Television Camera Channel Design

LIGHTWEIGHT EQUIPMENT USING PHOTOCONDUCTIVE CAMERA TUBE

By **J. E. Attew***

SUMMARY. *The design of a small, lightweight television camera and associated equipment with full programming facilities is described. The specification is capable of meeting full British transmission standards for studio and outside broadcasting use, as laid down by the British Broadcasting Corporation.*

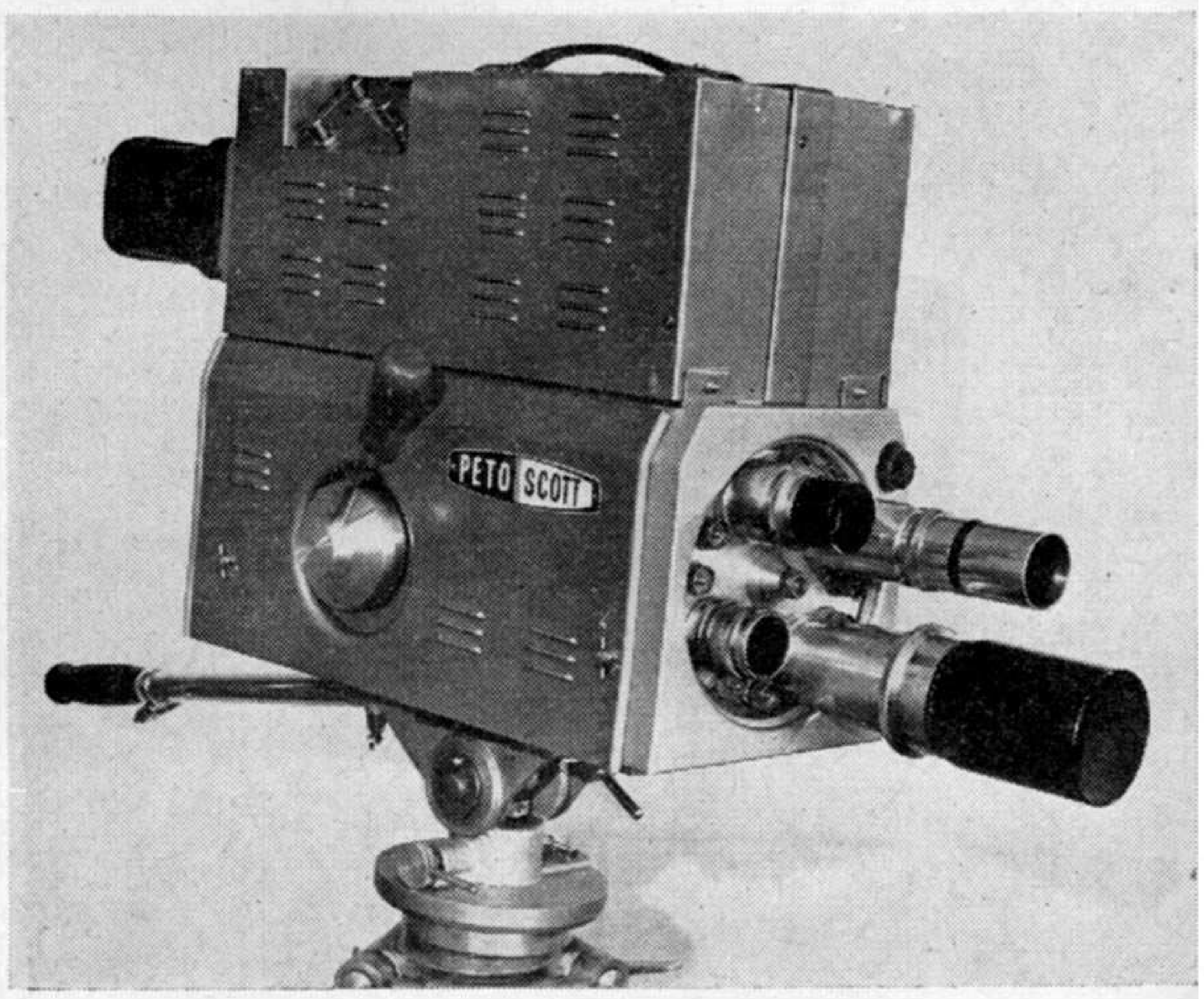
The reduced size of this equipment, electrically and mechanically, is governed by the use of the 1-in. diameter photoconductive camera tube, available in this country and abroad (i.e., Staticon, Vidicon, etc.). A general description of the complete equipment is given, portions of particular interest being treated in greater detail. The overall performance is described.

While many types of camera channels are available employing image orthicons, image iconoscopes, etc., giving excellent results, there is still the basic need for a camera channel using inexpensive, lightweight equipment, particularly for outside broadcasts where considerable mobility is required. An experimental lightweight camera equipment has already shown the increased potentialities for television entertainment (e.g., the B.B.C. transmission from a submarine in June 1956). This type of programme could not be carried out with larger equipment.

For a given performance, the size of the camera equipment is governed by the camera tube used. It had already been shown by its use in telecine equipments that the 1-in. diameter photoconductive camera tube could achieve the exacting performance demanded by the British transmission standards, so work was put in hand to find how this type of tube performed under 'live' conditions. This paper describes the design of a camera channel which is the result of these tests.

No ideal camera tube exists; all have their faults, which are difficult to overcome and have to be accepted. At low light levels, the photoconductive camera tube suffers from 'lag' or image retention, frame to frame, causing smearing of moving objects. This defect must be weighed against its numerous advantages, such as its small size (allowing reduced lens sizes), small scanning powers, complete stability at all light levels, true black level reference, ease of electrical control, absence of warming-up period and image 'stick-on', good gradation, and reduced running costs, among others.

The equipment described here has been designed with size and weight in mind, but not at the sacrifice of electrical performance or the reduction of programming facilities. It is felt that the result has been a well-balanced compromise, where ease and comfort of operation, convenience of maintenance and standard of performance have all been achieved. A precision 14-in. picture monitor is available with the channel and also a lightweight synchronizing generator, but these are not described in this article.



The camera with viewfinder

Factors Influencing the Design

The photoconductive camera tube has been fully described elsewhere, so a brief summary of its principal characteristics is sufficient here.

As shown in Fig. 1 (left), the tube consists basically of an evacuated glass envelope with a photoconductive target at one end, scanned by a low-velocity beam of electrons from an electron gun at the other. The image to be televised is focused optically on the target, which is composed of a thin film of material possessing the property of changing electrical conductivity in relation to the incident illumination. The target material is deposited on a transparent electrically-conducting coating which forms the signal electrode, which initially is deposited on the inside of the optical glass 'window'.

The electron gun consists of a cathode, a beam control electrode (grid 1) and an accelerating electrode (grid 2). The electron beam is focused at the surface of the photoconductive layer by the combined action of the uniform magnetic field of the external focusing coil and the electrostatic field of the focusing electrode (grid 3). A

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* *Peto Scott Electrical Instruments Limited.*

fine mesh screen (grid 4) serves to provide a uniform decelerating field between itself and the target layer, so that the electron beam approaches the layer in a direction perpendicular to it—a condition necessary for driving the target surface to cathode potential. This electron beam arrives at the target at low velocity due to the low operating potential of the signal electrode.

The target acts like a leaky capacitor, having one plate fixed at the positive potential of the signal electrode and the other plate floating [Fig. 1 (right)]. The conductivity at any element is related to the incident light on that element, so that there appears on the electron gun side of the target a positive potential pattern of the image optically focused on the target. When the pattern is scanned by the electron beam, electrons are deposited from the beam in sufficient quantities to reduce the surface potential to that of the cathode. This recharging of the capacitor elements causes current to flow through the load resistor R so constituting the video signal, which is negative-going towards highlights in the image.

Transfer Characteristic and Colour Response

A log-log plot of the transfer characteristic of a photoconductive tube shows a nearly straight line over a wide range of illumination and shows no 'knee' as with the image orthicon, etc. The average slope of the transfer curve is between 0·6 and 0·7. This is higher than the required channel characteristic of approximately 0·5, so that some additional gamma correction is necessary, amounting to about 6 dB increase in gain in the blacks up to a value of 0·2 of peak whites, referred to the output signal. Unfortunately, this correction appears to accentuate lag effects, due to small amounts of image retention being increased by a factor of 2. The gamma correction should, therefore, be removed under conditions of low light levels.

Measurements show that present tubes are essentially panchromatic.

Signal-to-Noise Ratio

The photoconductive camera tube has in itself an excellent signal-to-noise ratio, the noise output being equal to a temperature-limited diode with an anode current equal to the output current of the photoconductive camera tube. The signal-to-noise ratio is, therefore, almost entirely determined by the video amplifier noise characteristics, and can be more than adequate to allow gamma and aperture correction.

Aperture Characteristic

Owing to the finite size of the scanning beam and lens aberrations in the optical system, the aperture characteristic curve of the photoconductive camera tube shows a reduction of output with increasing frequency or line number amounting to a loss of 8–9 dB at 3 Mc/s. The inverse of this frequency response should be applied to the video amplifier as aperture correction.

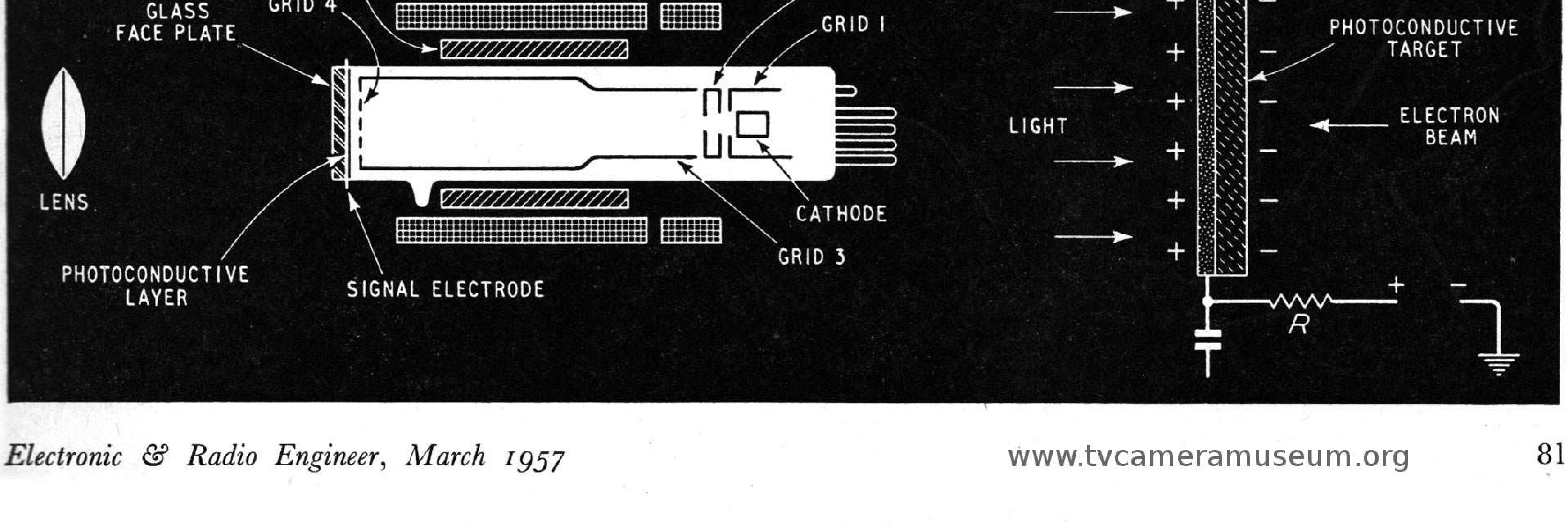
A number of methods are possible to provide aperture correction.[1,2] The method used in the present equipment is to match the aperture characteristic by means of staggered high peaking using L, C and R circuits. The phase distortion produced by these circuits is corrected by a bridged-T phase corrector. The advantage of this method is the relatively sharp cut-off above the maximum usable frequency which limits noise in this region.

Spurious Signals

Persistence of an image following the removal of incident illumination is termed 'picture lag', and can be measured as per cent output from the camera tube at a given time after removal of the illumination. If the illumination is removed during a frame-suppression period, then the third frame amplitude after this removal can be compared with the first frame amplitude giving the percentage lag in one picture period. Measurements by different workers do not agree, but subjective measurements show with present photoconductive camera tubes that approximately 150 ft/L off peak white is required with a lens aperture of f/2 to give no apparent lag effects, but these values are affected to some degree by the picture composition.

The use of the camera-tube manufacturers' curves shows that signal current increases with target bias voltage, as does the dark current. This dark current is a spurious signal originating in the photoconductive camera tube itself and is termed 'flare' or background. To obtain a satisfactory signal current to dark current ratio the target bias voltage must be kept low, which for a peak signal current of 0·2 μA again requires adequate illumination. Tests with normal photoconductive camera tubes show that flare or background is not a problem at lighting levels necessary to overcome lag.

Fig. 1. *Schematic layout of the photoconductive camera tube* (*left*) *with a diagram of the target electrode* (*right*)



Due to lateral current leakage, the photoconductive camera produces a picture framed with a white edge on all four sides. This white edge is only troublesome at the bottom of the picture, which is not normally covered by the system suppression pulses. To overcome this defect, the frame trigger pulses to the camera time-base must be delayed by 2 to 3 lines to ensure that this spurious signal occurs during the frame-suppression period.

The absence of charge redistribution effects in the photoconductive camera tube eliminates shading problems inherent in photo-emissive camera tubes, so allowing the generation of an absolute black level in the output signal. The camera-tube beam-current must be switched off by pulses applied to the control grid of the tube during the system suppression period.

The excellent signal-to-noise ratio obtainable ensures retention of this absolute black level throughout the system.

Deflection

The photoconductive camera tube uses the principles of low-velocity electron-beam scanning[3,4] and, due to the small volume occupied by the scanning field, relatively small line-frequency deflection power is required, a small output pentode working in class A being more than adequate. Consequently, it is quite easy to obtain adequate linearity of deflection but, due to the small size of deflection yoke, great care must be exercised in the construction of the coils to achieve good geometry.

By recourse to a type of construction in which the deflection coils are wound on precision-made jigs which are part of the final assembly, it has been found possible to reduce scanning errors to approximately 0·5% positional error of scan.

As can be seen from Fig. 1, there is no decelerating ring between the mesh and the target as in the CPS Emitron[5] so that there is no correction for spiral distortion of the image. This distortion amounts to about 5–10° of trapezium distortion, which can be corrected by electrical or mechanical skew of the scanning fields.

The present design incorporates mechanical rotation of the frame and line deflector coils relative to one another, but care must be taken to ensure that the resultant coupling between the two circuits does not cause spurious deflections outside the normal system suppression time.

General Mechanical Requirements

For maximum mobility, it was decided that the equipment should be divided into 3 units—camera, viewfinder and camera control unit. The camera plus viewfinder should weigh less than 50 lb. and the camera control unit less than 100 lb. The viewfinder should be capable of being detached from the camera and used on the end of a connecting cable to enable the use of servo-controls to operate the camera.

The connecting cable should be as small in diameter as possible and a new design of cable by B.I. Callender's Cables was ideal for this purpose.

Distribution of the Circuitry

It is obviously very desirable to keep the size of the camera as small as possible and, to help in this direction, the camera circuitry must be kept to a minimum, but at the same time thought must be given to the total size and weight of the equipment and of the camera cable, both of which will be increased considerably if the camera is simplified to an extreme. Consideration shows that there is an optimum condition here.

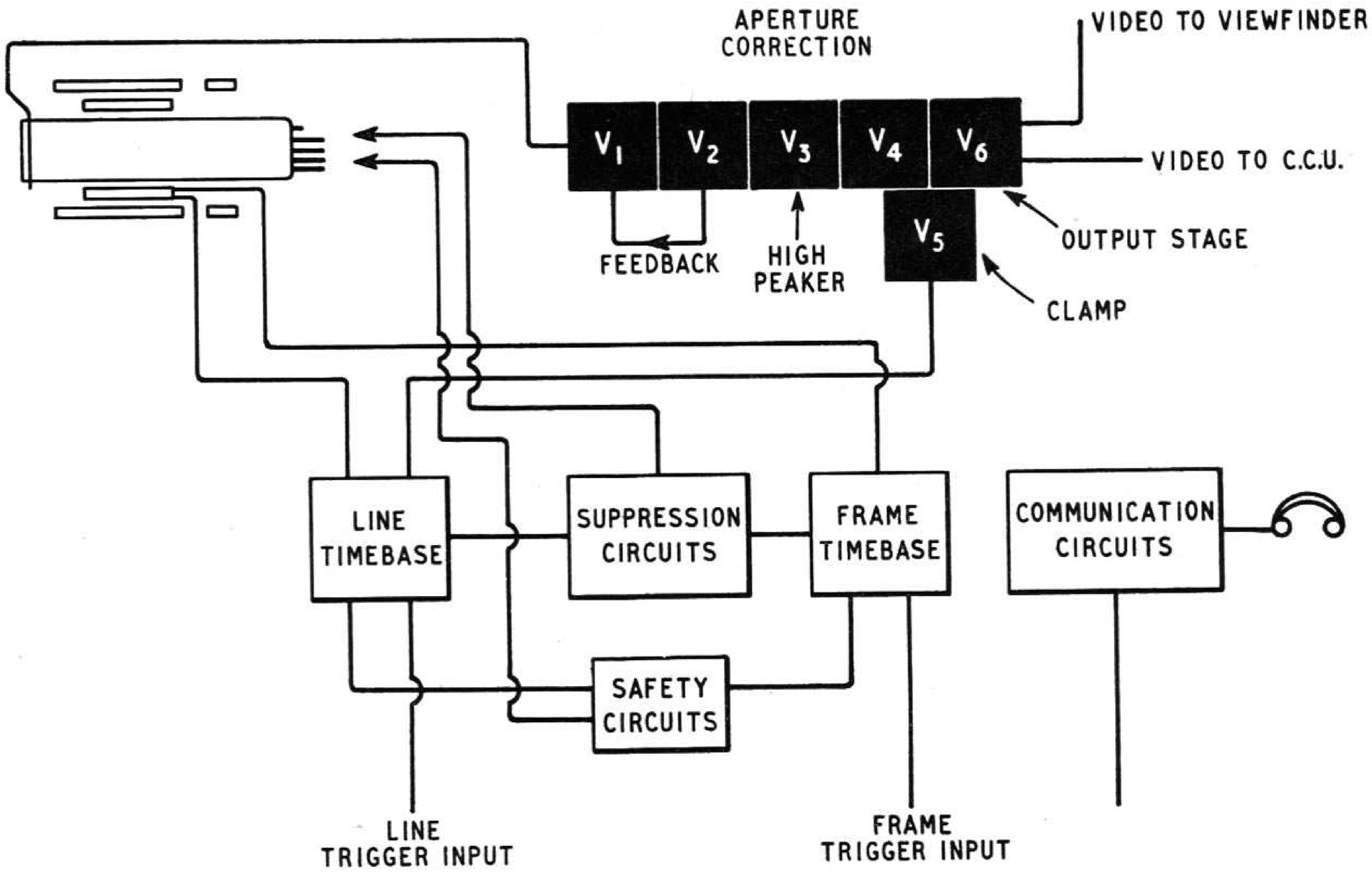


Fig. 2. *Schematic of camera circuits*

The use of an electronic viewfinder influences the circuitry to a great extent. First, the cathode-ray tube will require up to 50V p–p video modulation, so that considerable video amplification is required at the camera end of the camera cable if it is desired to save one coaxial cable. The video amplification may well, therefore, be employed in the camera itself to raise the video level into the camera cable well above interference level.

Secondly, the viewfinder will require drive pulses to operate the frame and line time-bases. These signals require coaxial conductors in the camera cable so that it is obviously desirable to place the very small camera-tube deflection circuits in the camera to save additional coaxial conductors in the camera cable. Scanning currents can be fed down camera cables, but must be generated by circuits, particularly at line frequency, requiring considerably more power than local scanning generators, also the linearity and amplitude of scanning currents are influenced by the camera cable length. The channel power supplies and the complexity of the camera control circuits must, therefore, be greater for the small reduction of the camera size made possible by this method of deflection.

Thirdly, the viewfinder which, for convenience operationally, sits on top of the camera will influence at least the length of the camera, the minimum length being governed by the cathode-ray tube used.

Optical Requirements

To keep the lighting level requirements to a minimum requires fast lenses of aperture f/2 or better. Fortunately, the small picture diagonal ($\frac{5}{8}$ in.) requires short focal-length lenses for given viewing angles, it being easier to obtain fast lenses with short focal lengths. The depth of field is also greater with the shorter focal lengths.

A few very good lenses are obtainable in the range designed for 16-mm cine work. These are generally fitted with a standard type 'C' mount and have been found to provide good coverage of the picture format size used ($\frac{1}{2}$ in. × $\frac{3}{8}$ in.), lenses in the range of 0·7 to 4 inch focal length providing most requirements for outside broadcast and studio use. Also readily available are small zoom lenses covering this focal length range with apertures of f/2·4.

The use of a manually-operated four-lens turret is desirable and the optical requirements of this turret tend to govern the minimum frontal size of the camera.

Camera

The camera channel consists of a camera, with detachable viewfinder, camera cable, camera control unit, picture monitor and synchronizing generator. A small rack is available to house the camera control unit, picture monitor and sync generator. The camera is intended to mount on a lightweight tripod and can be used with up to 1,200 ft of camera cable. The size and weight of the individual items is shown in Table 1.

TABLE I

	Height (in.)	Length (in.)	Width (in.)	Weight (lb.)
Camera ...	7	15	7	25
Viewfinder ...	5	15	6	15
C.C.U. ...	6¾	26	16½	85
Monitor ...	12	22	16½	60
Sync Generator	6¾	15	16½	34

The main structure of the camera is formed of light-alloy castings, so providing a rigid foundation for the optical system. The four-lens turret at the front is operated by a turret-rotating handle at the rear. The lens mounts, which are normally Type 'C' mounts but can be made to suit any lens, are quickly releasable by turning two thumbscrews, so that any combination of lenses can be fitted, the normal range being 1-in. to 4-in. focal length with f/1·9 aperture. Focusing is achieved by movement of the camera tube carriage on p.t.f.e. bearings by means of a handle which can be quickly set to any angular position. Cueing indicators are fitted front and rear, while communication sockets and controls are fitted beneath a sliding panel at one side of the camera.

Fig. 2 is a block diagram of the camera circuitry. All the circuitry is built as one unit, which is easily removable from the main camera body. This procedure facilitates easy maintenance.

The photoconductive camera tube is a constant-current or high impedance generator, the peak signal being approximately 0·2 μA. The signal voltage is developed by the flow of current through a load resistor R. This is indicated in a simplified diagram of the input stages in Fig. 3. It can be seen that the load resistor R is shunted by the input stray capacitance C, which is of the order of 15 pF. In order to reduce microphony and hum, the low-frequency input is made relatively large by making R large, approximately 0·5 megohm, which, of course, produces a drooping frequency response, approximately 44 dB of high frequency equalization at 3 Mc/s being required to ensure flat amplifier response. This equalization is provided partly by negative feedback applied across the load R and partly by a conventional cathode by-passed high peaker stage. The negative feedback applied from V_2 across the load resistor provides approximately 25 dB of the required equalization of the frequency characteristic.

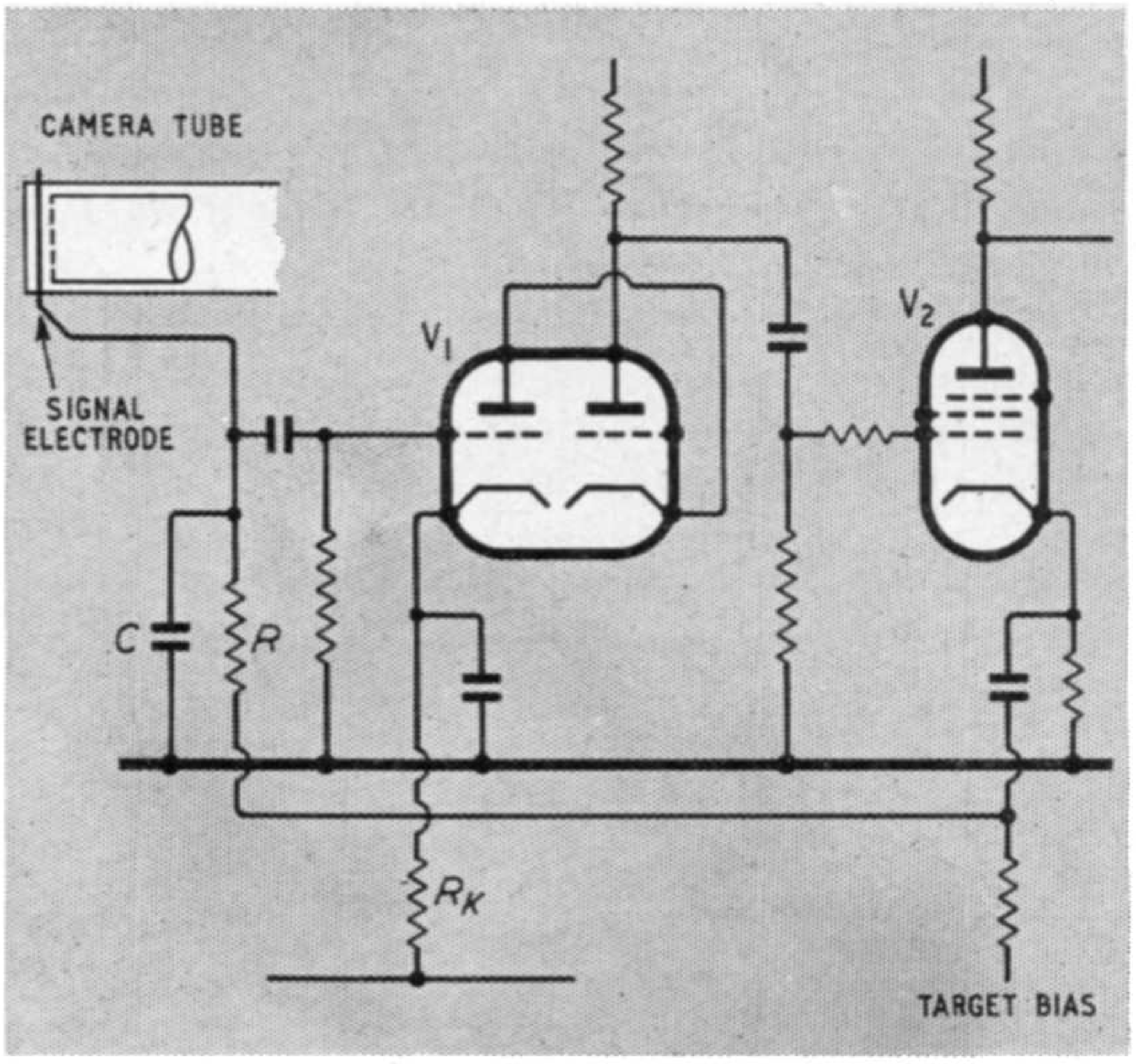


Fig. 3. *Simplified camera input circuit*

The first stage is a low-noise input circuit using a double-triode cascode amplifier. The triodes used have a working mutual conductance of 12·5 mA/V. To ensure constant gain within the feedback loop, the anode current of this stage is stabilized by heavy current feedback. The large cathode resistor is returned to a stabilized negative supply for this purpose.

The low-frequency response is accurately maintained by conventional compensated couplings between each valve stage. This procedure ensures complete absence of low-frequency streaking.

The aperture correction is achieved by two networks as in Fig. 4 (a) and one network as Fig. 4 (b), the resonant frequency of each network is arranged to be outside the required passband of 0–3 Mc/s. In Fig. 4 (a) the resistor R_D is adjusted to control the rate of increase of amplitude with frequency within the passband. Phase errors are corrected by a bridged-T network [Fig. 4 (c)].

The video output circuit is arranged to drive both viewfinder and camera control unit, the video input to this stage being clamped by a double-diode line-by-line clamp.

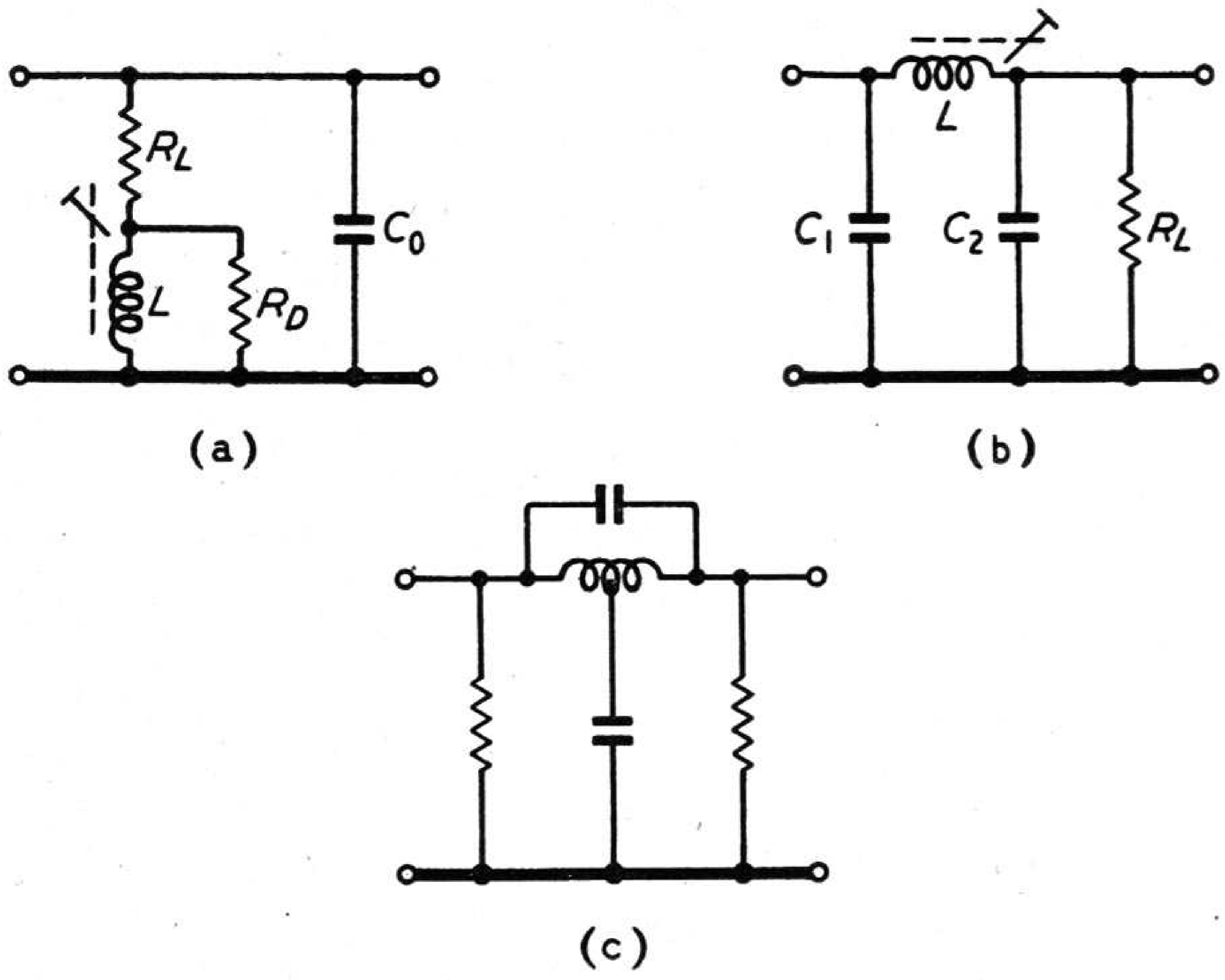
Both frame and line time-base circuits employ negative feedback to make linearity and amplitude of scan virtually independent of valve parameters. Fig. 5 is a simplified diagram of the line time-base.

The output stage V_7 drives low-impedance scanning coils via a small line output transformer using a ferrite core and potted in Araldite.

The valve V_8 is used as a switch, being put on by the positive-going input pulse and used to discharge the circuit at the end of each scan. During the scanning period, the time constants of the feedback network ensure a linear change of current through the scanning coils. The input pulse is an amplified version of the line trigger pulse sent down the camera cable from the camera control unit and is of suitable duration to be used as the line suppression pulse for the camera tube. To complete the suppression waveform to the camera tube, an amplified version of the frame trigger pulse is added to the line pulses. This pulse is also used to discharge the frame time-base.

The output stage of the frame time-base drives high impedance scanning coils directly, a large amount of negative feedback being used to ensure linear deflection current.

A camera tube protection circuit is used to prevent damage to the tube in the event of a scanning failure.



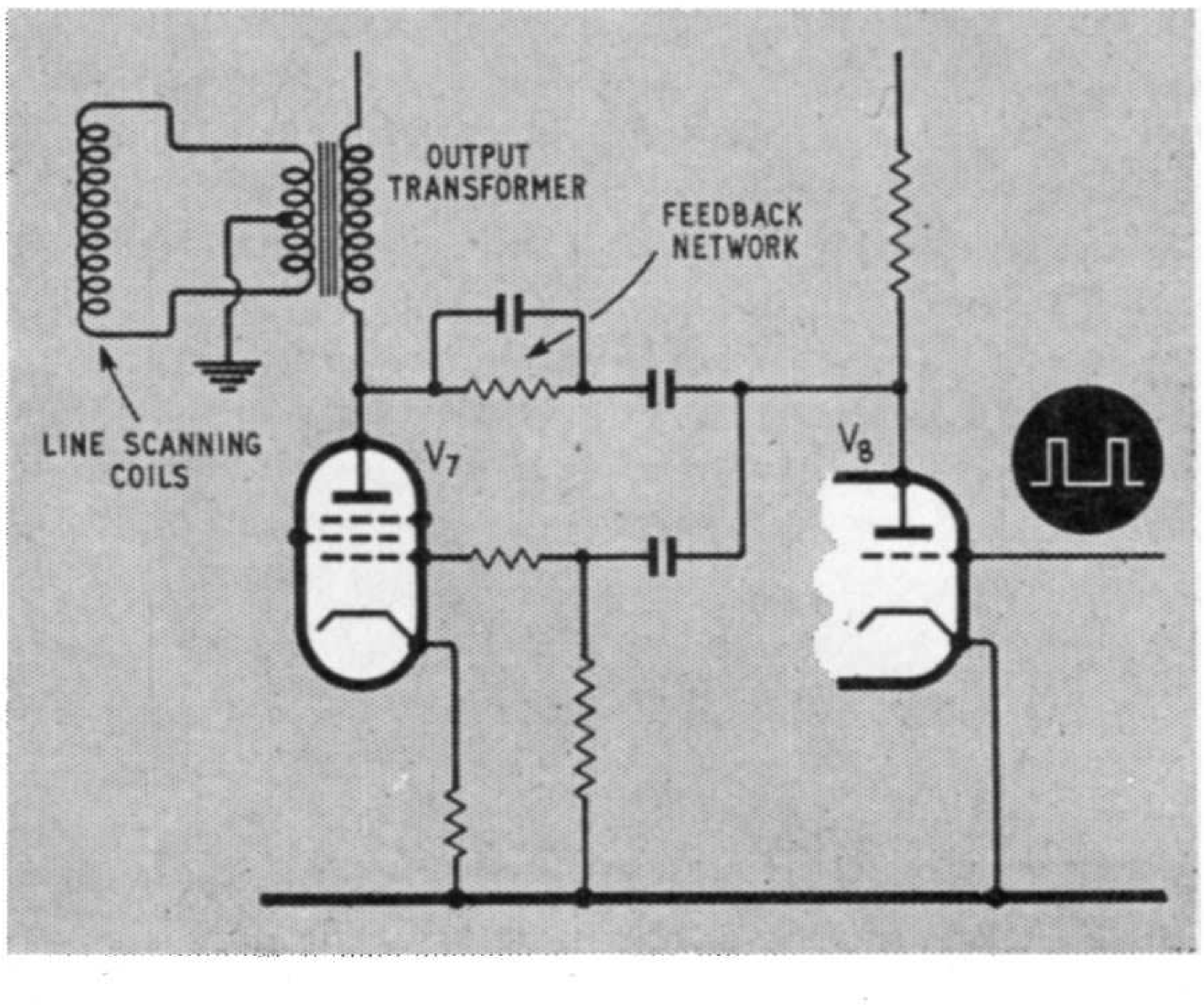
(a)

(b)

(c)

Fig. 4. *Aperture correction filter networks*

Fig. 5. *Simplified circuit diagram of camera line time-base*



Waveforms of the two time-bases are rectified and the resultant steady positive voltages used to control a pentode valve with a relay in the anode circuit. Loss of either of the voltages cuts off the valve, so releasing the relay. This causes the bias on the control grid of the camera tube to be taken below cut-off and also connects the wall anode to earth, preventing damage to the target.

Cueing lamps are fitted front and rear of the camera, operated via a relay which in turn is operated from the camera control unit. The rear cueing light is visible within the viewfinder visor to provide cueing information to the cameraman.

On the side of the camera, a sliding door hides a small control panel housing the camera scanning controls, a communication socket for headset, volume level controls for the headset, microphone switch and a camera control call button. This button operates a small neon lamp on the front panel of the c.c.u. to enable the camera operator to communicate with the c.c.u. operator without the use of the microphone.

The channel was designed to operate with the small Mk.4B camera cable manufactured by B.I.C.C. This cable has moulded end couplers and is only 0·7 in. diameter, but has 3 coaxial cables, 4 screened quads and 18 single wires. Up to 1,200 ft can be used, compensation for cable delay and frequency attenuation being provided by means of a switch in the c.c.u.

Viewfinder

The prototype viewfinder was designed around a 5-in. diameter aluminized magnetically-scanned electrostatically-focused cathode-ray tube, using an aspherical plastic lens to increase the apparent picture size. The production models use a 6-in. diagonal rectangular version of the tube.

Because of the small camera size, the viewfinder must be kept as small as possible or the combination of the two units looks awkward. Considerable thought must be given to the circuitry, to reduce the size and quantity of components. The use of an electrostatic focus c.r.t. helps by eliminating the need for a large and heavy magnetic focusing unit. The final design employs but 8 valves and achieves the high performance required by a camera viewfinder for accurate optical focusing of the scene.

The viewfinder video amplifier employs two triode-pentodes, providing sufficient gain and bandwidth to amplify the input signal of approximately 0·4V p–p to a level sufficient to modulate the cathode-ray tube. Due to the use of a line-by-line clamp in the camera, d.c. restoration of the video signal at the cathode-ray tube has been found adequate.

The line scanning current and e.h.t. are both derived from the line time-base, which is of the high-efficiency direct-drive type. More than adequate linearity has been achieved by the use of a circuit that provides damping proportional to scan velocity within the scanning field. This circuit has been found to be independent of valve samples and other components.

The source impedance of the 11-kV e.h.t. supply has been reduced to a satisfactory value over the working beam-current range of the viewing tube by a feedback circuit that feeds a direct voltage proportional to the flyback pulse height back into the control grid of the line output valve. This is shown in the simplified diagram of Fig. 6. Also shown is the velocity damping circuit coupled to the scan coils. It can be seen that the line amplitude is controlled by a variable resistor, which has no effect on the linearity of the scanning waveform. The frame time-base uses two valve envelopes, the output circuit being a triode-pentode. The scanning current is linearized by a frequency-conscious feedback network, values being selected on test to achieve the required linearity.

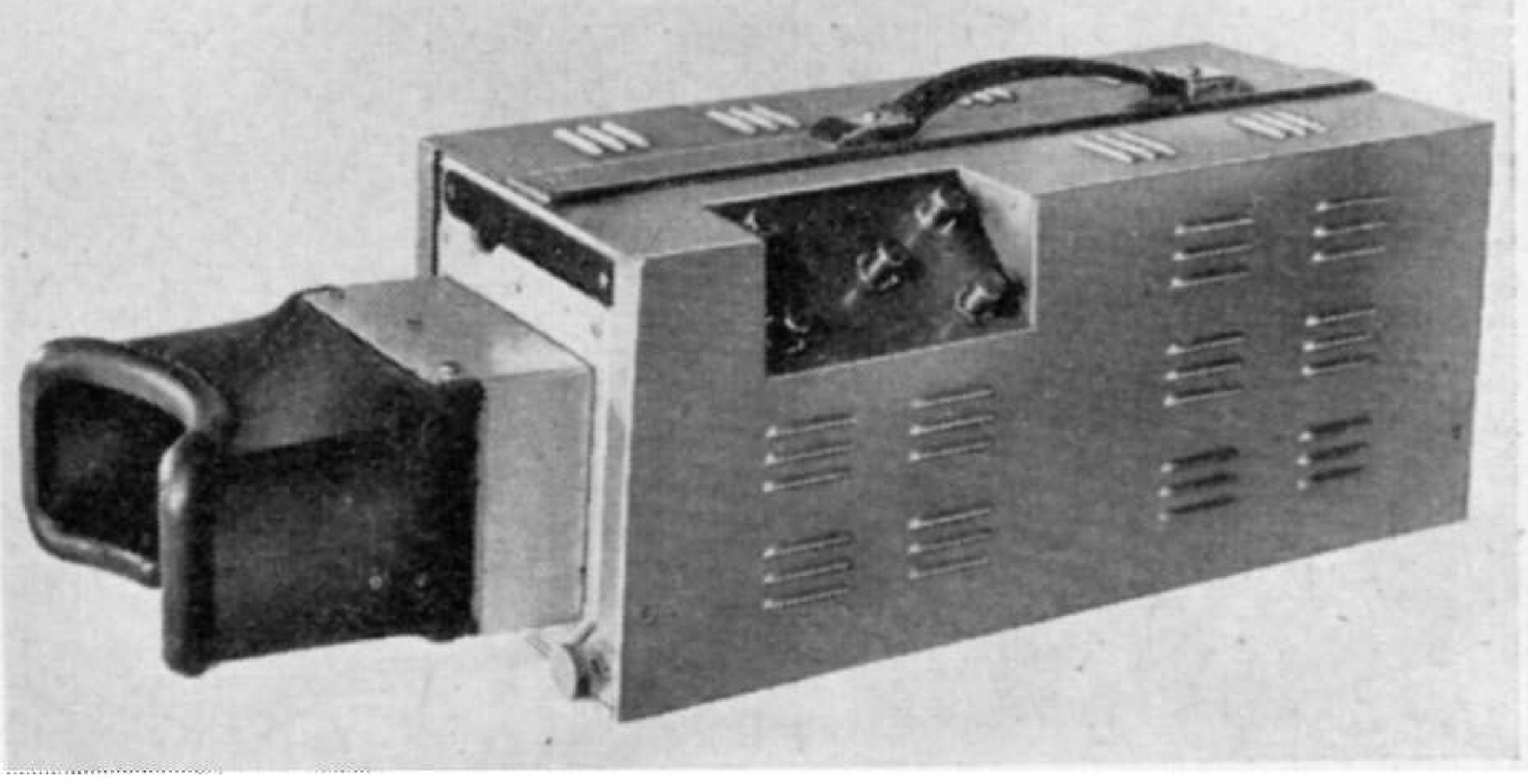
Camera Control Unit

The case of the camera control unit is fabricated from light alloy sections and houses the camera control chassis, waveform monitor chassis and stabilized power supplies for the complete channel. The mechanical design is such that all components are accessible by removing the top and bottom covers of the unit, so allowing easy servicing. The front and rear panels are protected from damage by rails which are also used as carrying handles.

The front panel houses the main operational controls for the camera tube, the waveform monitor and communications. All the controls necessary for setting up the channel prior to operational use are contained under the front portion of the top cover which can be raised for access to these controls.

A cooling fan is fitted to the rear panel, which also houses plugs and sockets such as mains input, camera cable, synchronizing generator connections, test input, communications socket and two composite video outputs.

The circuitry on the camera control chassis performs all the functions necessary to produce from the picture signal, arriving via camera cable, a complete composite video signal as shown in Fig. 7. This circuitry is shown as a block diagram in Fig. 8, and various other functions, such as pulse-timing delays, focus-current stabilization and various potential stabilizers, are incorporated on this chassis.



The viewfinder can be detached from the camera for remote use

The picture signal arriving into this chassis is fully aperture corrected, but contains phase errors which need correction. The phase corrector shown in Fig. 4 (c) is of the bridged-T type, with a characteristic impedance of 75 ohms, and is fitted before the video gain control, which is required to adjust the overall channel gain to ensure that the camera tube is working with the desired signal current of $0{\cdot}2\ \mu$A. A test signal can be fed into the camera input circuit to facilitate correct gain setting.

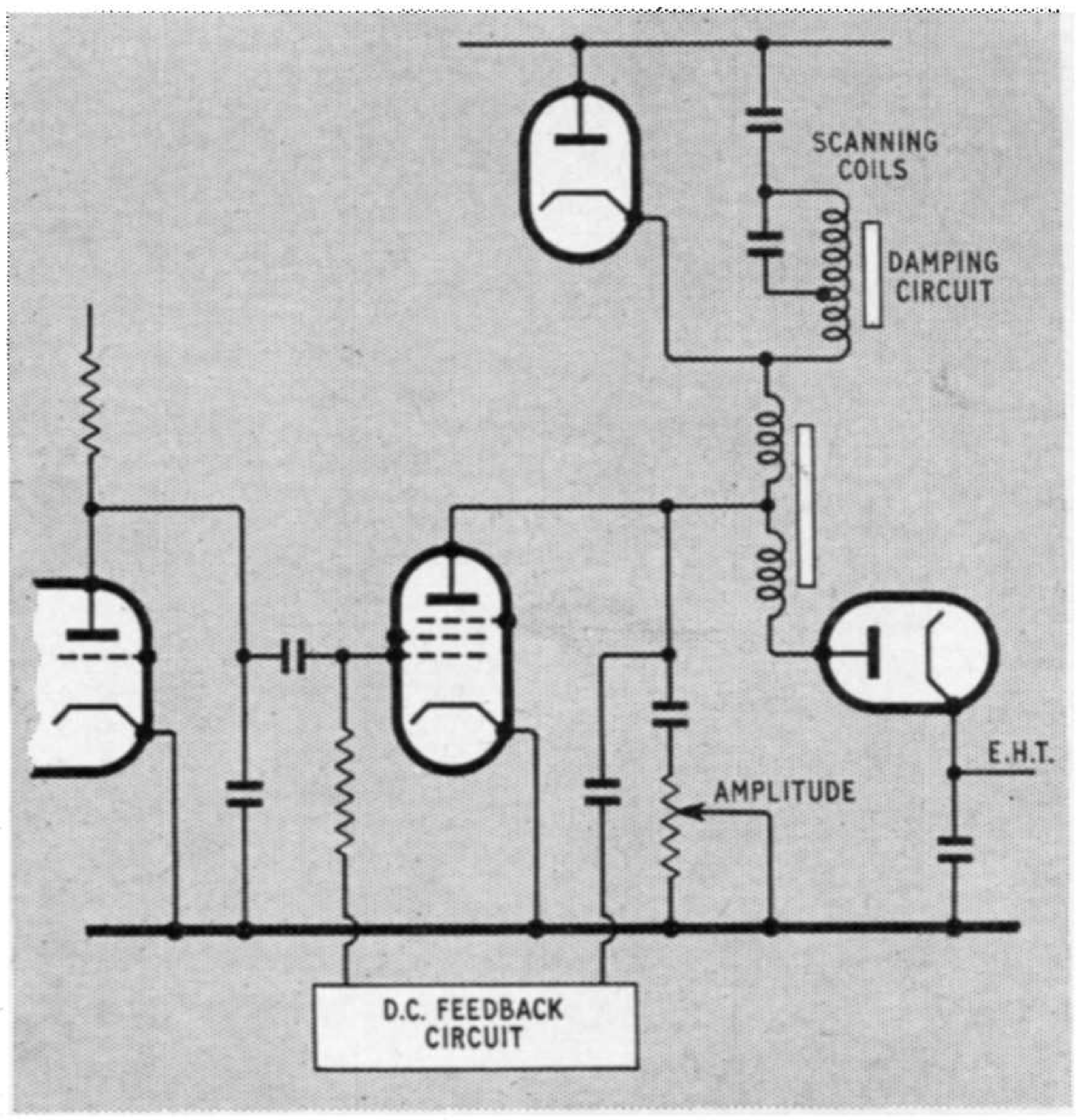
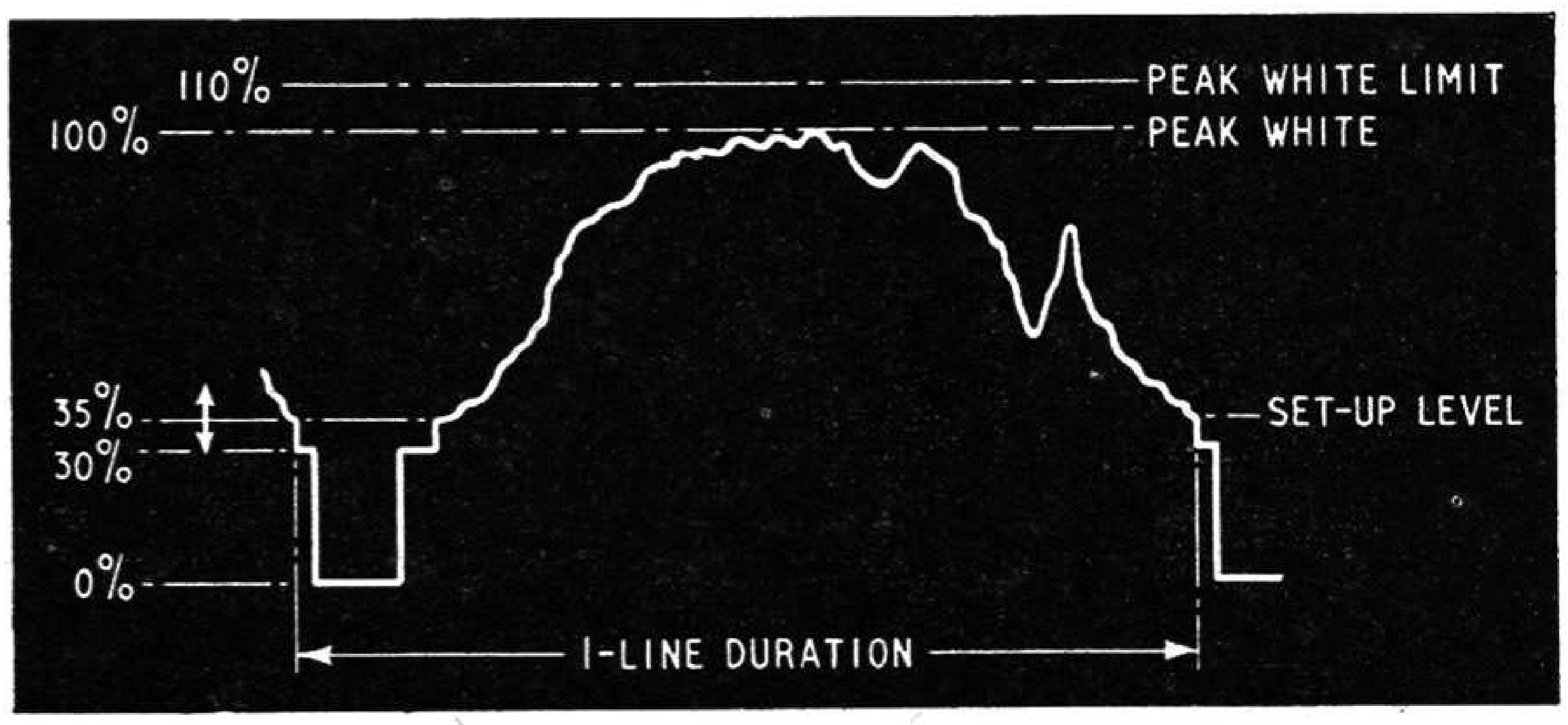


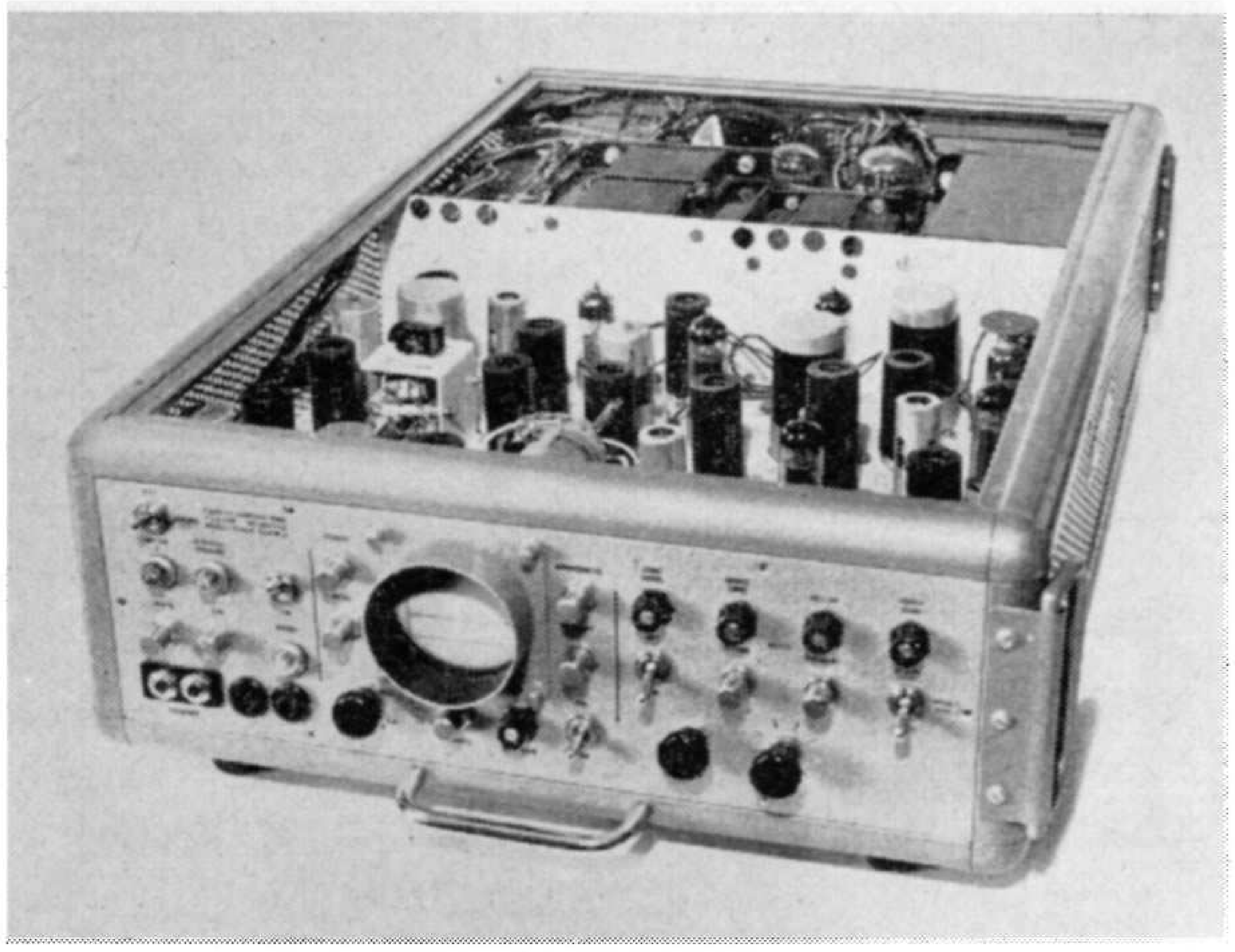
Fig. 6. *Simplified circuit of viewfinder line time-base circuit*

Fig. 7. *Composite waveform*



The first valve stage of the picture signal chain has, in the cathode circuit, switched compensation for camera cable high-frequency losses. A further section of this switch is used to adjust the tappings on the delay line used to provide compensation for camera cable delay. When 1,000 ft of camera cable are used, the total time delay in both directions is approximately $3\frac{1}{2}$ μsec. In order that the relative pulse timings at line-scanning frequency remain the same for shorter lengths of cable, artificial delay must be added to keep the total delay constant. It has been found adequate to provide compensation for camera cable length in steps of 200 ft up to a total length of 1,200 ft. The total delay of the delay line is 5 μsec to enable correctly timed clamping pulses to be formed. This is shown at V_{10} and V_{11} in Fig. 8. The camera picture signal is amplified further by V_2 before being clamped by V_9, which is a line-by-line two-diode clamp.

The simple gamma correction required is provided by a diode circuit in the cathode of V_3 and is shown in Fig. 9 (a). This provides an increase of 6 dB gain in the black region of the curve in Fig. 9 (b). The resistor values in the circuit are chosen to ensure that the knee of the curve is not sharply defined but is rounded. Adjustment of the bias controls the position of the knee on the curve. This is normally set so that the knee



Camera control unit with top cover removed

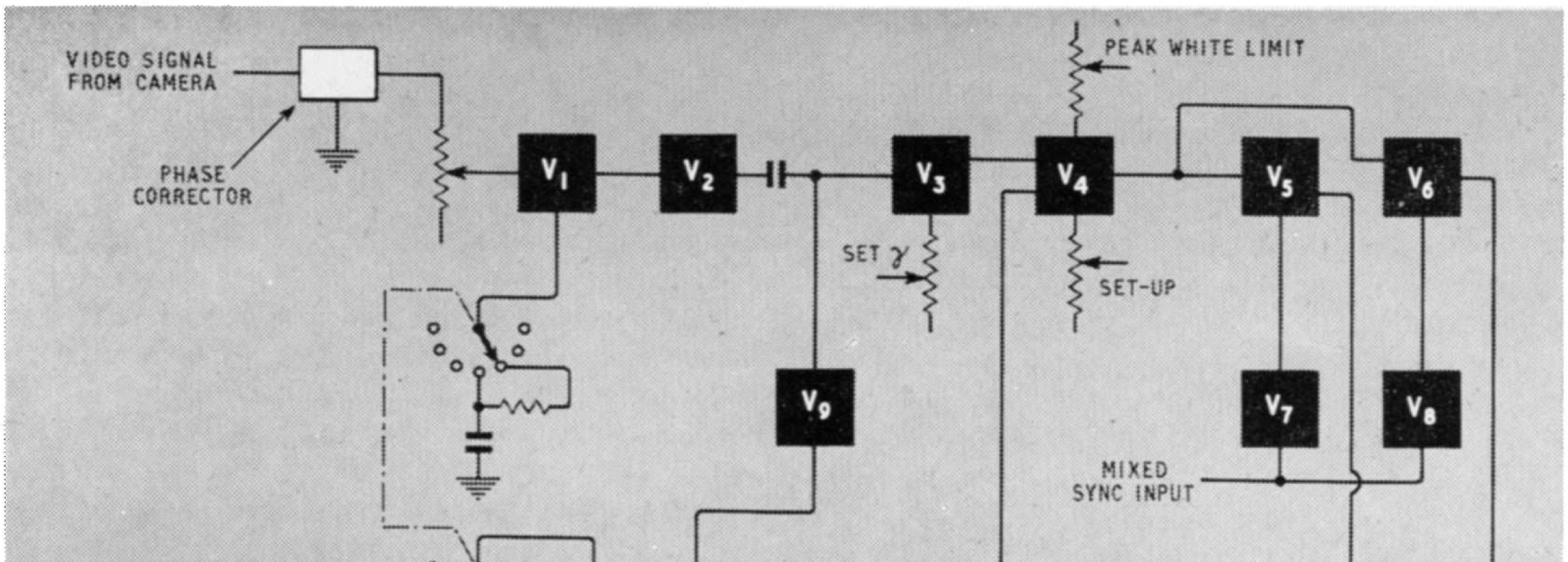
corresponds to 20% of the peak-white output current. Removal of the bias ensures that the diode does not conduct, so that no change of cathode impedance occurs over the working range of the input voltage. Gamma correction is, therefore, inoperative under this condition.

The method used for mixing system-suppression or blanking pulses into the waveform has been described by the author previously, but additional components have been added to provide control of set-up of black level as shown in the waveform of Fig. 7. This circuit is shown in Fig. 10. The black level of the positive-going picture signal fed to the control grid of V_3 is clamped to a bias level which is adjusted by the black-level control. Current over the curved part of the I_a/V_g characteristic of the valve V_3 flows through R_4, so that the black level control is set to the point where the picture signal black level just causes current to flow through D_2 and so adds to the current of V_{4b}. This eliminates black level compression of the picture signal due to the switching process of the mixed suppression pulses fed into the grid of V_{4a}.

It can be seen that, when the diode D_2 is passing no current, some current still flows through R_5, which is switched regularly by V_{4a}. The output signal black level, therefore, contains a 'set-up' which can be controlled by the potential to which R_5 is returned. This potential is adjustable between 0–10% of the output composite waveform.

A conventional series-diode limiter is used in the anode of V_{4b} as a peak white limiter, the output signal being fed into two output stages, providing an output impedance of 75 ohms. At these points are added the synchronizing waveform, which has been clipped and amplitude stabilized by the valve stages V_7 and V_8. The line drive waveform to the camera is derived from the tapped delay line and is 8 μsec in duration.

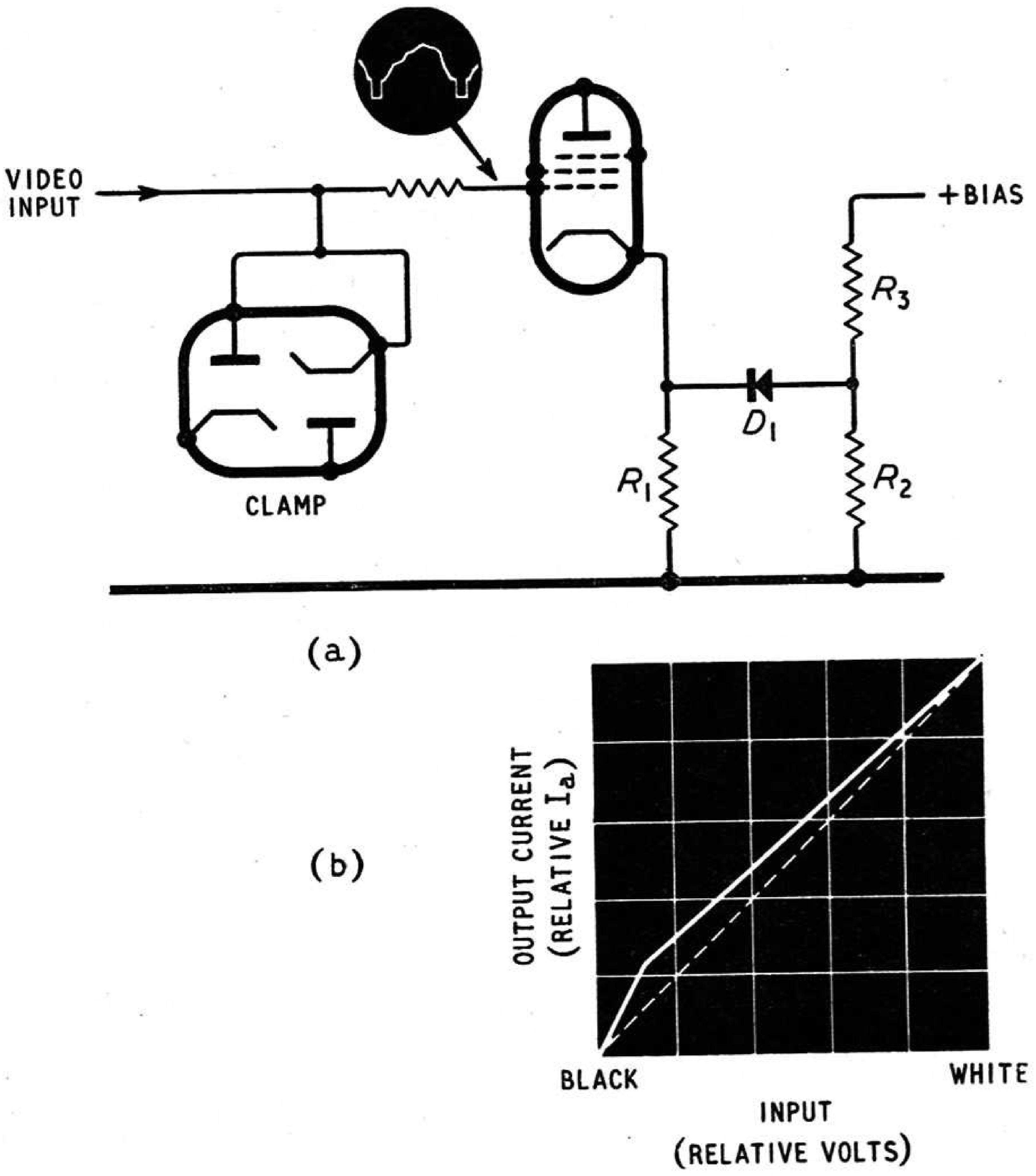
Fig. 8. *Schematic diagram of camera-control chassis showing the principal controls*



As indicated in the section dealing with the camera tube, it is necessary to delay the frame trigger pulse to the camera by 2 or 3 lines duration. It was shown earlier that this pulse is used as part of the camera tube suppression waveform and must, therefore, be of 9 to 10 lines duration. The frame drive waveform available from a synchronizing generator is of 4 lines duration and coincident with the leading edge of frame suppression pulse, and the above functions to this pulse are performed by a double-triode valve stage V$_{14}$. This stage is a Schmitt trigger circuit with a large input voltage 'backlash'. The two voltages at which a change of state occurs are widely separated. On the input grid is an integrating network to which is applied the input frame trigger pulse. The constants are arranged so that the first change of state occurs after two lines duration from the beginning of the input pulse and the circuit automatically recovers another 9 lines duration after. The output pulse is fed to the camera at 75 ohms impedance.

The camera-tube beam-focus coil current is adequately stabilized by a pentode valve stage with a large cathode resistor across which is a regulated voltage. The extremely large anode impedance of the valve prevents any change of focus current due to change of focus coil resistance with temperature. The beam focus control adjusts the value of this current.

Fig. 9. *(a) Simple gamma corrector; (b) characteristic of (a)*



Other circuitry on this chassis consists of conventional voltage stabilizers providing some of the voltages necessary throughout the camera channel.

Waveform Monitor

The waveform monitor has been designed to display the composite video waveform of either output from the camera control chassis on a $2\frac{3}{4}$-in. diameter cathode-ray tube.

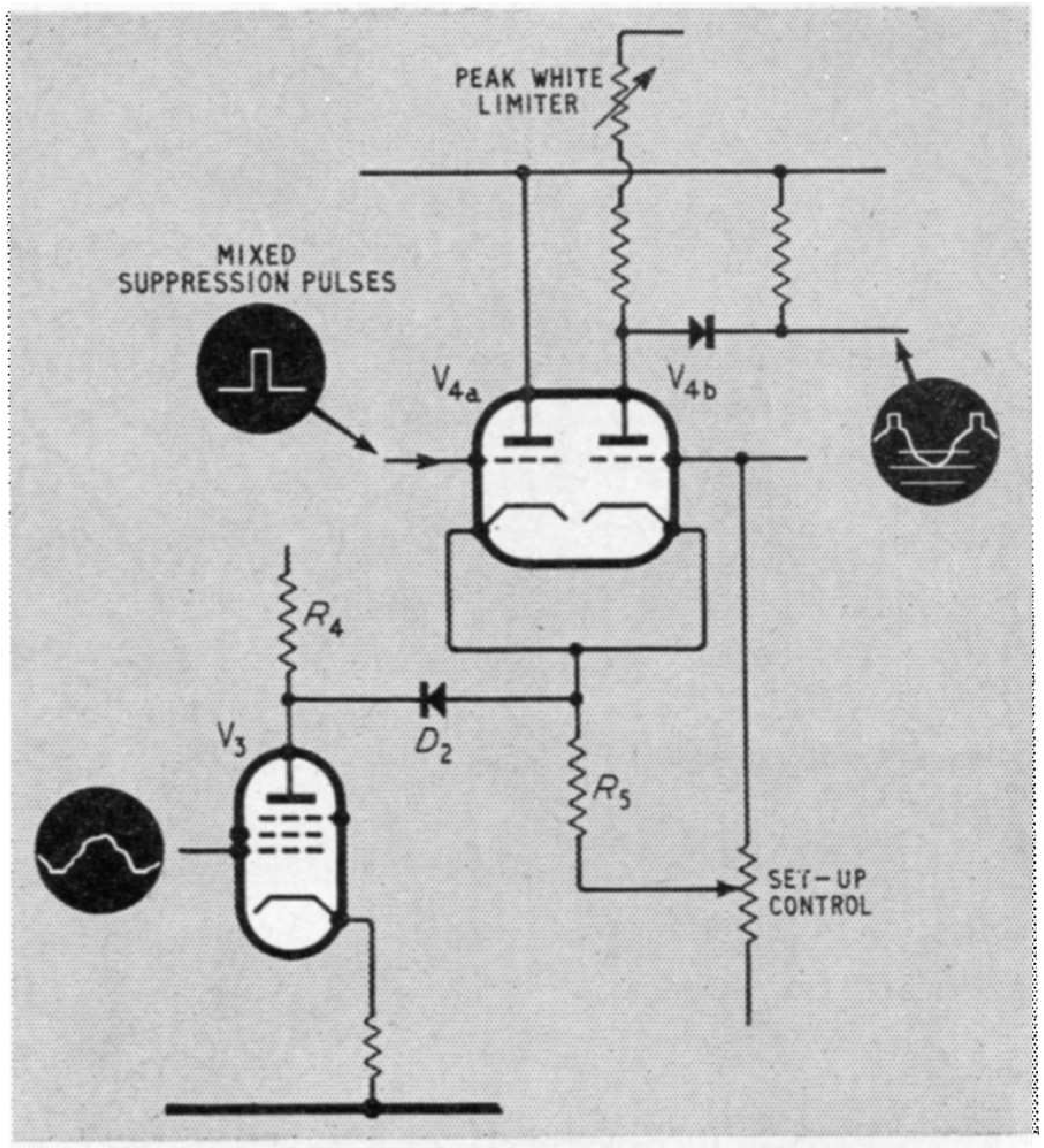


Fig. 10. *Simplified suppression-insertion circuit*

The time-base has been arranged to show (a) one complete frame period, (b) the frame suppression period, (c) one complete line period and (d) the line suppression period. This has been achieved by a triggered time-base using a Miller run-down circuit, with direct coupling between screen grid and suppressor grid. The potentials are arranged so that the circuit has one stable state. Fig. 11 is a simplified circuit of this time-base. It can be seen that V$_1$ is the Miller run-down stage, directly feeding into the cathode follower V$_2$, which provides fast recovery of the circuit after the run-down has been completed by virtue of the large charge current it can supply to the capacitor *C*. The potentials at the anode of V$_1$ and the cathode of V$_2$, when either valve is cut off, are used to limit the start and finish of the run-down and, therefore, keep the sawtooth amplitude constant. Consequently, once the run-down has been initiated by the appropriate trigger pulse, the time duration is determined by the values of *R* and *C*, the circuit quickly recovering to its initial state. The phase inverter V$_3$ is used to provide the inverted sawtooth required for push-pull operation of the cathode-ray tube.

The cathode-ray tube used requires approximately 120 volts peak-to-peak of video signal in push-pull to its Y deflecting plates for correct presentation. This level is provided by an amplifier with a large amount of negative feedback to stabilize the gain, as shown in Fig. 12. It can be seen that the output signals are d.c. restored at the Y plates. Calibration of the waveform monitor is achieved by the use of a scaled graticule and a 50-c/s calibration voltage derived from a bridge circuit having non-linear elements in two arms. This bridge reduces the effect of input voltage changes by 20 to 1 referred to the output. The cathode-ray tube has a stabilized e.h.t. supply, the voltage of which is adjusted during the calibration process.

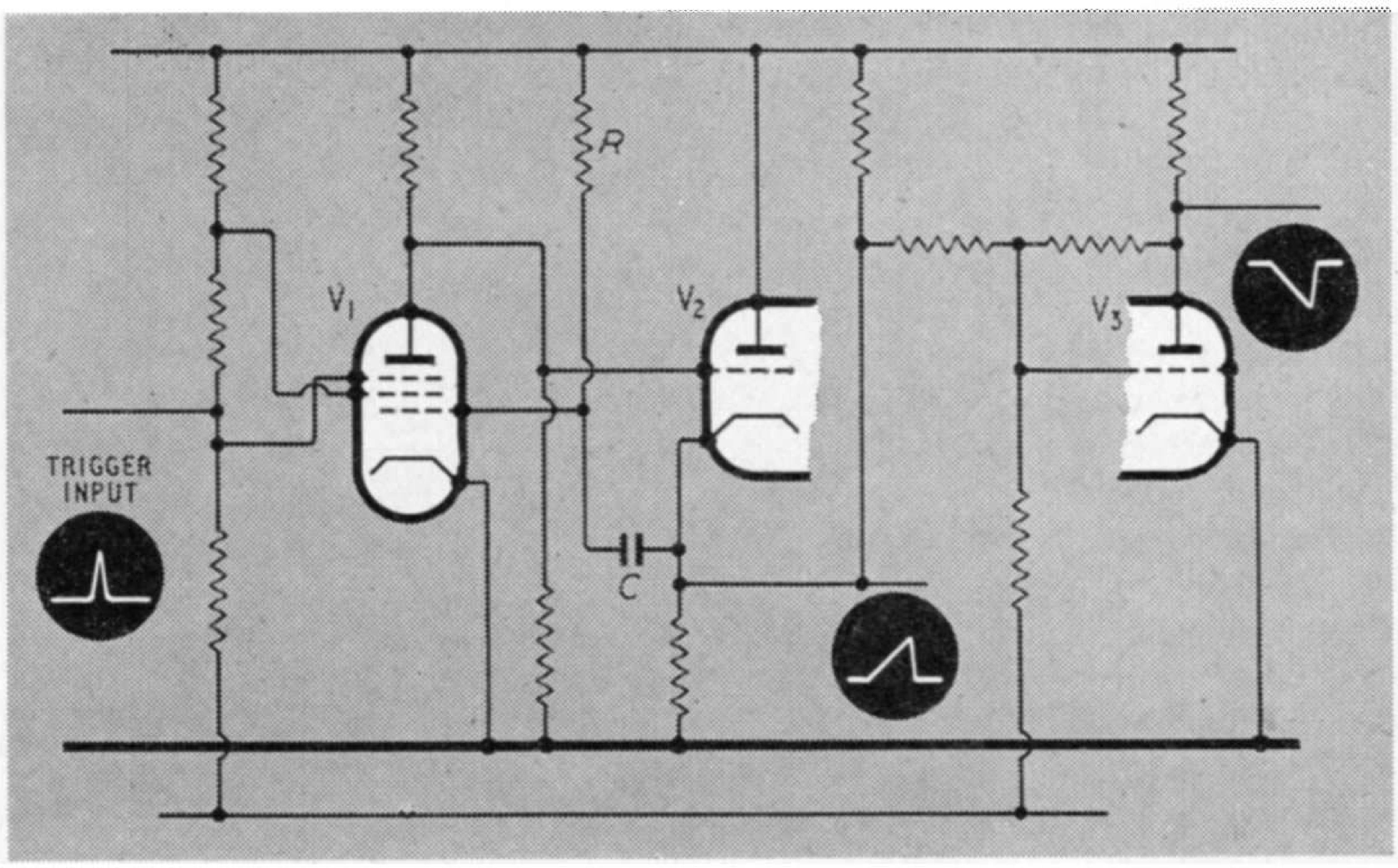


Fig. 11. *Skeleton diagram of waveform monitor time-base*

Normal operational controls, such as brightness, focus, astigmatism, are mounted on the front panel, while other controls, such as X and Y shifts, calibration switch and control, are mounted under the lift-up lid for use during calibration of the camera channel. This procedure reduces the risk of mistakes being made during operational use.

Communication Circuits

These circuits are located on the waveform monitor chassis, and consist of a double triode providing two isolating microphone amplifier stages. One amplifier provides amplification of the camera microphone signal and is distributed to camera control operator and to producer; the other stage amplifies the signal from the camera control microphone and feeds to the camera. Talkback from the producer and the programme sound is also taken in and fed to camera and camera control unit. A headset jack and volume level controls are on the front panel.

A cueing light, normally operated from a vision mixer, is provided on the front panel, the same switching line being fed to the camera cueing lights. Also on the front panel are an internal cueing switch, used when only one camera is in operation, and the camera-to-camera control call-light.

Power Supplies

All the d.c. potentials used throughout the camera channel are carefully stabilized against mains input variations, all the output voltages being referred to the main h.t. supply of 285V. Little need be said about these circuits, as they are more or less conventional. The power supply chassis is cooled by a blower fitted to the rear of the unit. The camera channel load is approximately 600VA.

Performance

The methods used of evaluating the performance of a television channel have been well discussed in literature[7,8] so that only the results are given here.

Definition

Sufficient aperture correction has been used to ensure that the response to 3-Mc/s bars at the centre of the picture is within — 1 dB of a black-to-white transition. The 3-Mc/s response at the corners of the picture will involve losses due to optics and electron-optics used. The corner loss due to the optics can be reduced to a small amount by stopping down the lens. This was done to enable measurements to be made of the losses due to the scanning assembly and the camera tube used.

The average results of a number of tubes show that, if care is taken with beam alignment, then the maximum average amplitude loss of the 3-Mc/s bars at any corner need not be more than 3 dB relative to a black-to-white transition in the corner.

Scan Linearity and Geometry

These measurements were made with a cross pattern test transparency and synchronous electronic grid pattern. With a good camera tube, it has been shown that it is possible to set up both scanning linearities and raster geometry to within a positional error of $\pm \frac{1}{2}\%$ of the picture width, so that the requirement of $\pm 2\%$ positional error is easily satisfied.

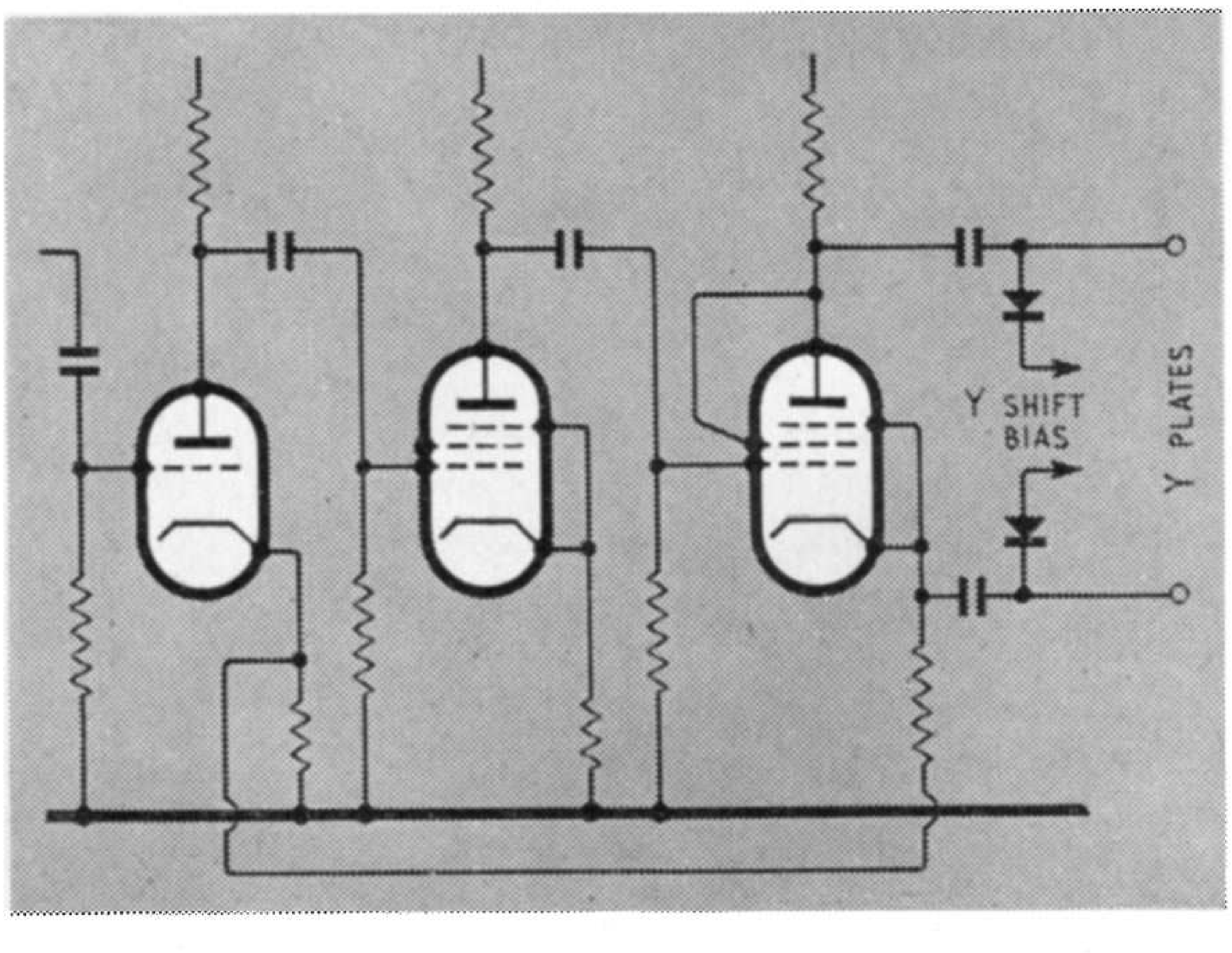
Signal-to-Noise Ratio

This has only been checked by the oscilloscope method but, at a video gain value required to produce a 0·7-V peak white signal at the output of the channel from a camera tube signal current of 0·2 μA, the peak signal to peak-to-peak noise has been measured at approximately 20:1.

Sensitivity

Because of 'lag' and 'flare' this parameter is very difficult to specify, being dependent largely on the type of scene being televised. Very good outside broadcast

Fig. 12. *Basic form of waveform monitor Y-amplifier circuit*



pictures have been produced of a low contrast scene, of motor cars travelling along a main highway at late evening, where the estimated high-light level has been approximately 20–30 ft/L.

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