THE BRITISH BROADCASTING CORPORATION ENGINEERING TRAINING DEPARTMENT

INFORMATION SHEET

AN INTRODUCTION TO THE COLORIMETRY OF COLOUR TELEVISION

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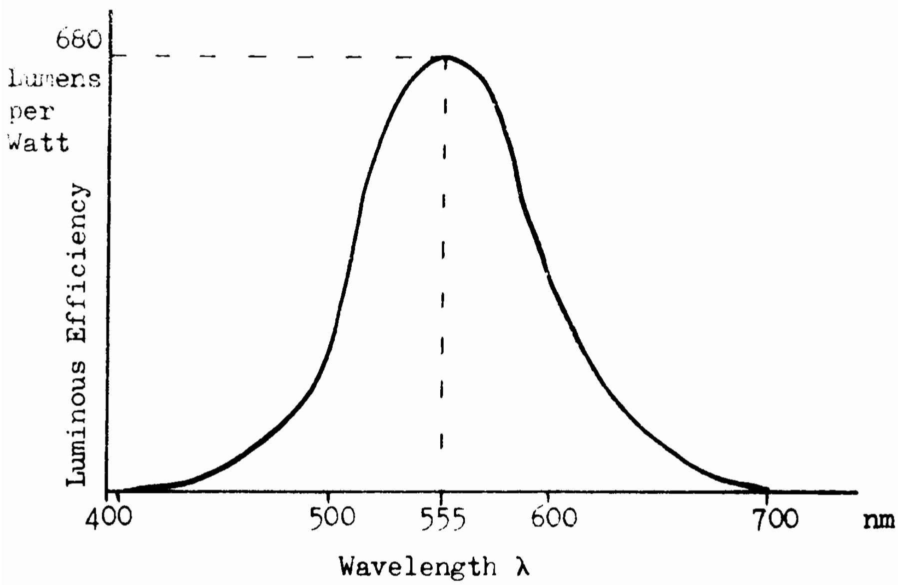


The Photopic or Average Eye Response Curve Fig (i)

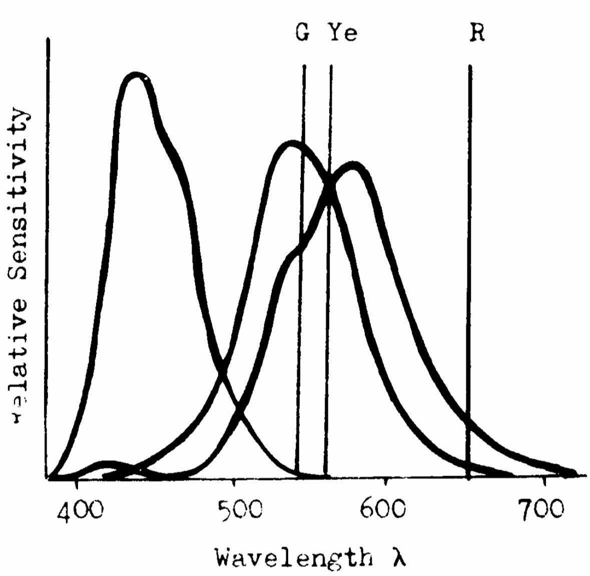


Fig (ii)

The probable sensitivity of the three colour receptors believed to be operating in the eye

The Eye's Response Curve

The eye responds to energy within the approximate limits 400-700 nano-metres, reaching peak sensitivity at about 555nm.

Thus if the eye is subjected to 1 Watt of radiant power, for discrete bandwidths throughout the visible spectrum, the response curve in Fig (i) is obtained.

The lumen is the unit of luminous power, 1 Watt at 555nm corresponding to 680 lumens. The lumen was originally defined as the rate of flow of luminous energy from one standard candle into unit solid angle.

The Perception of Colour

If the spectrum is displayed, the shortest wavelengths appear blue-violet and the longest appear red. Between these limits lie the remaining "colours of the rainbow."

The eye however does not interpret colours entirely on a wavelength basis. If a suitable monochromatic green light is mixed with a monochromatic red light in the correct proportions a match to monochromatic yellow is obtained, yet the resultant colour does not contain any of the wavelengths corresponding to yellow in the spectrum.

The Colour Receptors

The effect of colour matching is explained by the theory that the eye has three separate types of cone (colour receptor) on the retina. The probable response curves of these receptors are shown in Fig (ii).

It can be seen that the Monochromatic green light G and the Monochromatic red light R if correctly adjusted in amplitude will produce an identical "signal" to that produced by Monochromatic yellow, Ye.

If a third primary light at the blue end of the spectrum is used then all three receptors may be stimulated and a very wide range of colours synthesised.

Colour Measurement

The synthesis of colours by three primaries forms the basis of colour measurement.

If some colour (C) is matched by an addition of 5 lumens of Red, 6 lumens of Green and 7 lumens of Blue light the result is written:-

$$C \equiv 5 \text{ lumens } (R) + 6 \text{ lumens } (G) + 7 \text{ lumens } (B)$$

(The quantity of the unknown (C) will in fact be 5 + 6 + 7 = 18 lumens).

With a well chosen set of primaries most colours may be matched or "measured" in this way.

The general form of the matching equation being:-

$$C(C) \equiv R(R) + G(G) + B(B)$$

Where R + G + B = C and the letters in brackets simply serve to identify the lights specified.

The values R, G and B are known as the Tristimulus values of the unknown colour. Thus the equation is three dimensional having three independent variables.

In order to present colour specifications graphically it is usual to reduce the specification to a two dimensional equation. Thus instead of describing the colour in absolute amounts of (R), (G) and (B), only the proportions are quoted. This procedure dispenses with absolute quantity and the general equation:

$$C(C) \equiv R(R) + G(G) + B(B)$$

is reduced to:

$$\frac{C}{R+G+B}(C) \equiv \frac{R}{R+G+B}(R) + \frac{G}{R+G+B}(G) + \frac{B}{R+G+B}(B)$$

This is usually written:-

$$1\,(C) = r\,(R) + g\,(G) + b\,(B)$$

where $r = \dfrac{R}{R + G + B}$

$g = \dfrac{G}{R + G + B}$ Normalized.

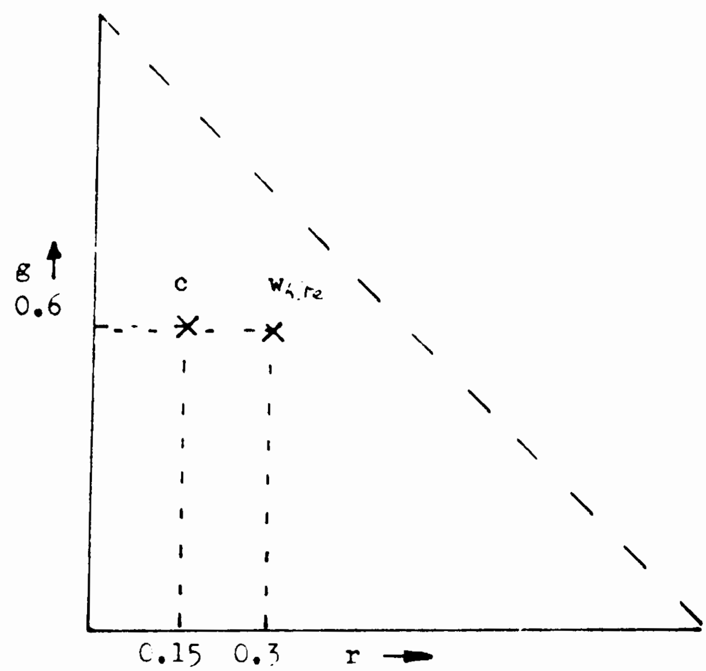
$b = \dfrac{B}{R + G + B}$

and $r + g + b = 1$

Since $r + g + b$ is always unity it is customary to define unit quantity of (C) in terms of r and g only.

The values r, g (and b) no longer describe colour - which involves both quantity and quality - but simply quality. They are referred to as the chromaticity co-ordinates - describing chromaticity rather than colour.

The Chromaticity Chart



Displays Hue and Saturation
Not intensity

Fig (iii)

<u>The Chromaticity Chart</u>

On this chart the chromaticities of colours are plotted in terms of their co-ordinates r and g. (b being implicit since $1 - r - g = b$).

For example, if some colour (C) is matched by 30 lumens of (R), 120 lumens of (G) and 50 lumens of (B)

then :- $200\,(C) \equiv 30(R) + 120(G) + 50(B)$

$\therefore\ 1\,(C) \equiv .15(R) + .6(G) + .25(B)$

The chromaticity of C would be plotted as shown in Fig (iii).

If the N.T.S.C. primaries are chosen for measurement and N.T.S.C. white is specified in terms of them, the chromaticity co-ordinates of white are known to be:-

Tristimulus Values

$1(W) \equiv .3(R) + .59(G) + .11(B)$

This point also is plotted in Fig (iii).

The considerable differences in magnitude of the co-ordinates of white are very inconvenient both for colorimetry and engineering. Since most of the commonly occurring colours plot very near white this in-balance will exist for most colours. It is therefore usual in both colorimetry and television engineering to employ units in which equal quantities of the primaries are required to match white. The new unit being the Trichromatic Unit or T unit.

Thus if one lumen of N.T.S.C. white is matched

by .3 lumens (R) + .59 lumens (G) + .11 lumens (B) and also
by 1_T (R) + 1_T (G) + 1_T (B)

then under these conditions ← Trichromatic Values

1 lumen of white corresponds to 3_T of white

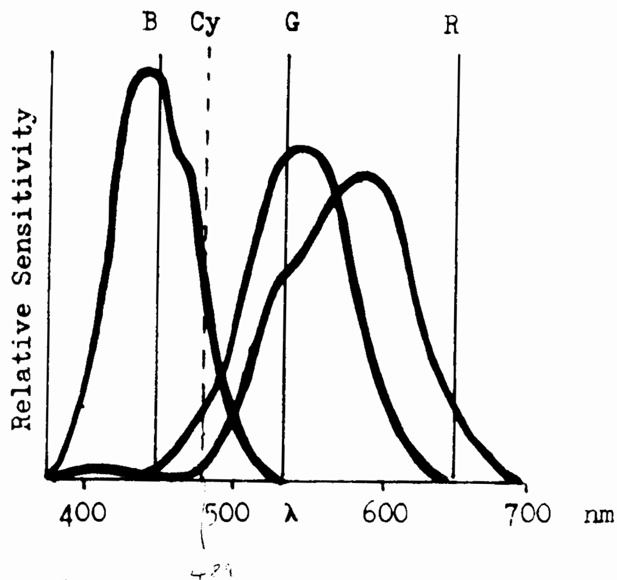
.3 lumen of (R) corresponds to 1_T of (R)

.59 lumen of (G) corresponds to 1_T of (G)

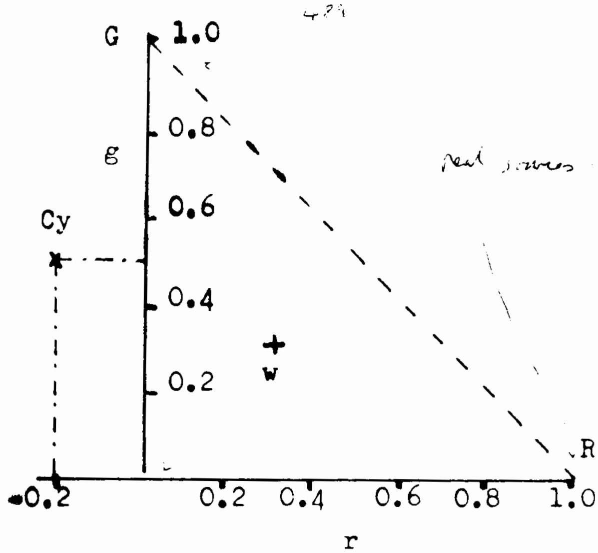
.11 lumen of (B) corresponds to 1_T of (B)

This establishes a conversion between T units and lumens for the N.T.S.C. system.

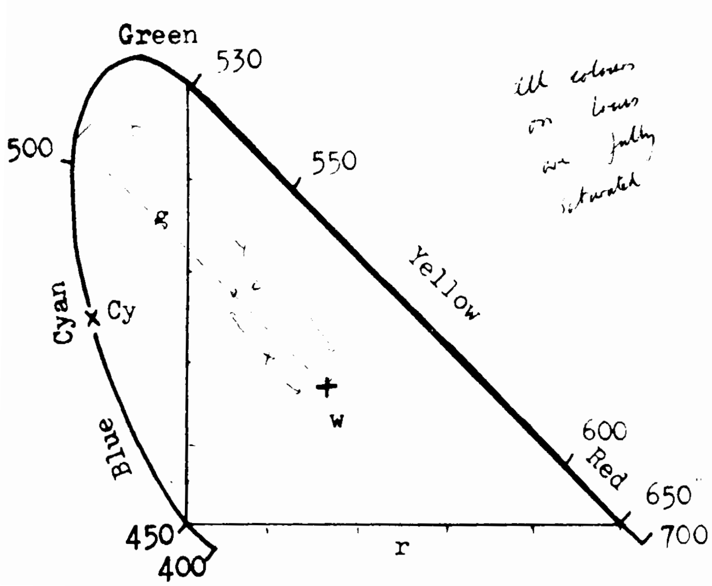
Chromaticity triangles are still employed but are plotted in terms of T units rather than lumens.



Receptor Responses showing monochromatic Blue Cyan Green and Red radiations Fig(iv)



Chromaticity Chart showing a Cyan light which cannot be matched by simple addition of the RGB primaries Fig(v)



Chromaticity Chart showing the locus of all monochromatic colours i.e. The Spectrum Locus Fig(vi)

Pure Monochromatic Colours

If monochromatic radiations are to be matched it is often found that they are too pure for the primaries in use.

For example if a monochromatic cyan is to be matched, blue and green are added till the result is neither too blue nor too green. A match is still not obtained even if red is switched off. The reason being that G stimulates the red receptor to a much greater extent than Cyan, see Fig (iv). The mixture required red removing from it.

Since production of negative red light is not possible the alternative is to add red to the Cyan until a match is obtained and then to predict that this is the amount of red that should be removed from (G) + (B) to match Cyan.

Hence if $50(Cy.) + 10(R) = 25(G) + 35(B)$

$$\text{then } 50(Cy) = 25(G) + 35(B) - 10(R)$$

$$\therefore\ 1\,(Cy) = -.2(R) + .5(G) + .7(B)$$

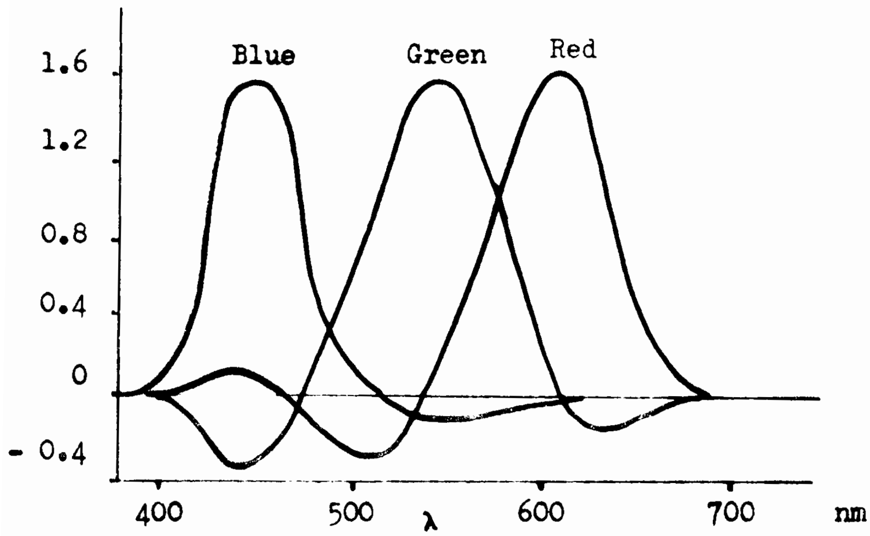
This point will plot as shown in Fig (v).

In fact most pure spectral colours are plotted in this way resulting in a spectrum locus around the chromaticity triangle Fig (vi).

The Photoelectric Colorimeter and the Camera

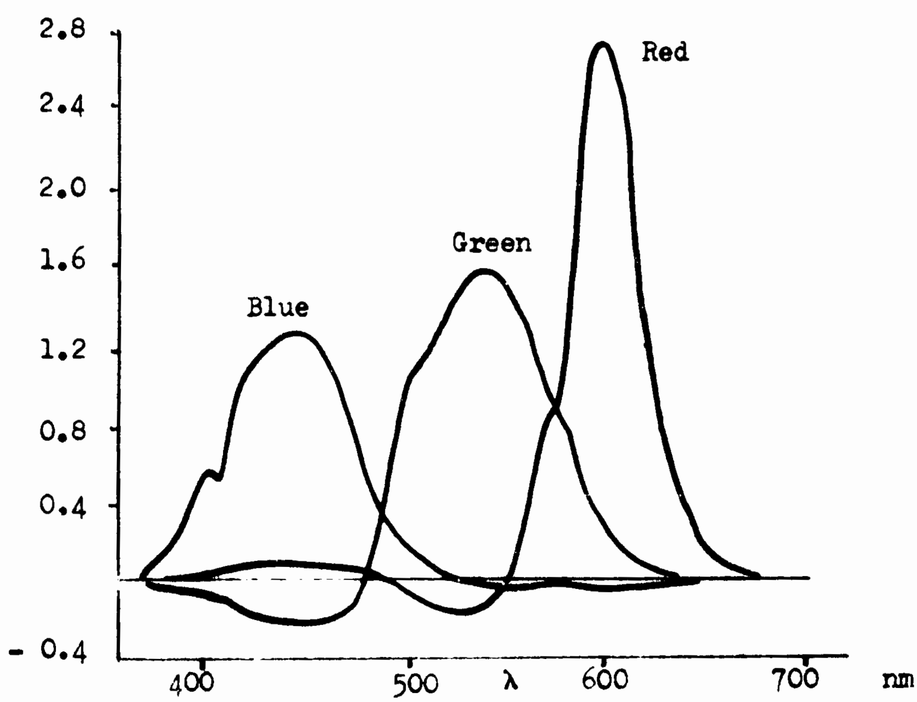
These devices replace the standard observer and are required to produce three signals which correspond to the observer's readings of the values of (R), (G) and (B).

The chromaticity chart provides the values r, g, b, for every colour and with the aid of these the response curves required of the p.e.cs or camera tubes are obtained. It is evident that one or more of them may be required to give negative signals when examining monochromatic radiations. In fact ....p.t.o.



Fig(vii)

Responses required for the Red Green and Blue Camera Channels
in order to feed correctly a picture tube having
N.T.S.C. phosphors



Fig(viii)

Practical response curves after matrixing

In fact the response curves required by the N.T.S.C. phosphor primaries are as shown in Fig (vii).

NB. The N.T.S.C. phosphor primaries are not the same as the monochromatic RGB primaries shown in the earlier diagrams.

One major difficulty in realising the curves of Fig (vii) is that no camera tube will provide negative signals at some wavelengths and positive signals at others. The present method of reducing this problem is to feed the signals from the positive only analysis of the camera tubes into a matrix. By cross-couplings of suitable amplitude and polarity in the matrix an approximation to the ideal characteristic is obtained.

Present matrices give very considerable improvement over simple positive only analysis. A typical set of practical response curves is shown in Fig (viii).

A quite separate but less serious problem is that even if the correct signals are fed to the receiver display tube the phosphors on the c.r.t. cannot glow negatively and thus it is impossible to reproduce colours lying outside the RGB triangle. This may not be very significant since few commonly encountered colours lie outside the triangle. Fig (ix) shows the locus for known pigments under N.T.S.C. white related to the N.T.S.C. chromaticity triangle.

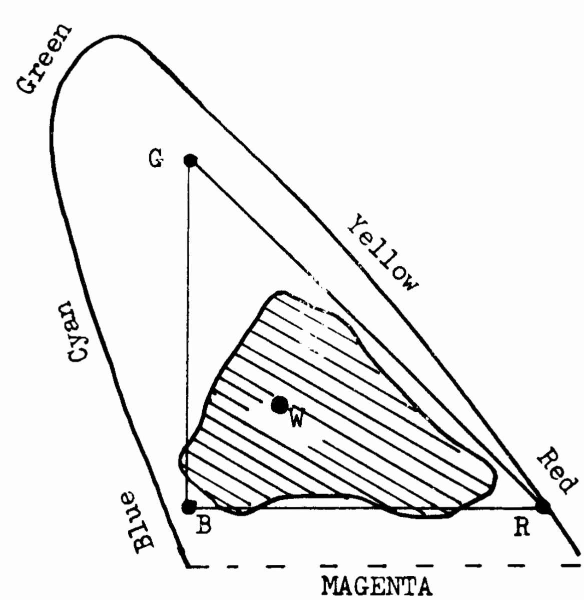
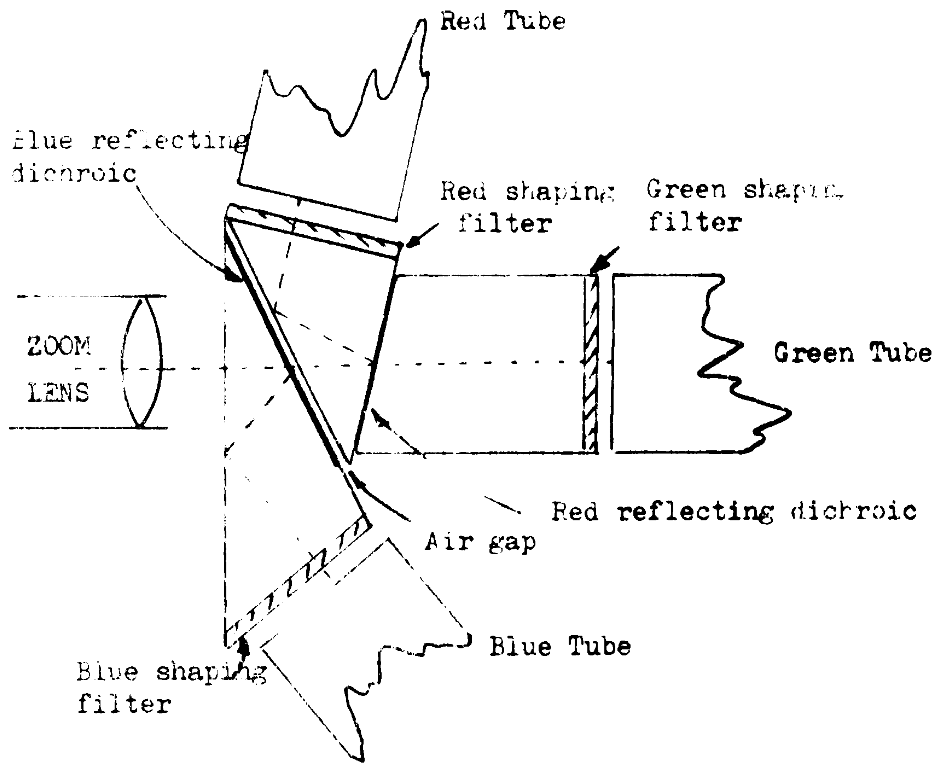


Fig (ix)

Practical Analysis Systems

In order to produce the separate Red Green and Blue signals in the camera, the camera tubes are fed with light which has been split by a mirror and filter system. (Fig x)

Frequency selective (dichroic) mirrors are employed to reduce the energy absorbed by the shaping filters, thus increasing the sensitivity of the system.



Fig(x)

The response characteristics required by the mirrors and filters are computed in conjunction with the matrixing circuitry to produce optimum RG and B signals. The curves of Fig (viii) are the result of such a computation.