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THE IMAGE ORTHICON

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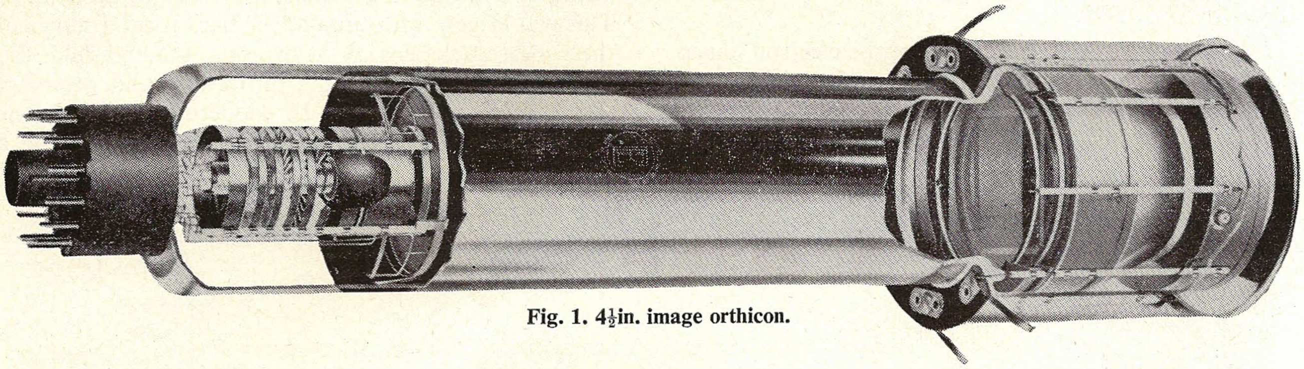


Fig. 1. 4½in. image orthicon.

A survey paper prepared for and presented at the 4th Television Symposium at Montreux

By W. E. Turk

English Electric Valve Co. Ltd.

PART 1

To many television engineers, a survey paper on image orthicons may have seemed to be completely out of place in the 1965 Montreux Television Symposium. This is especially so when one considers the very favourable reports of newly developed pick-up tubes which are presently circulating. However, as far as is known at the moment none of these new tube types has yet been adopted for regular broadcasting. On the other hand, by the time of the next Symposium in Montreux the position may quite well be very different. Cameras and camera circuitry to drive lead oxide photoconductive tubes are thought to be in the current production programmes of several manufacturers. The image orthicon, of which the 4½ in. version is depicted in Fig. 1, still remains the most widely used television pick-up tube and will continue to be so for many years yet. For this reason, perhaps, the inclusion of this paper may be understood.

FIRST USED a quarter of a century ago, the image orthicon(1) produces a video signal by causing picture charge to modulate a scanning electron beam—the picture charge being produced and stored on a very thin membrane by photoelectrons, released by the projected optical image of the original scene from a continuous photocathode.

Fig. 2 shows the tube in its familiar diagrammatic form.

The problems associated with the bulk transfer of photoelectrons to the target, the read out and amplification of the resultant target charge have largely been solved, even if they are not fully understood. Tubes of current manufacture have adequate sensitivity, are no longer considered difficult to handle and their performance specifications have been tightened to the point where manufacturers are having a very difficult time. But there still remain deficiencies which modern operating techniques demand to be reduced if not removed altogether.

Television today is no longer accepted as an adventure to be undertaken by highly skilled and, more important, completely devoted engineers. These latter gentlemen—the pioneers—are now directing whole teams of people who have not the time nor probably the inclination to study the intricacies of pick-up tube construction and operation. Their entire energies are directed towards using the television camera as a tool to satisfy the ever-growing market. Simplicity and reliability of operation are the essential features of modern equipment. Semiconductor devices are replacing the thermionic valve but whether it be image orthicon, vidicon, or plumbicon, we can see at this moment no all-solid-state switch which will dispense with the thermionic electron gun and its beam deflection system. It seems likely, therefore, that further progress in television pick-up tube performance and reliability will continue to be very much dependent upon the study of electron optics unless a device like the scanistor(2) rapidly develops into an acceptable form. Fig. 3 illustrates a typical problem. It shows the white signal waveform from the same image-orthicon operating in four different cameras and indicates the wide variation in signal uniformity resulting from the incompatibility of tube and yoke electron optics.

The image orthicon, with its two main electron optical systems, presents a major challenge to its designers and those of its attendant magnetic yoke system and it is the purpose of this paper to examine some of the relevant aspects of tube design and performance.

IMAGE SECTION

Fig. 4 shows how, in the 3in. tube, the electron image is, normally, reduced in size as it is transferred from the photocathode to the target. In the 4½in. version, however, a magnified image is produced. In each case, the effect is achieved by grading the magnetic field. Early 3in. cameras used the natural divergence of the end field of the focusing solenoid and located the tube as far inside it as the required optical lens system would allow. This was largely a function of the back focal distance of the widest angle lens. As it diverges, the end field also becomes weaker so making uniformity and geometry errors almost inevitable. In modern cameras, some measure of correction has been achieved by fitting a

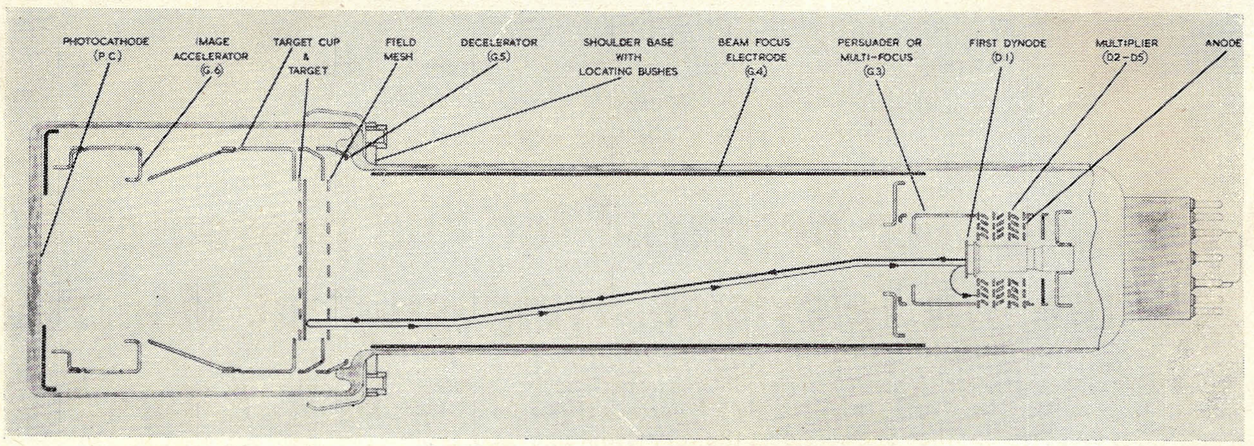
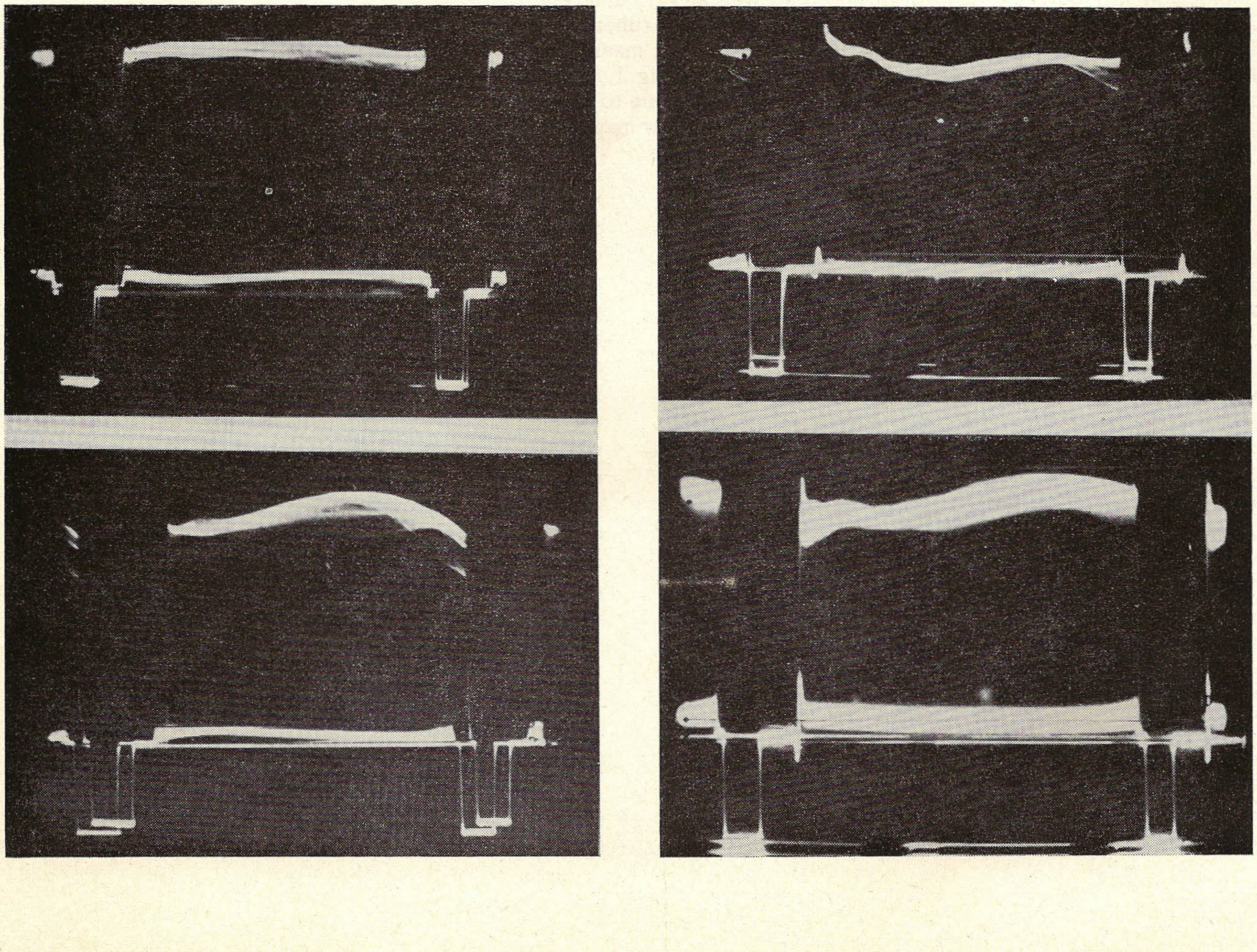
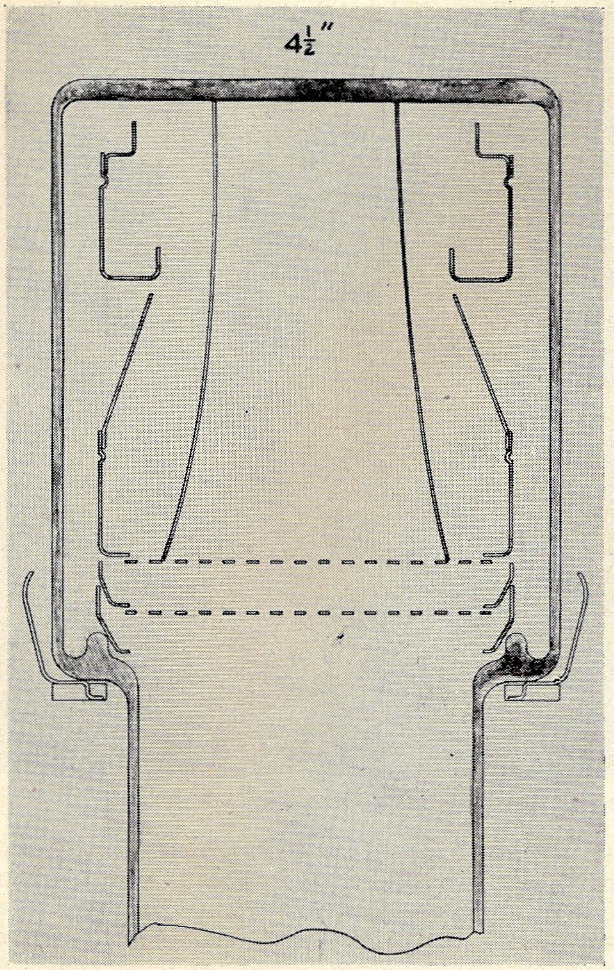


Fig. 2. Diagrammatic illustration of the 4½in. image orthicon.

Fig. 3. Shading wave forms in four different cameras.





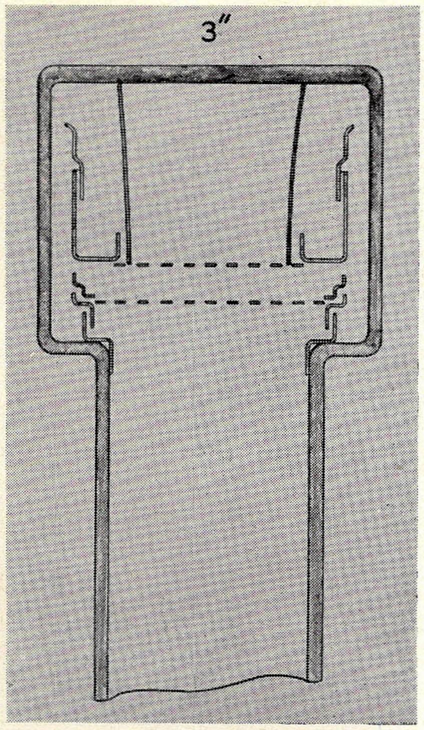


Fig. 4. Section diagrams of image orthicons.

faceplate mask of magnetic material and some cameras use a concentrating coil, but the chromatic aberration at the target still remains a problem. While this is a small order effect, it is noticeably reduced when higher potential differences are applied between photocathode and target. In this respect, the 4½in. tube design has an advantage over that of the 3in. since its image section can operate at a much higher voltage, although overall, the resolution capability of the 4½in. tube relative to that of the smaller tube is not yet fully realized. In new cameras, such as the C.S.F./Visual Electronics Mark 10, higher voltages are used in the image section to reduce this differential.

Professor Beurle of Nottingham University has examined the influence of the electron-optics of the image section on picture detail and shows that, overall, some measure of self-correction occurs as the picture analyzing process proceeds. He suggests the sequence of events in Fig. 5 as indicating the minimum degradation obtainable.

In this figure, the left-hand diagrams indicate the effect of various influences which tend to degrade the resolution. Thus, (*b*i) represents symbolically the effect of lens aberrations, (*c*i) represents the effects of electron-optical aberrations (*e*i) represents the potential distribution on the target for a point charge of infinitesimal dimensions. The two arrows indicate, approximately to scale, the distance between neighbouring picture elements. Finally, (*f* i) indicates the width of the scanning beam.

The diagrams in the centre of Fig. 5 indicate the result of the influence of these factors on the image of a point source of light as it is represented at various stages in its progression through the tube by the diagrams on the right-hand side of the figure. Thus, *a* represents the original pin-point of light in the scene being televised. (*b*ii) represents the distribution of light on the photocathode. (*c*ii) represents the width of the electron beam as it approaches the target, and *d* represents the positive charge image distribution built up on the target by secondary emission. In this consideration, it is assumed that the light level is low enough for target secondary emission redistribution to be relatively unimportant, so that the whole build-up process is linear. (*e*ii) represents the potential distribution on the target due to the charge distribution represented in *d*. This takes into account the effect shown in (*e*i).

The three diagrams (*g*i), (*g*ii), and (*g*iii) of Fig. 5 illustrate successive stages in the process of reading-off the charge distribution corresponding to the point source of light. In (*g*i), the scanning beam has reached the position indicated by the dotted curve, peaking at *A*. It has not yet reached the centre of the original charge distribution at *B* which is indicated by the dotted curve peaking at *B*, but it has succeeded in discharging to zero voltage those points of the target over which it has already scanned. Because of the inter-element capacitances the removal of the positive charge at *A* has also reduced the potential some way ahead of the beam at *B*. Thus, the peak of the potential distribution at *B* has dropped before the beam reaches it.

In (*g*ii), the beam has reached a central position directly opposite the peak of the original charge distribution. The potential at this central point has now been reduced to zero. Meanwhile, the potential at *A*, which had previously been reduced to zero, has now become negative owing to the removal of charge at *B* and the influence of inter-element capacitances between *A* and *B*. Also, it will be noted that the potential has already been reduced ahead of the beam at *C* through the influence of inter-element capacitances(3) between *B* and *C*.

Finally, in (*g*iii), the beam has moved to position *C*, where the potential is now reduced to zero, and at *B* the potential is now slightly negative as well as at *A*, owing to the effect of inter-element capacities. Thus, after the beam has passed across the charge distribution corresponding to a pin-point of light for the first time, there will remain a slight asymmetrical negative voltage

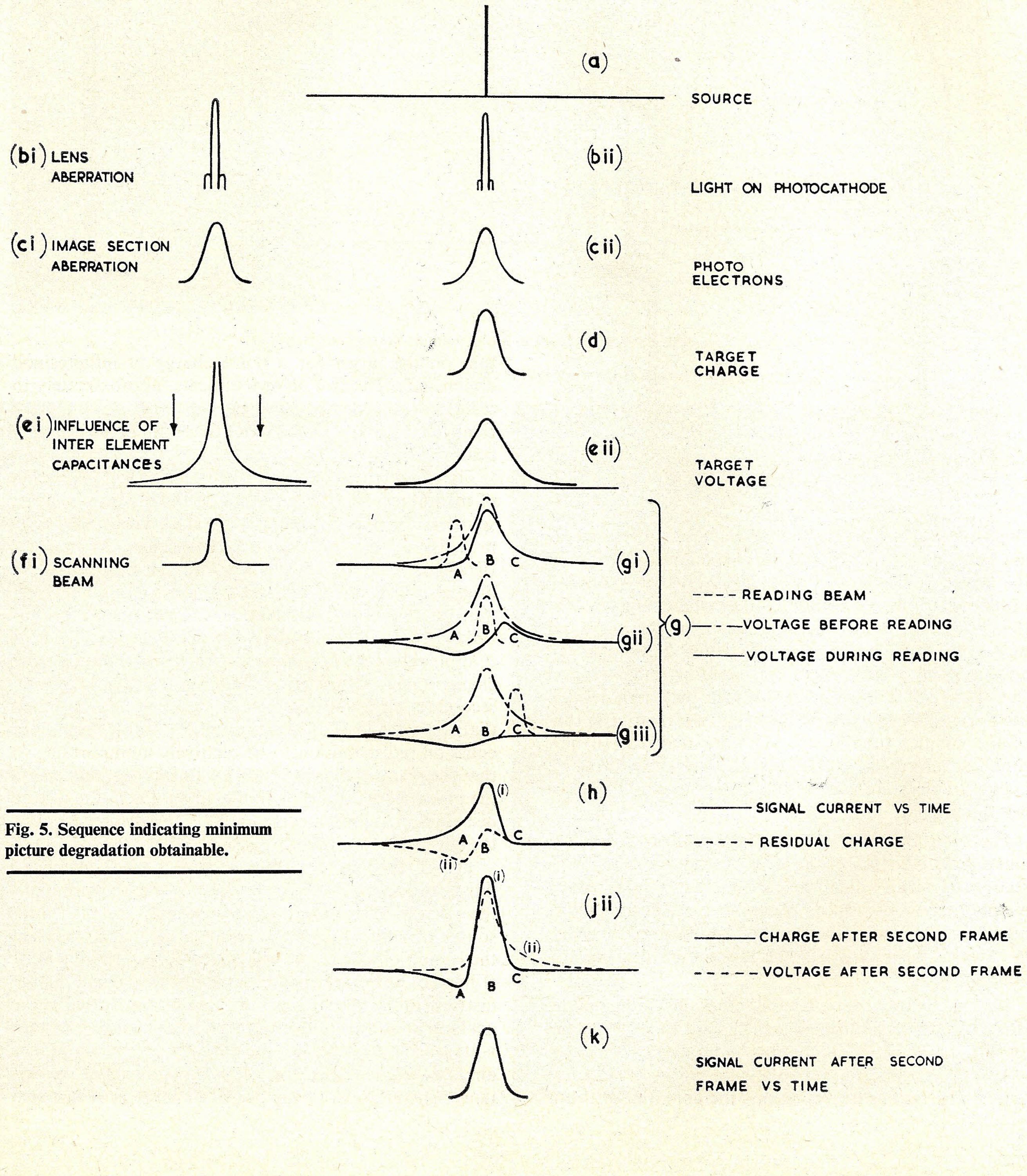


Fig. 5. Sequence indicating minimum picture degradation obtainable.

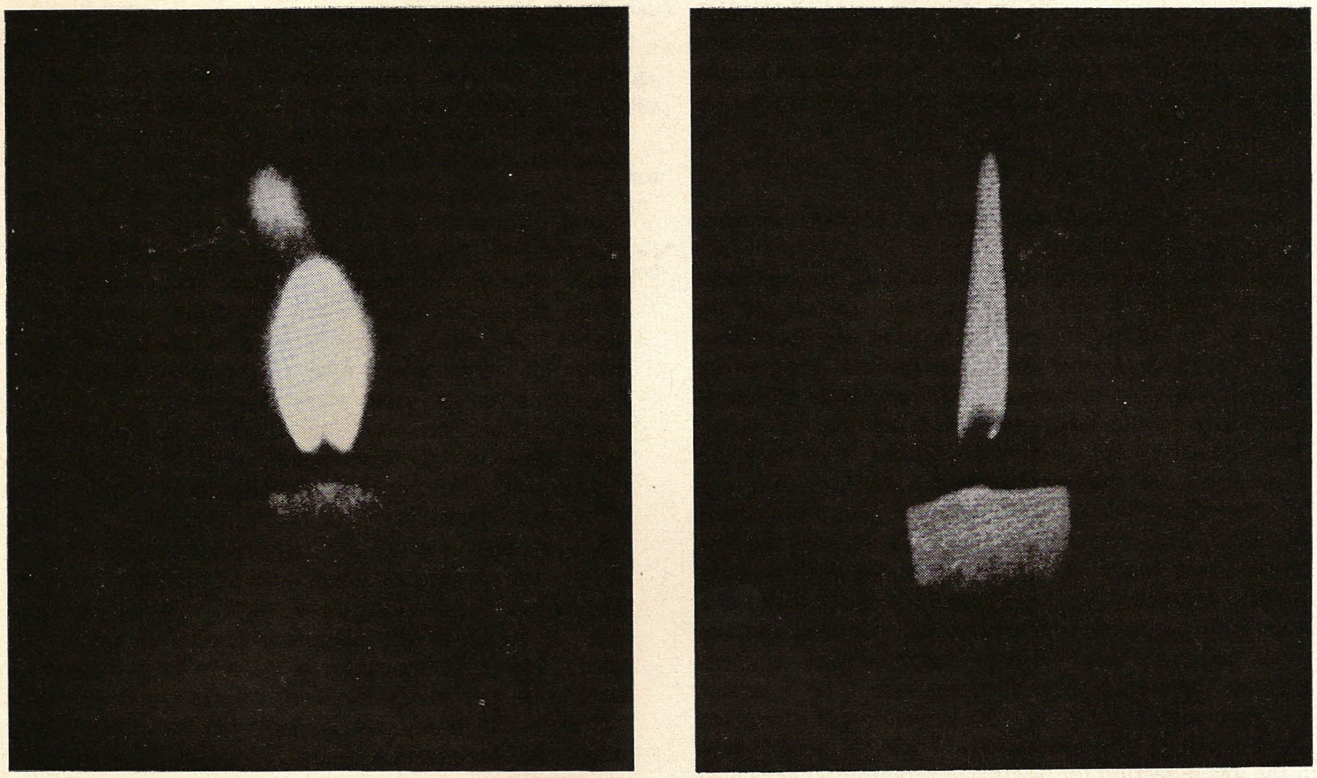


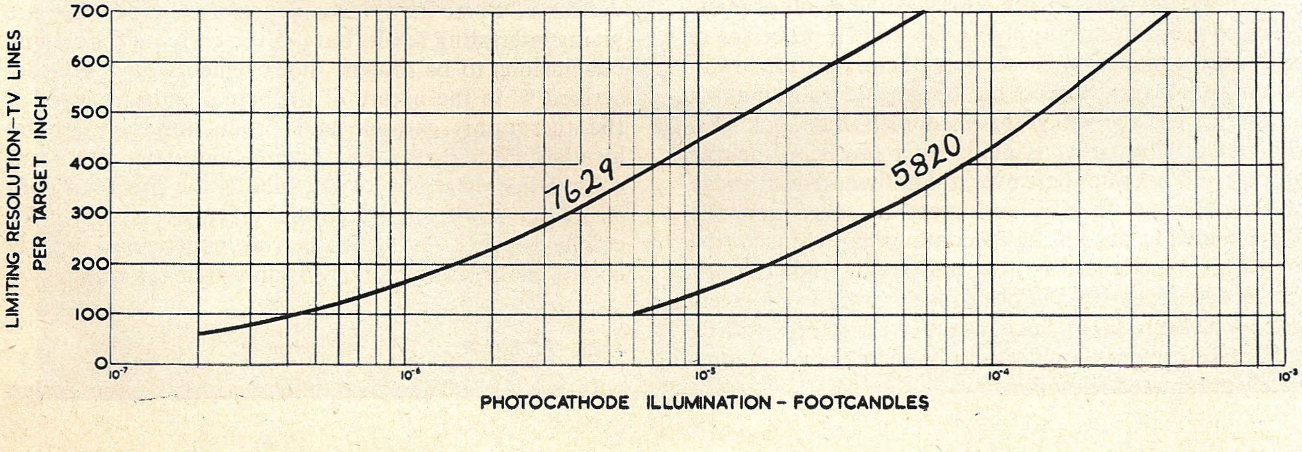
Fig. 6. Comparison of effects obtained by old design of image section (left) and anti-ghost design (right).

distribution. The corresponding charge distribution is rather sharper as shown by the dotted curve (*h*ii). The waveform of signal current against time is naturally also asymmetrical, as shown by curve (*h*i).

During the second frame of exposure to the pin-point source of light, a further charge having the distribution shown in (*d*) will be added to the residual charge distribution shown in (*h*ii). This gives a new charge distribution as shown in (*j*i), and this is of such a shape that the new voltage distribution shown in (*j*ii) is now much sharper than the original voltage distribution after the first frame's exposure, which was shown in (*e*ii). Thus, the second time the beam passes across to read the charge image, it will read the signal current waveform shown in (*k*), the shape of which corresponds very much more closely with the arriving charge distribution (*d*) than the signal current that was read during the first frame. In successive frames, the signal current approximates more and more closely to the distribution of charge arriving from the photocathode. This is only to be expected, for in a completely linear process, one could hardly go on reading off an asymmetrical charge from the target if the charge arriving at the target was completely symmetrical.

Unavoidable limitations in the design and construction of practical equipment are additive to these effects. The proponents of the 3in. camera are incorporating novel ideas to reduce these shortcomings. Fernseh of Darmstadt, for instance, has recently announced(4) specially-shaped magnetic screening to prevent the photo-electron image suffering deterioration from the

Fig. 7. Graph showing that magnesium oxide targets preserve their resolution at lower lightlevels than conventional glass targets.



scanning field leakage. This feature, coupled with a high resistance target material, results in very high resolution figures, but the image retention of such a target is considered by many too high a price to pay for high resolution.

TARGET

We consider next what happens to the photoelectrons when they reach the target.

In theory, they are all incident upon the storage plate and the resulting secondary electrons are completely collected by the target mesh. In practise this is not so—the target mesh absorbs photoelectrons and depletes the charge produced. The mesh emits secondary electrons which land on the target to further depress the signal. Photo-electrons are specularly reflected from both the target mesh and the target proper and return to it at a different point to cause ghost images. Fig. 6 illustrates this effect. The picture on the right shows how the new design of the image section(5) reduces the ghost seen on the left—provided that the correct setting-up technique is used. Suggestions to overcome this ghosting and the more general black halo by incorporating a mesh between the target and the photocathode(6a) have, so far, not been considered worth while due to the attendant spurious effects. The possibilities of using a variable field in the image section for electronic zooming(6b) have also been considered but as yet have not materialized and it is unlikely that continuous zoom, will ever be electronically practicable.

Moving to the target itself, we find progress from only two sources. Originated in the USA(7) the magnesium oxide target has seen only limited application—it is extremely prone to microphony and only tubes of low contrast handling ability have been used to any extent. There have been recent announcements of closer spaced targets carrying a mechanical damping mechanism but the writer has had no experience with tubes of this type. Fig. 7 shows how magnesium oxide targets certainly preserve their resolution at lower light levels than conventional glass targets. Like the tendency to microphony, this is due to their extreme thinness—some 200 times less than normal.

English Electric Valve Company announced last year(8) the second innovation in image orthicon targets—the non-stick glass target. This was the result of many years of research into applying the known processes of electronic conduction in semiconductors to the traditional glass target. Success has been achieved in making a titanium glass in which the phenomenon of sticking is eliminated. The target is made by a precision melting process and operates best over a slightly narrower range of temperatures than is customary in some cameras. Work aimed at preventing its contamination during the long lives experienced is now under way and it is felt that a definite move has been made towards the everlasting pick-up tube. Such a tube, combined with a solid-state camera, could easily open the way to completely automated television.

Both the magnesium oxide and the non-stick targets are unaffected by the active constituents of the high sensitive tri-alkali photocathode, so allowing tubes of higher sensitivity to be built, although the S.20 spectral response of this photocathode has been criticized by some broadcasters as being too red sensitive.

This is illustrated if a camera looks at the well-known Ilford colour test chart pictured in the Plate facing p. 940. Fig. 8 is a panchromatic celluloid photograph of a model wearing normal make-up. Fig. 9 shows the model holding the test chart as seen by a camera tube using the S.20 type of photo-surface—where the unreal appearance of the lips is noticeable. Fig. 10 shows the same scene as viewed by a normal camera tube. The new quartz-iodine lighting makes little difference to these results—Fig. 11 shows the comparison. The spectral emissivity curve of this type of lighting is shown in Fig. 12.

In each case, one sees the colours red—down to blue on the left of the test chart related to their daylight monochrome equivalents on the right. Although unsuitable for monochrome television, dependent upon the type of light splitting optics in a 3-tube colour camera, tubes with the tri-alkali photocathode could give an overall sensitivity increase of some two lens stops when used in the blue channel.

READING SECTION

When we consider the Reading Section of the 3in. image orthicon we find little new since the introduction of the field mesh except the incorporation of a suppressor electrode by Hendry in 1958(9). This invention serves to eliminate one disadvantage of the field mesh—namely the pollution of the video signal by secondary electrons produced there by the scanning beam. Field meshes of higher transmission than of old are now being used although some restrictions are imposed to avoid the production of Moire and beat patterns. The electron gun itself continues to receive attention with the aim of reducing the velocity spread in the scanning beam electrons, and various new materials and processes have been applied to the first stage of the electron multiplier but many of them are rather more susceptible to changes under the impact of the returning beam electrons than is desirable. Some new ideas at present under test are giving interesting results but it is too early yet for definite conclusions to be drawn. Improvements have been described(10) in the nature of the actual emitting layer of the thermionic cathode and production samples are awaited. Perhaps the least obvious but most important change in this region of the tube is the precision construction now common place in tubes intended for colour cameras. The shading errors, experienced in early colour pictures, have largely disappeared as a result.

4½in. TUBE

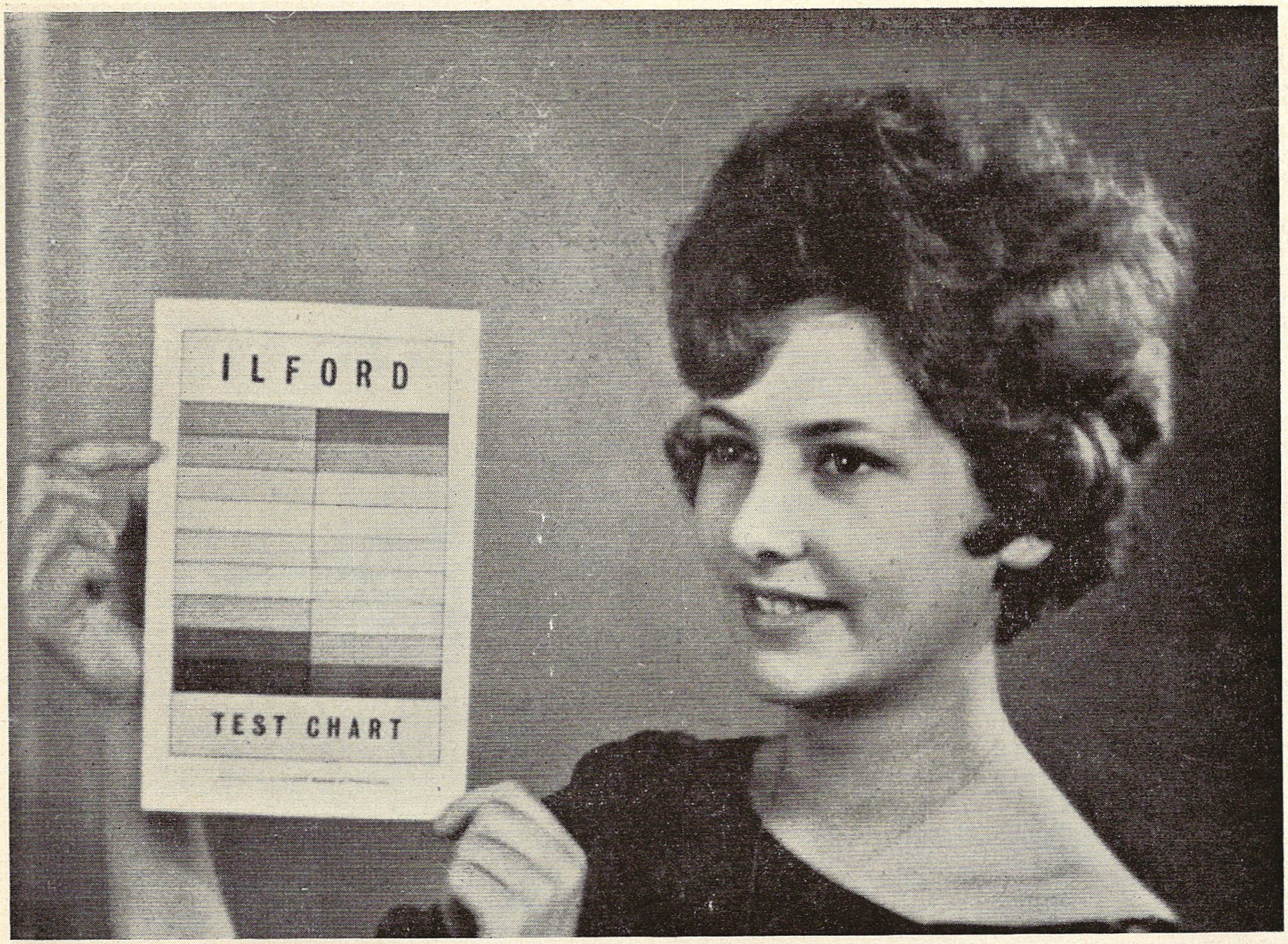
In the 4½in. tube field, the successful basic design

Fig. 8 (*right*). **Panchromatic celluloid photograph of model wearing normal make-up.**

Fig. 9 (*below*). **Model holding Test Chart as seen by a camera tube using the S.20 type of photo-surface (note unreal appearance of the lips).**

Fig. 10 (*facing page, top*). **The same scene as in Fig. 9 viewed with a normal camera tube.**

Fig. 11 (*facing page, bottom*). **Comparison of the Test Chart as it appears in Fig. 9 and 10. (Left) S-10 with tungsten lighting and (right) S-20 with quartz-iodine lighting.**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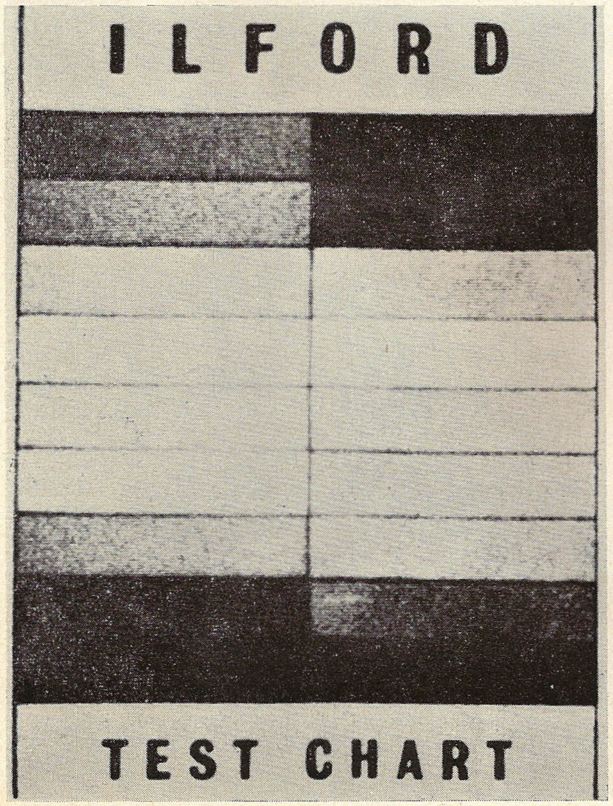
TEST CHART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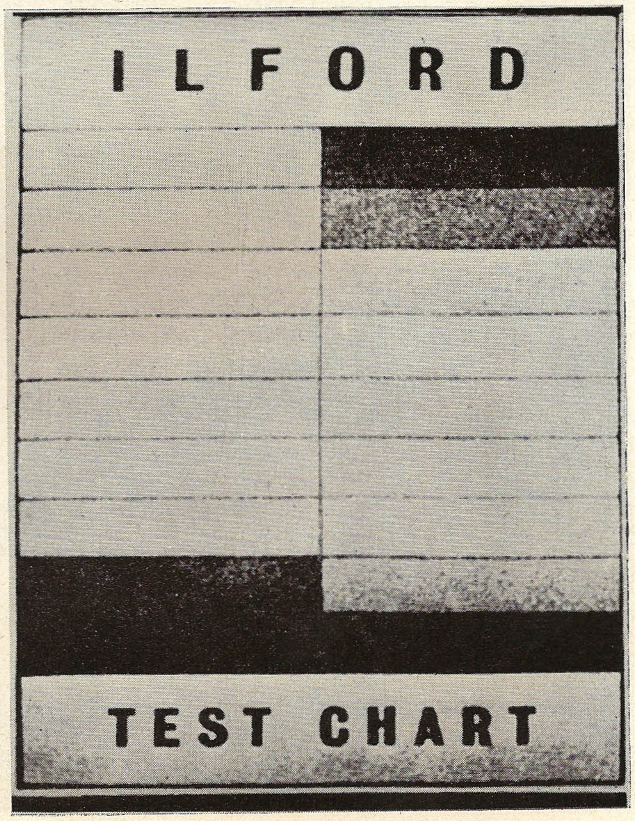
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TEST CHART

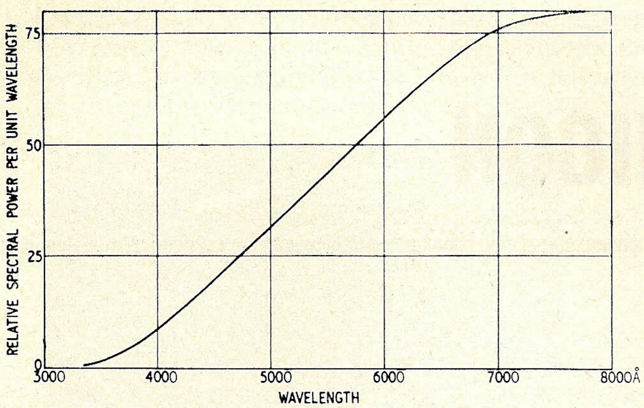

Fig. 12. Spectral emissivity curve of quartz-iodine bulb. *(Courtesy of Atlas Lighting Ltd.).*

launched by English Electric Valve Company some ten years ago has seen little change. As is well known, the main benefits of the larger tube over the 3in. design are Resolution and Signal to Noise Ratio. However, 4½in. tube resolution is not as high as theory predicts. Whereas, the average 3in. tube will give a depth of modulation of about 50% at 400 television lines one is not able to achieve much better than about 80% with the 4½in. tube, and, so far, the reasons are not clear. Obvious explanations such as scan field leakage have been shown to be not responsible. The noise level of the 4½in. image orthicon has shown a steady decrease over its relatively short development period. Apart from adopting high capacitance targets, beam modulation has been increased by careful attention to the thermionic cathode emission and by using increased transmissions for the field mesh electrode. Secondary emission from the latter is, of course, prevented from deteriorating the signal by holding its potential some 15V positive with respect to the beam focus electrode. Pictures from early tubes also suffered somewhat by having the gun anode aperture appear as a comet-shaped white flare but this is now eliminated by an electrode arrangement which deflects the return raster away from the first dynode aperture.

MICROPHONY

Another extremely disturbing feature of television pictures is microphony and careful design has virtually eliminated any contribution which the camera may have made. The tube, however, is quite a different problem. The 4½in. tube has proved much more difficult in this respect than the 3in. version. Although the target structure makes an ideal condenser microphone it has to be restrained from acting as such by all possible means.

It is not only mechanical vibration which can cause what is called microphony. It has been shown that a modulation as little as 5mV when superimposed upon the applied target operating voltage can produce a result exactly similar to microphony. Any mechanism which will produce on the return beam an effect equivalent to such a variation must be avoided. Inter-modulation between the line and frame scanning coils can be responsible and it is necessary to ensure that such coupling is reduced to an absolute minimum, certainly to less than 0·1%. This calls for special target component specification and processing techniques. Circuit design improvements in this area have also largely eliminated the disturbing phenomenon known as beam flutter.

Mention of beam flutter brings to mind the apparently unrelated subject of beam alignment, and, in particular, the setting-up procedure for the camera and pick-up tube. In Part 2 of this article (next month) some aspects of the various setting-up philosophies will be discussed, together with other factors such as the problem of noise, and also the possibilities of future development.

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THE IMAGE ORTHICON

PART 2

EVERYONE LOOKS forward to the day when a television camera tube can be plugged into the camera as easily as the cue light bulb, so that it can be switched on and become immediately ready to go on the air. Until that day arrives, a certain drill is necessary to ensure optimum performance and picture quality. The latter, of course, is entirely subjective. There is, however, a basic requirement for the picture to be free from spurious signals such as blemishes, noise, mesh and Moire patterning, grain and non-uniformities but, unfortunately, it is not yet possible to achieve all this with a pick-up tube as easily as one can with the simple light bulb. Apart from the complete dependence of the pick-up tube's performance upon the type of socket which receives it, the many variables and hazards associated with tube manufacture demand a reluctant, but nevertheless acceptable operational compromise—a second almost entirely subjective requirement insofar as the operational parameter which is considered most important.

BEAM ALIGNMENT

Much controversy surrounds the first major compromise adjustment—that of beam alignment(11). This is made after the elementary steps have been taken upon inserting the tube into the camera. The operation aims at correcting any angular differences between the electron optic axis of the camera system and the electron axis of the scanning gun. The operation is necessary because tubes cannot be constructed with sufficient accuracy, and is intended to normalize the approach of the scanning beam to the target over the whole raster. This means that, assuming no other irregularity, a uniform white scene will give a uniform video signal, and the alignment controls can be adjusted to give just this result. However, few operational locations possess a uniformly illuminated screen and one must therefore resort to other means. The most popular alternative depends on the fact that, when the beam is misaligned, a small variation in its focus voltage will cause picture information to change in position as well as in sharpness. This movement disappears when the beam is correctly aligned. "Auto-alignment", as this process is called, is often provided on a camera as a switchable facility which superimposes automatically a near square wave of some 10V on to the beam focus voltage. One drawback of the method is its inability to allow for possible variations in target sensitivity and, additionally, it can produce maximum beam flutter in some cameras. Although the latter can be generally removed by making a slight vertical adjustment in the alignment field, whenever possible, beam alignment for maximum uniform white is preferable. Fig. 13 shows the same tube aligned in the two ways and in two makes of camera, while Fig. 14 shows the effect due to yokes alone using an image orthicon metal target monoscope tube.

TARGETS

Having optimized beam conditions at the target one has next to optimize target conditions for the beam. This is not easy. The discharge process on the scanned side of the target is essentially a matter of neutralizing positive charges by depositing negative ones from the beam. The establishment of the positive charge pattern and its relationship to the information presented by the camera lens system to the photocathode is an extremely complex process which, is still not fully understood even today—many millions of camera hours after the first image orthicon was used. In order that this charge may produce a video signal as free from noise as is possible, it is necessary that the modulation of the scanning beam be as high as possible. However, since the beam is far from monochromatic, one cannot achieve 100% modulation. Modulation depends on how much beam is absorbed in the whites of the picture. This obviously depends upon the potential to which the scanned side of the target has been driven by the photo-electrons. Factors determining this are: input light intensity and its size; sensitivity of photocathode; transmission and secondary emission coefficient of the target mesh; the potential of the mesh;

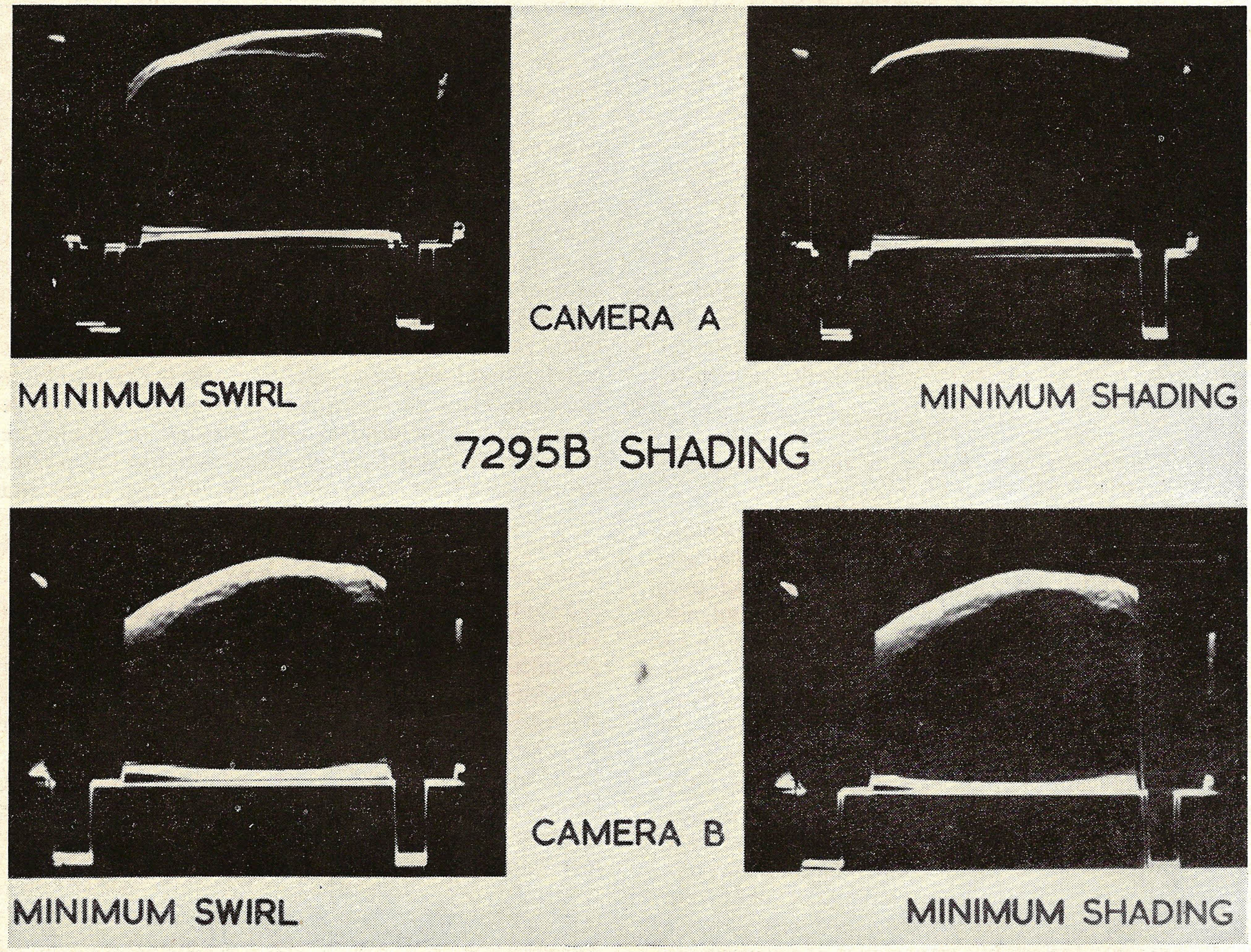

Fig. 13

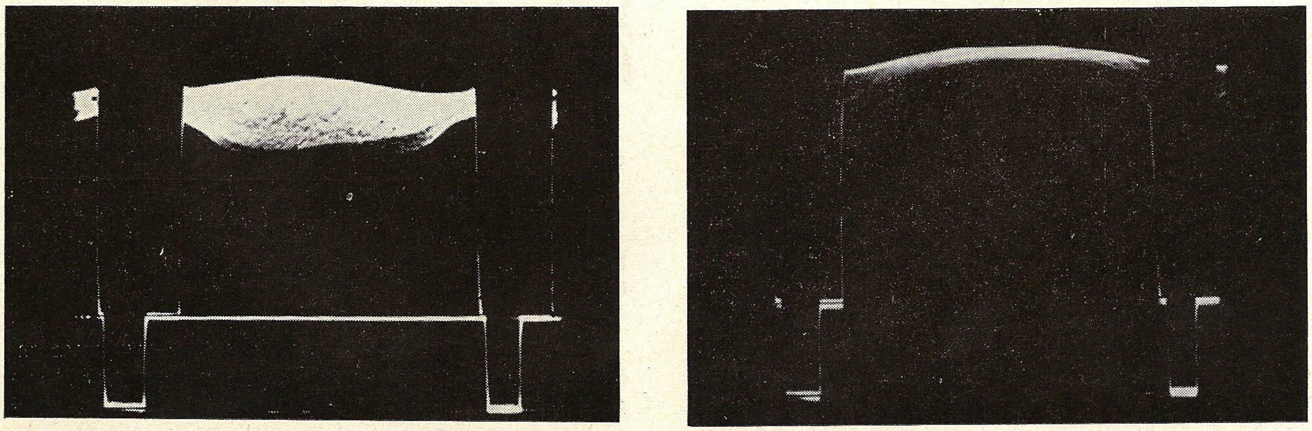

Fig. 14. White shading in two different makes of yoke using a monoscope target image orthicon.

spacing of the mesh to the target; the secondary emission coefficient and the photosensitivity of the photocathode side of the target, its thickness and resistivity. One can ignore the secondary emission coefficient of the scanned side of the target since, in general, its effect can be minimized by efficient process control. The effect of the photosensitivity of the target is also of negligible proportions. Of the above factors, those such as target mesh potential are under the control of the camera operator while the others are determined during tube manufacture. Variations, either from tube to tube or from manufacturer to manufacturer are inevitable, and opinions differ as to how to best cater for them to achieve a constant final result among a batch of tubes.

Consider for a moment the significance of target mesh potential. It is used as an external control for the potential, V, to which the scanned side of the target rises, and, in the simple analysis, this is determined by the normal condenser formula

$$V = Q/C$$

where Q is the charge produced on the photocathode side of the target and C is the target capacitance.

Given a fixed quantity of charge, higher voltages are clearly produced by low capacity targets. However, since V is limited, low capacity targets will give proportionate output to only a small range of light intensities. To extend this contrast handling ability it is necessary that the manufacturer increases the target capacity—*i.e.*, increases the amount of light necessary to fully modulate it which means, in other words, to decrease its sensitivity. Therefore, dependent upon the intended application, a tube is made with a high, medium or low capacity target. In manufacturing design, this involves fixing the spacing between the storage target and the collector mesh from very close through medium to very wide to produce a range of tubes from low to high sensitivity. The operator's choice is made dependent upon the relative importance of sensitivity or linear output over a wide contrast range of the input light. It is not possible, however, to extend either parameter indefinitely. As target spacing or sensitivity increases, noise increases and soon becomes unacceptable. As contrast handling ability is extended, the scanning beam becomes less to neutralize the high charges in one scan and picture smearing is produced. In non-field mesh tubes severe beam pulling also occurs(12). It can be understood, therefore, that between the practical extremes many possibilities exist and many tube types are possible. English Electric Valve Company makes a range of target spacings in the 4½in. tube from approximately 6μ to 3mm. Tubes with closest spaced targets are used for standards conversion while, at the other end of the range, one has the so-called "starlight" type of tube.

Potential is applied to the mesh so that it collects secondary electrons from the target glass to leave behind positive signal charge for the beam to read out. This it does, but one cannot ignore the effect that mesh potential has on the secondary electrons generated at the mesh.

In the near blacks, only a few mesh secondaries reach the target because of the adverse potential gradient, and signal production is near normal although beam modulation is low. In the whites, nearly up to the knee, target secondary saturation is complete but the low energy mesh secondaries begin to reach the target to cause some signal cancellation. Whites above the knee give proportionately decreased signals because target secondary saturation is less complete, and in this region maximum drift of mesh secondaries to the target takes place. It can be appreciated that this unavoidable conflict between mesh and target secondaries prevents accurate proportionality being established between target charge and light input over the whole range. The effect can be troublesome in colour luminance channels where exact tracking of colours at varying brightness is required. These effects mean that, involuntarily, the tube manufacturer determines the artistic or subjective character of his pick-up tubes according to the surface properties of the materials he uses for the target and meshes. Unfortunately, his control ceases once the tube is made. The character of the tube changes only as a result of its operational experiences.

From this argument it may be deduced that high values of target potential should be used. For picture parameters such as signal-to-noise-ratio this is true, but both knee sensitivity and resolution are reduced as target potential rises. The reasons are well known and need not be expanded. Figs. 15, 16, and 17 illustrate these points. Once aware of these facts, the camera operator must choose a target voltage most suitable to his needs since no fixed value can be recommended to suit all requirements and all conditions.

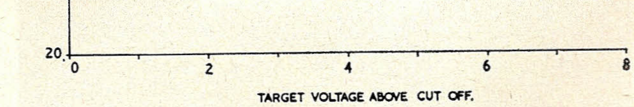

Fig. 15. Signal-to-noise ratio *versus* target voltage for the Type 7389 tube.

Traditionally 2V has been used for the medium-spaced target 3in. image orthicon and it is probably a good compromise for general use. However, to achieve special requirements, values other than 2V may be necessary. If an extra length of linear grey scale is needed then it is advantageous to raise the target operating potential. If, alternatively, one is concerned to have a near half gamma law over a restricted tone range then a value below 2V may be useful.

D. C. Brothers of the BBC has made an extensive study(13) of the properties of the 4½in. image orthicon and decided that a value of approximately 3·5V was the best target potential to use, while R. G. Neuhauser of RCA claims(14) that 2·0V gives a better result. The difference between the two philosophies lies in the type of picture required. With the higher value, black halo and edging are almost absent while at the lower value slight halo and edge crispening are evident—provided, of course, that in each case one uses a suitable exposure. Exposure, a subject on its own, is too complex a topic to be dealt with in this paper. Suffice it to say—it must be correct as judged by the camera man! The tube engineer claims that, with a particular tube and any chosen target voltage, it is possible to obtain unity gamma over only a limited range of contrast. It is possible, of course, to reduce the gamma of the reproduced picture by using the upper part of the transfer characteristic. Fig. 18 shows these two conditions. A wider contrast range can be handled by raising the target voltage or by allowing the brighter parts of the picture to go well over the knee of the curve—a practice which is popular in North America. To obtain a greater *linear* contrast scale one must have a higher capacity target, bearing in mind that the higher voltage swings on such a target cause beam pulling, especially at the lower values of beam focus potential, and unless field mesh tubes are used.

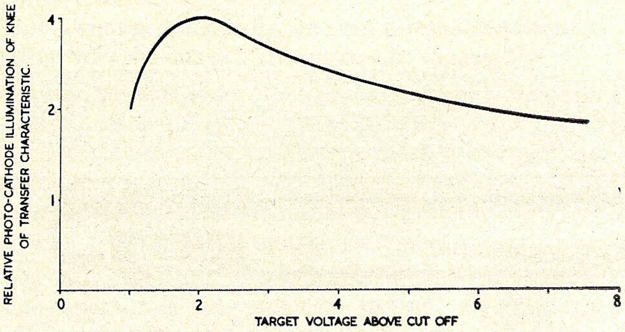

Fig. 16. Overall sensitivity *versus* target voltage for the Type 7389 tube.

COLOUR

The study of target operating potentials has yielded one interesting development. It has been found that for colour operation, where the natural degamma action of the image orthicon is unwanted, one can obtain an effective increase in sensitivity of about one lens stop by raising the target voltage in the 4½in. luminance tube of a four-tube camera and then exposing to one stop below the higher knee point.

One of the first operational colour cameras used three image orthicons and this created a particular problem in that it was difficult to obtain satisfactory registration of the three colour images. Tube manufacturing techniques have now improved to the point where geometrical coincidence is easily achieved and, by using special tubes in the blue channel, operational sensitivity can be increased to use a scene illumination as low as 100ft candles with a lens at f/5·6. It is doubtful whether, for studio operation, any more sensitivity is needed. For outside broadcasts, a higher sensitivity is obviously desirable but it is questionable whether colour really exists at the low light levels of, say, a night football game. On the other hand, perhaps pictures at such levels benefit by having artificial colour injected into them!

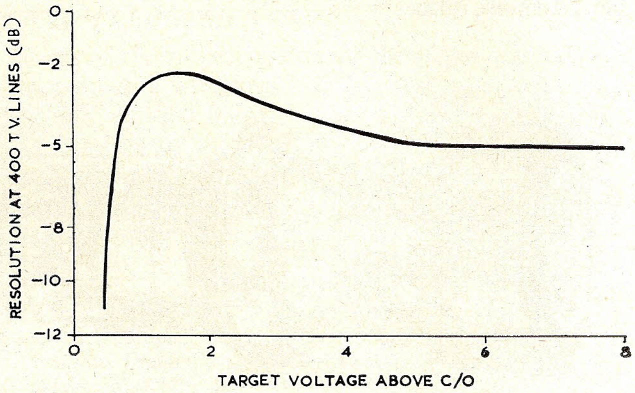

Fig. 17. Resolution *versus* target voltage for the Type 7389 tube.

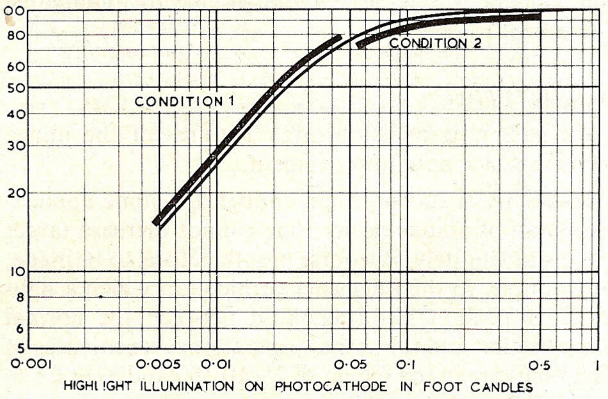

Fig. 18

The image orthicon features strongly in the controversy surrounding the three- *versus* four-tube colour camera.

The advocates of the four-tube camera claim that it is the only means of obtaining a good picture on monochrome receivers due to the separate luminance signal. To date, the best results have been obtained by using a 4½in. image orthicon for this purpose. The choice for the chrominance channels then lies between orthicon, vidicon, plumbicon or "X"-icon. Until the latter tube arrives, present weight of opinion is probably with the plumbicon—provided that it becomes readily available. This tube has a sensitivity which enables the four-tube camera to work at levels of illumination of about 125ft candles at f/5·6 comparing very favourably with the 250ft candles at f/5·6 quoted for the three-image orthicon camera and with 100ft candles at f/2·8 for the three-plumbicon camera. All these sensitivity figures are based on a certain minimum requirement of luminance signal to noise ratio.

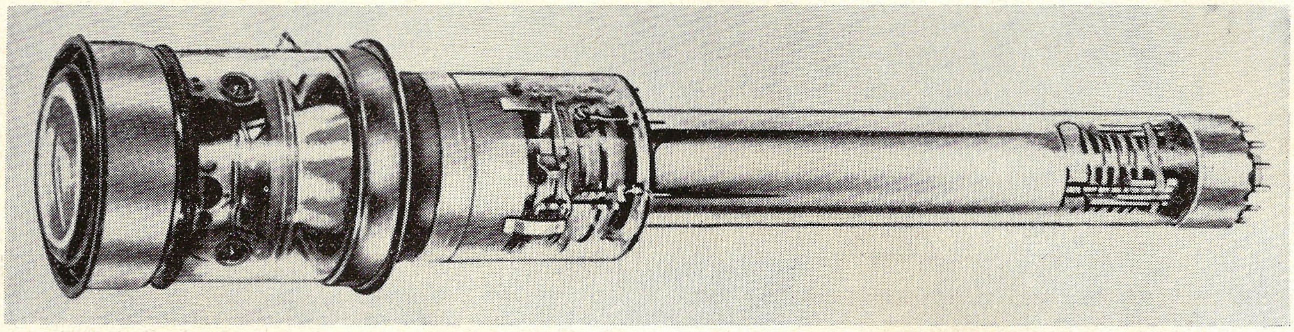

Fig. 19. An intensifier orthicon (*Courtesy of RCA*).

Two interesting points arose in connection with colour programmes. The first is that, in studio colour, depth of focus is undesirable—it is claimed that a well-focused coloured background detracts from the centre of interest. Secondly, one strong argument for the four-tube camera is that acceptable results are obtainable with unskilled operators.

SENSITIVITY

We pass now to some other features of the image orthicon which need improvement.

Sensitivity is still not high enough for some applications and, as stated earlier, one cannot increase target spacing indefinitely. Recourse has, therefore, to be made, for example, to the intensifier orthicon in which a light amplifier portion has been built between the normal image section and the scene—operational sensitivities of such tubes are in the region of 2×10^{-5}ft candles at f/5·6. Such a tube is shown in Fig. 19.

Astronomers have increased the sensitivity of the standard orthicon considerably by allowing charge build up to take place over much longer periods than the $\frac{1}{25}$s or $\frac{1}{30}$s customary in broadcasting. Dr. Livingston of Kitt Peak Observatory has obtained intelligible cathode-ray tube pictures of stars as low as the nineteenth magnitude by this technique(15).

NOISE

Noise is, perhaps, the most objectionable feature of the image orthicon and it can only be reduced by increasing the target signal. With tubes of conventional construction, one can increase the magnitude of this signal by using high-capacity tubes and high-gain surfaces for the initial multiplier stages. We have seen the limitations of the former and consequently much effort is being expended on secondary emission research to obtain more efficient surfaces for the first dynode of the multiplier system.

It is unfortunate that in the image orthicon, unlike the vidicon-type tube, one gets maximum output from the tube in the black parts of the picture—where noise is most visible. Proposals to remedy this were made as far back as 1949 when Weimer described the image isocon(16). This tube, built like an image orthicon, has an extra electrode system in the scanning section which separates the return beam electrons—the normal image orthicon signal—from those electrons which are reflected by the target charge. In this system, the degree of reflection is proportional to the charge. When these reflected electrons are used as the signal, then maximum noise appears in the white areas and is less objectionable. The lack of noise in the black allows a lower black to be seen and hence the contrast handling ability is improved. The setting of the beam separating electrode is said to be extremely critical and this fact has prevented the tube coming to fruition. However, it may well be that, with the extreme stability now achieved with solid-state circuitry, a new look at this tube is worth while.

THE FUTURE

To round off this survey paper it is worthwhile to consider, very briefly, the possibilities of further development. This is rather a chicken and egg question since development will depend upon usage and, somewhat naturally, the converse holds. Probably, the immediate future of the tube will be determined by the possible success of competitive pick-up tubes. At the moment, the plumbicon is enjoying a very successful phase after an extremely prolonged development period. At the 1965 NAB Convention in Washington, RCA announced its "selenicon" which one may deduce from the name is a development of the selenium vidicon of some years ago. Westinghouse is confident that its SEC vidicon will prove to be an extremely sensitive and versatile pick-up tube(17). There may be other tubes in the development laboratories, but one has to face the fact that the image orthicon is very firmly established. Old cameras never die—they do not even fade away—they are given an updating treatment and put back into service! It is said in the US that no 3in. image orthicon camera has ever been scrapped.

Somewhat prophetically, one can foresee two possible reasons why the image orthicon may be superseded.

Firstly, the tendency of television services to exist on conventional celluloid films may increase to the extent that live pick-up may become so much a background programme feature that the somewhat less acceptable picture typical of current photoconductive tubes may be good enough for "fill-in" work.

Secondly, the use of television cameras to produce video-tapes may be replaced by an Electronicam technique in which the lower quality vidicon type tubes will serve adequately well as the viewfinder tube in a standard celluloid film camera to produce film as easily as video-tapes are now made.

On the other hand, one is reminded of the recent success in Hollywood of Electronovision, a new kine-recording technique for making films. Feature films of 2½ hours cinema length are reported to have been made in about three weeks shooting on the studio floor—a result quite impossible by normal celluloid film camera practice.

And so, the image orthicon enters a very interesting phase of its life—a phase in which no spectacular development can be foreseen but a phase in which its minor irritations of performance will be eliminated gradually but definitely. One can fairly confidently look forward to improved yoke systems or perhaps the complete elimination of the camera yoke as we know it today by the emergence of an all electrostatic tube—a topic which, for reasons of space has not been included in this paper.

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