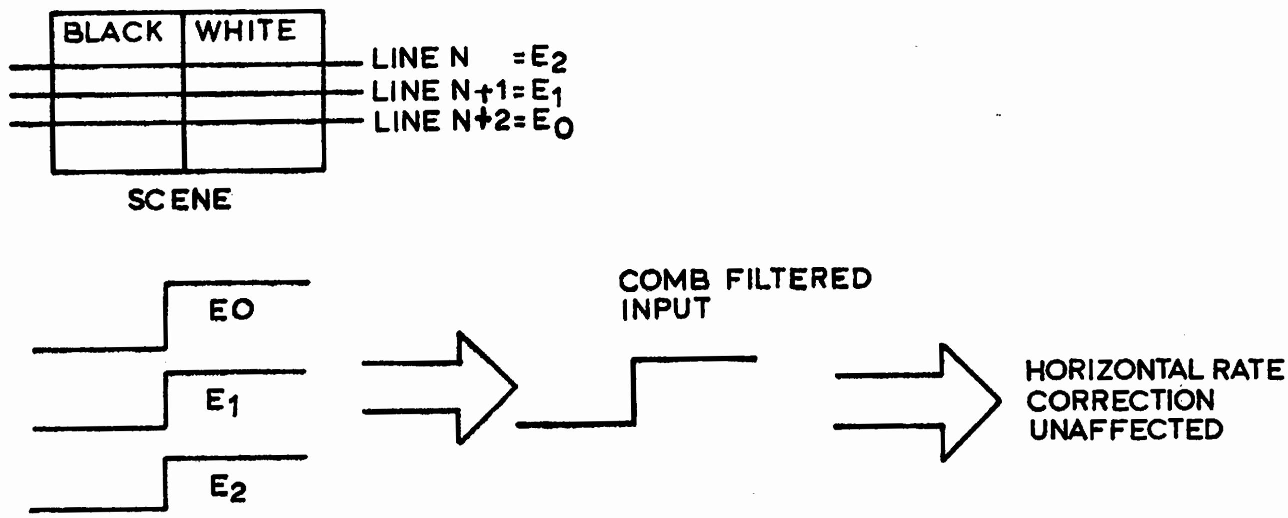

Figure 21

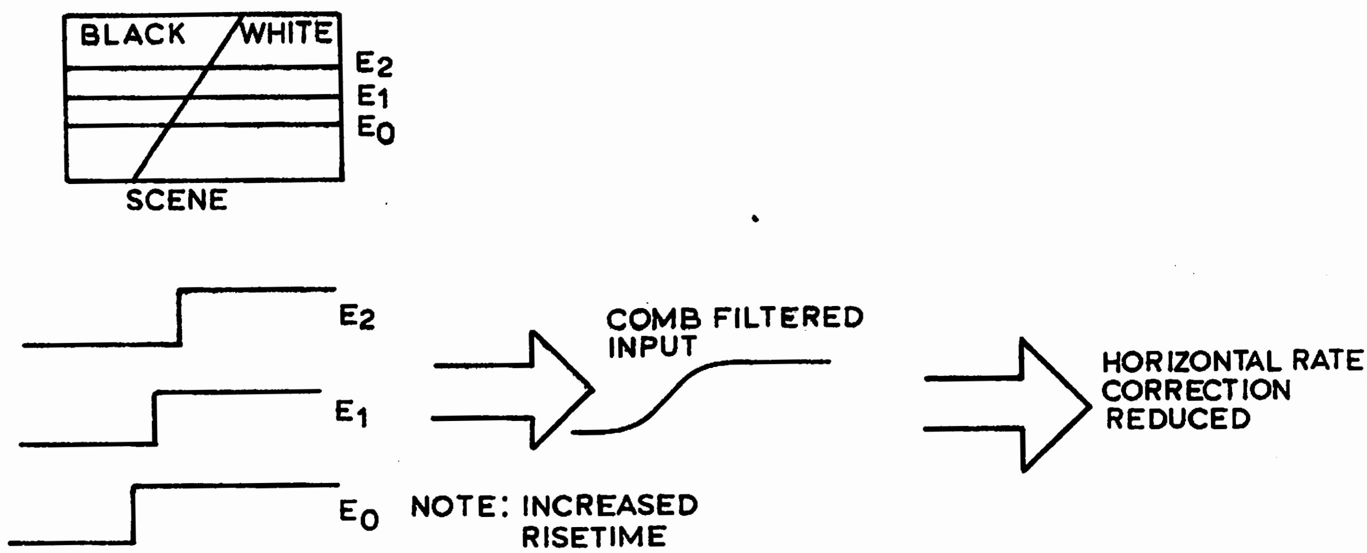

Figure 22

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Thus an improvement in S/N ratio is obtained at the expense of 'diagonal' resolution. This technique uses the delay lines already required for the vertical aperture correction.

In practice the addition is a compromise between loss of diagonal resolution and signal to noise improvement. Thus
$E_0/4 + E_1/2 + E_2/4$ is a commonly used formula.

The name of this type of filter is derived from the frequency response.

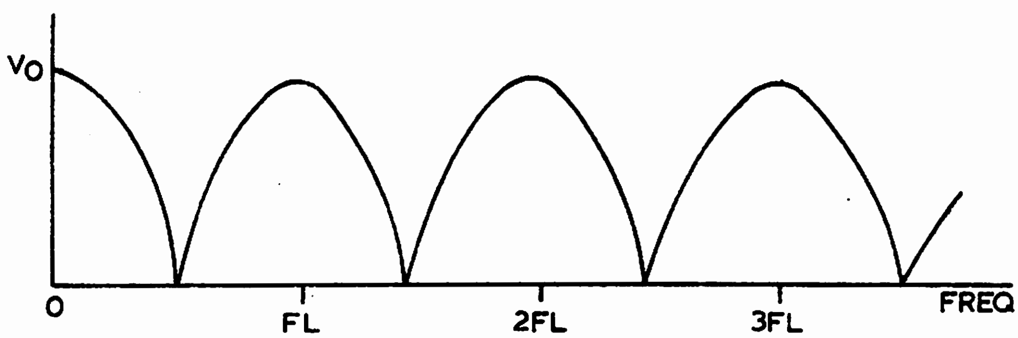


Figure 23

The response passes information about the line frequency and attenuates the noise located between line spectra.

d) Level Dependent Contours (ONSET)

Another technique to reduce noise is to prevent correction in the darkest areas of the picture where noise visability is heightened by gamma correction. This is achieved by a level dependent switch.

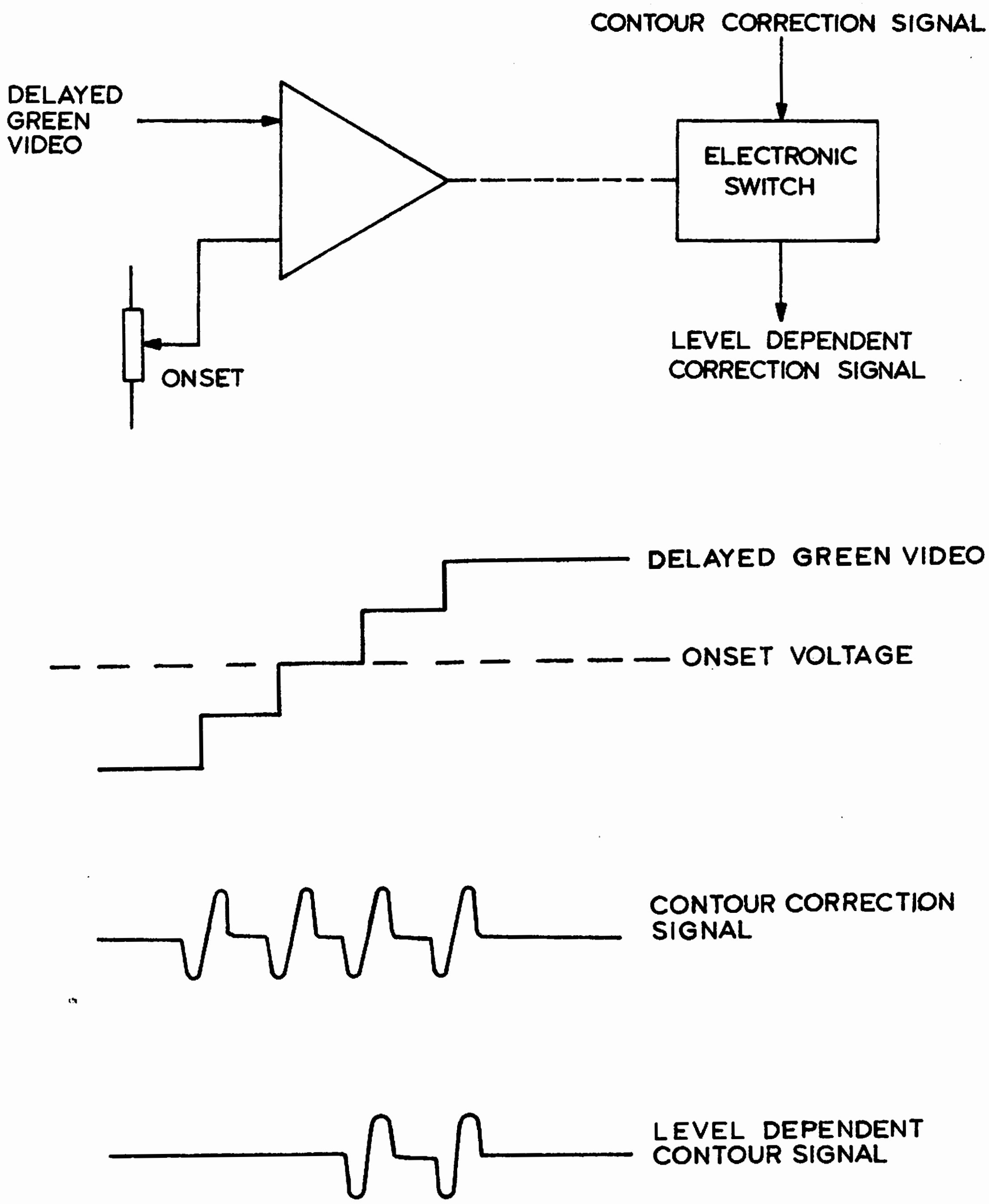
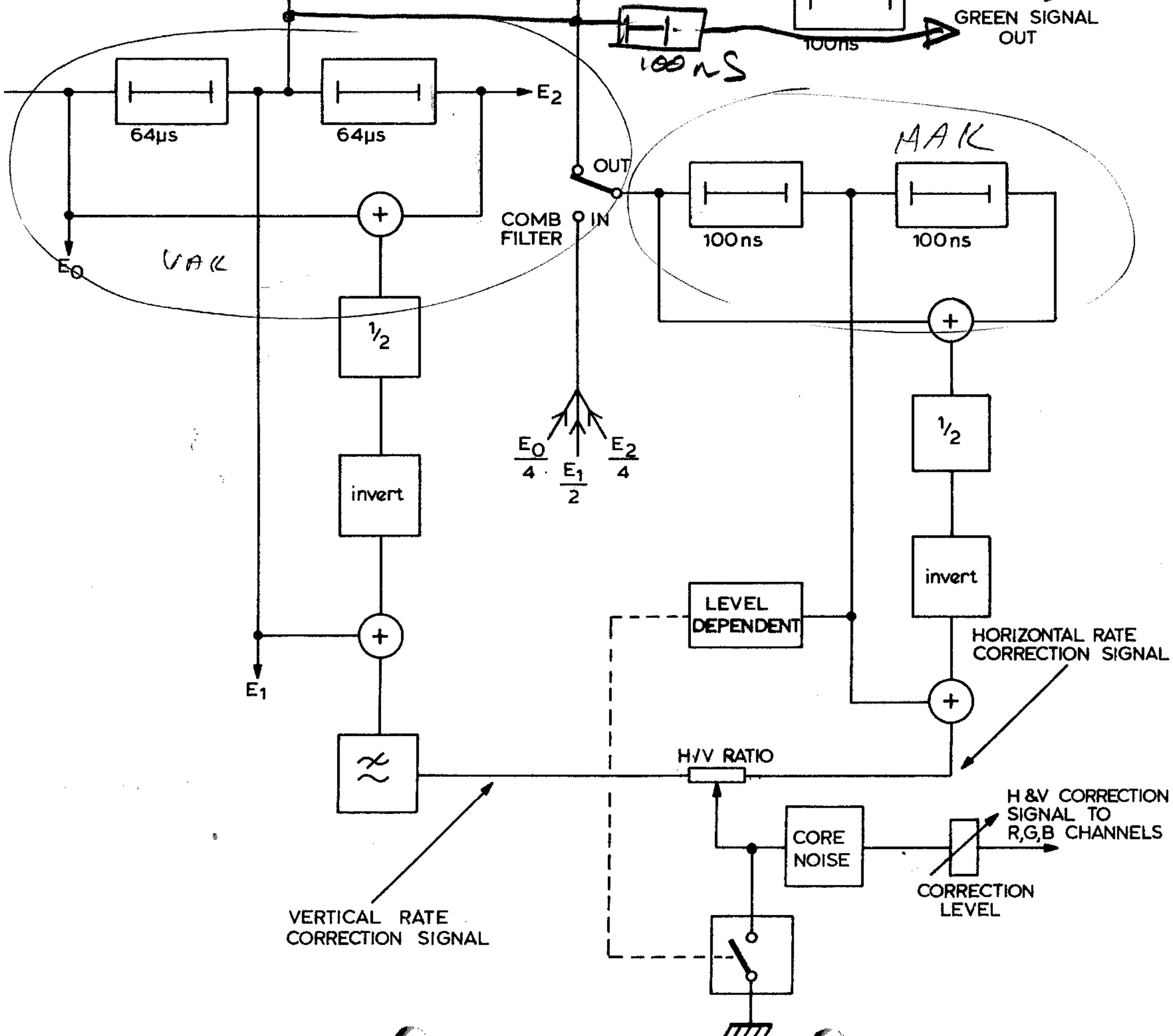


Figure 24

A practical combined vertical rate and horizontal rate corrector is shown in figure 25.


GREEN SIGNAL OUT
100ns
100nS
64μs
64μs
E2
E0
VAK
MAK
OUT
COMB FILTER
IN
100ns
100ns
1/2
1/2
invert
invert
E0/4 · E1/2 E2/4
E1
LEVEL DEPENDENT
HORIZONTAL RATE CORRECTION SIGNAL
H/V RATIO
H &V CORRECTION SIGNAL TO R,G,B CHANNELS
CORE NOISE
CORRECTION LEVEL
VERTICAL RATE CORRECTION SIGNAL

In-Band and Out-of-Band Correction

The choice of horizontal rate corrector delays will affect the frequency response. A typical Plumbicon resolution response requres a corrector which would match its falling response by an exact opposite correction. This would require a peak in the corrector response at around 10MHz and require a large amount of correction to provide the necessary effect. Also it would introduce a large amount of noise onto the video signal. In practice a horizontal corrector for a studio/O.B. camera uses a peak between 5MHz (Edge of Band) and 6MHz (Out of Band).

This peak corrects fine detail loss but the combination of Plumbicon tube loss and this out-of-band correction can result in an error at mid-band. A second horizontal rate corrector with an 'In-Band' peak is required to obtain a more correct response.

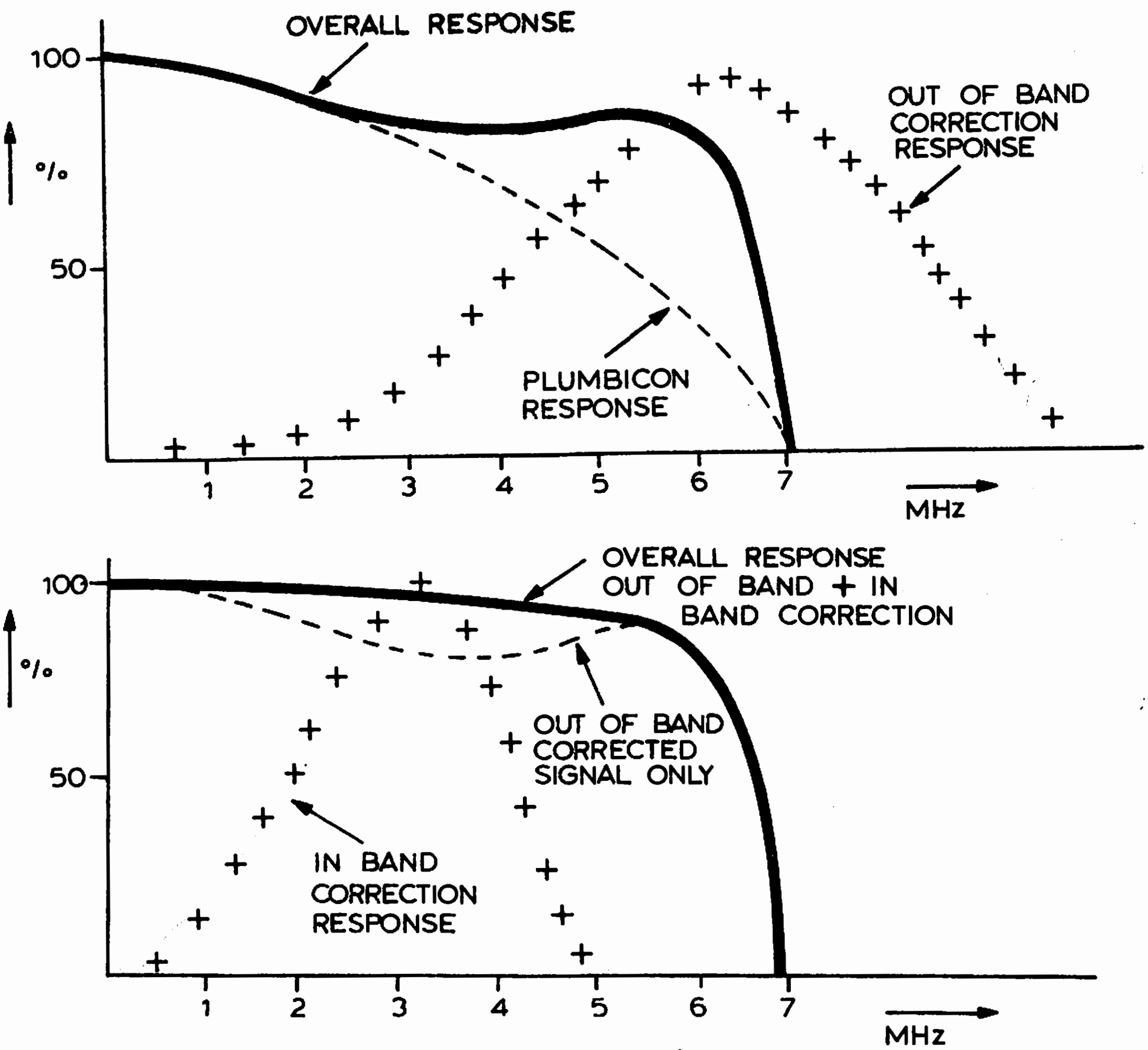


Fig. 26(b)

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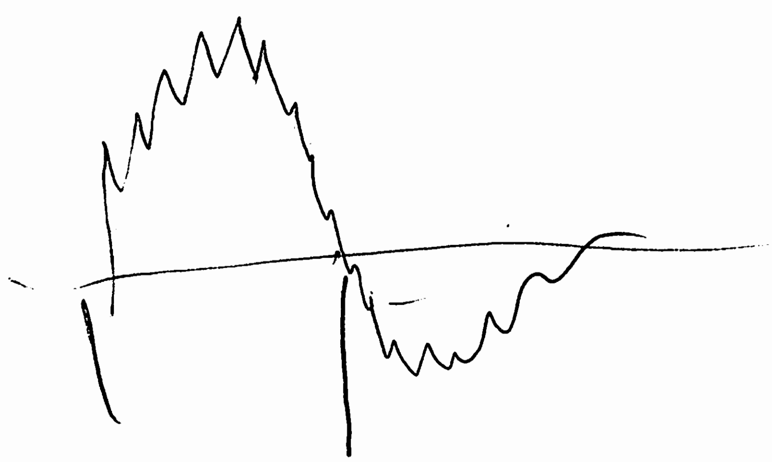
From figure 26 it can be seen that two horizontal correctors can be used to closely match the resolution losses of the Plumbicon tube and camera optics.

Caution must be shown when operating 'In-Band' correction to avoid 'coarse' black edging although slight over correction is sometimes used on light entertainment programmes.

Some cameras (e.g.: E.N.G. camera's) only employ 'In-Band' correction, this has the advantages of lower noise and ensure that the effects of correction are still seen after recording on a colour-under V.T.R. The pictures however look artificial, suffering coarse black edging.

Contour Correction Applied after Gamma

Further noise improvement can be obtained by deriving the contour correction signal before gamma correction and applying correction after it. This results in pictures suffering undercorrected grey-black edges and overcorrected grey-white edges.



1.4 Gamma Correction

The 625 line System Iassumes that a display gamma of 2.8 ± 0.04 is required, however, subjective improvement is produced with an overall gamma between 1 and 1.3.

The current (1985) BBC camera specification requires that a true power law of $\gamma = 0.4$ be maintained over an input contrast range of at least 50:1.

(That is the gamma corrector will have an accurate power law between the limits of 100% and 2% (1/50) of input signal levels).

The gain of the corrector is limited below 2% of input level to reduce the effect of flare, noise, shading and other spurious electrical signals.

The characteristics of a gamma corrector are shown in Figure 27.

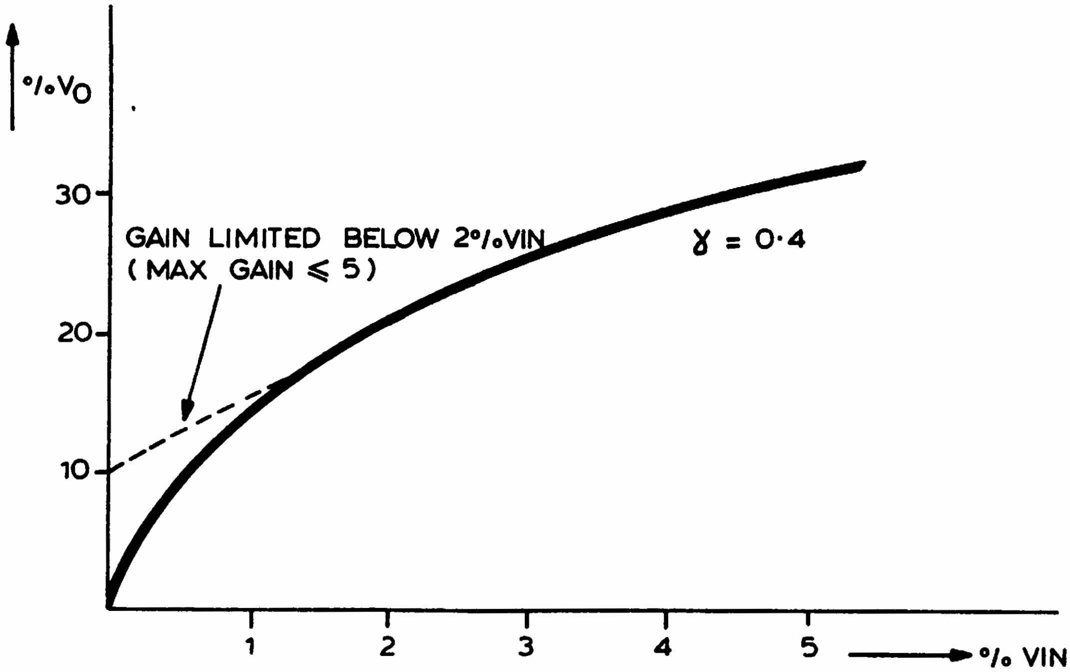


Figure 27

From figure 27 it can be seen that the effect of limiting the gain produces an overall 10% reduction in output. The loss of level is restored by increasing the overall gain of the corrector by 1.12. The resultant transfer characteristic is a 'pseudo γ = 0.45' with gain limited to 5 in the near black region.

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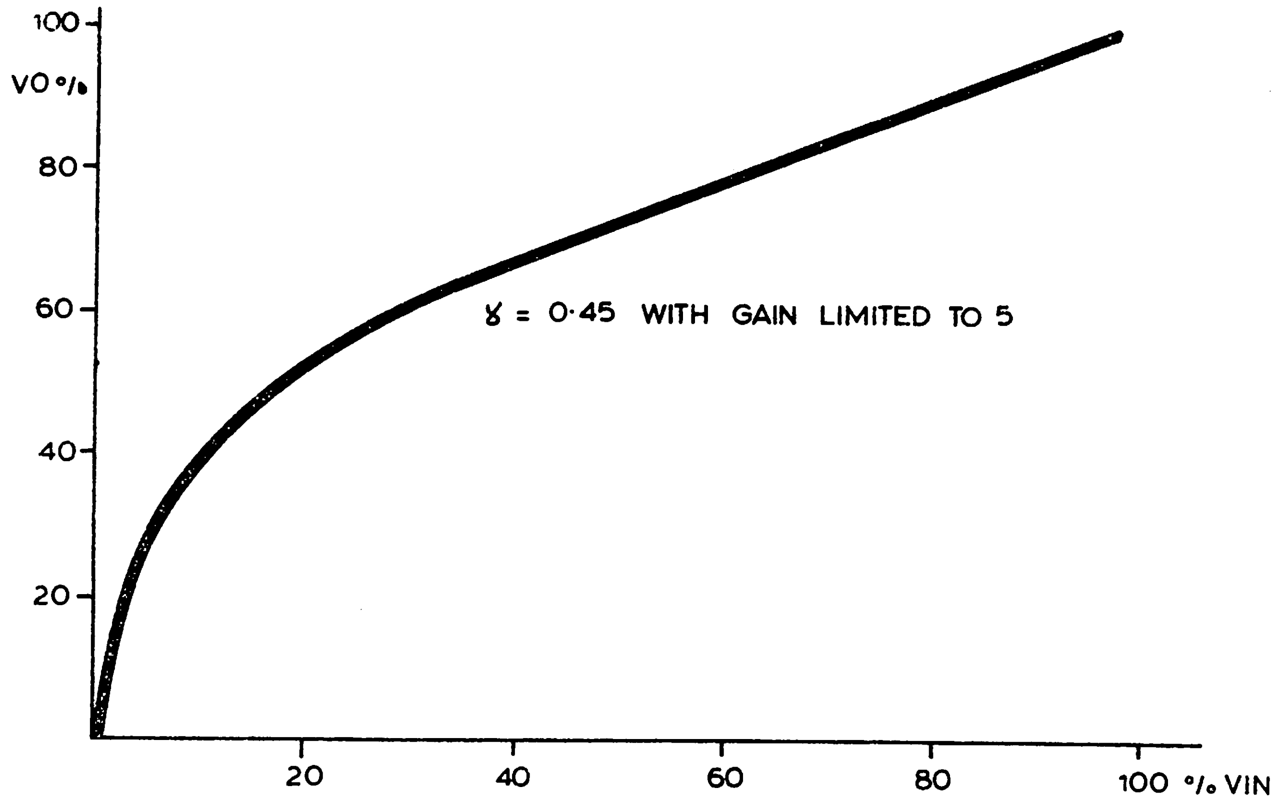

Figure 28

Higher values of gamma (γ = 0.5, 0.6 etc.) are sometimes required to deal with situations such as inadequate light level in which an imperfect luminance characteristic is preferable to the excessive visibility of lag, noise etc.

The gamma correctors of the three channels must track accurately to avoid grey scale errors.

1.5 Japanesse Knee

With the use of dynamic beam control on cameras, extra dynamic range is available from the tube, (up to 3 stops overload), this is usually white clipped at 100% (0.7V). However if a non linear circuit introduces a knee at say 80% of output, some of this highlight signal can be compressed within the normal signal range. (Note: most of picture is left unaffected, this includes flesh tones, but highlights such as sky is compressed).

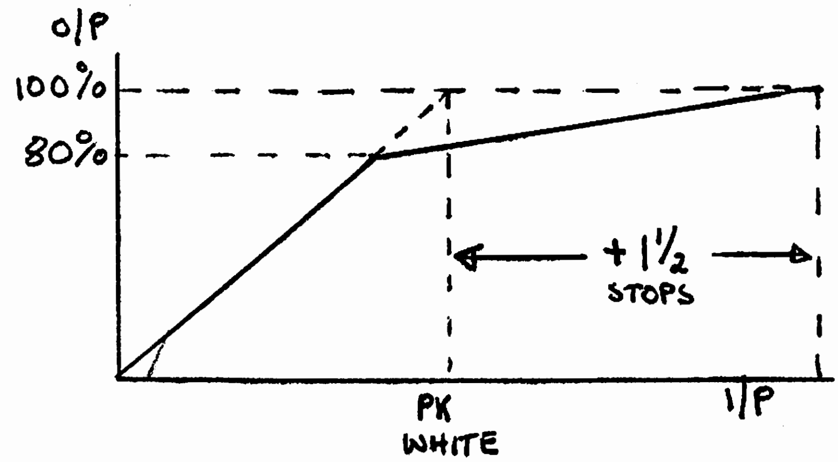

Figure 29: Japanesse Knee

1.6 Black Stretch

Another modification of the contrast law fitted to some cameras is to introduce a knee circuit near black to increase contrast handling in the dark areas of picture. The knee circuit is introduced into the luminance channel of the encoder to avoid worsening signal to noise ratio of the chrominance.

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APPENDIX 1

The noise performance of a Plumbicon tube is due to shot noise:

$$I_{noise} = \sqrt{2e\, I_s\, B}$$

where Is = Signal Current and B = Bandwidth.

For 200nA signal current and 5.5MHz Bandwidth this would give a signal to noise ratio of 333 or 50dB at White level.

For 10nA bias light and 5.5MHz Bandwidth this would give a signal to noise ratio of 1540 or 64dB at Black level and this is the condition for measurement of camera noise. This figure is very much better than the channel noise performance and the tube can be considered noise free.

S.P. Westlake/VC/PROC&NOI
12th August 1985