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The contrast handling requirements of a colour television display

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RESEARCH DEPARTMENT

THE CONTRAST HANDLING REQUIREMENTS OF A COLOUR TELEVISION DISPLAY

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R.N. Robinson, B.Sc.

Head of Research Department

(PH-96)

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THE CONTRAST HANDLING REQUIREMENTS OF A COLOUR TELEVISION DISPLAY

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Summary

A survey of domestic television viewing conditions is described. These conditions were reproduced in a laboratory in order to determine the contrast range of the eye. The dependence of the contrast range visible to the eye upon ambient illumination and upon the form and brightness of the displayed picture have been investigated; these results are then interpreted in terms of the contrast range available from a practical display tube under similar conditions.

It is found that under normal viewing conditions the visible contrast range of a television picture is severely limited by flare within the display tube and ambient light reflected from the tube face. A reduction of the reflectance of the tube face to approximately 28% of its present value is required for good reproduction of the luminance range visible under typical viewing conditions.

1. Introduction

Much work has been carried out to determine the optimum reproduction characteristics of cinema film, transparencies and reflection prints.[1,2,3] The problems associated with the reproduction of scenes by colour television have received much less attention.

The experiments described in this report were carried out to measure the luminance range which is visible to the eye under typical television viewing conditions; the measurements were made using a simulated television display in order that the limitations of the eye could be isolated from any shortcomings of the cathode-ray tube as a display device.

The peak luminance of a practical television display tube is a function of the properties of the phosphors and the maximum permissible beam current. The minimum luminance of any point on a display tube is dependent on two main factors; these are the reflection of ambient light incident on the tube face and light from the remainder of the display, the so-called 'flare' of the display tube.

Measurements were made to determine by how much these factors limit the luminance range which is visible to the eye.

2. Viewing conditions

2.1. Domestic viewing conditions

A survey of domestic viewing conditions was carried out in order to determine suitable test conditions. Forty viewers were asked to measure the incident light falling on the screens of their home receivers, after sunset, under the lighting conditions they normally used for television viewing. Measurements were made using a selenium photocell incident-light photometer held immediately in front of the receiver screen.

Viewers were also asked to measure the distance from the screen at which they normally sat when viewing television. Most of the viewers who took part in this survey owned colour television receivers. It was, however, found that the values recorded by viewers with monochrome receivers did not differ significantly from those with colour receivers. No distinction is therefore made for the type of receiver in the results of the survey, which are shown in Figs. 1 and 2.

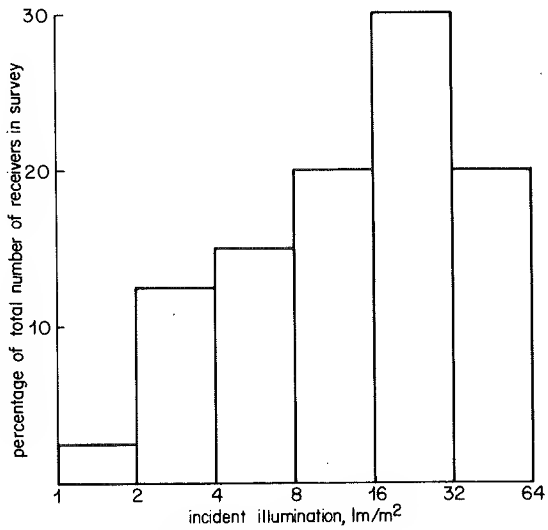

Fig. 1 - Domestic viewing conditions — distribution of incident illumination

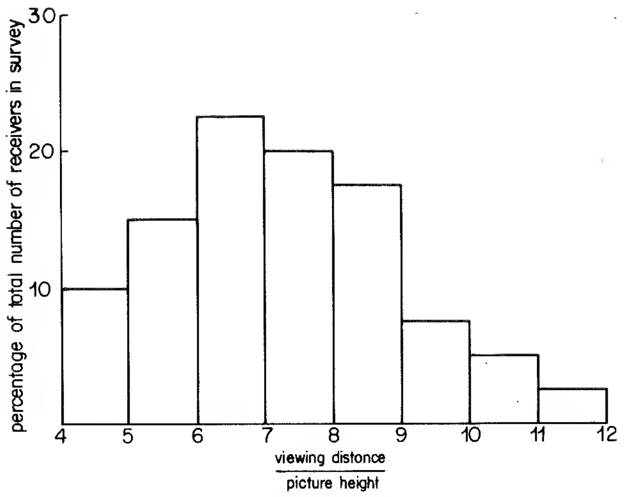

Fig. 2 - Domestic viewing conditions — distribution of viewing distance

Fig. 1 shows the distribution of the incident illumination. The maximum and minimum values recorded in this survey were 55 lm/m^2 and 1·6 lm/m^2 respectively. The mean of the distribution is approximately 16·0 lm/m^2.

The distribution of viewing distances, in terms of picture height, is shown in Fig. 2. The total range of these results was from 4·2 to 11·5 times picture height, the mean value being approximately seven times picture height.

2.2. The viewing room used for experimental measurements

The experiments described in the following sections were carried out in a viewing room in which domestic viewing conditions could be simulated. The room was illuminated by overhead fluorescent lighting controlled by a thryistor dimmer; a range of illumination from 0·3 to 30 lm/m^2 could be provided with negligible change in colour temperature of the illuminant (D_{65}). The walls of the vlewing room had a mean reflectance of 60%, a value typical for domestic wall covering.

3. The visible contrast range under television viewing conditions

The experiments carried out in order to make direct measurements of the properties of the eye, under conditions simulating television viewing, were carried out using a translucent perspex screen 200 mm x 320 mm which was illuminated from the rear to a level of 13 cd/m^2, corresponding to the mean luminance of typical scenes portrayed on a television screen.* Reflective test charts were then attached to the screen and illuminated from a light source in front of the screen. The screen was positioned a distance of 2 metres from the observer, so that the angle it subtended at the eye of the observer was approximately the same as that subtended by a television screen under typical viewing conditions.

* The value of 13 cd/m^2 assumes a peak display luminance of 100 cd/m^2.

3.1. The luminance of subjective black as a function of ambient lighting

This test was designed to measure the luminance which the eye perceives as black when bright and dim areas are viewed simultaneously. It was found that tests carried out using separate illuminated test charts of high and low brightness attached to the illuminated screen produced results which varied over a wide range and were usually very inconsistent. The cause of this inconsistency lay in the fact that it was found difficult to prevent the eye from temporarily resting on either the bright or dim area, and accommodating to suit that particular luminance. A test chart which included bright and dim areas was designed so that it required the eye to look simultaneously at the two areas. This chart (see Fig. 3) consisted of a grey scale (105 mm x 50 mm) with five steps of reflectance ranging from 4·5% to 13%, together with a strip of white card (105 mm x 20 mm) of reflectance 95%, which was attached centrally along the length of the grey scale. The chart was mounted vertically on the rear-illuminated screen. One slide projector, containing a suitable mask and equipped with an iris diaphragm, was used to illuminate the whole chart at a low brightness level. A second projector produced a bright illuminated area (20 mm x 20 mm), with a fine horizontal indicating line across its centre, on the white strip of the test chart; this latter projector was mounted on an adjustable stand which enabled the illuminated area on the test chart to be moved up and down the white strip of the test chart.

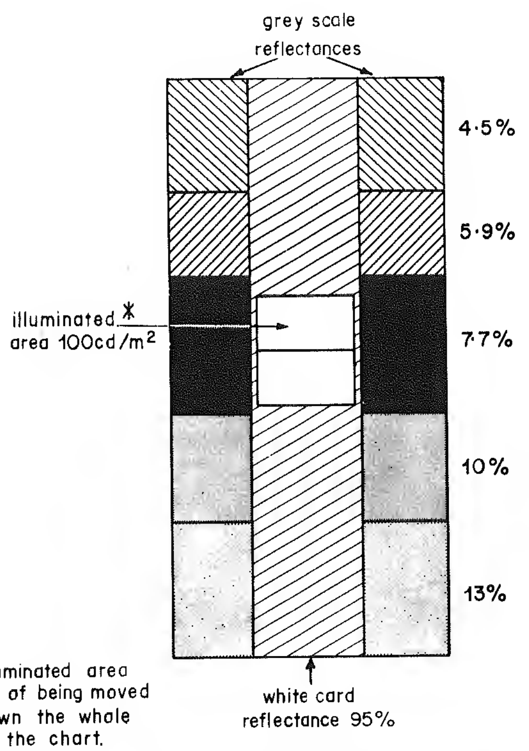

Fig. 3 - Test chart for measurement of visible contrast range

Measurements of the perceived black level of the eye were made by asking the subject to move the spot along the chart until the indicating line across the bright spot was opposite the first step in the grey scale which was distinguishable from black.

The incident light falling on the whole test chart from the first projector was set initially to a predetermined level. The second projector was adjusted so that the luminance of the bright square was 100 cd/m^2, corresponding to a picture highlight.

If the subject set the bright spot accurately at a division in the grey scale other than that between the two darkest steps, it was assumed that the perceived black level lay between the luminances of the grey-scale steps on either side of the division. A more refined measurement of the black level was made by reducing the level of grey-scale illumination until the subject found great difficulty in accurately positioning the bright spot. When this condition occurred, the threshold of luminance was defined as the luminance of that grey scale step, of higher luminance, adjacent to the division at which the bright spot had been set. It was assumed that below this luminance all objects appeared black and that detail was invisible.

This test was carried out on each subject at six levels of room lighting adjusted to produce a range from 1·0 to 30 lm/m^2 incident upon the test chart. The mean values of the luminance threshold obtained from six subjects are shown in Fig. 4, plotted against ambient illumination. The standard deviation of the results at any level of ambient illumination was approximately 20%.

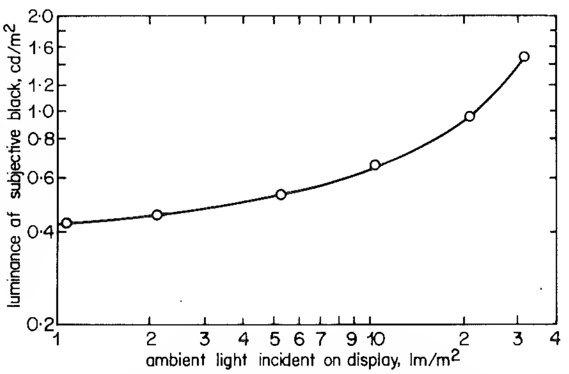

Fig 4 - Luminance of subjective black as a function of ambient lighting for a low luminance area 20 mm square at a viewing distance of 2 m

Fig. 4 shows that, for a typical value of ambient lighting level of 16 lm/m^2, areas of a television picture at a luminance of less than 0·8 cd/m^2 will appear black. If the peak luminance of the display is 100 cd/m^2 the contrast range visible to the eye will be about 125 : 1. At higher levels of room lighting the adaption of the eye is controlled principally by the luminance of objects surrounding the screen, and the luminance of subjective black rises rapidly with the increase in lighting level. At low levels of room lighting the luminance of the screen itself becomes dominant and the room lighting has little effect on the visible luminance range. Experiments carried out at very low levels of ambient lighting indicate that the characteristic shown in Fig. 4 asymptotes to a value of luminance of approximately 0·3 cd/m^2.

3.2. The variation of the luminance of subjective black with object size

It has been found[4,5] that the measured low luminance threshold is greatly dependent on the area of the test field which is used. Tests were therefore carried out to determine the variation of the threshold with the dimensions of a low-luminance area, under television viewing conditions.

Square test-areas with dimensions from 10 mm to 80 mm were used; each consisted of two strips of photographic paper with reflectances of approximately 6% and 8%. These test areas were attached in turn to the illuminated screen used in the previous experiments and a projector, containing a suitable mask, was used to illuminate the test area without affecting the illumination of the rest of the screen. At a fixed level of room lighting, subjects were asked to reduce the illumination of the test area, by means of an iris diaphragm on the projector, until the difference in brightness of the two sections of the test area could only just be distinguished. The luminance of the strip of higher reflectance was then measured and regarded as that of subjective black. The mean results of this test are shown in Fig. 5.

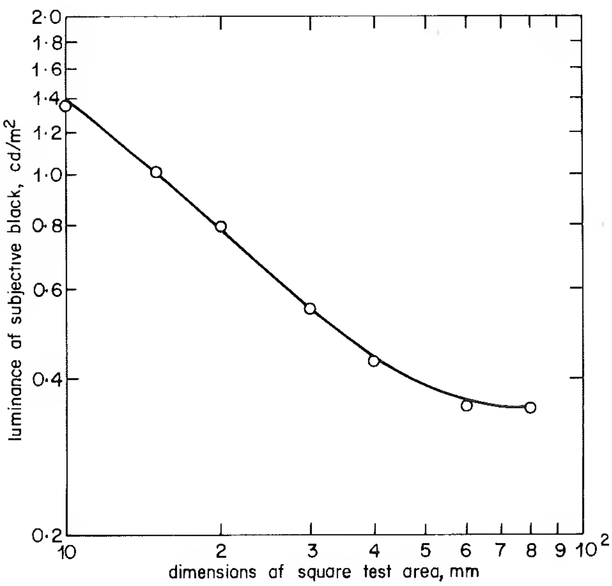

Fig. 5 - Luminance of subjective black as a function of area
Ambient light incident on display = 16 lm/m^2
Viewing distance = 2 m

This curve shows that at a viewing distance of 2 m the eye regards, as black, a value of luminance which, for images of less than 50 mm square, increases rapidly as the size of the image is reduced.

An object 50 mm square, viewed at a distance of 2 metres, subtends an angle of approximately 1·4° at the eye, and the above result agrees well with experiments carried out by Lowry.[4]

4. Limitations of the display tube

Measurements were made of the contrast range which can be displayed on a typical shadow-mask display tube. These measurements were made in such a way that the contrast range of the tube could be compared directly with the limitations of the eye described in Section 3.

It was found that the minimum luminance which can be displayed on a shadow-mask tube is limited by two factors; these are the flare in the display tube, and the reflectance of ambient light incident on the tube face. These are considered separately using typical viewing conditions where applicable.

4.1. Flare

The flare was measured on a typical 630 mm shadow mask colour display tube mounted in a television monitor. A switching signal was fed into the monitor such that the left-hand half of the screen only was energised to approximately peak white (100 cd/m^2). A mask made from low reflectance paper was placed in front of the monitor such that only a vertical strip of the screen, 3 mm by 50 mm, was visible through a slit in the mask. The light output from the tube at various distances to the right of the illuminated area was measured with a photometer as the mask was moved across the tube face. The results of these measurements, which are shown in Fig. 6, indicate an approximately logarithmic relationship between screen luminance and distance from the illuminated area.

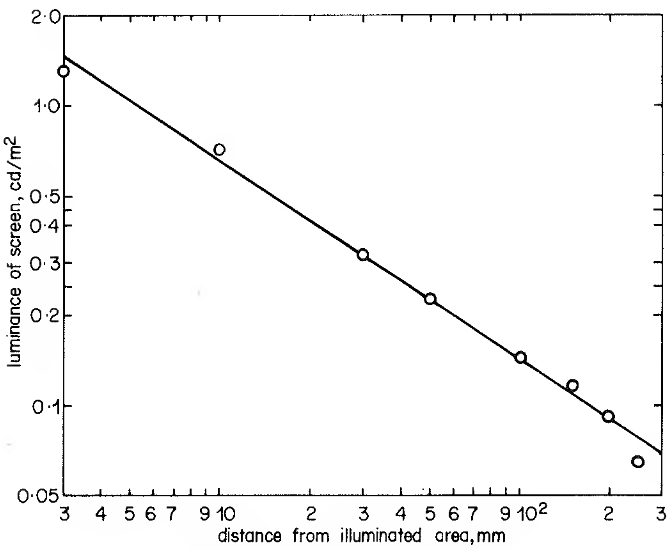

Fig. 6 - Display tube flare
Luminance of energised portion of screen = 100 cd/m^2

Flare in a display tube may be introduced by two different effects. So-called optical flare is caused by internal reflection of light within the faceplate of the tube. A second type of flare, which will be referred to as electron flare, is caused by electrons landing on parts of the screen other than where intended.

The effects of these two forms of flare in a colour display tube are different. If a coloured area is displayed on the tube, optical flare will cause a cast of the same hue to be seen on surrounding areas of the screen. In the case of electron flare there is an equal probability of stray electrons landing on a phosphor dot of any of the three colours. The colour of light emitted by electron flare will therefore be independent of the colour of an illuminated area displayed on the tube, and will tend to be neutral (depending upon the relative phosphor efficiencies).

The relative significance of the two types of flare was estimated by switching off two of the guns of the display tube so that the left-hand half of the screen displayed one primary colour. The flare which could be seen on the right hand half of the screen appeared highly saturated close to the illuminated area, but gradually became desaturated at greater distances. At about 50 mm from the illuminated area the flare appeared almost neutral and was virtually independent of the colour displayed on the left-hand half of the screen.

From these observations it can be concluded that optical flare in the faceplate of the display tube may cause hue and saturation errors in areas of the picture in close proximity to regions of high luminance. Electron flare causes desaturation of the picture over a wider area, although of a less pronounced form. Both types of flare decrease the available contrast range which can be displayed in a picture, by increasing the luminance of the dark areas.

Further experiments were carried out to estimate the extent to which flare reduces the contrast ratio which can be displayed in a typical picture. A waveform was applied to the monitor such that the whole of the screen was illuminated to a level of 13 cd/m^2 (assumed to be the mean picture luminance) except for a small black square in the centre of the screen. The mean luminance in the central square due to flare was measured whilst masking the remainder of the picture with low-reflectance paper. Measurements were made with different sizes of square from 10 mm to 80 mm.

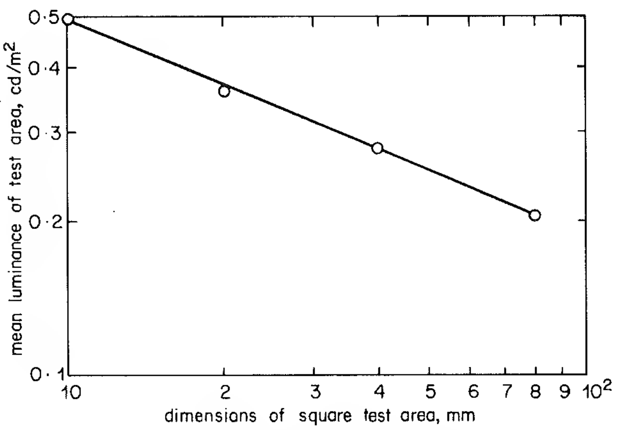

Fig. 7 - Mean luminance of flare vs dimensions of test area
Luminance of energised portion of screen = 13 cd/m^2

The results of these measurements, shown in Fig. 7, indicate that the mean luminance due to flare decreases logarithmically with increase in size of the low luminance area.

4.2. Reflection of ambient light

Ambient light is reflected from both the front surface of the display tube faceplate, and the phosphor coating at the rear of the faceplate. The polished front surface causes specular reflections to be seen by the viewer, while reflections from the phosphor are diffusely reflected with a luminance proportional to the mean incident light.

The reflectance of a display tube was measured in the viewing room in which the previous subjective tests were carried out; overhead room lighting was used to provide the illumination. A spot photometer was placed in front of the receiver in a position from which direct specular reflections of the room lighting in the screen could not be seen. The mean luminance of the screen was compared with that of a magnesium carbonate block placed in front of the screen.

The reflectance of the tube measured in this way was found to be 21%.

5. Discussion

The separate effects of flare and reflection of ambient light on the performance of a colour display tube have been described in Section 4. These effects combine to produce an effect which will be termed 'background luminance': this is inevitably added to the displayed picture. The greatest subjective impairment is the increased luminance and desaturation of colours in low luminance areas of the picture.

In order to estimate the subjective impairment which it causes, the background luminance level due to flare and reflected ambient light must be compared with the luminance of subjective black under similar viewing conditions. Ideally, any background luminance in the displayed picture should be well below the luminance of subjective black for the particular viewing conditions considered so that it causes a negligible change in perceived brightness within the visible luminance range.

Although no tests have yet been carried out to grade the subjective impairment of picture reproduction due to background luminance, it will be assumed that significant impairments are caused when the background luminance exceeds the luminance of subjective black since the displayed contrast will be reduced. These effects will be discussed in terms of a display tube with a diagonal of 630 mm viewed at a distance of seven times picture height (approximately 2·8 metres).

It should be noted that the measurements of luminance of subjective black described in Section 3 were carried out on a smaller screen at a viewing distance of 2 metres. Since it has been found that these measurements are a function of the visual angle subtended by the image they must apply to an increased size of aperture when the viewing distance is increased. In order that the visual angles be comparable under different viewing conditions, the dimensions of test areas must be changed in the ratio of the viewing distances. Fig. 4 thus shows the luminance that would be seen as black in an area 28 mm square at a viewing distance of 2·8 metres. This can then be compared with the characteristic of display-tube background-luminance for a similar aperture.

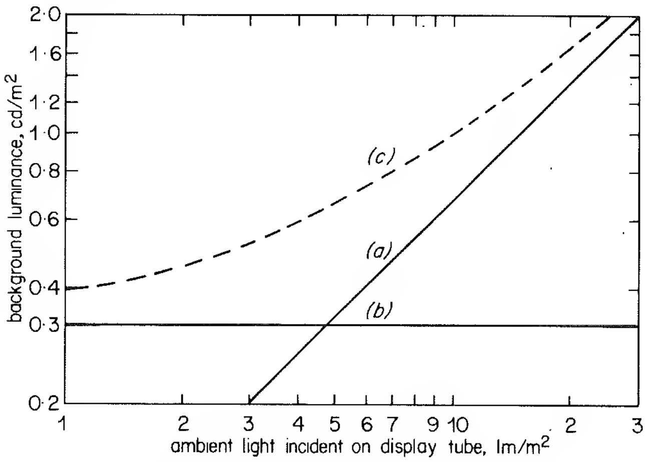

Fig 8 - Background luminance of a 630 mm display tube as a function of ambient lighting for a 28 mm square test area

(*a*) Reflection of ambient light from tube face
(*b*) Display tube flare (optical + electron) measured with surround luminance of 13 cd/m^2
(*c*) Flare + reflection of ambient light

The luminance caused by reflection of ambient light is shown in Fig. 8(*a*), as a function of ambient light for a display-tube screen-reflectance of 21%. The mean luminance due to flare in a 28 mm square area, derived from Fig. 7 is shown in Fig. 8(*b*). The total background luminance for a 28 mm square area can be obtained by addition of these two characteristics (Fig. 8(*c*)).

The characteristic showing the variations of background luminance, with area, at a fixed ambient illumination can be derived by a similar method.

Fig. 9(*a*) shows the luminance of the screen due to reflection of ambient illumination at a level of 16 lm/m^2. The variation of flare luminance with the area is shown in Fig. 9(*b*). The total luminance of the area, Fig. 9(*c*), is obtained by addition of the ordinates of 9(*a*) and 9(*b*).

The variation of screen background luminance with ambient illumination and size of test area have been replotted in Figs. 10 and 11 together with the characteristics of the luminance of subjective black under similar viewing conditions.

From Fig. 10 it can be seen that for an area of 28 mm square the background luminance of the display tube exceeds the luminance of subjective black for levels of ambient light above 1·5 lm/m^2. At high levels of illumination, above 15 lm/m^2, the luminance of the area is nearly twice that of subjective black.

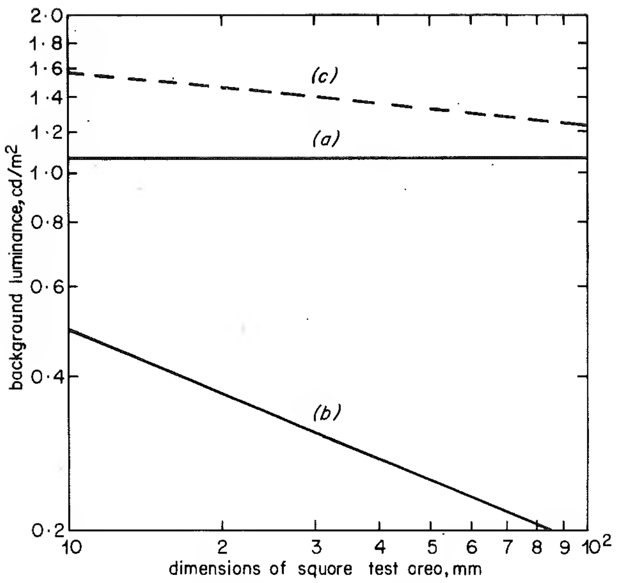

Fig. 9 - Background luminance of display tube as a function of dimensions of test area at an ambient lighting level of 16 lm/m²

(*a*) Reflection of ambient light from tube face
(*b*) Display tube flare (optical + electron)
(*c*) Flare + reflection of ambient light

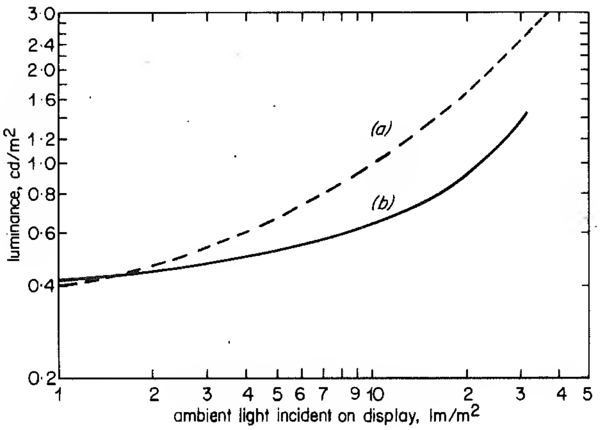

Fig. 10 - A comparison of the background luminance of the display tube and the luminance of subjective black as functions of ambient light

(*a*) Background luminance of display tube
(*b*) Luminance of subjective black

Fig. 11 shows the variation of background luminance, and subjective black, with the size of the test area at the mean domestic lighting level of 16 lm/m². It is apparent from these characteristics that, despite the reduction of the influence of flare, the difference between the background luminance of the display tube and the luminance of subjective black increases rapidly with the size of the test area. This implies that a greater impairment of luminance reproduction will occur if the picture contains large areas of low luminance. If areas 100 mm square are to be displayed as black the background luminance must be reduced to 27% of its present value. The curvature of the characteristic of the luminance of subjective black for large areas, shown in Fig. 11(*b*), suggests that no further reduction of background luminance is necessary for portrayal of areas larger than 100 mm square.

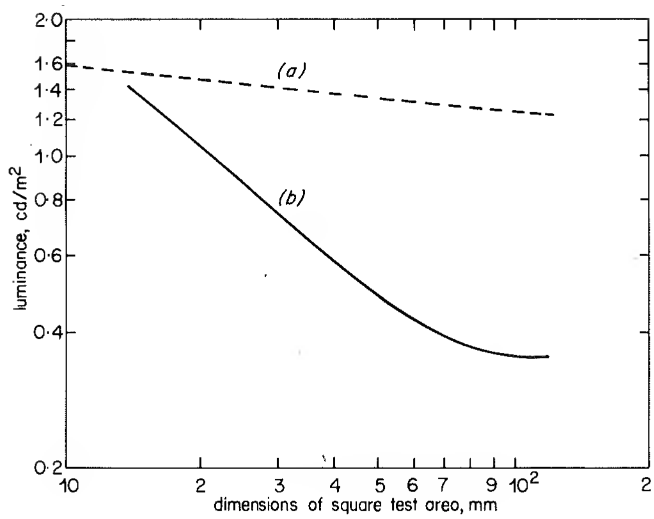

Fig. 11 - A comparison of the background luminance of the display tube and the luminance of subjective black as functions of the dimensions of the test area

(*a*) Background luminance of the display tube
(*b*) Luminance of subjective black

It can be seen from Fig. 9 that, at an ambient lighting level of 16 lm/m², it is the reflection of ambient light from the tube face which gives rise to the major component of the background luminance. It is therefore necessary to reduce the reflectance of the tube face in order to extend the contrast range of the tube.

In the type of tube used in these experiments, the reflectance of the phosphors is approximately 70%. The light reflected from the phosphor coating is reduced to approximately 21% of the incident light by a neutral faceplate with a transmission of 54%. In order to reduce the reflectance of the tube face to 27% of its present value, the transmission of the faceplate could be reduced from 54% to 28%. This would require the light output of the phosphors to be increased by 93% to maintain the peak luminance at its present value.

Alternatively, the reflectance of the phosphor coating could be reduced. One method which may be used to reduce the effective reflectance of the phosphor coating is to cover the non-emitting areas of the screen between the phosphor dots with a matrix of low-reflectance black material.[6] This technique enables the reflectance of the phosphor coating to be reduced by up to 50% without reduction of the peak luminance of the tube. A tube incorporating a black-matrix phosphor coating would require a neutral faceplate with a transmission of 40% to reduce the background luminance to 27% of that of the measured tube. In this case the light output of the phosphors must be increased by 36% in order to maintain the same peak luminance.

6. Conclusions

When a television receiver is viewed under domestic conditions, background luminance is added to the picture due to flare and the reflectance of ambient light from the tube face. This causes an increase in the luminance of black areas of the picture, and a reduction in saturation of colours displayed at low luminance. These impairments are most noticeable when the picture contains large areas of low luminance.

In order to minimise these effects the reflectance of the tube face must be reduced, so that the background luminance is less than the luminance of subjective black. Under typical viewing conditions this requires the transmission of the tube faceplate to be reduced from its present value of 54% to approximately 28%. The light output from the phosphors must then be increased by about 90% in order to maintain the present value of peak luminance.

If a tube incorporating a black-matrix phosphor coating is used, a satisfactory value of background luminance will be obtained if the transmission of the faceplate is 40%. In this case the light output of the phosphors must be increased by 36% in order to maintain the present value of peak luminance.

If phosphors can be developed to enable these modifications to be carried out, it should be possible to display a contrast of 250 : 1 under typical viewing conditions. In order to make full use of this improvement, it would be necessary for the contrast characteristic of the transmitted signal to be modified accordingly.

Despite the limitations of currently available display tubes, a contrast of 200 : 1 can be portrayed if the level of ambient light incident on the face of the tube is sufficiently low. Such low lighting levels do prevail in some viewers' homes; it is therefore expected that a considerable improvement in picture quality would be apparent for these viewers if the transmitted contrast range could be extended.

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