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VIDICON CAMERAS

THE PHOTO-CONDUCTIVE PICK-UP TUBE, the vidicon,[1,2] is well established as a relatively simple and reliable device and is used in cameras with widely differing design aims and purposes. Advantage may be taken of its small size and simplicity to produce a camera head with the minimum of electronics and of small dimensions. Such a camera is inexpensive yet very flexible, with a vast range of usage from broadcasting to closed-circuit applications in industry and even domestically.

On the other hand, the modern vidicon has the potential as an image transducer which, under suitable conditions, can rival the best in quality. Used in a high-grade camera to view transparencies in slide or film form, the reproduced picture quality is such that the most critical of observers have compared the performance favourably with that of the flying-spot scanner, hitherto regarded as the unapproachable in standard of telecine picture quality. The advantage of the vidicon camera for this purpose is that the same camera may be used to view opaques or be used as a studio camera to provide pictures of the same high standard. There are further advantages in less bulk and lower cost.

SENSITIVITY AND "LAG"

The scene illumination required in the studio when using the vidicon camera may be up to five times that normally employed with image-orthicon cameras. Present vidicon tubes exhibit a slow response to changes in light when operated at low illumination levels and the phenomenon, known as "lag", causes a blurring of the image with rapid movement. In severe cases the original image may be superimposed on the new scene; this is called "print-through". Increased illumination reduces the effect to negligible proportions, but obviously the defect presents no difficulties when the camera is used to view scenes with little or no movement, for example captions or a continuity announcer.

RESOLUTION

The scanned image size on the faceplate of the tube is only $\frac{3}{8}$ in. by $\frac{1}{2}$ in. so that the diameter of the scanning beam can be large compared with the spacing of the raster, possibly as large as that of three lines. This would give rise to very poor vertical resolution, but for the fact that it is possible to adjust so that only the tip of the beam "reads off" the greater part of the information charge on the target of the tube, in the width of one scanning line and a relatively small amount from the adjacent area. When the beam is scanning in the direction of the raster lines, only the leading edge of the beam releases the charge of the picture element so that the inherent horizontal resolution can be very high. As the signal output current, and hence beam current, is increased, however, the effective beam diameter increases and resolution falls off.

The beam diameter is also a function of the voltage applied to the focusing electrode, G4, and an improvement is obtained by operating at relatively high values.[3] In the Mark IV Vidicon Camera the beam focusing voltage has been raised from the usual 250 V to 450 V, enhancing both the vertical and horizontal resolution by some 20%. There is the usual law of diminishing returns in increasing the voltage beyond about 1,000, with the greater focusing and scanning power requirements and increased bulk of high-voltage components.

SIGNAL-TO-NOISE RATIO

The vidicon tube itself generates little noise; the visual signal-to-noise ratio is approximately 50 dB but the signal output current is very low, 0·1 to 0·5 μA, so that considerable amplification is required of the camera head amplifier where some noise addition is inevitable. The final value of the ratio for a given signal current is therefore determined mainly by the noise generated in the first amplifier stage, and by the bandwidth of the system.

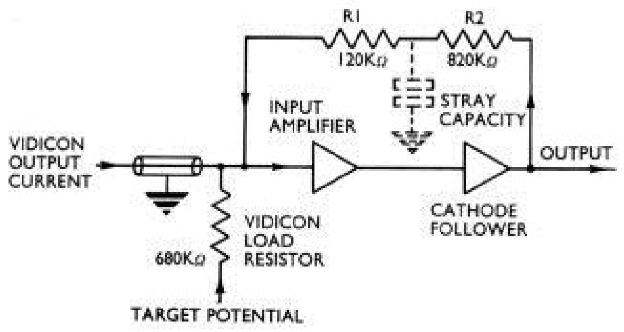

Fig. 1. Application of negative feedback to reduce LF noise.

The vital parameter in design is the total capacity presented to the tube signal electrode, comprising the output capacitance of the tube when mounted in the scanning yoke, the capacity of the screened lead connecting the tube to the amplifier and the dynamic input capacity of the amplifier. The total capacity must be kept as low as possible and with careful design and layout can be less than 25 pF, giving a signal-to-noise ratio approaching that of the tube itself.

Low-frequency noise, including that due to microphony of the valves in the input stage of the amplifier, can be greatly reduced by using a large-value resistor as the load resistance of the vidicon, and applying shunt negative voltage feedback to the input of the amplifier. Fig. 1 shows the essentials of this technique as applied in the Mark IV Vidicon Camera head amplifier. The feedback resistance is split into two resistors, R1 in series with R2 with the stray capacity shown at the junction decoupling to earth, a device to compensate for the internal shunt capacity of the resistors, which would otherwise enhance the feedback at the higher frequencies.

GAMMA

The light transfer characteristic of the vidicon tube is inherently about 0·6 over a large light-input range, but in practice a value of about 0·75 is obtained over a light range of ten to one.[4] For studio operation, therefore, where the contrast range is under the direct control of the lighting engineer, very little additional correction is required, but with the larger range of films and slides, some further correction, by increased gain in the dark grey range, is necessary.

SHADING

The standard type of vidicon tube has a target layer which is not uniform, the thickness of the deposited photo-conductive layer being greatest at the centre and tapering to the outer edge. Hence, with applied target voltage, the stress increases towards the edge producing a white surround or flare to the reproduced picture, and increases with increasing target voltage.

However, a complementary "port-hole" effect is produced by the non-orthogonal approach of the scanning beam to the target. This effect decreases with increasing target voltage, so it follows that, with a suitable choice of voltage for a particular tube, flare may be cancelled by the beam-landing error. Tubes may be graded so that this critical voltage is obtained at the value suitable for a particular application—at a low voltage for telecine, where the light level is to be high to reduce "lag", or at a high voltage for studio application or where maximum sensitivity is required.

Vidicons with a uniform target layer[5] do not suffer from "flare" but at the lower target voltages under telecine conditions, port-hole shading is prominent and steps must be taken to cancel it.[6,7] The method adopted in the Mark IV Vidicon Camera is to modulate the target to cathode voltage by complementary correction voltage waveforms at line and field rate.

CONTROL OF SENSITIVITY

For a constant light input, the output signal is a function of the target voltage, and, therefore, this can be used as a control of sensitivity of the tube.

There are, however, several disadvantages in the use of the target voltage as an operational control, probably the most serious being the variation in the current produced at camera black, i.e. the dark current of the tube. Whereas at low light levels the signal output current is proportional to the approximate square of the target voltage, the dark current varies as the cube, so that with increasing target voltage, the signal current increases but there is a disproportionately larger increase in the dark current. The beam current must be increased to accommodate this dark current with the consequent fall in resolution. The value is also a strong function of temperature so that the operator is forced to "ride" both the beam and black-level controls in addition to the target voltage.

The recommended operating method is to set the target voltage at the optimum value determined by the operating conditions and to vary the light input to the tube as an operational control using the lens iris or, in telecine equipment, a remotely controlled projector light shutter.

PRACTICAL APPLICATIONS

The vidicon, it can be seen, possesses many features that can be turned to advantage in many applications. Where proper account is taken of its limitations it can become an efficient tool of industry and commerce, providing a means of remote control in areas that have been difficult or impossible before. In a more sophisticated form it can be used as a studio camera for broadcast purposes, incorporated in telecine equipment to give a high-quality picture that equals in performance equipment of a hitherto accepted standard. Examples are given below of three equipments in which the various features of the vidicon tube discussed here have been exploited to the best advantage for a particular application. It will be seen, however, that there are many other uses to which the vidicon could be put.

TELEVISION CAMERA CHANNEL BD871

This, the simplest form of vidicon camera, comprises two units, the camera head and the control unit. Together with a suitable monitor or receiver, the two units form a camera channel capable of producing pictures of surprisingly good quality even under adverse conditions. Although primarily intended for closed circuit industrial applications, it has also been employed for broadcasting purposes.

The camera head, tubular in shape and of robust construction, contains only the yoke, vidicon tube and the head amplifier. The single lens may be focused at the camera or remotely at the control unit where all other controls are situated. Once the camera has been set up, it can be completely controlled at the Camera Control Unit from which it may be separated by 1,000 feet of camera cable.

Scanning currents and power are supplied via the camera cable from the Control Unit. The line scanning generator may be operated free-running and the field scanning locked to the frequency of the mains supply for closed circuit operation, or both driven by a synchronizing generator when the channel is used for broadcasting.

To enable the line scanning current to be passed down the camera cable, the scanning coils circuit is

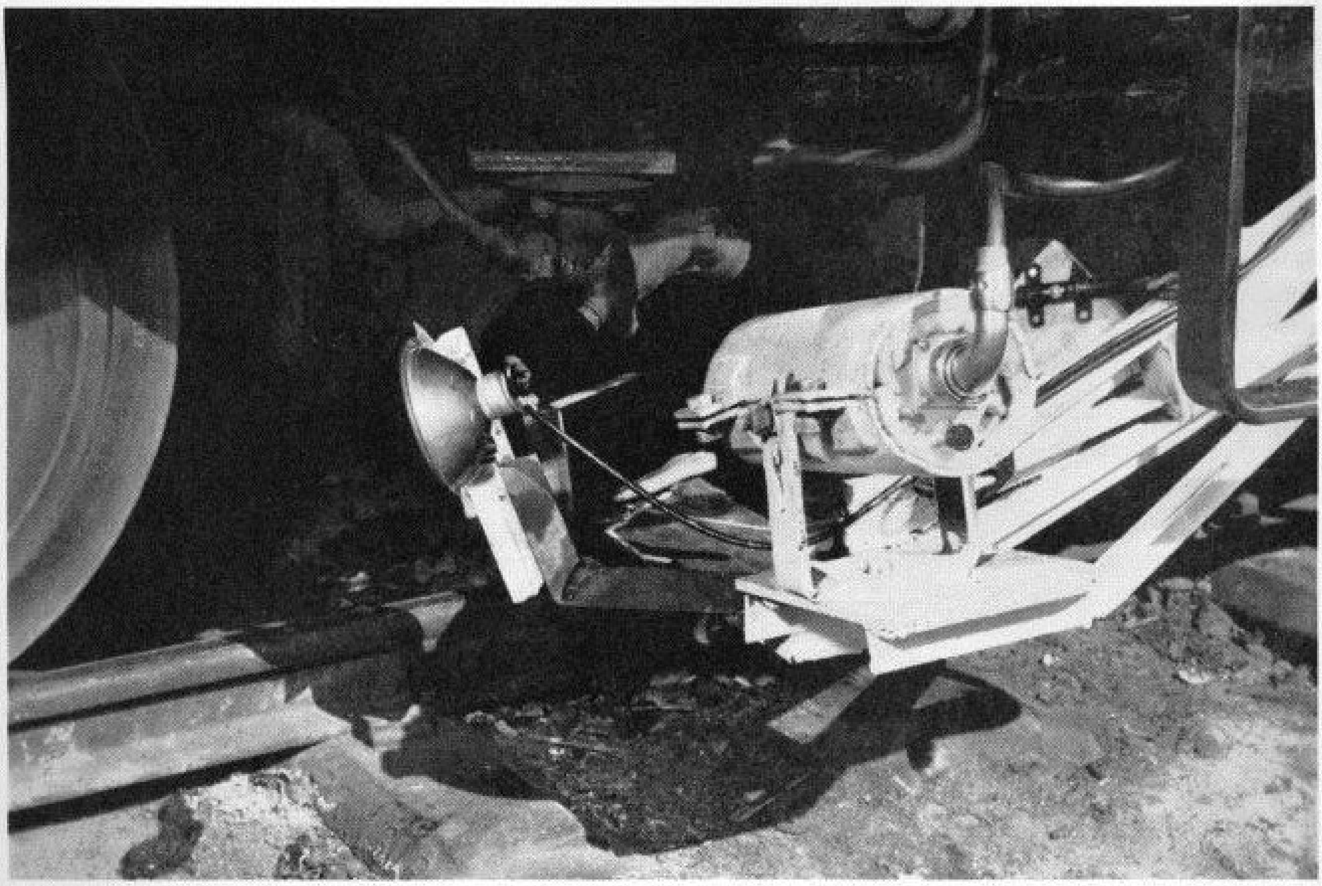

Fig. 2. The BD871 Vidicon Camera is shown here being used to check wear on railway tracks. This is a good example of the rugged nature of the equipment and the sort of uses to which it can be put.

modified to present a constant impedance of 50 ohms to the coaxial cable carrying the current as shown in Fig. 3. The field coils, being mainly resistive at field frequency, are fed with scanning current via unscreened wires in the camera cable.

AUTO TARGET CONTROL

Automatic control of sensitivity of the vidicon by variations in the target voltage is available as an alternative to manual control. The video output signal is rectified, compared with a reference potential and the amplified difference voltage operates to increase the target voltage when the video level falls. The voltage is reduced only when more than 10% of the picture content is at the peak value in each field, thus ensuring that the circuit does not operate fully on small areas of peak white information, which would result in small high-lights reducing the average level of the signal. The action of the auto-target control is to adjust the sensitivity of the vidicon to accommodate large variations in light input.

The vision output of the channel is a composite signal, 1·5 V peak-to-peak. There is also a modulated RF output at a frequency of 20 Mc/s so that a television receiver can be used as the monitor. Pictures of reasonable quality can be obtained with a scene highlight brightness of only 15 ft-lamberts and with a lens aperature of *f*/2. The limiting resolution of the channel is 450 lines.

THE BROADCAST VIDICON CAMERA, TYPE 3263A

The advantages of small size and low power requirements of the vidicon tube will allow almost the whole channel to be contained within a camera body of small dimensions.

This camera represents the ideal for general-purpose broadcast studio work where an adequate lighting level is available, and when the use of the more complex image-orthicon camera is not warranted. It has been designed for one-man operation and contains a 7-in. electronic viewfinder, the camera control unit, a $2\frac{3}{4}$-in. waveform monitor and all operational controls. The output of the camera, fed out down the camera cable, is a fully processed signal, gamma corrected and compensated for the aperture loss of the tube. The output voltage is at standard level with a sending impedance of 75 ohms; the picture polarity may be switched to positive or negative.

A four-station lens turret is rotated manually by means of four, colour-coded spokes attached to the turret and projecting beyond the sides of the camera. Focusing is achieved by moving the vidicon tube and scanning yoke relative to the lens, and operated by a lever at the side of the camera, geared to give a sine law motion of the yoke carriage, thus providing the operator with a fine control of focus near the infinity position.

The beam-focusing potential employed is 250 V and the loss in horizontal resolution is about 8 dB at 400 lines per picture height. With the aperture correction adjusted to reduce this loss to 2 dB, the signal-to-noise ratio with a signal current of 0·2 μA is still better than 31 dB.

The recommended minimum lighting level to produce pictures of good quality is 100 ft-candles (1,000 lux) with the lens aperture at *f*/2. Increasing the scene illumination would further reduce the vidicon "lag" effect or allow a smaller lens aperture to be used to provide a greater depth of focus field.

THE MARK IV VIDICON CAMERA BD896

The prime objective in the design of this camera was to exploit to the maximum the potential of the

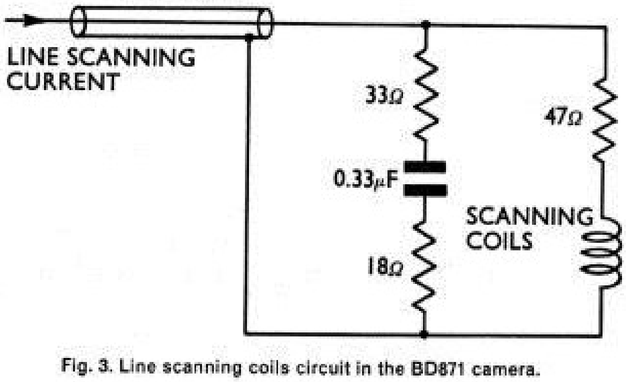

Fig. 3. Line scanning coils circuit in the BD871 camera.

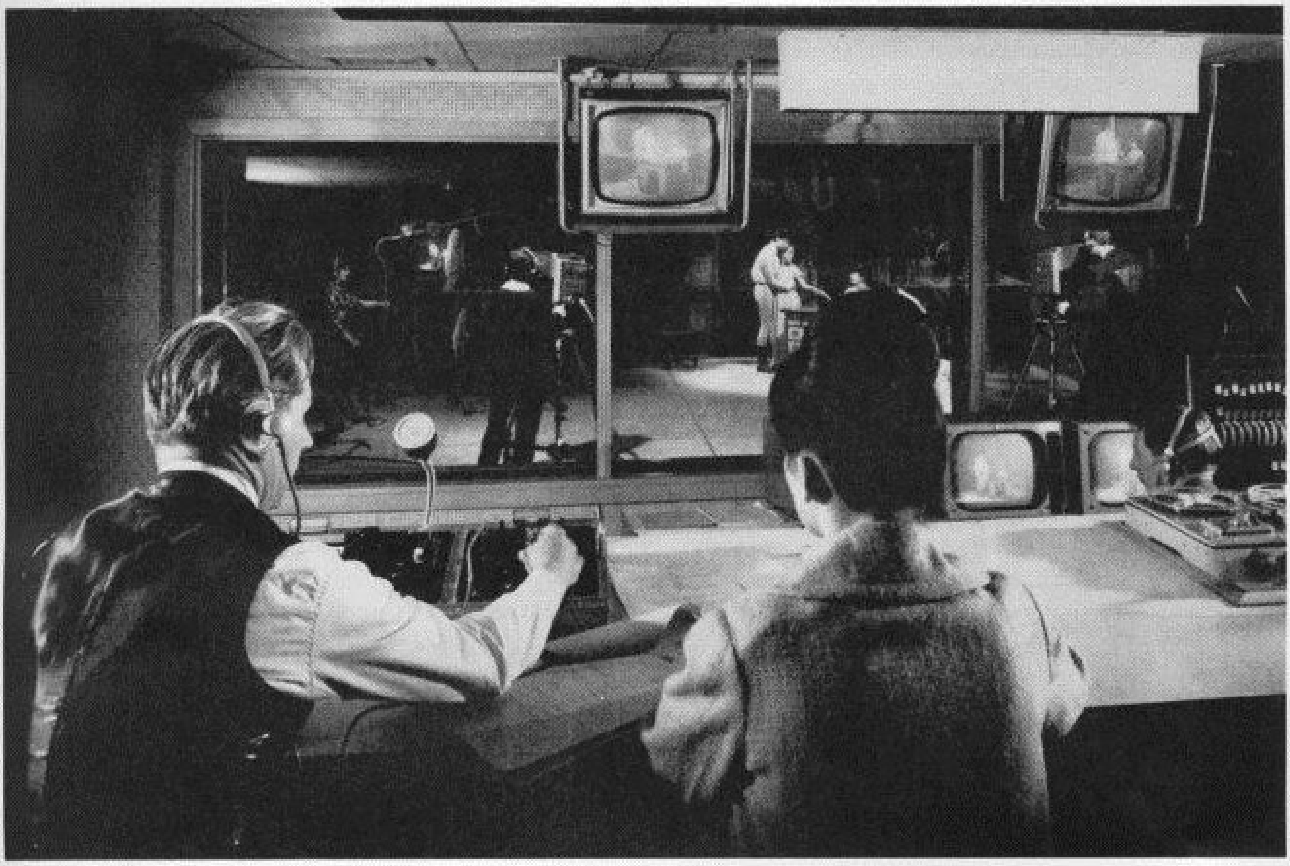

Fig. 4. The Broadcast Vidicon Camera in use in the studio of the College of Dramatic Art of the Royal Scottish Academy of Music.

vidicon as a high-grade pick-up tube, in particular for telecine work, but capable of adaptation for studio application. The stability and ease of operation were to be comparable to the highly successful Mark IV Image Orthicon Channel. With these objectives, there was every reason to adapt the vision processing and power supplies of the image orthicon channel for use with a vidicon camera head.

This adaptation was entirely successful so that, by a change of three plug-in units, the camera control unit and power supply unit of the image orthicon channel will operate with the vidicon camera head. Apart from the obvious saving in manufacturing costs, there is the advantage to broadcasters of standard high-grade equipment with the minimum of spares stocking.

The construction of the camera head is quite unique—the main body is a light alloy frame on which are mounted the printed boards containing the electronic circuits. These boards plug into a "mother" printed board carrying interconnections between the units and to the camera cable plug.

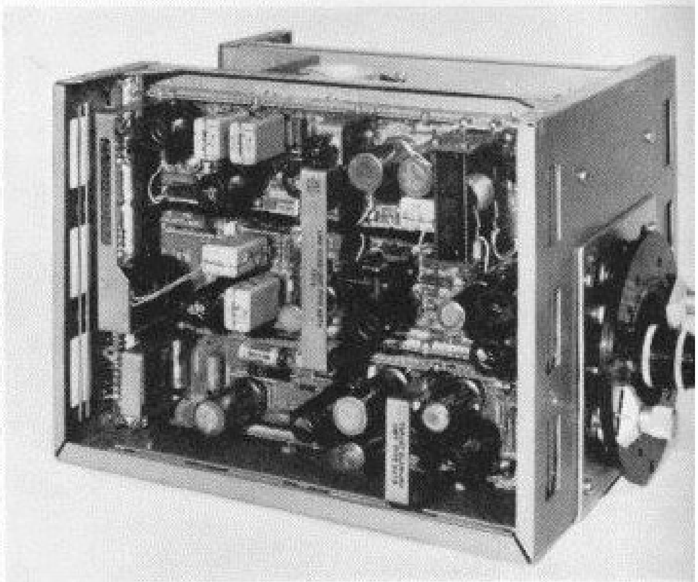

Fig. 5. The Mark IV Vidicon Camera with its covers removed showing the printed board construction.

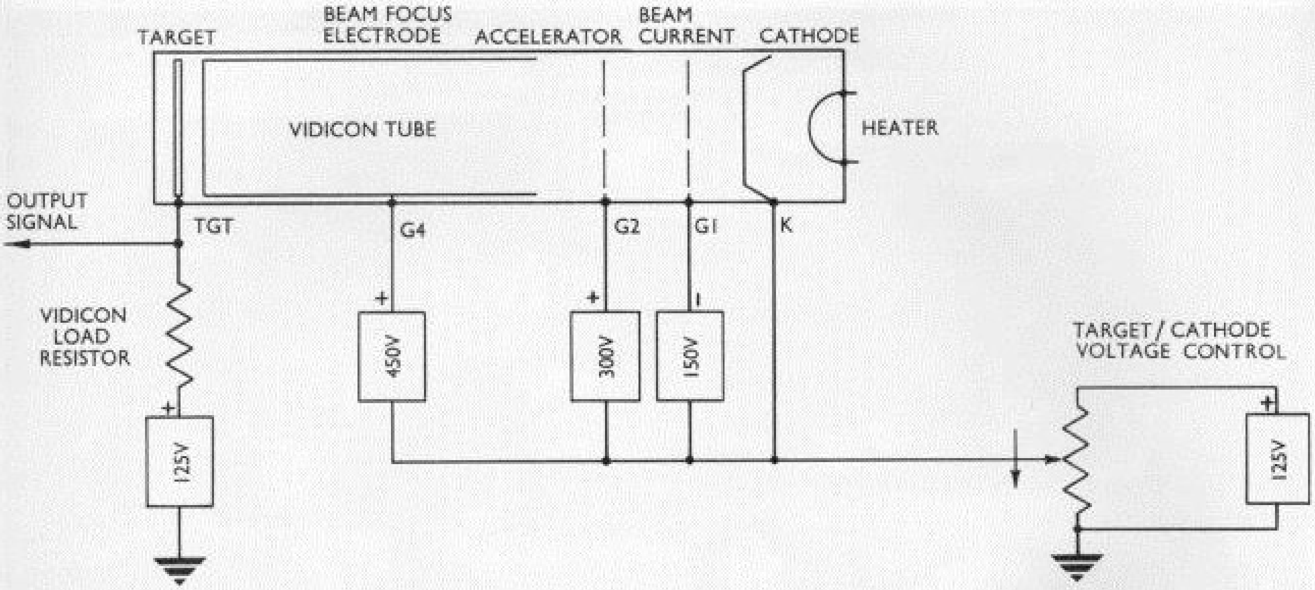

Fig. 6. Showing method of connecting vidicon electrode supplies in the Mark IV vidicon channel to control target-to-cathode voltage.

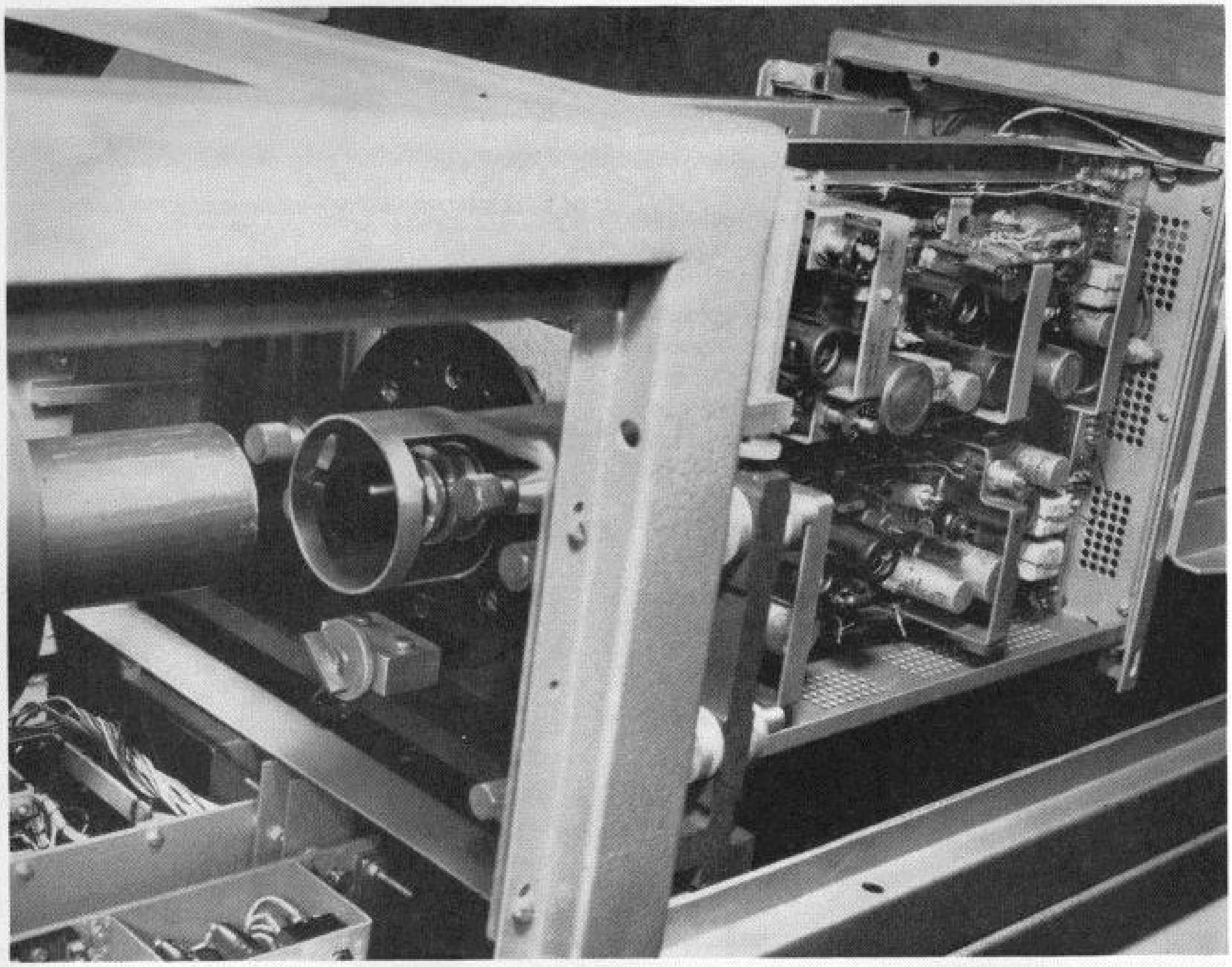

Fig. 7. The Mark IV Vidicon Camera mounted in a large-size pellicle multiplexer (BD923), with covers removed. The method of mounting the camera lens can be seen.

The yoke is mounted with the camera lens on a metal plate separate from the camera body, the assembly providing an accurate location of lens to tube face-plate.

In allowing the yoke and camera lens to "float" partially independent of the main camera body, the design enables the camera to be aligned accurately to the optics in the telecine multiplexer. Thus camera heads may be interchanged with the minimum of adjustment. For studio operation the yoke is fixed to the camera in either of two positions 90° apart.

The electrical design of the channel was made flexible to meet varying requirements and provision has been made so that the adaptation is simple.

The channel will operate on 405, 525 or 625 lines systems, the selection being made either by a remotely switched supply which operates relays within the channel or by substituting adaptor plugs for the relays.

Normally, for telecine operation the output of the camera will be adjusted by a light shutter on the lamp-house of the projector, controlled by the operator at the camera control panel or by an electronic servo control.

Where shutter control is not available or for purposes where light control is not practical, the facility of target-voltage adjustment will be required. Apart from the disadvantages mentioned previously which must be accepted with this form of output control, it is necessary to ensure, when the target potential is altered, that the voltage surge produced does not overload the channel amplifiers. The amplitude of the voltage surge can be many times that of the voltage at the input amplifier produced by the output signal current of the vidicon, but by increasing the time constant of the control, the surge can be reduced to an acceptable level.

In cases where only occasional alteration in target voltage is necessary, slow action of the control can be tolerated.

A more satisfactory method of target sensitivity control is to vary the target to cathode voltage at the cathode rather than at the target. Fig. 6 shows how this is achieved in the Mark IV Vidicon Camera, where the vidicon target is held at a fixed potential of 125 V with respect to chassis, and the cathode-to-chassis voltage is controlled to values between 125 V and zero. Hence the target to cathode voltage varies from zero to 125 V.

The supplies providing potentials to the remaining electrodes of the tube are connected to the cathode so that these potentials are not changed with respect to cathode by the changing cathode potential.

SHADING CORRECTION

In order that vidicons with either uniform or non-uniform target construction could be employed in the camera, beam-landing correction is obtained by applying voltage waveforms at line and field rate to modulate the mean target-to-cathode voltage. The correction voltage is applied to the cathode, and the

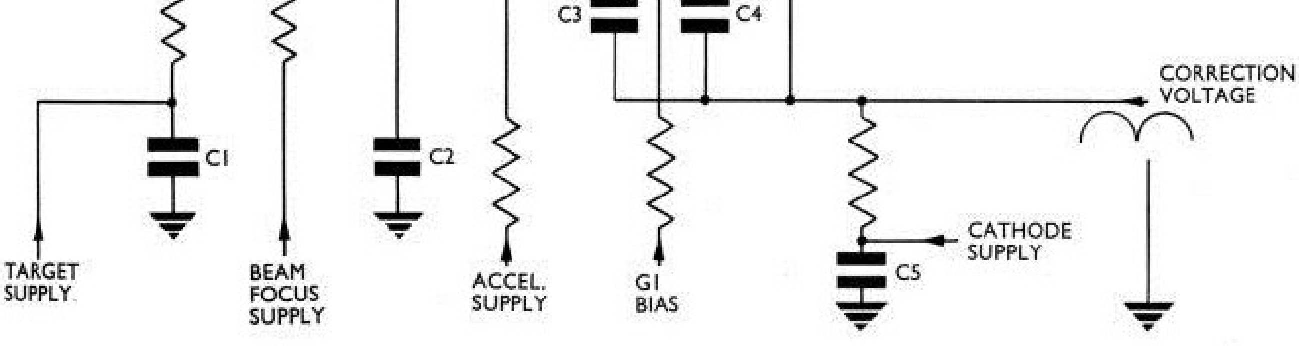

Fig. 8. Method of modulating target-to-cathode voltage to provide shading correction.

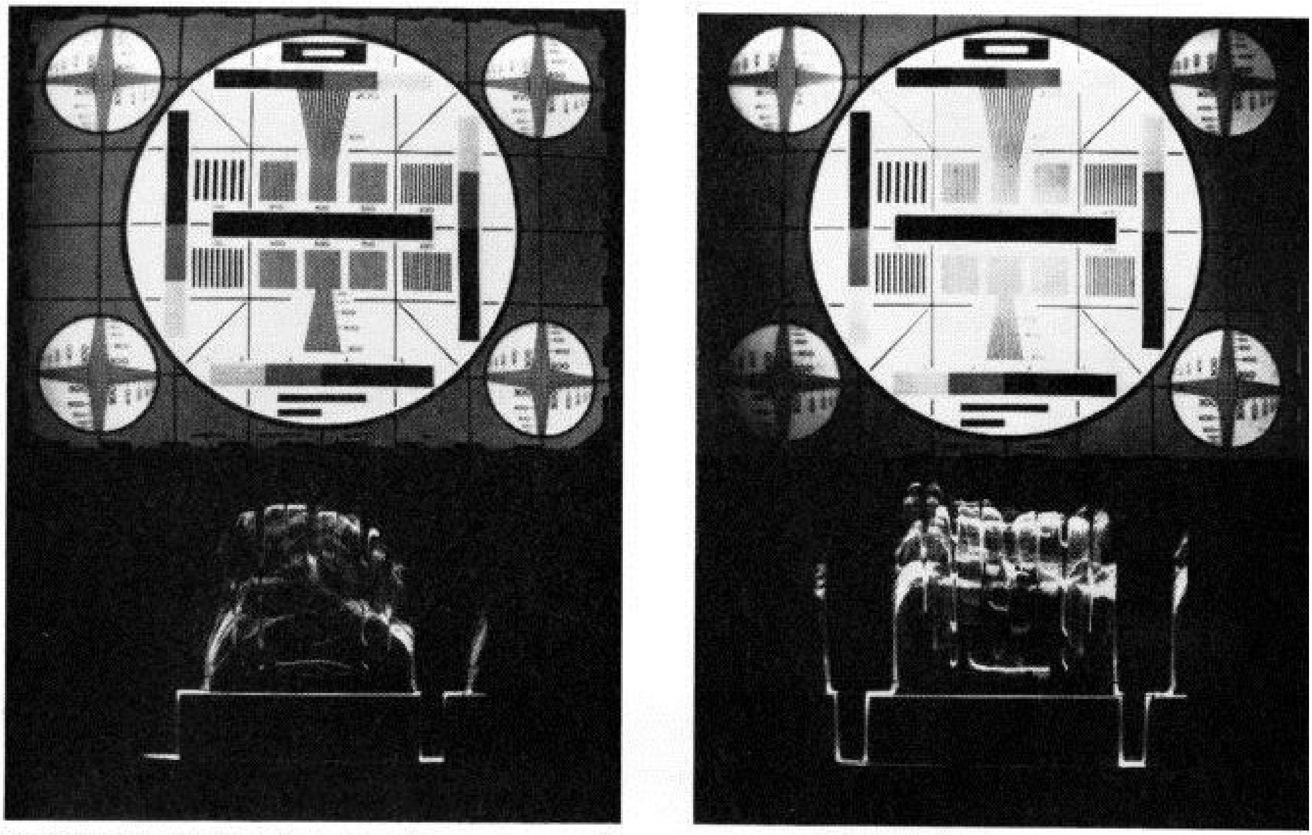

Fig. 9. The improvement in signal uniformity by shading correction modulation in the Mark IV Vidicon Camera.

circuits to the tube electrodes are arranged so that the beam current control grid G1 and the accelerator electrode G2 are not so modulated.

Referring to Fig. 8, the capacitors C3, C4 connected from G1 and G2 to cathode cause these electrodes to follow the waveform introduced at the cathode, so that the DC potentials between G1, G2 and cathode are unmodulated. The target and the beam-focusing electrodes, however, are connected via C1 and C2 to the common point, the chassis, so that the potentials from these electrodes to cathode are modulated by the correction waveform appearing at the cathode.

Fig. 9 shows the improvement in signal uniformity produced by shading correction modulation, linear and parabolic, in the Mark IV Vidicon Camera.

FILM RESOLUTION

In addition to the aperture loss of the finite beam diameter of the vidicon there is a loss in resolution in the film, film projector and the total optical path to the camera tube which must be corrected. The loss in typical 16-mm film is quite considerable as shown in Fig. 10a. Correctors for the loss in both 16-mm and

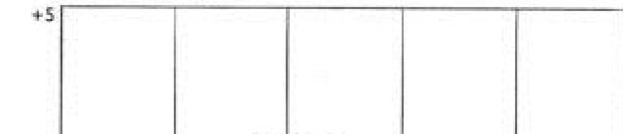

Fig. 10. Resolution of 16-mm film. (a) Uncorrected. (b) Using film corrector in Mark IV Vidicon Camera.

35-mm film are incorporated with the Mark IV Vidicon Camera, and the appropriate corrector may be selected automatically when switching between projectors in a telecine installation. The frequency of peak correction is also changed to a corresponding value when switching between television standards. Fig. 10b shows the corrected response of the 16-mm film.

OPERATION WITH NEGATIVE FILM

One essential feature of the telecine camera is to produce a positive picture output from negative film, and it is desirable that the camera should be rendered capable of accepting either polarity quickly. To this end, separate pre-set controls of gain, lift and gamma-correction are provided for each film polarity and the changeover switching effected either at the camera control panel or automatically at the projector.

When operating with negative film, the reversal of action in the controlled parameters can be quite confusing. With no light input the picture is at peak white, and as the light is increased the signal increases towards black. Hence the light shutter controls the picture black-level, and the so-called "black-level" or pedestal control now operates at picture white. To ease operation, the two main controls of the Mark IV Vidicon Camera are labelled "Black Level" and "White Level", and the electrical parameters controlled are interchanged when switching to each film polarity.

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