THE TESTING AND OPERATION OF 4½ IN. IMAGE ORTHICON TUBES

by

D.C. Brothers, B.Sc.

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The Testing and Operation of $4\frac{1}{2}$-in. Image Orthicon Tubes†

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D. C. BROTHERS, B.SC.(ENG.)‡

A paper read on 3rd July 1959 during the Institution's Convention in Cambridge

Summary: The methods used by a broadcasting organization to check the performance of image orthicon tubes are described. Aspects dealt with include: the transfer characteristic; sensitivity; contrast handling ability; signal/noise ratio; picture sharpness; geometrical distortion and linearity; microphony; uniformity of picture background; freedom from spurious effects; lag, movement blur, sticking, etc.; colour response; freedom from drift; ease of adjustment. Some conclusions are drawn on particular aspects of operating these tubes.

1. Introduction

It is highly desirable that the quality of the pictures produced by cameras operated by broadcasting authorities for entertainment should be of consistent high quality for a wide variation of scene content, and that the operational effort required for each camera channel should be kept to a minimum. The basis of consistent camera picture quality is the camera tube, and therefore there is a need for adequate measurement and selection of tubes by the broadcasting authority.

Such tests are not intended to replace the testing done by the manufacturer, who has to perform special tests related to the manufacturing processes in use, but is an objective check to ensure that the tube has not deteriorated since leaving the factory and to show that the tube will meet the standards required under the particular conditions of use prevailing. The aim has been to avoid tests of a subjective nature since with such tests it is always a matter of opinion whether a borderline tube is acceptable or not and valuable time and effort can be wasted in deciding whether such a tube should be rejected.

Much work has already been done on measuring many of the parameters of the image orthicon[1,2] but little of it refers specifically to the $4\frac{1}{2}$-in. image orthicon or, more particularly, to this tube operated in a "contrast-law corrected" condition. Some of the parameters which are important to the performance of the tube will be enumerated and relatively simple measurement techniques explained.

2. Parameters affecting Picture Quality

The principal parameters are:

- Sensitivity
- Contrast law
- Signal-to-noise ratio
- Sharpness of picture
- Geometrical distortion
- Microphony
- Uniformity of picture background (both white and black)
- Freedom from spurious effects
- Lag, sticking, movement blur etc.
- Colour response
- Ease of adjustment
- Freedom from drift

The order of the above parameters has no particular bearing on their relative importance. Unless any given tube can achieve a performance between certain limits in each of the parameters at the same time and at the same setting of the various controls of the camera, it can be said to be unable to produce a reliable picture of sufficient quality to be acceptable.

Each parameter will, therefore, be given a detailed examination and as a result of this examination, an attempt will be made to show how the tube may be set up and operated to

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‡ The British Broadcasting Corporation, Planning and Installation Department, London, W.1.

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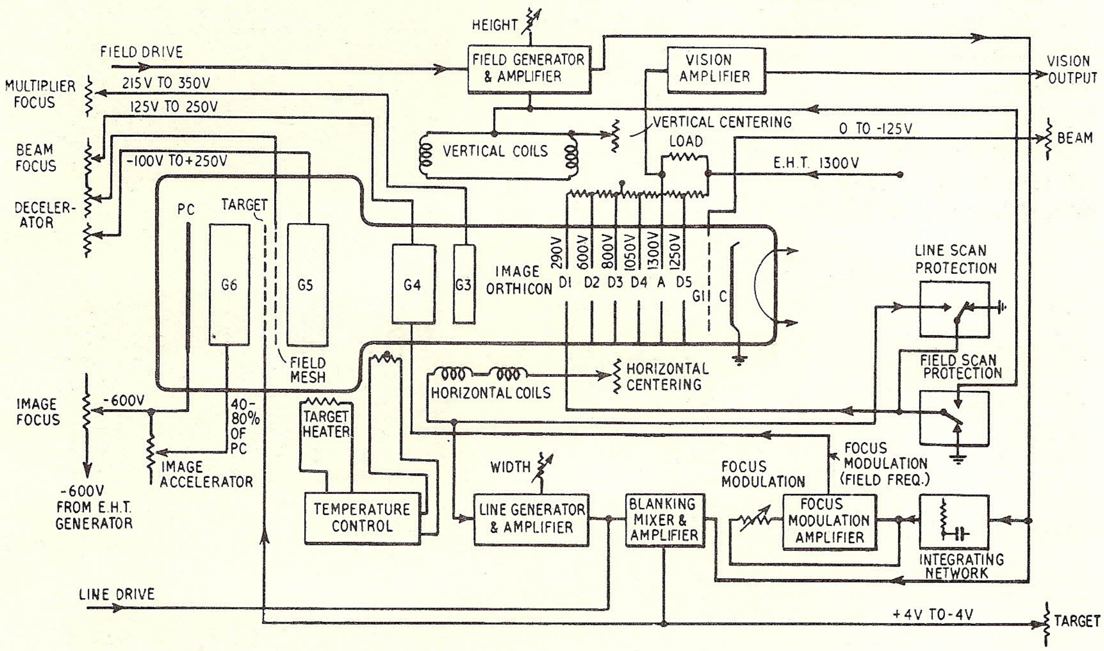

Fig. 2. Block diagram of P811 and associated control units.

(modified by the electron multiplier and partition noise through the field mesh).

The majority of this paper will deal with the ways in which the operation of the tube differs from the idealized summary given above, and the objective measurement of that departure.

4. The Transfer Characteristic

4.1. *Definition*

So far as this paper is concerned, the transfer characteristic of the tube may be defined as the relation between the photocathode illumination (L) and the signal current (i_s). If the signal current is fed into a resistive load R_L, then the signal voltage $V_s = R_L i_s$. It is often convenient to deal with V_s and this will therefore be used in this paper.

If the transfer characteristic is plotted with logarithmic scales, the gradient of the curve at any point is known as the point gamma. The point gamma ($\dot{\gamma}$) may be defined as

$$\dot{\gamma} = \frac{\mathrm{d}\,(\log V_s)}{\mathrm{d}\,(\log L)}$$

This definition is used as the basis of the following method of measuring the transfer characteristic of the image orthicon.

4.2. *Measurement of Transfer Characteristic and Point Gamma*

The block schematic of the arrangement is shown in Fig. 3. The camera is exposed to an illuminated transparency of the type required

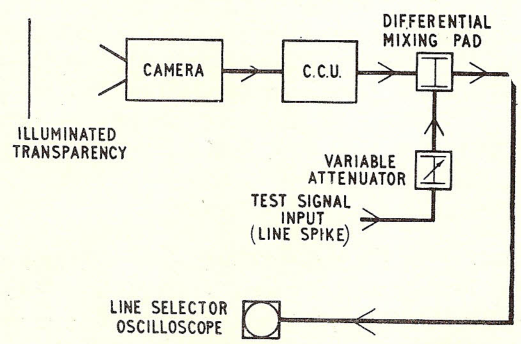

Fig. 3. Schematic of equipment for measuring transfer characteristics.

for the particular test being made. For this example consider a dark surround, dimensions approximately 9 in. by 12 in., with a small illuminated window approximately 0·4 in. square in the centre (see Fig. 4(b)).

The illumination in the window represents white and the camera exposure is set to the condition required for the test.

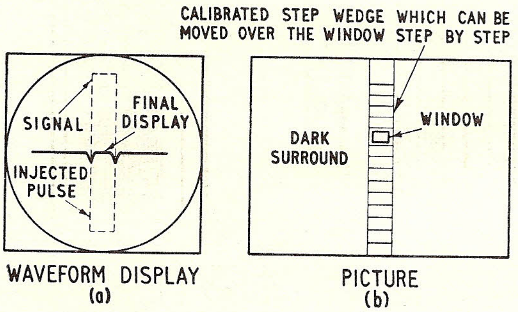

Fig. 4. Measurement of transfer characteristics—display of test object.

A line "spike" test waveform of approximately 2 microsec duration is mixed differentially with the output of the C.C.U., the camera is panned until the signals from the window and test waveform are overlapping in the waveform display, and the attenuator adjusted until the test waveform just cancels the signal in the output (see Fig. 4(a)).

A neutral light filter of known density is then placed in the window (see Fig. 4(b)) and the attenuator readjusted until the test waveform amplitude once again cancels that of the signal excursion in the display (Fig. 4(a)). Figures 5, 6 and 7 show photographs of the actual waveforms obtained in such a test.

The transfer characteristic can be obtained by plotting density against attenuator reading. Also if the attenuator reading in decibels is $Y = 20 \log_{10} V_s / V_{s(\max)}$ and density of light filter is $X = \log_{10} L_0 / L$ then

$$\dot{\gamma} = \frac{|Y|}{20|X|}$$

where V_s is the signal voltage after insertion of the neutral step, $V_{s(\max)}$ is the signal voltage before the insertion of the neutral step, L is the illumination after insertion of the neutral step, and L_0 is the illumination before insertion of the neutral step.

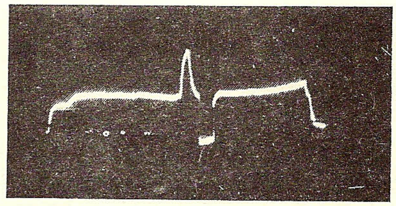

Fig. 5. Sensitivity and contrast law measurement. Electronic and camera pulse before superimposition.

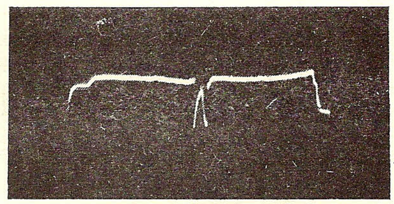

Fig. 6. Sensitivity and contrast law measurement, Electronic and camera pulse after superimposition, before complete cancellation.

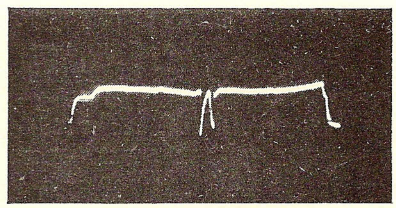

Fig. 7. Sensitivity and contrast law measurement. Electronic and camera pulse after complete cancellation.

The point gamma can be found at any value of illumination to any accuracy required by making the steps small enough. In practice density steps of 0·15 give a sufficiently accurate reading for most purposes. In this way it is possible to read either the point gamma around any given light value or to plot the complete transfer characteristic.

5. Sensitivity

For the purposes of sensitivity measurement, the usual definition of the "knee" of the transfer characteristic is not sufficiently precise, so an arbitrary but precise definition for the purposes of measuring tube sensitivity has been adopted, namely that the "knee" of a small illuminated area in a dark surround shall be defined as that point on the transfer characteristic at which the point gamma of the tube just drops to 0·5 on increasing the tube exposure.

The operating point can then be accurately defined in terms of increasing the exposure above or below the knee by a prescribed amount. Appendix 1 gives details of the particular operating point recommended for B.B.C. studios and the reasons for it.

In order to specify sensitivity of the tube alone, without involving the lens, highlight brightness on the photocathode is used. This is related to scene brightness by the formula

$$I_{pc} = \frac{BT}{4f^2(m+1)^2}$$

where

B=brightness of subject
I_{pc}=photocathode illumination
T=transmission of lens
f=relative aperture of lens
m=linear magnification from scene to photocathode.

If B is in foot-lamberts, I is in lumens per sq. ft. (foot-candles).

The sensitivity can then be given in terms of the highlight brightness required to reach the preferred operating point. This is preferable to giving sensitivity in terms of highlight brightness required to reach the knee, since the other tests have to be performed with the tube exposed to the operating point if they are to bear any relation to the results likely to be obtained in the studio.

Referring once more to Appendix 1 the highlight point in mode A would be at approximately $\frac{1}{2}$ the light value to reach the "knee", whilst in mode B it is at the knee, mode C 1·5–2 times the value just to reach the knee and mode D about 4 times.

It follows from the above that the mode of operation has a very pronounced effect on the working sensitivity of the tube, and this is one more reason for selecting modes B/C rather than D.

Finally, it is perhaps worth mentioning that the working sensitivity measured in this way is a function of sensitivity of photocathode, secondary emission factor of the target, potential and capacity of target, transparency of target mesh and storage time. It may be seen that the single overall measurement of the function is a great deal quicker than measuring each factor separately and calculating the overall sensitivity from them. Some typical results of sensitivity measurements are given in Table 1.

Table 1

	Target Volts above Cut-off	Sensitivity (Lumen/sq. ft. incident on photocathode)
Tube A	1	0·04
	2	0·04
	3	0·04
	4	0·04
	5	0·055
Tube B	1	0·1
	2	0·1
	3	0·1
	4	0·1
	5	0·125
Tube C	3	1·1†
	3	0·125‡

† Image focus/target potential=600.
‡ Image focus/target potential=280.

Note.—At a lens magnification of $\frac{1}{8}$, a highlight brightness of 25 ft. lamberts and lens aperture of 5·6 at 80 per cent. transmission factor, the photocathode illumination is 0·125 lumen/sq. ft.

The above tubes would all be satisfactory for use in studios, tubes B and C being just sufficiently sensitive for normal use, whilst tube A has about $1\frac{1}{2}$ stops in hand.

These results are interesting in that they show that over a wide range, target potential does not affect the sensitivity. On the other hand, the highest image focus potential (i.e. the most negative) on which a focus can be obtained, gives an appreciable increase in sensitivity over the lower potentials (presumably owing to the greater energy of the primary electrons causing more secondary emission at the target).

6. Contrast Handling Ability

This is a subject that has sometimes been misunderstood in the past. The scenic contrast range which a camera can handle with reasonable faithfulness is a function of several parameters, namely:

(1) Signal noise ratio
(2) Background blemishes

(3) Spurious effects

(4) Limitations due to imperfections at the lower end of the transfer characteristic.

Limitations due to effects (1), (2) and (3) are discussed in this paper under those headings. This section is concerned with the measurement of effects under heading (4), the definition and importance of this parameter being discussed in detail in Appendix 2.

Limitations caused by the lower part of the transfer characteristic fall into two groups:—

(1) Those which exist in small details in a dark surround.

(2) Those which exist in details in a light surround.

6.1. *Small Details in a Dark Surround*

Reproduction of these is limited by an effect fully described in Appendix 2 and called "ultimate contrast range". As described in the appendix, this parameter can be measured by recording the change of point gamma at the lower end of the grey scale. However, any tube suffering from such a defect can be detected in the test for contrast handling of details in a Light Surround described below, so that it is not normally necessary to test for this alone.

6.2. *Details in Light Surround*

The case where a detail is surrounded by a background of a lighter tone is somewhat more complex and may best be considered in reference to Fig. 8.

6.2.1. Small white square on black surround

First consider Fig. 8(a), a picture of a small white square on a black surround. If the exposure of a tube regarding this object is gradually increased, starting from well below the knee, several changes take place.

(a) Well below the knee, the behaviour of the tube is substantially as might be predicted from simple theory.

(b) As the light is increased towards the knee, the signal from the background (A) increases very slightly owing to veiling glare in the optical system and equivalent effects in the tube. This increase is very small indeed and may be neglected for all practical purposes.

(c) As the white area (D) is exposed above the knee, a defocused white halo of fairly large area appears around it (area B). This can be shown to take place on the image section side of the target and the area of it is affected by the image acceleration potential. Its mechanism has been described by Janes and Rotow[7]. It is caused by some of the secondary electrons having sufficient velocity to pass through the mesh and eventually return to the target with enough energy to cause the emission of other secondaries.

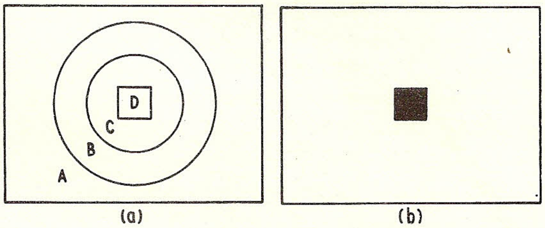

Fig. 8. Test object for examination of white and black halo.

(d) If the target voltage is low, or if the tube has very large target/mesh spacing, an area of black halo, C, caused by slow secondary electrons from areas above the knee being repelled from the mesh and returning to the target, cancels the white halo near to the illuminated area. It is unfortunately not possible to use this cancellation to dispose of white and black halo at one stroke, since the white halo moves its position relative to the lighted patch according to the position of the illuminated square on the target, whilst the black halo is of smaller area and is always symmetrically dispersed around it.

6.2.2. Dark detail on white surround

If the above considerations are now applied to a dark detail on a white surround (Fig. 8(b)), the following is the sequence of occurrence.

(a) When the surround is well below the knee, the behaviour is substantially as predicted by simple theory.

(b) As the brightness of the surround increases towards the knee, there is a very slight increase in brightness of the patch due to veiling glare. Although larger than in case 6.2.1, owing to the larger illuminated area, this is still generally small enough to be negligible.

(c) On the surround reaching or exceeding the knee, there is a sharp increase in the brightness of the reproduction of the dark square, owing to white halo, which in this case covers the test patch completely and evenly.

(d) On certain critical sizes of patch, it is possible to arrange for black halo just to cancel white halo if the tube is operated at a low target/mesh potential. This is more of academic than practical interest, since it only applies to small sizes of picture detail.

(e) It is relevant to consider the transfer characteristic of the dark square under these conditions.

 (i) In general, at all points where the surround is above the knee, a component B will have been added to the voltage. This gives a typical curve with decreasing point gamma towards black.

 (ii) In order to understand the other effects, it is of interest to explore the transfer characteristic, ignoring the effect mentioned in (i) above. The method described in Section 4.2 can be used to do this, it being arranged that on cancellation of the pulses, the zero level on the detecting waveform monitor is that which would obtain on a small black square in place of the dark square. A transfer characteristic taken in this way for a 50 per cent white surround brightness is shown in Fig. 9 (the white in this graph is considerably brighter than normal in order to demonstrate the effects more clearly). It may be seen that it is substantially as for the black background case, except for an apparent decrease in sensitivity which is, in fact, caused by an evenly distributed black halo.

It follows from the above that tubes with a low value of ultimate contrast range will have a rather worse behaviour than other tubes in areas affected by black halo, since the effect of the decrease in sensitivity is equivalent to a corresponding decrease in the ultimate contrast range.

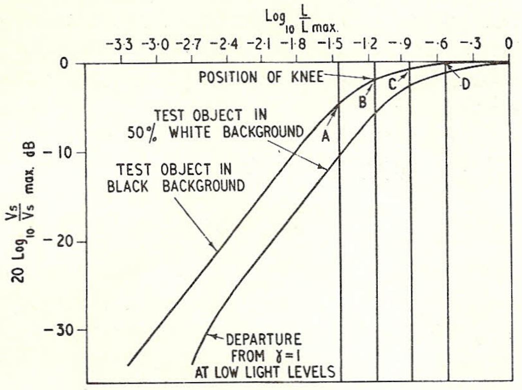

Fig. 9. Light transfer characteristics.

To sum up, the most sensitive test for the ability of a tube to handle scenes of large contrast range is that of a small dark square surrounded by a light background, the test consisting of two parts:

(a) A measurement of the rise in black level caused by white halo and veiling glare.

(b) A measurement of the point gamma at dark grey values disregarding the rise in black level mentioned in (a), to ensure that the ultimate contrast range is sufficiently great.

Figure 9 illustrates contrast laws that were plotted by the methods outlined in Section 4.2. These represent the normal tube. It will be seen that over a very large contrast range the point gamma below the knee remains at 1. Table 2 illustrates the behaviour of a tube that has a poor

Table 2

Density	Voltage Change (db) Black Background	White Background
1·5		
	3·0	4
1·65		
	3·0	4
1·80		
	3·5	4
1·95		
	4·0	(not readable)
2·10		

contrast handling capacity. Density 0 represents white, set to the preferred operating point. The black level is set to zero for no light in.

This tube displays a limiting contrast range of approximately 250 : 1 under conditions of grey background and would be found rather unsatisfactory in service. It might be serviceable if used with a higher target/mesh voltage (these readings were taken with target/mesh=3·2 volts) and would certainly be completely unserviceable at lower target/mesh voltages.

7. Signal/Noise Ratio

One of the most important parameters in a television picture is the signal/noise ratio. For the purposes of this paper, signal/noise ratio will be taken to mean the peak signal voltage/r.m.s. random fluctuation voltage at the output of the camera chain. It is most important to measure the signal/noise ratio of a tube accurately and it is very useful to have an idea of the distribution of that noise throughout the frequency spectrum. In addition, in order to ensure that consistent results are obtained by different people, it is essential that an indicator is used giving a true r.m.s. reading of the noise voltage, since, in theory at any rate, the peak voltage of any random noise is infinite.

A method of calculating the signal/noise ratio by measuring all the contributing factors has been suggested by Pilz[2] and this avoids the difficulty of an actual signal/noise measurement. The formula used is

$$S=i_s\sqrt{\frac{m}{1-m}}\sqrt{\frac{1}{f_m \cdot 2e \cdot X}}$$

where

i_s=signal current

m=modulation depth of return beam

f_m=bandwidth of transmission channel

e=charge on an electron

X=factor expressing the increase in noise in the electron multiplier.

To this should be added a factor (which is usually small) for partition noise and noise caused by field mesh secondary emission in some tubes using a field mesh, so that it may be seen that this method involves a fairly large number of measurements and calculations.

In order to obviate the necessity for this a direct measurement method has been developed by Weaver[10] which gives a reliable and consistent reading with an accuracy of repetition within less than 1 db.

The method consists of a narrow bandpass filter, the centre frequency of which can be placed accurately in the "dead" area between the signal harmonics of line frequency. (A communications type receiver may be used for this purpose.) The energy in these areas is the r.m.s. noise (all components caused by picture, shading, syncs, etc. being rejected) and by a simple comparison with a standard noise source, using an r.m.s. indicator, a value of the noise at any given frequency within the band can be obtained. Normally it is only necessary to check the noise on a known type of tube in a known channel at about two or three frequencies and, in fact, in the case of any given type of 4½-in. tube a check at, say, approximately 1 Mc/s gives a fairly accurate idea of the noise of the tube.

It is strongly recommended that the noise is not measured by the height of "grass" on an oscilloscope, as under differing conditions, widely differing results can be obtained by this method, since its accuracy depends on subjective assessment as well as objective observation of the oscilloscope.

Some results of signal/noise measurements on tubes set up in different ways are given in Table 3.

The results on tube D are interesting in that they show the way in which signal/noise ratio improves with increasing target volts. If the target/mesh potential is increased to more than 3·5 volts, it will be noticed that the improvement is quite small. However, between 1·5 and 3·5 volts the improvement is 3·5 db which is really worthwhile.

Similarly in tube A which has already been used as an example in the sensitivity tests, the improvement in signal/noise ratio on changing the target/mesh potential from 2 to 4 volts is about 3 db.

Tube E is an example of how the noise spectrum may be used to check the aperture correction in the C.C.U. Basically the frequency spectrum of electron beam noise is flat and any departure at high frequencies must be due to inadequate or excessive correction in the camera or C.C.U. In the case of tube E it will be observed that there is $\frac{1}{2}$ db of high-frequency tip-up in the C.C.U. at 3 Mc/s. This is an extremely reliable way of checking aperture correction and C.C.U. frequency response, since the measurement is performed with the tube in position *and working*.

The results on tube F illustrate the effect of G_3 potential on gain and noise. It is fairly clear from these results, which are quite typical, that there is an appreciable contribution to the noise from the multiplier since the signal/noise is better at positions of maximum gain. In addition, the signal/noise ratio is affected by the potential of G_3 and at two positions of equal multiplier gain signal/noise is best at the lower potential of G_3.

If the measurements are made without contrast law correction in the camera, when assessing the tube in terms of measurements on signal/noise ratio it is necessary to allow for the contrast correction which it is anticipated will be used when the tube is in service (this will increase the noise in the blacks). In the case in point, tubes D and A would appear rather noisy in the blacks if correction were added, whilst E would be reasonably satisfactory and F adequate. Apart from the objectionable nature of the noise itself, noise in the blacks tends to be rectified in the suppression mixer or c.r.t. and will distort the grey values of the lower tones by adding a small d.c. component to them. In this sense, signal/noise ratio may be said to limit the contrast handling ability of the tube.

Table 3

Tube	Exposure	Target	G_3 Potential	Frequency	Relative Gain	Signal/Noise/ kc/s
D	Preferred	1·5	185	1·0 Mc/s	0	70
	,,	2·5	185	1·0 Mc/s	+3·5	72
	,,	3·5	185	1·0 Mc/s	+6·0	73·5
	,,	4·5	185	1·0 Mc/s	+7·0	74
A	,,	1	max. sig.	1·0 Mc/s		70
	,,	2	,,	1·0 Mc/s		72
	,,	3	,,	1·0 Mc/s		74·5
	,,	4	,,	1·0 Mc/s		75
	,,	5	,,	1·0 Mc/s		75·5
E	,,	3	,,	0·5 Mc/s		75
	,,	3	,,	1·0 Mc/s		75
	,,	3	,,	1·5 Mc/s		75
	,,	3	,,	2·0 Mc/s		75
	,,	3	,,	2·5 Mc/s		75
	,,	3	,,	3·0 Mc/s		74·5
F	,,	3	155	1·0 Mc/s	+1·5	78
	,,	3	185	1·0 Mc/s	+6·0	80
	,,	3	237	1·0 Mc/s	+1·5	77
	,,	3	272	1·0 Mc/s	+4·0	78
	,,	3	320	1·0 Mc/s	+1·5	77
	,,	3	335	1·0 Mc/s	0	75·5

Note.—In a rectangular noise spectrum of bandwidth 0–3 Mc/s a signal/noise ratio of 70 db/kc/s gives an overall ratio of 35 db.

8. Picture Sharpness

The ability of a camera tube to reproduce fine detail depends upon its horizontal and vertical resolution and other factors such as edge effect, which in turn depend upon redistribution. If a picture is sufficiently good in horizontal and vertical resolution, it is not necessary to resort to spurious responses in order to make a picture appear sharp. For example, a picture from a good 35 mm flying spot telecine is free of spurious responses and always appears sharp.

The main object of this section is to discuss the measurement of vertical and horizontal resolution. Spurious effects and redistribution are discussed in Section 12.

8.1. *Horizontal Resolution*

Television is a bandwidth limited system and good depth of modulation within the passband is the criterion rather than a very high limiting resolution. Horizontal resolution measurements on tubes are, therefore, confined to measuring the amplitude response of the tube to test patches of various frequencies within the passband and in particular to the response at the upper limit of the passband.

Several other considerations are of the utmost importance in measuring horizontal resolution.

(a) In order that resolution measurements should not be confused with contrast law limitations in a tube, it is important that any resolution patterns should have a low contrast range and be placed in the upper middle part of the grey scale.

(b) Comparatively large areas of low frequency (< 100 kc/s) information of equal density range to the test frequency pattern should be situated immediately beside it.

(c) All patterns of frequency $f_m/3$ or more, where f_m is the bandwidth of the system, should be of approximately sine distribution of transmission, in order that the subtraction of harmonics by the system (or tube) bandwidth limitation will not artificially boost the response to the fundamental. (The amplitude of the fundamental in a square wave is $4/\pi$ greater than the amplitude of the square wave.)

A special test transparency (B.B.C. Test Transparency No. 51)[11] to fill these and other requirements has been produced and has given consistent results in the measurement of horizontal resolution.

Once the channel has been set to its working condition, a reading of the horizontal resolution can be taken in the centre and corners by measuring the amplitude response on a line selector oscilloscope, in every case relative to the low frequency transition placed immediately beside (or astride) the test frequency patch.

Figures 10 and 11 show the waveforms obtained in a typical horizontal resolution measurement on a test chart 51.

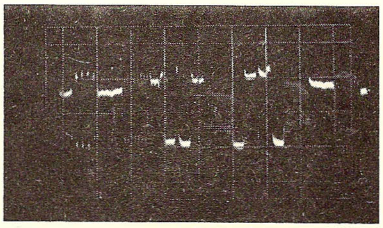

Fig. 10. Horizontal resolution, Test Card 51. Target/mesh potential 1·5 V. Preferred exposure.

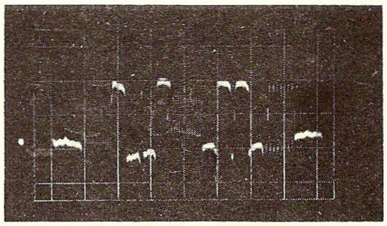

Fig. 11. Horizontal resolution, Test Card 51. Target/mesh potential 3·5 V. Preferred exposure.

It is interesting to examine the change of horizontal resolution with change of target/mesh potential. Table 4 shows these results.

Of the results in Table 4, tubes A and G are typical and B unusual in respect of change of resolution with change of target/mesh potential. It will be noticed that in tube A the loss of resolution is less than the gain in signal/noise and this result is also typical.

Tube G is an example of a tube with good resolution, and A and B are poor. The resolution at the junction of Zones II and III should normally be not more than about 3 db worse than the centre resolution (Fig. 15).

Table 4

Tube	Target	Centre Resolution at 3 Mc/s. relative to black/white %
A	1	50
	2	53·6
	3	50
	4	44
	5	40
B	1	40
	2	50
	3	50
	4	50
	5	55
G	1	75
	2	75
	3†	72·5†
	4	68
	5	65

† Corner resolution at 3 Mc/s—%:—top left 56, top right 51·5, bottom left 46, bottom right 38.

8.2. *Vertical Resolution*

Of great importance in the rendering of detail in a television picture is the vertical resolution of the tube. Good vertical resolution in a picture gives it the property of "travelling well" since the sharpness of such a picture is not so badly affected by any loss of horizontal resolution as that of a picture which lacks vertical resolution.

The horizontal resolution of a tube is not necessarily a good measure of its vertical resolution. This may be due to straightforward astigmation in the beam focus, but even when this is not present, the vertical resolution may be (and generally is) considerably worse than the horizontal. The reason for this is not fully understood by the writer but is believed due to the fact that in the horizontal direction most of the work is done by the leading edge of the spot, whilst in the vertical direction this does not apply to the same extent, probably owing to the ability of a charged portion of the target that has been partly discharged by an overlapping spot on another line to recharge whilst the spot is in a different part of that line.

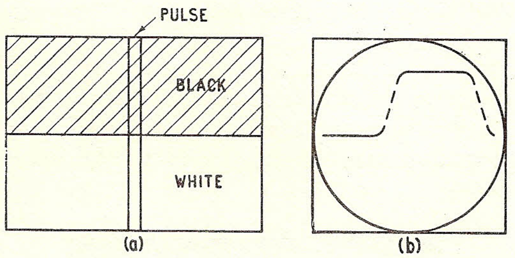

Fig. 12. Field strobe. Test object and waveform display for vertical resolution.

A measurement of the vertical resolution of a tube can be made using an instrument showing a section of a picture in the vertical direction.

This method was used by Theile and Pilz[1] and is a very powerful tool for various measurements on the image orthicon. The instrument is very simple and its principle may be understood with reference to Fig. 12. A short pulse (say 2–8 microsec) is generated at the same point on each line and applied to the cathode of the display oscilloscope as a brightening pulse. The oscilloscope is run at field speed and the resulting display (which is actually composed of small dots) gives a vertical "slice" through the picture. By varying the width of the brightening pulse and its position in the line, it is possible to explore the properties of the picture in the vertical direction.

If such an instrument (sometimes referred to as a "field strobe" in distinction to the more usual "line strobe") is used to observe the display of a sharp horizontal step from black to white (or vice versa) the vertical resolution of the tube can be measured in terms of the time of rise or fall (measured in lines or fractions thereof) on the display. If the test object is very slightly tilted it is possible, by moving the position of the "slice" along the line, to adjust the phase of the dots of which the display is composed in order to start the transition exactly on a given line.

Under these conditions, a "perfect" camera tube should not take more than 1 line (it cannot take less) to change from black to white. Practical camera tubes show anything from 2–3 lines down to just over 1 line and obviously the difference in picture sharpness between such tubes is quite marked.

Finally, it must be mentioned that in all measurements of tube resolution, due allowance must be made for losses in the lens and in any filters that may be interposed in the optical system.

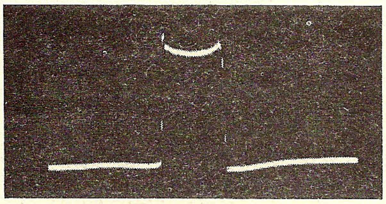

Fig. 13. Vertical resolution, edge effect and halo. Target/mesh potential 2·0 V. Below knee.

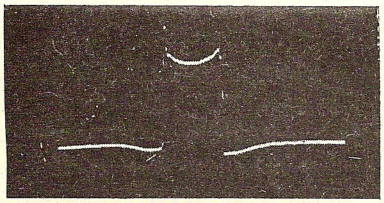

Fig. 14. Vertical resolution, edge effect and halo. Target/mesh potential 2·0 V. Above knee.

Figures 13 and 14 show vertical resolution oscillograms taken for various target/mesh potentials. It is quite usual for tubes to take more than 1 line to rise (and fall) on a sharp horizontal edge, and this is a feature of tube performance to which more attention should be paid, since sharpness is as much a factor of resolution in this direction as in the horizontal direction.

9. Geometrical Distortion and Linearity

Whilst most television engineers are familiar with the effects of geometrical and linearity distortion on pictures, most measurements used at present do not separate faults caused by the tube from those caused by faults in the yoke design or the scanning waveforms in the camera.

One obvious method of showing the difference from tube to tube is to measure them in the same camera, or in cameras calibrated in terms of a known standard, and this method is recommended as a basis for tube selection. In order to select the mean value and limits, a large number of tubes has to be tested (specially constructed tubes can also be used to aid the result of these tests). As a result of a large number of measurements, all in the same yoke, it should be possible to distinguish any random differences between tubes from any consistent error on all, or most, of the tubes. Such a consistent error is either a basic constructional fault in the tube or incorrect yoke design and it is necessary to decide whether it is best eliminated by a change of yoke design or by an alteration within the tube.

In addition to separating errors caused by the tube from other errors, it is also important that the limits should be specified in a way most nearly connected with their subjective effect. Undesirable effects of geometrical distortion (including linearity distortion) in a picture can be analysed into the following components.

(a) Certain areas of the picture are more critical than others.

(b) Sharp changes of linearity are very objectionable, whilst a fairly large total error can be tolerated if it is evenly distributed.

(c) To a first approximation, changes are equally objectionable in whatever direction they occur, i.e. the same "goodness" is desirable in every direction.

The above requirements suggest that geometrical errors should be measured in terms of the differential of the error, i.e. the change of error per unit distance in any direction on the picture. Furthermore, the picture may be divided into zones in which a different limit can be placed on the distortion allowed. Figure 15 shows the zones used by the B.B.C. in specifying tube performance for studio purposes.

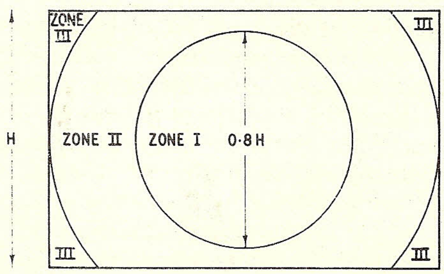

Fig. 15. Zones of interest in studio television picture.

It is fairly easy to see why a differential method of specification meets the requirements. Requirement (b) is satisfied since the maximum rate of change has been set. On the other hand, a maximum latitude for errors is given by relaxing the specification in zones of the picture where most receivers will not be showing the picture (e.g. Zone III). Furthermore, a larger total positional error can be allowed by this method than could be allowed in the traditional way of specifying geometry, for equal "spoiling" of the picture subjectively.

The actual method of measurement is simple. An electronic grille is injected into the output of the channel and the camera caused to observe a chart with a grille with similar number of squares to the electronic one drawn onto it

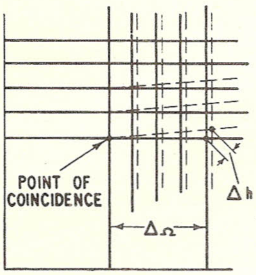

Fig. 16. Measurement of differential linearity.

(see Fig. 16). Then if the camera is so positioned that the image of a point on the test card coincides with the corresponding point in the grille pattern, the differential can be approximately calculated by measuring the positional error at any other point and dividing it by the distance δr from the point at which the pictures coincided. The limit of $\delta h/\delta r$ as h and $r \to 0$ is the differential. For most practical purposes, it is sufficiently accurate to use $\delta h/\delta r$ if h and r are small.

In other words, the method differs from the traditional method of specifying linearity only in that the error is divided by the distance over which it occurred, rather than by a fixed number such as the height or width of the picture.

In the 4½-in. image orthicon cameras in general use at present typical readings are a maximum differential error of 6 per cent at the corners (in Zone III) due to a type of barrel distortion. In Zones I and II the error is normally less than this, and in some cases, too small for accurate measurement. (A typical reading is 2 per cent.)

As mentioned previously, more work is yet to be done in very carefully calibrating a yoke to be used as a standard.

10. Microphony

10.1. *Theory*

Owing to their construction, image orthicons are inherently liable to produce annoying amplitude modulation of the picture signal if disturbed by mechanical shock or acoustically induced vibration. In most cases the disturbance is caused by relative movement between the target and the mesh, and it is this type of microphony which will be discussed in this paper.

Because of their target and mesh, some versions of the 4½-in. tube have proved in the past to be more troublesome in respect of microphony than the 3-in. tube. In addition, the disturbance has tended to be aggravated as the distance between the target and mesh has been reduced.

The effect of the relative vibration of target and mesh on the signal is complex. The behaviour of the target/mesh to acoustic disturbance has some resemblance to that of a condenser microphone. For constant relative movement, the disturbance produced on the output signal is proportional to the charge between the target and mesh and the impedance of the circuit connected to it (i.e. principally the beam impedance).

Now when no light is landing on the target there is a considerable charge between the target and mesh, the exact magnitude of which depends on the potential to which the mesh has been set. In this condition, however, the beam does not land, so that the beam impedance is infinite and no microphonic effects are visible. When a very small amount of light falls on the target the charge is reduced, but the beam begins to land so that its impedance becomes finite but large, and a small disturbance becomes visible. This process continues until a compromise between beam impedance and charge is reached which gives a maximum disturbance. As the light is increased beyond this point the charge approaches zero, so that there is little disturbance although the beam impedance is now comparatively low. When the light is again increased the charge begins to build up again, in opposite polarity, the beam impedance remains low and eventually another point of maximum disturbance occurs when the exposure is somewhat above the knee.

Although the disturbance of the picture appears as a series of horizontal bars running up or down the picture, or occasionally stationary, the basic disturbance is normally a time modulation of the signal. However, the beam does not land at any part of the picture on which no light is falling and at such a point there is no microphonic disturbance even when the remainder of the picture is illuminated. Furthermore, the impedance across the target is high and it is not easy for charge to travel across the target, so that the effect may well be more dependent on the charge at the point at which the beam is landing at any given moment than on the charge on the target as a whole.

The effects can be further complicated by the fact that the maximum vibration is probably in the centre of the target structure and the minimum at the edges. Modes can also be excited where more than one node occurs, but these are generally more difficult to excite and of less importance than the fundamental single node vibration.

10.2. *Method of Test*

In order to investigate the microphonic properties of the tube, the apparatus was set up as shown schematically in Fig. 17. A commercial vibrator unit was placed in contact with the spigot on the base of the tube via a metal bar. A constant output oscillator whose frequency could be varied between 400 and 2000 c/s was connected to the vibrator unit via a changeover unit. The changeover unit consisted of a switch which either fed the output of the oscillator to the vibrator unit via a calibrated attenuator, or through a resistance pad to the camera channel output, or to neither.

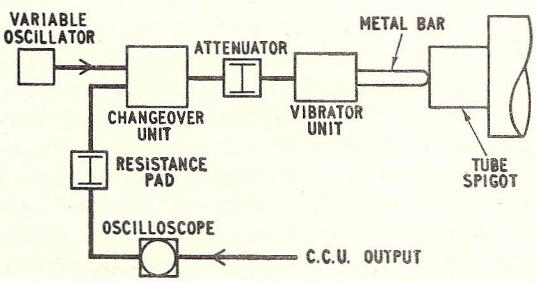

Fig. 17. Microphony test by variable oscillator.

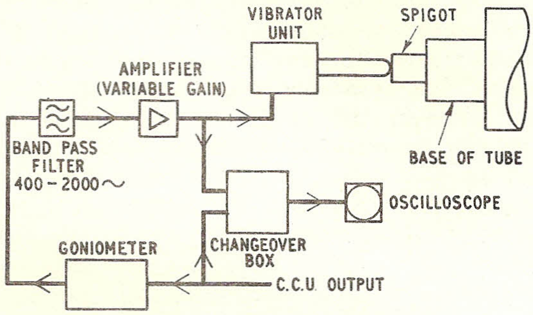

Fig. 18. Measurement of microphony by self excitation method.

The resistance pad was so arranged that when the oscillator voltage was mixed into camera output through it, a known small percentage of sine wave from the oscillator appeared superimposed on the picture. A suitable amount was found in practice to be 3 per cent of white picture signal. This apparatus was tuned to the microphonic resonance of the tube and the excitation required just to reach 3 per cent excitation of the signal (checked by comparison with the standard 3 per cent in the changeover box) was measured. The excitation was then removed and the time taken for the microphony to die away was noted. This method proved quite effective and consistent in use, but suffered from the disadvantage that it was rather slow and tedious to use, since the mechanical Q factor of the resonance is very high indeed.

An improved method which has now displaced the earlier method is shown in Fig. 18. In this method the output of the channel is fed through a goniometer to a bandpass filter with its passband from 400–2000 c/s and thence to an amplifier with variable gain (or a fixed gain amplifier and variable attenuator in series) the output of the amplifier being fed to the input of the vibrator unit. An oscilloscope is arranged via a changeover box so that it can be used to measure the input to the vibrator unit or to monitor the signal. The goniometer is then adjusted to obtain a simple positive feedback loop which produces continuous microphony, the loop gain being increased (or reduced) until continuous microphony of about 3 per cent of white signal can be obtained if the tube is lightly tapped to start the microphony. The excitation at the input to the vibrator is then measured on the oscilloscope. The loop is cut and the time taken for the microphony to die away is noted.

This method has proved very quick and simple to use in practice and the results check very well with those obtained by the method described in Fig. 17 and also correlate very well with the complaints of operational crews about the nuisance value of certain microphonic tubes.

Table 5 shows a typical result on a tube rejected by the studio.

Table 5

D.C. Sensitivity of Vibrator = 400 grams/ampere

Tube	Excitation (Vibrator current) decibels relative to 1 amp. (for modulation of 0·03 V. at C.C.U. output)	Die Away Time (seconds)
H	−61	3
K	−51	15
L	−55	10

Table 6 shows the variation of microphony with target/mesh potential and exposure on a tube rejected as microphonic.

Table 6

Target/ Mesh Volts	Exposure Relative to knee	Excitation relative to 1 amp. decibels (for modulation of 0·03 V at C.C.U. output)
3·5	+3 stops	−69
3·5	−2 stops	−71
1·5	+3 stops	−69
1·5	−2 stops	−71

The reason for selecting exposures of +3 and −2 stops is that at these points maxima occurred as explained above. It may be of interest to note that the fundamental microphonic mode in most tubes is at approximately 800 c/s.

It is quite usual also for tubes to exhibit an increased sensitivity to microphony at high target/mesh potentials.

The target/mesh potential also has a bearing on the position and relative magnitude of the microphony maxima above and below the knee. This accords very well with the theory given above, since the potential to which the mesh is set will determine the charge between the target and mesh when no light is reaching it and also the maximum charge that the target can hold.

11. Uniformity of Picture Background

11.1. *Uniformity of Dark Current*

This is affected by the uniformity of response over the 1st dynode surface, and how far out of focus this surface is when the other conditions necessary for satisfactory operation of the tube are met. The uniformity of transmission of the field mesh is also involved, since the beam has to pass through this twice. Any secondary emission effects at the field mesh may also affect it.

11.2. *Uniformity of Sensitivity up to the Knee*

Primarily this is a function of variation of sensitivity of the photocathode, together with variation of secondary emission over the image side of the target (caused by impurities and/or "burning") and uniformity of transmission of the target mesh. Efficiency of transfer of charge through the target can affect this parameter, also variation of contact potential between different parts of the target[3], so that an image previously "burnt" on a tube may be seen in negative if the tube observes a plain white background. Linearity of scan also plays a very important part in this and the next parameter and although this is really a camera rather than a tube function, it is clearly necessary that any camera used for this test should have a very high order of scan linearity.

11.3. *Uniformity of Signal above the Knee*

In the simple theoretical case, above the knee the output of the image orthicon is constant at all parts of the target for all light values. Practical tubes do not achieve this and there are several possible reasons for it. Lack of uniformity of target/mesh spacing over the picture area is one possible contributary cause. This has the very objectionable operational effect of causing the tube to act as a low capacitance tube in one part of the picture and a higher capacitance tube in another part. Thus in one part of the picture area the knee occurs at a lower light level but there is a low signal output above the knee, whilst in another part the knee occurs at a high light level but there is a high signal output above the knee. Tubes of this sort cause the operators to make frequent adjustments as the object of interest traverses the picture area.

Due to beam landing errors, beam alignment also seems to affect the behaviour of a tube in this parameter and in many tubes alignment of the beam for evenness of target cut-off or minimum movement of the picture for change of beam focus does not produce the best white background above the knee. Misalignment and beam landing errors may well cause different parts of the target to be stabilized at different voltages and this may be used to counteract effects similar to uneven target/mesh spacing provided the misalignment is sufficiently small not to cause other harmful effects.

Linearity of scan, as previously mentioned, also affects background above the knee, also efficiency of transfer of charge through the target and variation of contact potential. (A "burnt on" image shows above as well as below the knee.)

11.4. *Methods of Measurement of Background*

Background variations of the above mentioned types can occur as large area blemishes or as "spots", and together constitute one of the most serious defects on the $4\frac{1}{2}$-in. image orthicon to-day. The effects referred to under 11.1 and 11.3 are far more serious than those quoted in Section 11.2. Thus an objective method of measurement related to the subjective nuisance value has had to be devised.

Examination of the problem showed that, like scan linearity, the nuisance value of background defects varies according to the part of the picture in which it occurs and also the rate at which it changes. Once again, a differential measurement has been devised in order to get the closest possible correlation with subjective effects. This can be done by reasonably simple methods which will be described below.

11.4.1. Measurement of dark current variations

An illustration of a single line oscillogram of the dark current of an image orthicon is shown in Fig. 19. The overall amplitude of the variation is simply the voltage excursion of the trace, whilst the rate of change is represented by the gradient or dv/ds (where v is the voltage excursion and s the linear distance across the picture).

If the X and Y scans of an oscilloscope are of known sensitivity, then it is a simple matter to inscribe a line (or lines) at a suitable angle to represent the limit permitted for dark current

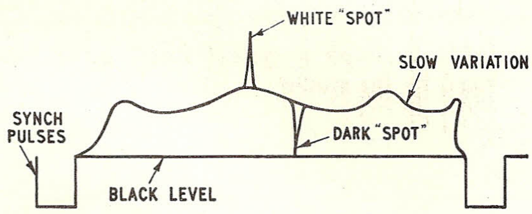

Fig. 19. Single line oscillogram of image orthicon dark current.

rate of change. By means of the line selector and field strobe (Figs. 14 and 15) it is then possible to examine the entire field of the tube to ensure that the limit is not exceeded. It is particularly important to note that in this test the tube should not be exposed to a chequer-board pattern. It is possible to be grossly deceived on the black background of the tube when using such a pattern since white ghost and black halo from the white areas may affect the signal from the black areas.

Figures 20 and 21 show dark current shading, the graticule line at 45° representing a differential rate of change of shading of 20 per cent. In fact, this tube only exceeded that figure in Zone III and is quite acceptable for studio use.

An alternative method of testing dark current variation is to use in front of an evenly illu-

Fig. 20. Dark current—line direction. Slope of 45° represents $\delta V/\delta H = 0{\cdot}2$.

Fig. 21. Dark current—frame direction. Slope of 45° represents $\delta V/\delta H=0{\cdot}2$.

minated scene an opaque card with two small holes in it, one above the other, a known small fraction of the picture height apart, the holes being at the left hand edge of the picture. The oscilloscope is then set to trigger off the signals produced by the white spots instead of the synchronizing pulses, and the display is checked as previously described in the line direction. In the field direction the differential is within a given limit if the two lines on the oscilloscope are not displaced by more than $\delta V=L\delta S$ where L is the limit, and δS the distance apart of the two holes. In order to cover the whole picture area, the card may be

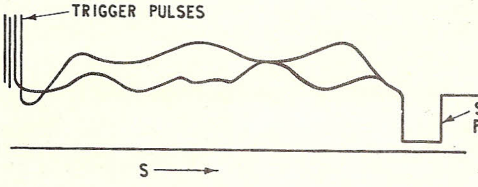

Fig. 22. Measurement of dark current—vertical direction.

moved and the check repeated as often as necessary. Figure 22 illustrates the type of display obtained in this method. Differential limits that are suitable for diffuse background effects are generally unreasonably tight for "spots" when they are not in the centre of the picture, and provided the linear dimensions are smaller than a certain specified size, spots are best measured by a simple amplitude check. Both the amplitude, number and distance apart of the spots must be specified.

11.4.2. Measurement of sensitivity variations below the knee

If the tube is exposed to a plain white background and the tube exposure adjusted so that all parts of the picture area are below the knee, line or field oscillograms represent the sum of the background measured in 11.4.1 and the variation of signal caused by sensitivity variations. In order to measure the variation of sensitivity alone it is, therefore, necessary to find some means of subtracting the dark current variations automatically. A simple and effective means has been devised to achieve this.

Figure 23 shows diagrammatically a single line oscillogram of the signal produced by the

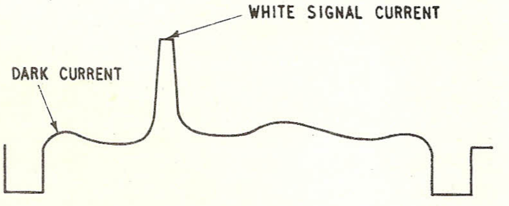

Fig. 23. Measurement of white background—waveform display (uncorrected).

tube if it is exposed to a white spot on a dark background. It will be seen that there is a sharp pulse caused by the white spot and a residuum of comparatively slow variation of the dark current.

If the camera output is delayed by a time slightly longer than the duration of the white pulse and this is fed to one input of a differential oscilloscope, the undelayed signal being fed to the other input, the delayed signal will effectively cancel the low frequency variations, but not the pulse; the oscillogram will then appear as in Fig. 24.

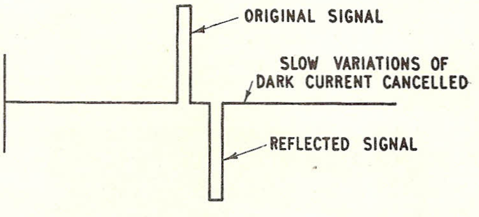

Fig. 24. Measurement of white background—waveform display (corrected).

It may be seen that the dark current variations have been effectively subtracted. If the camera is exposed to a card with a diagonal slot such as is shown in Fig. 25 a white pulse occurs on

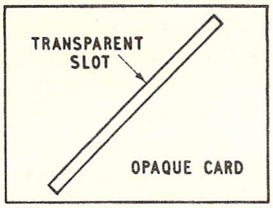

Fig. 25. Measurement of white background—test object.

each line and the resulting positive signal peaks from an oscilloscope whose time base is running repetitively at line frequency, will effectively draw the contour of the sensitivity along the diagonal. A simple cursor line whose angle determines the limit of white background variation permitted may be used on the oscilloscope as a check. The diagonal slot can be moved across the picture, the card reversed, turning the angle of the slot through 90 deg, and the procedure repeated to cover the whole picture in two directions at 90 deg. The light source may be masked in order to check for the different limits in the different picture zones.

Figures 26 and 27 show white shading when the tube is exposed below the knee, firstly with black shading also present, and secondly with black shading eliminated by the delay line method. The 45 deg line here represents 40 per cent differential shading, a reasonable acceptance figure for sensitivity variations below the knee.

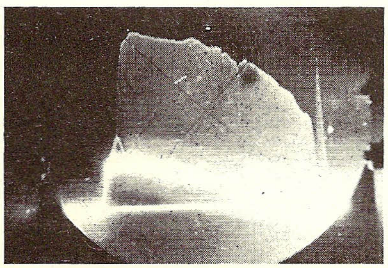

Fig. 26. Sensitivity variations (below knee). Before cancellation of dark current (shown by thick line at base).

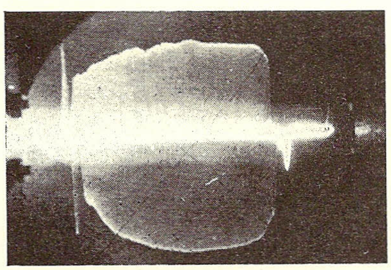

Fig. 27. Sensitivity variations shown in Fig. 26 after cancellation of dark current.

11.4.3. Measurement of signal variations above the knee

The method used in 11.4.2 will effectively work for variations above the knee if the exposure of the tube is increased so that all parts of the transparent slot are above the knee on all parts of the target.

The limits specified for this parameter should be somewhat more stringent than those measured under 11.4.2 (e.g. 20 per cent instead of 40 per cent) because of the much greater operational nuisance value of defects above the knee. As in 11.4.1, so in 11.4.2 and 11.4.3 it is better to deal with the "spots" separately, since differential methods of specification virtually eliminate any picture disturbances that occur suddenly. However, the size, amplitude, number and distance apart of such spots, if permitted, should be carefully specified.

12. Freedom from Spurious Effects

The main spurious effects in the image orthicon, other than those already dealt with, are edge effect and halo.

According to the literature[1, 3], edge effect is the resultant of two other effects. One is the apparent increase in capacitance which takes place above the knee around the edge of a charged portion of a target. The second is the attraction of the beam towards the charged object—generally known as "beam pulling" or "beam bending." The apparent increase in capacitance around the edge of charged areas is a function of the ratio of transverse to through capacitance. It is in this respect in particular that the $4\frac{1}{2}$-in. image orthicon is superior to the 3-in. type.

Attraction of the beam towards a charged portion of the target is a function of the potential of the charged portion and the strength of the decelerating field. In this respect the influence of the field mesh is very important, as shown by Theile and Pilz[1].

Black halo is caused by the collection by surrounding areas of the target of slow secondary electrons emitted by an area above the knee which is already fully charged and therefore unable to accept further electrons.

Both edge effect and black halo are reduced as the target/mesh potential is increased, owing to the greater efficiency of collection of secondary electrons by the stronger field. It is possible with tubes of reasonably high capacity to reduce black halo to negligible proportions by this means.

12.1. *Measurement of Edge Effect*

Edge effect is best measured in the field direction, since in this direction it is greater than across the line. A sharp horizontal black/white transition exposed for the preferred operating conditions makes a suitable test object. The field strobe may be used to measure overshoot at the leading and trailing edges of the test object. As this measurement is in the field direction it is insensitive to the amplifier frequency and phase response.

12.2. *Measurement of Black Halo*

The same white object surrounded by a grey tone of 3 per cent white, is suitable for the measurement of halo. There should be no measurable darkening of the grey surround close to the white test object when the white is just exposed to the preferred operating point.

These tests may also be used as an indication of the target/mesh spacing and potential.

13. Lag, Movement Blur, Sticking etc.

These effects may be divided into three:—

(a) Build-up time of charge image.
(b) Failure of beam erasure.
} These effects are sometimes called capacitance lag.
(c) Image retention.

In a low velocity tube, effects (a) and (b) have been shown by Meltzer and Holmes[12] to be due to the low velocity beam acceptance mechanism. An idea for reducing its effects by means of biasing the target was suggested by the same authors but this is not easily applicable to the image orthicon as constructed at present and the necessity does not exist except in tubes of very close target/mesh spacing since redistribution usually reduces lag to negligible proportions.

Image retention is a function of the inability of the target to transfer charge from one side to the other. The target suffers a change of contact potential and conductivity in places where charge has passed through it. This fatigue effect becomes important when too much charge has passed through the target, or when the target temperature has been too low when the charge passed through it. Thus, when a portion of the target suffering from fatigue is exposed, chiefly owing to the change in contact potential, a negative image of a scene previously "burnt on" will appear when the camera observes a plain white background.

13.1. *Measurement of Build-up and Erasure Time*

Figure 28 shows the schematic of apparatus used for measuring the lag of pick-up tubes. It consists of a shutter which is synchronized with field pulses but with variable delay so that it can be set to operate at any part of the field

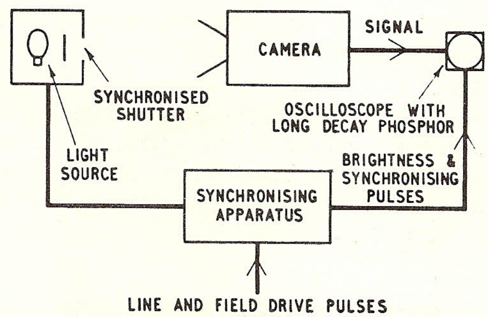

Fig. 28. Measurement of lag.

period. An oscilloscope with a slow speed time base is also triggered by the same apparatus. There is also a variable delay in the oscilloscope trigger. In addition, a brightening pulse is fed to the oscilloscope so that only that part of the picture in which the shuttered light appears is displayed on the oscilloscope.

A display of the sort shown in Fig. 29 is obtained. Both the build-up and decay can be registered by this method. In order to obtain consistent measurements, it is usual to adjust the phasing of the shutter so that the last completely bright signal is just equal to the

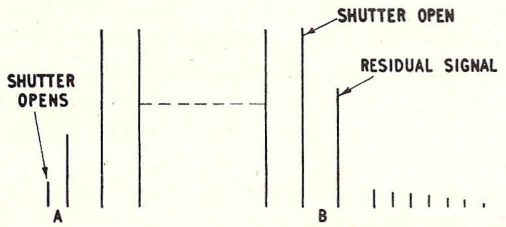

Fig. 29. Oscilloscope display of lag test.

exposed amplitude, i.e. any further advance of the shutter opening begins to reduce the last completely bright signal. As an additional check, a light sensitive cell is mounted outside the shutter, so that an electrical signal showing the opening time of the shutter is available if required.

The lamp brightness and iris are adjusted until the tube just reaches the preferred operating point on the image of the light source when it is exposed to it continuously.

It is reasonably easy to show that all except the super-high-capacitance tubes (e.g. P 812) have lag values that are acceptable for all normal purposes, when exposed to the preferred operating point.

Where lag is troublesome, it is of interest to note that an increase of target voltage greatly improves the signal/lag ratio. This may be due in part to the tube behaving as though it has a small bias on the target, as discussed by Meltzer and Holmes[12].

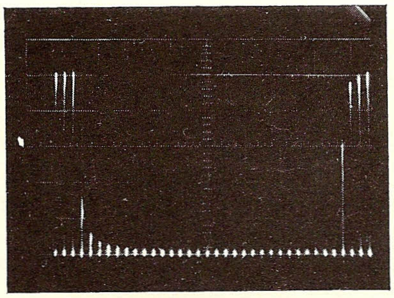

Fig. 30. Lag. Decay and build-up time below knee. Target/mesh potential 4·5 V.

Figure 30 shows the build-up and decay lag in a tube with high target voltage, exposed with highlights below the knee. It will be noticed

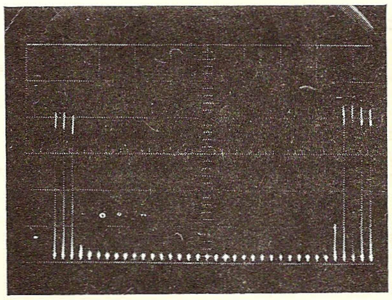

Fig. 31. Lag. Decay and build-up time above knee. Target/mesh potential 1·5 V.

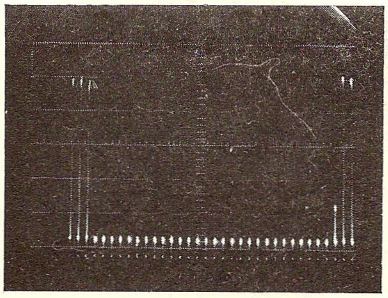

Fig. 32. Lag. Decay and build-up time above knee. Target/mesh potential 4·0V.

from Figs. 31 and 32, which show the same tube exposed to the preferred operating point, that the decay is appreciably slower at low target. The lag is still negligible in this tube under these conditions.

13.2. *Image Retention*

One method of image retention measurement has already been mentioned in Section 11 (under the measurement of sensitivity variations above and below the knee). In this measurement it is readily distinguished from the other types of sensitivity variation in that it is not affected by whether exposure is above or below the knee. However, although this is a possible quantitative method of checking the "burn-in" it does not indicate the ease or otherwise with which the tube became burnt.

A more usual test is to expose the tube to a standard test scene for a measured period (say 30 seconds) and then check that any resultant "burn-in" after removal of the scene clears within a time of, say, 10 seconds.

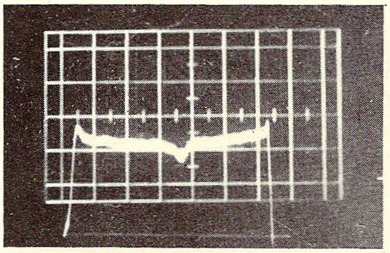

Fig. 33. Image retention—burnt-in image after removal of test object.

In this connection, the effect of target voltage on the life of the target is an interesting subject which is frequently raised.

It is sometimes assumed that the "burn-in" is an increase of resistivity of the target. However, the signal produced by the "burn" does not seem to be proportional to the signal current, but to be a constant. This supports the statement that "burn-in" is a change of contact potential[3] rather than resistivity. If this is the case, it is obviously an advantage to keep the signal through the target as large as possible in order to keep a maximum ratio of signal/burn-in (i.e. by keeping the target/mesh potential high).

The liability of the target to become permanently affected is a function of quantity of charge passing through the target. However, the efficiency of collection of secondary electrons is also a function of target voltage, as is the total charge that can be stored by the target. It is believed by the writer that, provided the tube continues to be used at a high target/mesh voltage, this increase of signal balances the additional "burn-in" effect. Naturally, if a tube is used at a high target voltage which is later reduced, the additional burn-in will then appear. Thus, as the tube gets older, the target voltage should, if anything, be increased in order to minimize the effect on the background of previous burns.

Figure 33 shows burnt image shown against a white ground, 15 seconds after removal of a test object to which the tube had been exposed for one minute. This tube is quite acceptable for use, but many tubes are much less liable to burn-in than this.

14. Colour Response

Until recently, it has been the custom to check the colour response of camera tubes by comparing the response of the tube to a coloured surround with that to a calibrated neutral density strip inset in the colour. One chart of this type, with three coloured portions each with its neutral density strip, is B.B.C. Test Chart 50[11].

However, more recently Warren[14] has introduced a method which the writer considers superior and which has yielded very valuable practical results.

Figure 34 shows a schematic of the method. A diffraction grating slit spectroscope is adjusted to produce a spectrum of a tungsten lamp of known colour temperature on the tube face. A displaced display of the spectrum of a calibrating source such as a helium lamp, is also produced on the tube face.

The camera is exposed so that the image of the spectrum is below the knee and it is also necessary that the sensitivity and dark current shading over the area used for the display should be negligible. By means of a line selector oscilloscope a display of the amplitude response of the camera to the spectrum is obtained. The spectroscope deviation is such that there is a nearly linear relation between the wave-length of the light and position across the picture. By selecting for display on the oscilloscope the portion of the picture on which the image of the calibrating source is displayed, lines of accurately known wave-length may be used to obtain a complete calibration of the X axis of the oscilloscope in relation to the wave-length of the light. Thus a complete calibration of the tube can be obtained from about 3500-8000 Å which is the working range of most of the tubes in use at present.

A suitable allowance can be made for the known colour response of the lamp if it is desired to obtain the equal energy response of the tube.

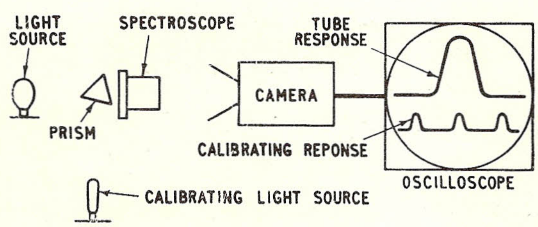

Fig. 34. Spectroscope method of measuring colour response.

The response of most tubes is continuous, so that an accurate check of the amplitude response at 2 or 3 points is all that is required. In particular, the response of the tube in the region 5500–7000 Å should be very close to the photopic curve if satisfactory results are to be obtained on studio productions. Figures 35 and 36 show two tubes which differ in this region, that in Fig. 36 being too sensitive in the red for reliable results in the studio.

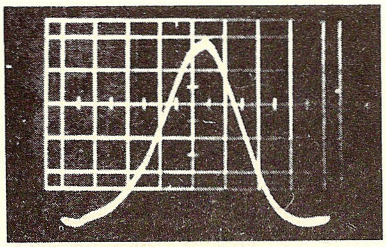

Fig. 35. Colour response—normal tube, light source of colour temperature 2900°K.

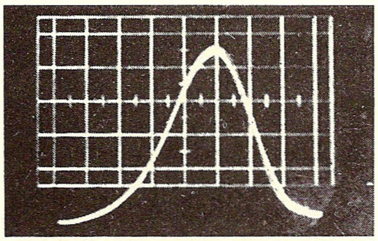

Fig. 36. Colour response—tube with excessive red response. Illumination as in Fig. 35.

Curiously, the excessive response at 4500 Å shown by most tubes seems to have very little subjective effect on studio pictures, presumably owing to the rarity of saturated blue tones in most scenes.

15. Freedom from Drift

It is of the greatest importance that a tube, once correctly set up, should not drift with time. Although, for obvious reasons, it is not possible to test every tube for long term stability, one should occasionally be selected for such a check. In most cases, drift is a function of the C.C.U. (e.g. change of the potentials fed to the tube, amplifier gain etc.), but some tubes do exhibit changes of characteristic after they have been in use for a considerable number of hours.

Checks should be made on resolution, sensitivity, background, microphony etc. after a period of several hours running at maximum temperature, in order that any change may be detected. Tubes exhibiting drift in their characteristic generally cause a great deal of trouble operationally since the transmission is often at the end of a day's rehearsal, and such tubes, if set up during rehearsal, give poor pictures on transmission.

16. Ease of Adjustment

Various defects in a tube can cause great difficulty in the setting-up process although it may be able to meet the test limits when critically adjusted. It is very hard to outline such effects in a paper such as the present one, but one example will be given.

In some tubes, if the potential of G_1 is advanced beyond the point at which the whites are just discharged, the beam current apparently decreases and the whites cease to discharge. Such a tube is known as a "Beam Dip" tube. These tubes are normally rejected by the manufacturer before leaving the factory and rarely appear in the studios. Other tubes may have insufficient or excessive dynode gain, awkward pulses in the blanking period which upset the clamps in the C.C.U., heater-cathode leaks that cause difficulty in asynchronous operation and so on. Such faults are rare, but any new tube type and a few samples of normal production should be examined from time to time for these and any new factors in behaviour that may have occurred.

17. Mechanical

It is, of course, necessary that tubes should be checked dimensionally to ensure that they will fit into the cameras in the studios. If a special camera is used for testing tubes, a convenient way to do this is to make the yoke in the test camera on the lower limit, so that any tube which can be fitted into this is sure to fit any camera which is itself within tolerance. An occasional check of orthogonality of face-plate and optical flatness is also a good thing.

18. Conclusions

Some details of various methods of testing the performance of $4\frac{1}{2}$-in. image orthicon tubes have been given in the preceding sections, as well as a small number of examples selected to illustrate various points. From these and other tests which have been made on a number of tubes it is possible to draw some conclusions on the setting up and operation of the tubes.

Before proceeding to this, however, it is worthwhile summarizing those tests which are necessary for every tube, together with the time taken to perform each test in a suitable camera, with test gear to hand.

Test	*Time (Minutes)*	*Ref. Para.*
Preliminary examination	10	6.2
Contrast handling	3	6.2
Signal/noise	5	7
Horizontal resolution	3	8.1
Vertical resolution	3	8.2
Geometrical distortion	5	9
Microphony	5	10.2
Uniformity of dark current	5	11.4.1
Uniformity of signal below knee	5	11.4.2
Uniformity of signal above knee	5	11.4.3
Edge effect, halo etc.	5	12
Image retention	5	13.2
Colour response	5	14
Total	64 minutes	

Thus, the total time taken to test a tube is approximately one hour. It may be possible to reduce this time somewhat with a special test camera with appropriate metering etc. built in.

It will be seen that this is no longer than the time taken to perform some of the much less objective tests which are currently in use.

The other tests described in the paper can be made as occasional checks, or as required.

18.1. *Setting Up*

The writer recommends that tubes should be set up at a target/mesh voltage in the region of 3·5–4·0 V. The exact voltage will vary a little from tube to tube and could be recorded during its initial test. Factors militating against high target/mesh potentials are beam flutter, loss of resolution and in some tubes, increased microphony. Factors in favour are lower noise, vastly improved contrast handling and reduced spurious effects.

In this connection it is worth mentioning that with other types of image orthicon without field meshes, beam pulling at high target is also a limitation. With the current types of 4½-in. image orthicon, careful tests of the type suggested by Theile[1] have revealed that there is a negligible increase in beam pulling even at large target and highlight values.

The multiplier focus should be set to the lowest potential at which a gain maximum is obtained, in order to get maximum signal/noise ratio.

Alignment is set for minimum rotation of image with change of beam focus. Image focus (potential between photocathode and target) should be set to the position of maximum voltage for focus as at this potential there is a minimum number of focus loops, and the electron trajectory is less affected by residual fields from the scanning side of the target, so that better resolution is obtained.

Image accelerator is set as near to photocathode potential as possible to reduce white halo and ghost, the limit being where the S distortion becomes objectionable.

Beam focus is generally best used at the highest potential on G_4 that will give reasonable geometry in most yokes about 140 to 210 volts. It is of great advantage if the camera control unit is arranged so that only the relevant nodes of focus for image and beam are obtained. This gives a much finer control of focus.

It is also a great advantage if the multiplier gain can be adjusted, in its later stages, so that the tube can be set to a standard signal current at its preferred operating point. In this way the video amplifiers under normal conditions are worked at constant gain and tests made for pick-up, hum etc. on one tube will remain valid for other tubes. It is most important to keep the gain of the first dynode as high as possible in order to prevent the multiplier from increasing the noise.

The setting of beam current is very important. This should be set so that the beam is just able to discharge a white about 1·4 times greater than a white at the preferred operating point. This will allow for all likely contingencies in use. In practice the beam current is sometimes set even higher than this, and this adds about 2–3 db to the noise.

Shading should, of course, be set to a minimum with the tube capped.

Lastly, the method of exposing the tube just over the knee, and adding a small amount of additional amplification to the blacks is very highly recommended. The reasons for this are twofold—firstly a considerable saving in light compared with operation with highlights 1–2 stops over the knee, and secondly in order to achieve a constant black level and reduce spurious effects in the white and light grey regions to negligible proportions. Under these conditions a high capacitance (e.g. English Electric Type P822 JEDEC No. 7389) $4\frac{1}{2}$-in. image orthicon tube has an excellent contrast handling capacity and grey scale reproduction.

18.2. *Operation*

When tubes are selected as adequate in all the parameters discussed in this paper and are then set-up in the way mentioned above (parameters not mentioned being assumed to be set up in the traditional manner), operation may be regarded somewhat more scientifically than has sometimes been thought in the past.

If the supplies to the tube and the electronics of the camera and C.C.U. are made stable, then there remain only two parameters of the tube that it is necessary to vary from scene to scene:—

(a) Light input.
(b) Contrast Law in the broadest sense, including "lift" and gain.

18.2.1. Light input

It is obviously necessary to vary the light input to the channel so that the relevant highlights in a scene can be placed at the preferred operating point. Experience has shown that this is achieved better by a remotely controlled iris than by a variable neutral density filter. This is because if the iris is fixed, it must be fixed at the value required by the darkest scene and minimum depth of field. In order to be able to continuously adjust the neutral filter, it is never possible to operate it at its lowest density, since then there is nothing "in hand". In this way about 1–2 stops of sensitivity tend to be lost. Remotely controlled iris systems, however, merely exchange depth of field for light input, so that automatically the maximum depth of field for the brightness available is obtained. On those comparatively rare occasions when it is desirable to limit the depth of field, this can be done either by reducing the light on the scene or by putting a fixed neutral density filter in the camera.

18.2.2. Contrast law

This is a broad subject sufficiently large for a paper in its own right and it is only possible to mention it somewhat briefly here.

Any given contrast law, over any given contrast range (measured from white downwards), can be achieved to a very close approximation by more than one combination of lift, gain and black stretch. There is, however, one combination of these components which will achieve the most evenly distributed and hence least objectionable, signal/noise ratio.

This combination for optimum signal/noise ratio is most unlikely to be obtained by continual variation of three continuous controls whilst observing a monitor. If the tube exposure can also be varied, thus altering the camera tube law as well, it is not unreasonable to state that on any given scene, for any given effect, it is only by luck that optimum signal/noise can be obtained by empirically varying the controls and observing a monitor.

On the other hand, it is essential that it should be possible to change the contrast law from time to time in order to denote changes of mood, night to day, interior to exterior and so forth, some of which can be achieved by the lighting, but a part of which must be done by the camera if, once again, optimum signal/noise ratio is to be obtained.

In the writer's opinion this situation is best met in the following way:

> The operator is provided with a light input control (preferably remote iris), a very fine "lift" control (for trimming out glare, flare and similar effects) and a selector switch at each position of which is a preset combination of lift, gain and black stretch, carefully set for optimum signal/noise ratio for the particular contrast law required.

18.2.3. General

Other than these controls, the tube itself does not require any other adjustments operationally. In many cases unnecessary operational controls are left on channels for reasons of tradition, or because the design of the channels themselves has not been as good as could be desired and it is necessary to compensate continuously for variations in supplies to the tube or even for amplifier gain or black level drift. With care, these and other sources of unnecessary variation can be eliminated, and indeed, in fairness to the operator, should be eliminated.

Finally, a word on picture "matching". The necessity to "match" one picture to the next when they are to be transmitted in sequence is obvious. It is hardly necessary to add that if the above mentioned procedures are followed and the lighting on the scene and tube exposure critically adjusted, tubes do match each other. Matching is certainly not improved by continuously varying shading controls (which of course should always be set up with no light admitted to the tube), target/mesh potential, multifocus, beam current etc. The ideal arrangement of operators seems to be a team of vision control and lighting staff working in collaboration directed by a lighting engineer and vision control supervisor who work together.

Ways of achieving this collaboration and the best method of controlling a number of cameras to obtain a good match between their pictures are beyond the scope of this paper, and will no doubt be dealt with elsewhere.

Summing up, it may be said that the foundation of better pictures, more logical vision control methods and, in particular, predictable, consistent results, is adequate testing of camera tubes to ensure that a sufficiently good standard is achieved and maintained.

19. Acknowledgments

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21. Appendix 1: Operating Point of the Tube

There are many different ways of operating the 4½ in. image orthicon so some space will be given to explain the particular way preferred in B.B.C. studios, since every parameter of the tube tends to behave somewhat differently in the different regions of its characteristic.

Using the method detailed in Section 4.2, transfer characteristics can be plotted for different exposure conditions and a graph of the type shown in Fig. 9 will be obtained. One of the typical features of such a graph is a bend towards white where the target becomes fully charged. This point of departure from linearity in the white regions has been called the "knee"[7] and this term has become accepted into general use. In Section 5 the question of measuring the position of the knee has been dealt with.

The behaviour of the tube is quite different if the highlights are exposed in different ways as shown at points A, B, C and D on Fig. 9. In condition A the characteristic of the tube is linear, storage at the target is taking place during the entire cycle from the time the beam leaves a given place until it reaches that place again, and there is a negligible number of excess electrons to cause spurious effects. The transfer characteristic being linear, it is necessary (owing to the contrast law of the reproducing cathode-ray tube[9]) to apply contrast law correction to achieve reasonable reproduction of normal scenes, and this correction amplifies the voltage representing black and reduces the voltage representing white. Unfortunately, the signal/noise ratio of tubes at present in use, together with the background and spurious effects in the dark tones, normally prevent the tube being used in this manner.

Points B and C show the transfer characteristic when the exposure is increased by 1 and 2 stops respectively. It will be seen that the point gamma in the region of white has dropped to approximately 0·5 or just below, whilst the majority of the characteristic is still linear.

Good reproduction of a wide range of scenes can be obtained if a small amount of contrast law correction is applied, amplifying those regions representing the darker portions of the scene. The amount is considerably less than that required for operation in condition A.

Operating in this manner, a reasonable proportion of tubes have a signal/noise ratio that is acceptable (both in dark and light tones) and also a reasonable proportion have acceptable backgrounds. This is the mode of operation preferred in the B.B.C. studios at present.

In mode B/C and also in the next mode of operation D, which are both generally known as operating with the highlights at or above the "knee", there is another great operational advantage. Should the highlight brightness of the image change somewhat (on panning around a scene for example, or on changing from one scene to the next) there is a tendency for the peak signal voltage of the camera to remain reasonably stable owing to the reduced gain in the white regions. This stability of output voltage helps the operators not to become too "jumpy" for small changes of scene highlight brightness but, of course, does not remove the necessity to adjust iris or variable light filter on appreciable changes of scene brightness, since the grey tones would otherwise suffer distortion.

A third method of operating the tube is shown at point D. Here the highlights are located about 2 stops over the "knee", the point gamma in the highlight regions is reduced to a low value, and no contrast correction is applied in the camera amplifiers. The omission of contrast correction has the advantage of realizing the best signal/noise ratio from the tube and of reducing dark current effects to a minimum. It has, however, several disadvantages. Redistribution effects such as "black halo" and "white edge effect" cause distortion of the picture and, owing to "white halo"[7], the voltage level corresponding to black at any point is liable to vary according to the content of the remainder of the scene. In this condition operational adjustments to the channel are required more frequently and at best the pictures have a kind of spurious quality that has tended to give the image orthicon tube (quite unjustifiably in the case of the 4½-in. version) a reputation for poor reproduction of the grey scale. However, it must also be said that in certain conditions of poor reception such as fringe areas or areas of heavy interference, the exaggerated edges and black halo tend to help the picture to be recognizable, and such pictures have therefore gained a reputation for "travelling" well.

22. Appendix 2:

Contrast Law and Contrast Ratio

To explain the reason for some of the measurements made in Section 6, it is necessary to discuss some basic principles of contrast laws.

Consider two representations of the same imaginary transfer characteristic. Figure 37(a) shows the linear representation and Fig. 37(b) shows a logarithmic representation. From Fig. 37(a) it may be seen that this transfer characteristic is a straightforward linear relation between light input and signal voltage, except that the tube produces no signal until the light reaches a value A. The same characteristic plotted on logarithmic co-ordinates gives a line whose gradient (i.e. point gamma) varies from point to point but which is asymptotic to $\dot{\gamma}=1$ for large values of light below the knee and asymptotic to $\dot{\gamma}=\infty$ at A.

Analytically, the following equations may be used to represent these graphs:—

In Fig. 37(a)

$$v=m(l-A)$$

$$\frac{\mathrm{d}v}{\mathrm{d}l}=m=\frac{v}{l-A} \qquad \ldots\ldots(1)$$

In Fig. 37(b)

$$\dot{\gamma}=\frac{\mathrm{d}\,(\log v)}{\mathrm{d}\,(\log l)},$$

$$=\frac{\frac{1}{v}\frac{\mathrm{d}v}{\mathrm{d}l}}{\frac{1}{l}}=\frac{l}{v}\frac{\mathrm{d}v}{\mathrm{d}l} \qquad \ldots\ldots(2)$$

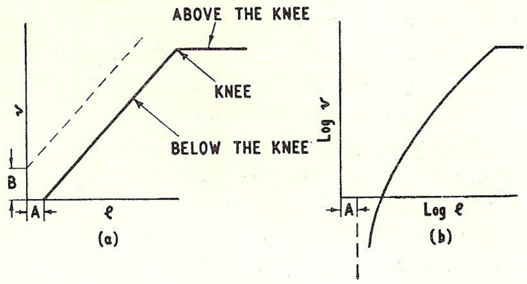

Fig. 37. Idealized transfer characteristic of contrast limited picture source.

Substitute (1) in (2) and

$$\dot{\gamma}=\frac{l}{v}\frac{v}{(l-A)}=\frac{l}{(l-A)}. \qquad \ldots\ldots(3)$$

In the more general case of light transfer characteristic of camera tubes,

$$v=m(l-A)^{x}$$

and

$$\frac{\mathrm{d}v}{\mathrm{d}l}=mx(l-A)^{x-1}=\frac{xv}{l-A},$$

and

$$\dot{\gamma}=\frac{l}{v}\frac{\mathrm{d}v}{\mathrm{d}l}=\frac{l}{v}\frac{xv}{(l-A)}=x\frac{l}{(l-A)}. \qquad \ldots\ldots(4)$$

To a first approximation the image orthicon, when exposed over the knee, has a transfer characteristic that may be treated as two straight lines (Fig. 37(a)) and the relationship shown in eqn. (3) applies to that part of the curve below the knee.

Therefore, if a transfer characteristic shows an increasing point gamma for decreasing values of l, the value of A can be calculated.

The contrast range represented by l/A will be defined for the purposes of this paper as the *Ultimate Contrast Range* of the tube.

In practice, a certain percentage of camera tubes, measured under most carefully controlled conditions, exhibit this increasing point gamma at low light values and it may, in these cases, be used to calculate the ultimate contrast range of the tube. Equation (4) also expresses the effect of subtracting "sit" from a picture or decreasing the black level. For example:

> Tube A gives a point gamma of 1·5 at a density of 1·6 (where white is represented by density 0). Using relation 3

above, such a tube has an ultimate contrast range of 120 : 1.
Tube B gives a point gamma of 1·2 at a density of 2. The ultimate contrast range is, therefore, 600 : 1.

Of course, using exactly the same method, a tube with $\gamma < 1$ in the low light regions may be shown to have a value of A that is negative, which in fact means that the transfer characteristic intercepts the Y axis at a point $B=mA$, since it is impossible to have negative values of light! This is one way of expressing the effect of adding "sit" to a picture or increasing the black level. Similarly it shows the effect of origin shift if there is any error in the measuring equipment used for taking transfer characteristics.

22.1. *Effect of Ultimate Contrast Range on Picture Quality*

In any given tube, if $A=0$ or is completely negligible, it may be seen that black level can be accurately set by removing all light from the tube and adjusting the output voltage to zero. A curve of the correct shape will then be obtained for any form of contrast law correction that may be required and grey areas in scenes of any contrast range will fall into the correct relation to each other.

Now consider a tube which has an ultimate contrast range of 100 : 1, worked in the purely linear condition. Figure 38(a) shows the curve obtained if black is set to zero voltage

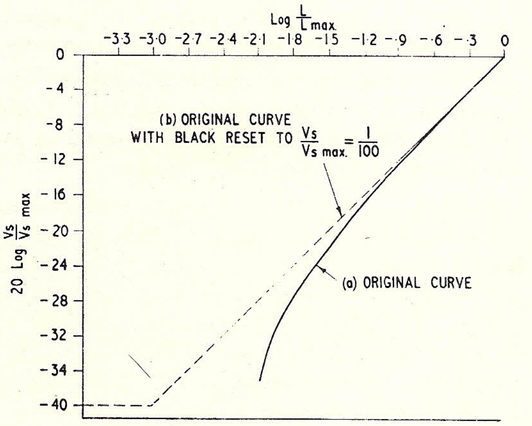

Fig. 38. Theoretical curve. Tube with linear response and contrast range limited to 100 : 1.

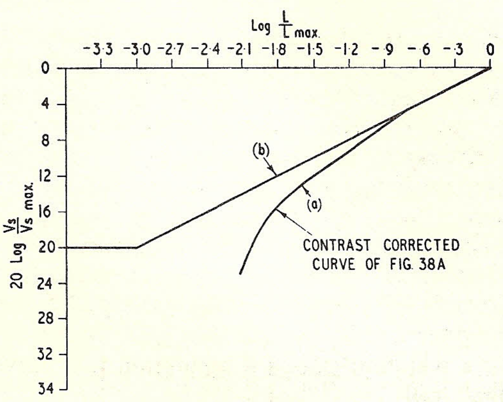

Fig. 39. (a) Curve of Fig. 38 after passing through a gamma=0·5 corrector. (b) Curve of (a) with blacks set correctly.

and Fig. 39(a) the result when this signal is passed through a contrast law corrector which would convert a $\gamma=1$ law to $\gamma=0{\cdot}5$. It may be seen that severe black crushing results and that the curve is unsatisfactory in that the steeply increasing γ in the blacks leads to small changes of grey in the original scene giving exaggerated changes of grey in the reproduced image.

There is, however, another way of setting up such a tube. If a test pattern with a grey tone known to be well within the ultimate contrast range of the tube is used, the signal voltage resulting from this tone can be set to be on the correct part of the desired curve. This results in transfer characteristics of the type shown in Figs. 38(b) and 39(b) and gives satisfactory results on grey values down to 100 : 1 on the example given.

Present practice, however, is either to set tubes so that the signal voltage is 0 for no light input, or to set the black subjectively by an operator being available to adjust it all the time it is in use. It is the writer's personal opinion that much of this continuous adjustment is necessitated by the presence in the system of a certain number of tubes which, for various reasons of operation or imperfection, have too high a value of A. Tests on a fairly large number of tubes show that, with reasonable target/mesh spacing, and operated with sufficient target volts ($>2{\cdot}5$ V above cut-off), such tubes are rare, but if the target voltage is too low ($<2{\cdot}0$ V above cut-off) it is quite usual for tubes to exhibit this effect. Similarly, tubes with large target/mesh spacing or operated too far below the knee also exhibit this effect. For reasons already mentioned, tubes operated too far above the knee also exhibit undesirable effects of a different type.

22.2. *Contrast Handling Capacity of Picture Monitors*

It will probably be asked why a tube need be capable of dealing with scenes of high contrast ratio, and in order to answer this question it is necessary to consider the behaviour of a picture monitor in respect of varying contrast range in the signal.

The transfer characteristic of the cathode-ray tube is basically a power law with an exponent between 2 and 3, depending on the design of the tube and the way in which it is operated[9]. In any practical picture, two other components modify the characteristic, namely a general veiling glare, which is an evenly dispersed brightness component proportional to the integrated scene brightness, and a "flare" or white halation surrounding each white point in the scene and proportional to its brightness.

The contrast ratio which the monitor can usefully reproduce is therefore a function of the contents of a scene, and it is fairly simple to verify that a monitor can reproduce scenes consisting of a few fairly small details on a dark surround having a ratio of several hundred to one, whilst it will only reproduce small dark details on a white ground with a ratio of ten or fifteen to one or even less.

Subjectively, it is frequently the case that pictures appear best when they are so arranged that the contrast range presented to the monitor is as great as it can handle on that subject. If this is so, the camera (including the camera channel) should be capable of handling a signal that will produce a very large contrast ratio on the monitor screen on suitable subjects. Fortunately, the type of subject which requires the longest contrast range on the monitor screen is also the type in which the camera reproduces its longest contrast range.

There are two alternative methods of producing a television picture of given contrast range and law. The original scene may have a contrast range lower than that required for the monitor and the camera may artificially increase the contrast in the signal to give a suitable effect. Alternatively the camera may be made capable of handling scenes of wide contrast range and the original scene can be designed and lit to give the required result visually, the overall process from studio to c.r.t. screen being linear.

In practice a compromise between the two alternatives is found to be the best solution. There can be only a limited control over costumes, scenery etc. and the scenic artists and actors only work at their best if the scene in the studio bears some relation to a real scene. Studio contrast ranges may be as low as 5 or 10 : 1 for say, interviews or talks, and may be as high as 80 or 100 : 1 for certain light entertainment shows.

On many of the scenes, therefore, the contrast law of the overall signal has an exponent averaging somewhat more than 1, and the precise value is in general arrived at by subjective assessment on the monitors in the studio. It may be seen, however, that it is impractical and probably undesirable to reduce the contrast ratio of all scenes to 20 : 1 or even 30 : 1, figures that tend to be quoted as limiting values of contrast range in studio productions. With modern camera tubes, correctly operated, it is unnecessary.