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THE MARK VII COLOUR CAMERA- THE CAMERA IN RELATION TO THE SYSTEM

THE TRANSMISSION of colour television pictures by any of the current and proposed systems, NTSC, PAL or SECAM, does not permit the reproduction of colour pictures which are perfect in all respects, at any rate if we are to limit ourselves to reasonably priced receivers. The limitations arise largely because the addition of colour has been achieved without increase of channel bandwidth, because of the requirement that colour transmission should permit the reception of high-quality black-and-white pictures on existing monochrome sets, and finally because of the tristimulus nature of the colour reproduction system. The quality of the final picture, whether colour or monochrome, essentially depends on three factors, the originating equipment, the transmission system and the receiver. The systems engineer is limited by the requirements mentioned above and the receiver designer by price. The design of the originating equipment, on the other hand, is dictated by the necessity for exploiting the full potential of the transmitting and receiving systems.

THE TRANSMISSION SYSTEM

NTSC, PAL and SECAM have in common that high-frequency information is transmitted entirely on a wide-band luminance signal while colour information is conveyed by two narrow-band colour difference signals. The true luminance signal is related to the green, red and blue primary signals by the well known equation:

$$Y = 0.59G + 0.3R + 0.11B. \quad (1)$$

As with black-and-white television it is necessary to precorrect the transmitted signal for the non-linear characteristic, or gamma, of the picture tube and until recent years it was universal practice to modify

equation (1) to the following form for this purpose:

$$Y' = 0.59G^{1/\gamma} + 0.3R^{1/\gamma} + 0.11B^{1/\gamma}. \quad (2)$$

It is at once evident that Y' is not equal to $Y^{1/\gamma}$, except for the one case where $G=R=B$, and that the correct luminance value is not in general transmitted when this signal is used. The most significant failing of this is in the reproduction of fine detail which is outside the spectrum of the narrow-band colour difference signals, and which is therefore transmitted entirely as part of the luminance signal. The actual loss in the depth of modulation at which fine detail is reproduced may be simply derived by evaluating the quantity:

$$\frac{(Y')^\gamma}{Y} \quad (3)$$

for various colours, and figures for the three primaries and their complementaries are given in Table 1.

Since the introduction of the earliest television systems engineers have constantly striven to improve definition and it was not therefore long before an alternative to Y' for the luminance signal was considered. The use of this luminance signal resulted largely from the type of 3-tube camera then exclusively in use, the GRB camera. The derivation of the luminance signal from three separate primary signals involves not only the loss in resolution shown in Table 1, but a further and often greater loss due to imperfect registration of the three primary images.

SEPARATE LUMINANCE

Both causes for this reduction in resolution are avoided if the luminance signal is firstly derived from a single tube, and secondly transmitted in the form:

$$Y^{1/\gamma}, \quad (4)$$

the associated colour difference signals taking the form:

$$R^{1/\gamma} - Y', \quad (5)$$

$$B^{1/\gamma} - Y'. \quad (6)$$

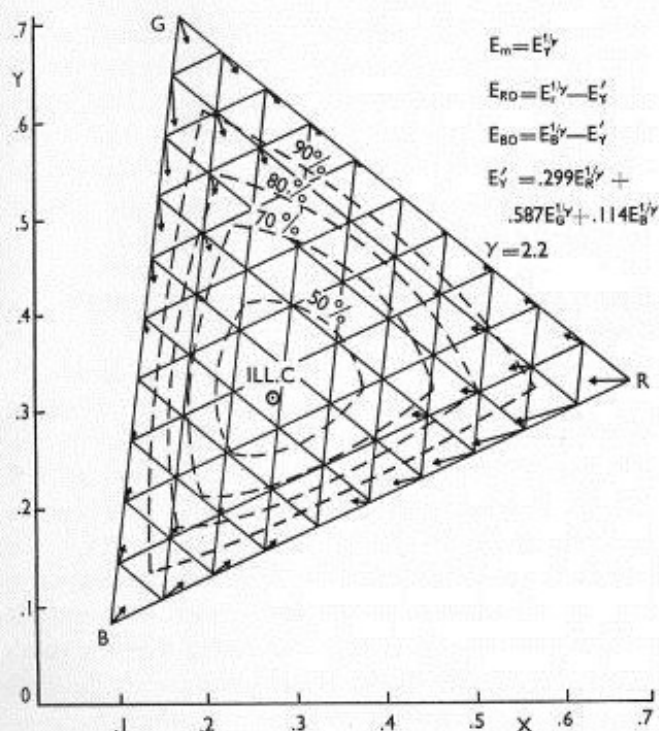


Fig. 1. Chrominance distortion diagram reproduced by permission of The Institute of Electrical and Electronics Engineers Inc. Dotted lines indicate the percentage colour saturation.

The use of the luminance signal Y' of equation (2) in the formation of the colour difference signals, is necessary in order that the third colour difference signal $G^{1/\gamma} - Y'$ may be recovered at the receiver without the use of non-linear circuits.

At the receiver, however, the addition of the separate luminance signal to the three colour difference signals introduces in each case a component of magnitude,

$$Y^{1/\gamma} - Y'. \quad (7)$$

PERFORMANCE OF YGRB ARRANGEMENT

Although the YGRB arrangement has been discussed for many years the exact nature of the luminance component of equation (7) is sometimes not fully appreciated. In particular figures tend to be quoted only for 100% colour saturation, a situation almost impossible to produce in real scenes. Although solely a luminance component, the non-linear nature of the picture tube translates it into changes both of hue and saturation. The chrominance diagram in Fig. 1 is reproduced from D. C. Livingston's paper on the NTSC system and its variants published in 1954.¹ Dotted lines have been added to indicate the degree of colour saturation, and it will be noted how rapidly the error (as indicated by the length of the arrows) diminishes as the saturation falls to the values likely to be realized in practical scenes.

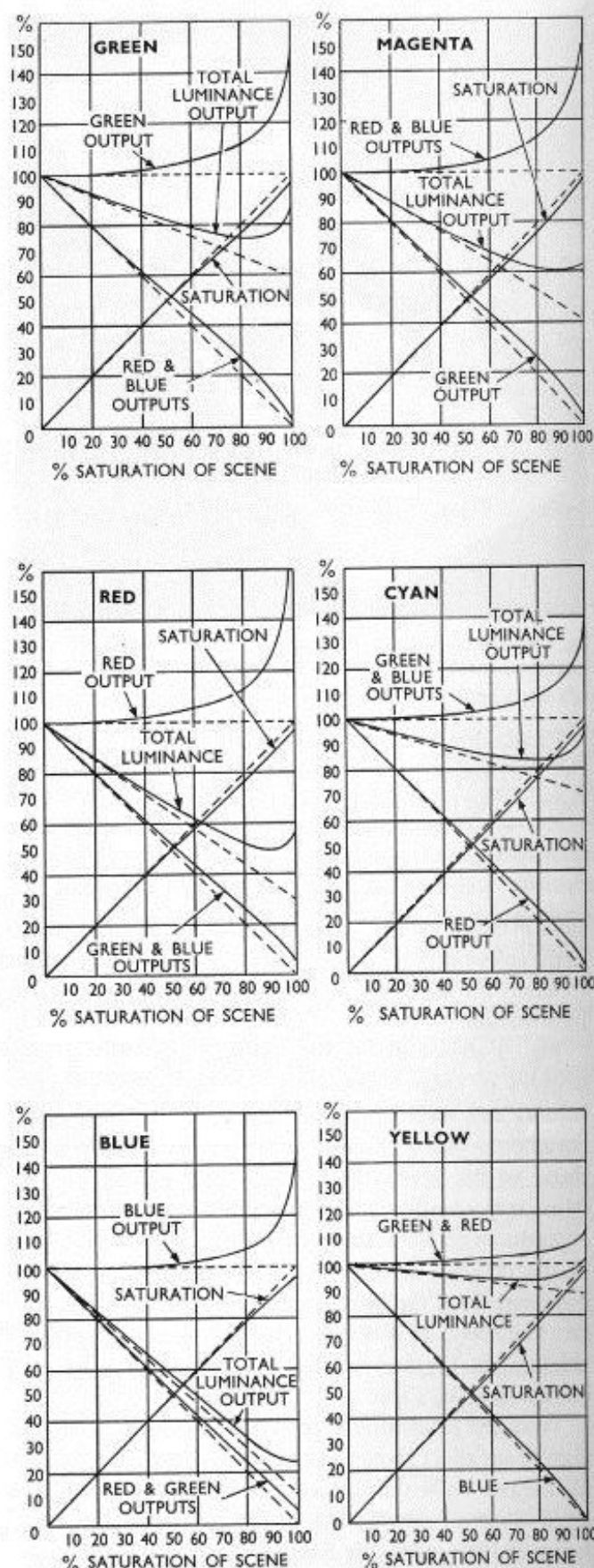


Fig. 2. System performance. The broken lines indicate values in the original scene and the full lines indicate the reproduced value.

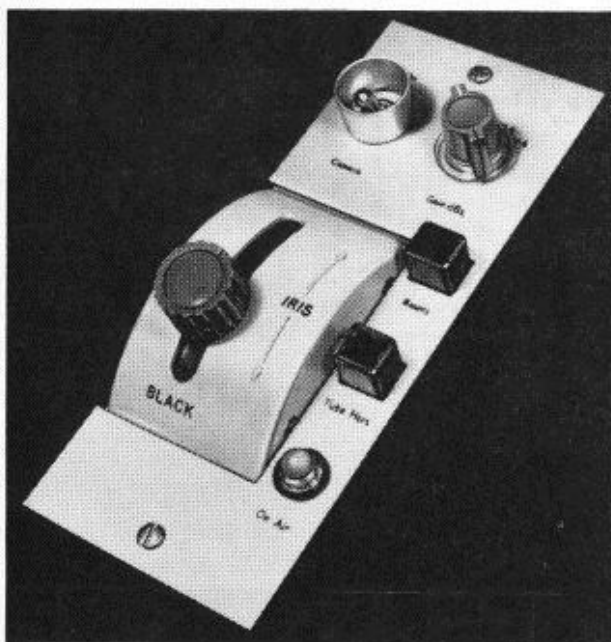


Fig. 3. Remote Control Unit. The quadrant control is used for Iris adjustment and the knob is rotated for Master Black Control.

Employing the three signals specified in equations (4), (5) and (6) the three quantities representing the light output from the picture tube are:

$$(G^{1/\gamma} - Y' + Y^{1/\gamma})^\gamma, \quad (8)$$

$$(R^{1/\gamma} - Y' + Y^{1/\gamma})^\gamma, \quad (9)$$

$$(B^{1/\gamma} - Y' + Y^{1/\gamma})^\gamma, \quad (10)$$

since in the encoding process all wide-band information in the colour difference signals is lost it should be noted that only the third term in each case includes wide-band information.

Fig. 2 shows the system performance for various degrees of colour saturation for the three primary colours and their complementaries. In each case the parameters of the original scene are shown dotted and those of the reproduced image are shown in full. Most importantly, it will be seen that in all cases the reproduced colour saturation is very close to the value in the original scene, much more so than might be expected from the variation in total luminance. The fact that this is so is borne out in practice in cameras of this design. Figures for the various combinations are summarized in Table 2.

With the saturation approximately unchanged, the significant effect shown to a greater or lesser extent on all the curves is that of enhanced luminance. This in itself is not of significance in the reproduced picture, being indistinguishable from a slight change in light level on the scene. More importantly, the increased luminance would cause a receiver overload on one or

more guns if this condition were allowed to occur. This situation may be simply prevented by monitoring the camera iris setting with respect to a GRB display, the GRB signals being derived exactly by the process used in a conventional receiver. By this means, any excursions of the tristimulus signals above the nominal 100% level will automatically be avoided.

OPERATIONAL CONTROL OF A YGRB CAMERA

Essentially the operational control of a 'hands-off' camera channel reduces to adjustment of the iris setting to accommodate variations in light level over the set. It is also normal to provide a black level control which may on occasion be used to off-set the limited contrast handling ability of the television system. These two functions are combined in the single control shown in Fig. 3. Movement of the knob over the quadrant provides iris control while rotation of the same knob varies the Master Black. Slight pressure on the knob operates a microswitch by means of which the associated camera may be switched to a common monitor.

As shown in Fig. 2, adjustment of the iris, to give a standard normal level output from one or more of the YGRB channels, may result in the levels of one or more of the GRB primary signals, derived from the YGRB signals, exceeding their normal 100% level. Although this effect is only significant at very high colour saturation, any possibility of causing receiver

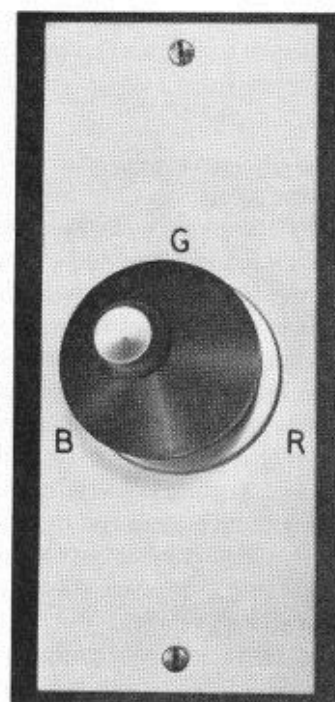


Fig. 4. Colour Balance Control Unit.

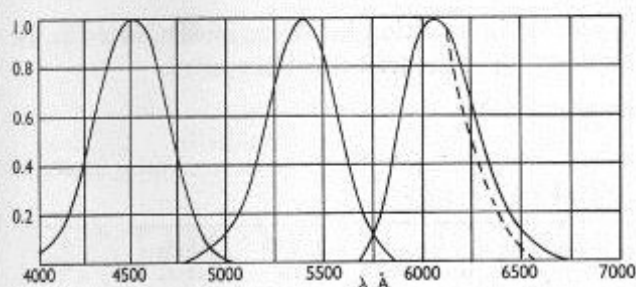


Fig. 5. Overall spectral characteristics of the GRB channels. The broken line indicates the limitation imposed by presently available Plumbicons.

overloads is eliminated by the setting of the iris control with reference to a set of derived GRB signals. To conserve the number of monitoring cables, the coded output signal is employed for monitoring purposes, a coder with GRB outputs being provided at the control position.

In a multi-camera operation it is also desirable to provide a remote control of colour balance so that any minor differences between cameras, as academically set up, may be removed. Let us first consider this in its simplest form, that is three independent controls, G, R and B. If one or more of these controls are adjusted to produce a desired effect on the picture, it cannot be verified by looking at the derived GRB waveform display that none of the signals direct from the camera have exceeded their normal standard level, and more importantly a series of such adjustments may over a period of time produce a condition where the mean level of the GRB outputs from the camera is significantly different from the level of the camera Y output. This problem is overcome by mechanically coupling the three controls in such a way that the arithmetic sum of their angular rotations is zero. The arrangement, shown in Fig. 4, is operated by a joystick which may be moved in any direction over what is effectively a two-dimensional colour triangle. Whatever adjustments are made, the mean level of the GRB channels is unaltered and the condition where the relative levels of the four channels of the camera are upset is avoided.

THE TRISTIMULUS COLOUR REPRODUCTION SYSTEM

In any colour reproduction system employing three primaries it is not possible to achieve a theoretically perfect set of spectral characteristics in the colour channels of the camera owing to the inability of the camera tube to reproduce negative lobes. Under all normal lighting conditions the best compromise results from the use of narrow lobes of the type shown in Fig. 5, although the reduced area beneath the curves

tends to decrease sensitivity. This effect is less serious in a four-tube camera, however, since only a fraction of the total light is used in the colour channels. The dotted line on Fig. 5 indicates the upper limit at the red end of the spectrum imposed by the spectral sensitivity of presently available Plumbicon* tubes, and it will be seen that the full response is maintained to within 50 Å of the ideal wavelength.

An important advantage of the four-tube camera is the low signal currents which may be used in the colour channels, and this makes it possible to use taking characteristics of the type shown in Fig. 5. The consequent improvement in colour fidelity more than offsets the system errors discussed previously.

The shape of the luminance channel spectral characteristic also influences the colour fidelity of the camera. As already seen the difference between the quantities $Y^{1/2}$ and Y' of equation (7) produces an additional luminance component even though the value of the quantity Y is identical in each term. In the practical case the term $Y^{1/2}$ is derived from the fourth tube, while Y' is derived from the three colouring tubes. If therefore the spectral characteristic of the luminance signal from the fourth tube is different from that of the derived luminance signal, the magnitude of the term $Y^{1/2} - Y'$ will be modified and hence also its effect on the final picture. If the spectral characteristic of the derived luminance signal is computed from the curves of Fig. 5 using the relationship of equation (1), a triple humped curve will result having three peaks roughly proportional in amplitude to the coefficients of the corresponding terms in equation (1). To achieve exactly this response in practice would seriously affect the sensitivity of the luminance channel and the photopic curve, shown in Fig. 6, is therefore

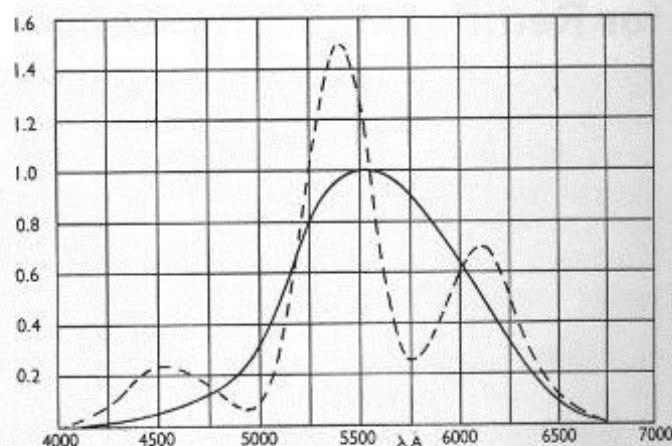


Fig. 6. Overall spectral characteristic of the luminance channel. Shown dotted for comparison is the spectral characteristic of the luminance signal derived from the GRB signals according to equation (1).

employed. Referring to equation 7, evaluation of the term $Y^{1/\gamma} - Y'$ for 100% saturated colours gives the following results:

Green	0.20	Yellow	0.06
Red	0.28	Cyan	0.15
Blue	0.26	Magenta	0.26

It will be seen from Fig. 6 that the luminance channel response is lower than that of the derived luminance signal for each of the three primaries, and the value of $Y^{1/\gamma} - Y'$, which is greatest in the cases of green, red, blue and magenta, tends therefore to be reduced. In the case of yellow and cyan, where $Y^{1/\gamma} - Y'$ is below the mean value, the opposite effect occurs. It can thus be seen that the divergence between the two curves of Fig. 6 tends to compensate for the quantity $Y^{1/\gamma} - Y'$. Although good use can be made of this feature to improve fidelity at very high colour saturation, it is important to remember that at normal saturations the comparison is to be made between values integrated over a significant portion of the spectrum so that the compensating effect diminishes in sympathy with the error as the saturation is decreased—see Table 2.

COMPENSATING FOR SYSTEMS LIMITATIONS

On economic grounds the amount and nature of the information transmitted are limited by taking every advantage of the physiological properties of human vision. In particular, the luminance signal only is transmitted in fine detail. The four-tube camera exactly complements this property, the camera being designed

to provide information in a form ideally suited to the requirement of the transmission system.

Table 1

Percentage Resolution obtained in Final Picture using Luminance Signal Y' . $\gamma = 2.2$.

% Saturation of scene	0	50	70	80	90	100
Green	100	97.1	92.4	87.9	80.3	53.1
Red	100	97.0	90.9	84.2	71.3	23.6
Blue	100	98.4	94.4	88.9	75.5	7.1
Yellow	100	99.0	97.6	96.4	94.3	87.0
Cyan	100	97.6	94.0	90.7	85.1	65.2
Magenta	100	96.8	90.8	84.7	73.7	34.3

Table 2

Colour Saturation obtained in Final Picture using Luminance Signal $Y^{1/\gamma}$ shown as Percentage of Value in the Original Scene. $\gamma = 2.2$.

% Saturation of scene	0	50	70	80	90	100
Green	100	99.0	98.0	97.3	96.6	98.1
Red	100	98.8	97.9	97.0	95.9	96.5
Blue	100	99.4	98.9	98.3	97.4	97.0
Yellow	100	99.6	99.3	99.0	98.9	99.8
Cyan	100	99.2	98.3	97.8	97.2	98.9
Magenta	100	99.0	97.7	96.9	95.9	97.0

REFERENCE

- 1 D. C. LIVINGSTON: Colorimetric Analysis of the NTSC Colour Television System; *Proceedings of the I.R.E.*, January 1964.

* Registered trademark, Philips Gloeilampenfabrieken.