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A. N. HEIGHTMAN, A.M.I.E.R.E, and W. T. UNDERHILL, Assoc.I.E.R.E

A NEW FOUR-TUBE COLOUR TELEVISION CAMERA

INTRODUCTION

MR N. N. PARKER-SMITH has given the reasons for the choice of a four-Plumbicon or four-vidicon arrangement.[1] The camera, which has been designed to produce both colour and black-and-white pictures of high quality, has to be stable in performance and to be comparable with modern black-and-white cameras in sensitivity, flexibility and ease of operation. This article covers the features of the camera channel together with some details of the engineering aspects of the design.

GENERAL

The Mark VII Colour camera (Fig. 1) employs four Plumbicon tubes in a Y.R.G.B arrangement, giving a separate luminance signal and red, green and blue colour signals. The advantages in having a separate tube for luminance are well known. They are, briefly, that a high-quality luminance signal is obtained, both for the colour and the compatible black-and-white picture, that is not dependent on image registration. In addition, the dominating influence of the separate luminance signal on the reproduced luminance in the picture greatly reduces the visibility of tube blemishes and similar errors originating in the colour channels.[1]

The camera is primarily intended for use with zoom lenses, and a relay optical system is employed that enables standard 40 mm image orthicon lenses to be used. It can operate on either the 625- or 525-line standards, and in conjunction with external encoding equipment for any of the proposed colour television transmission systems. The complete camera channel comprises the camera itself, the camera control unit (C.C.U) (Fig. 2), which includes the main control panel, and the power supply unit (P.S.U). In addition, a simple operational control panel (O.C.P) is available. All the active circuit elements are semiconductor devices except for one valve in each head amplifier and a corona regulator in the power supply unit. Altogether the camera channel employs 500 transistors, of which half are in the camera.

'Hands-off' Operation

The high operational stability achieved in the design of the Mark IV and more recently in the Mark V[2] black-and-white cameras has encouraged many broadcasting organizations to adopt the simplified operating technique which is usually called 'hands-off' operation. In 'hands-off' operation the camera channel setting-up adjustments are carried out at the main C.C.U control panel, and control is then switched to a simple operational panel containing only those adjustments necessary to obtain the desired artistic effect: Iris, Master Black and Master Gain. The small size of the operational control panel permits a number to be mounted closely together so that several cameras can be under the supervision of one operator. These panels can be located in production areas, whilst the camera control units can be concentrated in a central technical area.

Black-and-white Operation

The camera has been designed so that it may be quickly converted to full-sensitivity black-and-white operation, employing the luminance channel only. Since the luminance channel is, in effect, a high-quality black-and-white camera, it has been possible to provide this facility without adding significantly to the basic colour camera. All the usual facilities of a modern black-and-white camera are present, and a simple change in the optical system enables all the incoming light to be directed to the luminance tube for full sensitivity. During black-and-white operation the heater supplies to the colour pick-up tubes can be switched off, thus avoiding unnecessary waste of tube life.

Telecine

Vidicon tubes are at present preferred for film cameras where the higher light level available enables an acceptable performance to be obtained in respect of lag and dark-current. An advantage that the vidicon has over the Plumbicon for this purpose is that control of sensitivity can be obtained by variation of the target voltage. This is useful in automatic video level control, a facility often necessary to avoid the need for continuous adjustment by an operator during film transmission, and provision has been made for the camera to operate with automatic target voltage control from an external unit. This will normally be associated with automatic control of the projector light source. Since the vidicon and Plumbicon are both photo-conductive tubes and have similar external circuit requirements, only minor differences exist in the camera and C.C.U circuits for the 'live' and telecine versions. These include, for example, changes to the gamma-correctors. For shading correction an additional external unit is available which connects to the C.C.U. By adjustment of the optical system the correct image size for the vidicons can be obtained, and the deflexion yokes can be adapted by a simple modification to accept vidicon instead of Plumbicon tubes.

Camera Cable

Present-day operational requirements have made it necessary to design the camera so that it can be used with up to 2,000 ft (600 m) of camera cable. This demands a cable with large conductors to avoid loss of voltage and for the camera channel stability not to be adversely affected by conductor resistance and the effects of temperature. For studio use, however, it is advantageous for the cable to be as light and as flexible as possible. So that both requirements can be satisfied two cables are available. The lighter and more flexible cable is intended for use in studios or in similar situations in lengths of up to 500 ft (150 m), and the heavier cable for permanent installations or where greater lengths of cable are required.

Monitoring Facilities

To ensure that the full performance can be readily obtained under operational conditions, comprehensive facilities have been provided for the monitoring of signals to aid the setting-up and operation of the camera channel. By means of two independent groups of switches, one for picture and one for waveform display on the C.C.U control panel (Fig. 3), the desired signals may be selected and fed out to a picture and waveform monitor. The pictures from each of the four tubes can be displayed independently, or combined in either polarity. This facility enables signal subtraction to be used as a precise indication of image registration.

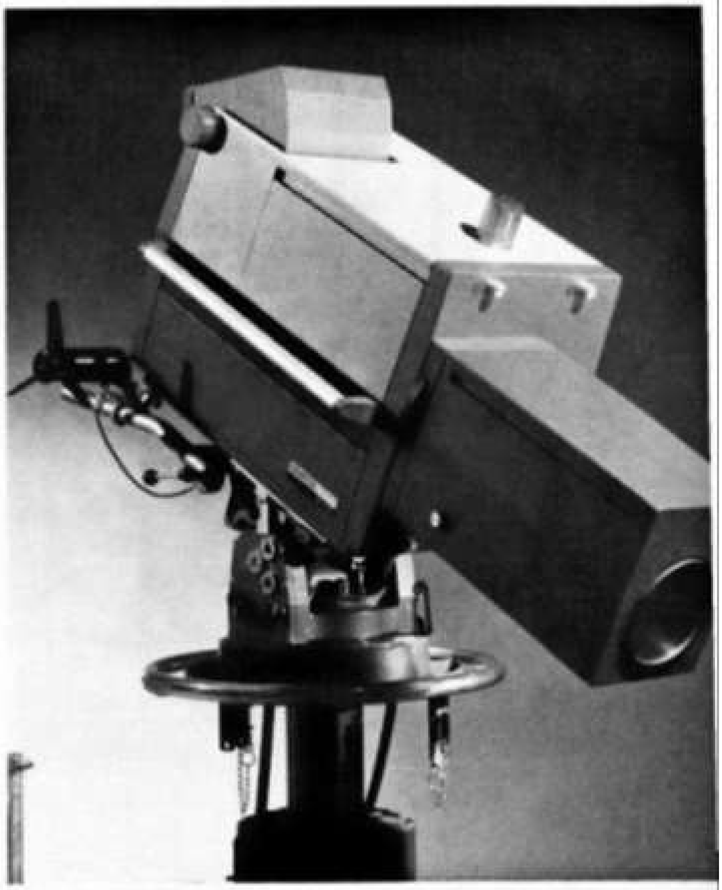

Fig. 1. The Mark VII colour camera using four photoconductive tubes in a Y.R.G.B. arrangement.

The waveform monitoring switch enables the video signal at important points in the video chain to be selected and displayed on a picture and waveform monitor. This has provisions for colour camera signals, and a triggering pulse fed to the monitor from the C.C.U enables the signals from corresponding points in the Y, R, G, and B channels to be displayed simultaneously. The sequential electronic switching of the signals is carried out in the C.C.U.

A further facility, which greatly aids the rapid setting-up of equal gains and amplitude characteristics in the four channels, is the provision of 'bridging' switches. When operated, the corresponding circuit points in the four channels are joined together, and any difference in signal levels can be easily seen on the waveform monitor.

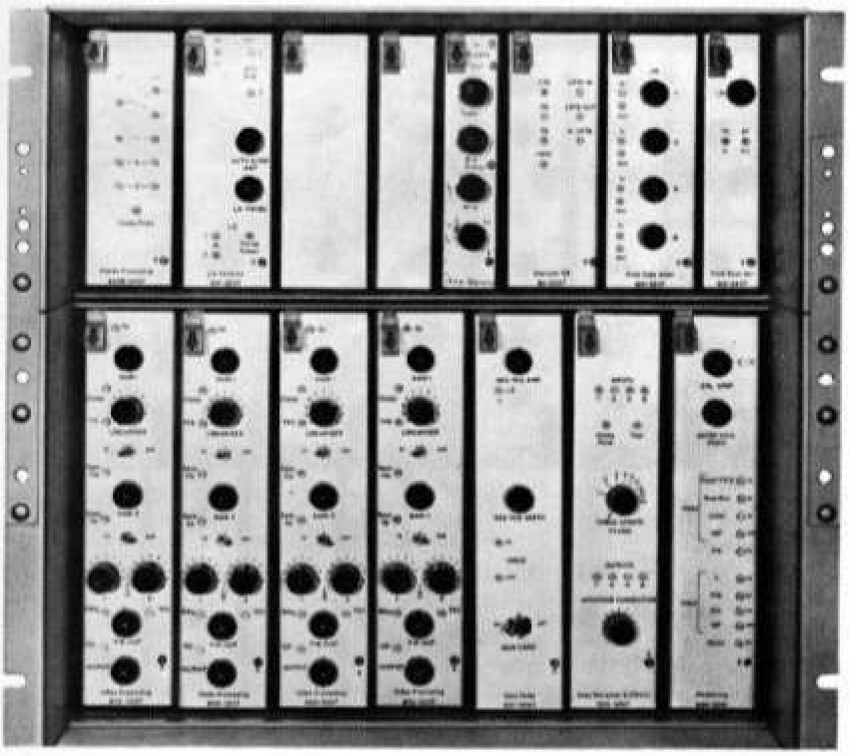

Fig. 2. The Camera Control Unit.

The monitoring facilities include a signal, derived from the four camera tube signals, containing only the maximum and minimum excursions of any of the four signals. This may be displayed on a simple oscilloscope at a remote operational control position. Thus the task of the video operator is eased, for in maintaining the correct signal excursions by means of the Lens Iris control and Master Black Level control, he need only observe one waveform display instead of four. All the monitoring signals can be displayed on the camera viewfinder for setting-up procedures in which the assistance of the cameraman may be required. Additionally, the viewfinder signals may be fed through a socket on the camera to an auxiliary monitor.

Test Facilities

Under control of the Test Switch on the C.C.U control panel, test signals from external sources fed into the C.C.U can be sent over the camera cable to the input of each camera head amplifier through a tube simulator circuit, or alternatively fed into the input of the C.C.U video circuits. An internal calibration waveform generator is also provided in the camera for use in setting the gain of the head amplifiers for the desired tube signal current. This is also controlled by the C.C.U Test Switch. An additional test input socket is fitted to the camera to permit the direct injection of signals into the head amplifiers when it is desirable not to pass the signal over the camera cable.

A meter on the C.C.U control panel and an associated selector switch enable all important supply potentials and focus and camera main supply currents to be quickly checked. To aid in the checking of circuit performance and the location of faults, test sockets connected to important circuit points are fitted on the front of each circuit module in the camera and C.C.U.

Viewfinder

The Mark VII viewfinder is of the type also used in the Mark V black-and-white camera. It employs a 7-in. (18-cm) flat-faced rectangular picture tube operated at 14·5 kV giving a bright high-definition picture with a highlight brightness of 200-ft lamberts. The viewfinder is self-contained and mounted on pivots with friction clamps which allow it to be tilted over a wide angle and locked in the most convenient viewing position. It can be detached and used up to 30 ft (9 m) from the camera. Controls for brightness, contrast, height and width are mounted below the picture tube, and a preset control inside the viewfinder case can be set to give an accentuated high-frequency response as an aid in the precise focusing of the camera.

A three-position switch is fitted at the rear of the camera for selection of the signal displayed on the viewfinder, which can be either the luminance channel signal, the signal selected by the Monitor (Picture) Switch at the C.C.U or a signal from an external source. The luminance signal will be displayed in normal operation, and for setting-up adjustments the monitor signal can be used. The external signal is fed into a socket at the C.C.U where a further switch gives the choice of either displaying the external signal alone or mixed with the luminance signal. These external signal facilities are primarily intended to help the cameraman align his camera picture in precise relationship to the picture from another camera, as is often necessary for special effects.

OPTICS

Lenses

The camera has been designed to use standard image-orthicon zoom lenses of 40-mm image diagonal and in particular those by Evershed Power Optics (Angenieux) and by Rank Taylor Hobson having a 10 : 1 focal ratio and apertures of $f/3{\cdot}8$ and $f/4$ respectively, equivalent to an aperture of $f/2$ of the Plumbicon image size. The range of focal lengths is approximately 1·6 to 16 in. (40 to 400 mm) and the corresponding range of angular field of view is 44° to 4·4°. Attachments are available to change the ranges of these lenses up to 4·8 to 48 in. (22 to 220 mm). They normally incorporate servo-control of zoom, focus and iris in the lens assembly, although mechanically operated versions are also available.[3] In each case the controls for zoom and focus are fitted to the panning handles attached to the camera pan-and-tilt head. The iris is remotely controlled from the camera control position, being the main operating control.

A zoom preselection unit (or 'shot box') is available for use with servo-controlled lenses, by means of which a number of zoom positions may be preset, the selected positions then being automatically obtained by operation of corresponding push-buttons.[4] By means of an adaptor the camera can also use a single fixed-focal length image-orthicon lens, a sufficient range of focusing adjustment for most normal purposes being provided in the camera.

Optical Filters

Two filter wheels are fitted, each having four positions, one for unobstructed light transmission and three into which detachable filter discs may be fitted. One of the filter wheels would normally be used for neutral density filters to extend the camera flexibility in respect of light levels and depth of focus. The other is intended for colour filters to accommodate variations in lighting colour temperature.

Internal Optical System

A relay optical system is employed to provide an adequate optical path length in which to accommodate the light-splitting systems, and also to permit a favourable disposition of the camera tubes. The primary image is of 40-mm diagonal size, the same as that of the image-orthicon tube, so as to allow a wide range of standard objective lenses to be used. The final images are, of course, of the correct Plumbicon size (or vidicon size in the case of the telecine adaption of the camera).

The two filter-wheels are between the external objective lens and the field lens. After the field lens is the luminance-chrominance light-splitting prism surface, reflected light passing to the luminance tube and the transmitted light to the chrominance tubes. An interesting feature of this surface, which helps in making efficient use of the incoming light, is that it

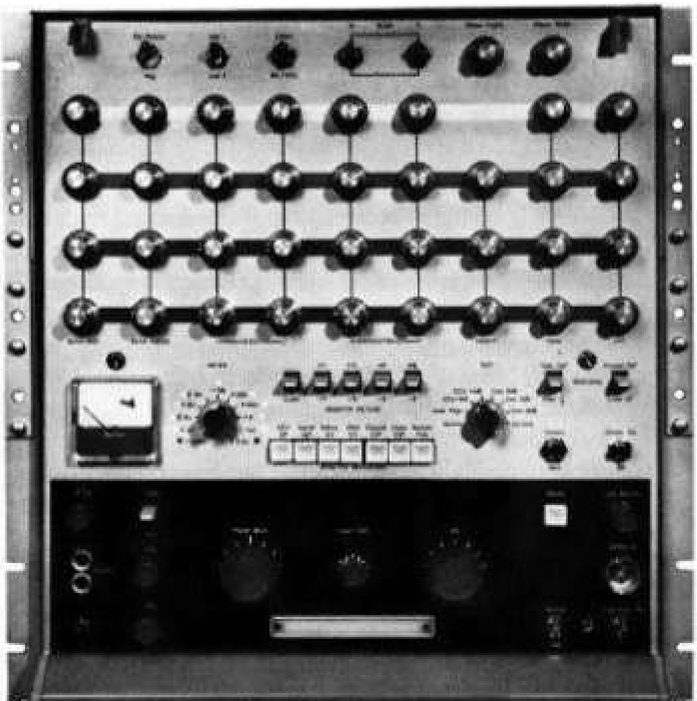

Fig. 3. The C.C.U Control Panel contains the controls required for the engineering and operational control of the camera channel.

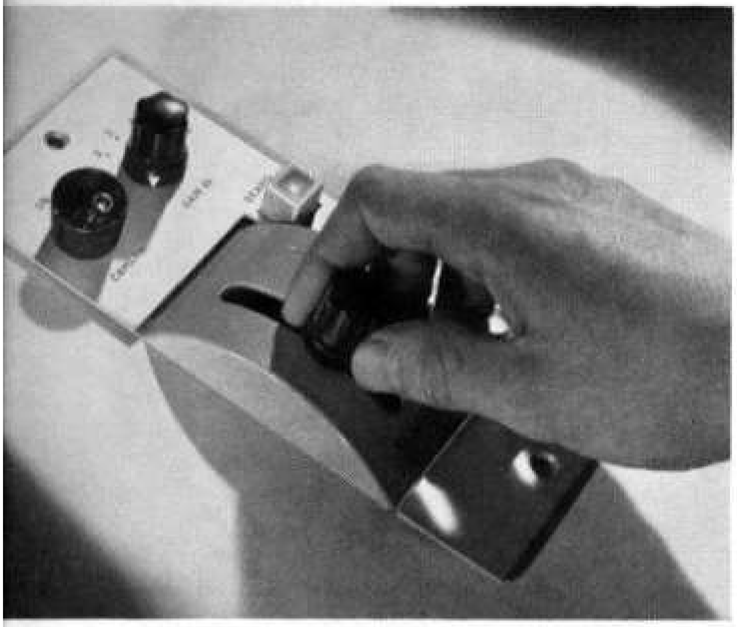

Fig. 4. The Operational Control Unit for the Mark VII.

serves, at the same time, as the luminance spectral response-trimming filter, so that only that part of the incoming light required for the correct spectral response is passed to the luminance tube. Additional light is thus available for the colour tubes.

The chrominance light is then split into the red, green and blue components by prism-type dichroic surfaces. This type of dichroic is superior to the plate type employed in some early cameras, being free from ghost images and astigmatism. A colour-trimming filter is included between the dichroics and each relay lens; a separate relay lens is in the light path to each tube. The design of the optical elements, including the relay lenses, is optimized over the spectral range appropriate to each light path.

For black-and-white operation a fully reflecting surface is moved into position in place of the luminance–chrominance light-splitting surface so that all the incoming light passes to the luminance tube.

CONTROLS

Camera

The only electrical controls on the camera used in normal operation are those associated with the viewfinder and those controlling the talkback facilities and are all at the rear of the camera.

C.C.U Control Panel

The C.C.U control panel (Fig 5) contains the controls required for the engineering and operational control of the camera channel. The camera may be operated entirely from this panel although it has been designed for 'hands-off' operation. The arrangement of controls on the C.C.U panel follows a logical pattern. The upper, light-coloured section carries setting-up controls, whilst the lower darker section contains operational controls. The four horizontal rows of controls in the upper section are those associated with the luminance and the three colour channels. The top row is for luminance, and above it is a group of controls mainly for black-and-white operation. Monitoring and test facilities are concentrated in the lower part of the light-coloured section. The three main operational controls, Master Black, Master Gain and Iris, are grouped in the centre of the operational section. The area at the left is occupied by communication facilities, and that to the right by the main channel switches.

Operational Control Panel (Fig. 4)

This can be located up to 500 ft (150 m) from the C.C.U and carries only the main operating controls, Iris, Master Black and Master Gain, together with switches for the channel mains supply, the camera-tube beams and camera-tube heater supplies. The latter switch enables the camera-tube heater life to be conserved during waiting periods without switching off the whole channel. The panel is small enough to permit four to be mounted side by side in a console desk for control by a single operator. For ease of operation the Iris and Master Black are combined in a composite lever control, the control knob for Master Black being fitted to the end of a lever which controls the Iris.

The stability of performance of the camera is such as not to require readjustment of the individual colour channel gain controls during transmission; some organizations, however, prefer to have the controls available at the operational position for correction of errors in colour in the scene, as for example, when light reflected from a coloured object in the set falls on the face of an artist. Provision has therefore been made for this requirement in the design of the camera, which also allows further controls to be available at a remote point if necessary.

Power Supply Unit

The front of the power supply unit carries only the main on–off switch and the cable-length control. This is set according to the length of camera cable in use and compensates for voltage drop over the cable.

PERFORMANCE

Sensitivity

The sensitivity of a television camera can be defined in terms of the amount of light required at a given depth of focus to produce an output signal of a certain signal-noise ratio. In the design of the Mark VII camera particular care has been taken to eliminate all avoidable losses in light transmission through the optical system, and to reduce the noise contributed by the first stage of the head amplifier. In order to achieve the best possible noise performance one Nuvistor valve is employed in the first stage of each of the four head amplifiers. The choice of a valve here, the only one used in the camera channel, is necessary because no transistors are at present available having an adequate low frequency noise performance.

The camera sensitivity obtained in practice will depend, of course, on the sensitivity of the particular pick-up tubes in use, and on other factors which may vary slightly from camera to camera. Assuming the use of average tubes, the following gives an indication of what sensitivity may be expected:

Illumination: 230 ft-candles (2,500 lux)
Scene highlight reflectance: 60%
Illumination colour temperature: 3,000°K
Lens aperture: *f*/8
Peak/peak signal to r.m.s noise ratios (unweighted):
Luminance channel: 40 dB
Red channel: 36 dB
Green channel: 44 dB
Blue channel: 37 dB

The figures relate to the linear condition, that is, without gamma correction, and also assume that the aperture corrector in the luminance channel has been set so as to give an effective modulation of 100% at 400 lines per picture height. With the iris opened to *f*/4 and the Master Gain increased by 6 dB an acceptable picture can be obtained with 30 ft-candles (325 lux) illumination. The noise figures are for a bandwidth of 5·5 Mc/s in the luminance channel and of 1·8 Mc/s in the colour channels. By adjustment of the head amplifier the bandwidth of the luminance channel can be increased to 6·0 Mc/s, with a reduction of approximately 1·5 dB in signal/noise ratio.

Resolution

The resolution of the luminance channel is such that only a small amount of aperture correction is required with an average Plumbicon tube to obtain 100% modulation at 400 lines. This is achieved by careful design of the deflection yoke and by operating the tube with the relatively high-focus electrode potential of 750 V. The vidicon tubes used in the telecine version of the camera are operated at 1,000 V and give a similar or slightly better resolution. The video bandwidth of the channel exceeds 5·5 Mc/s and thus imposes no limitation on resolution. In the colouring channels the resolution that can be realized is limited by the comparatively narrow bandwidth of the chrominance transmission channels, and it is permissible therefore to operate the Plumbicon tubes at a focus electrode potential of 250 V.

Image Registration

The outstanding advantage of the four-tube camera, both from the user's and the designer's point of view, is the high quality of the luminance signal and, being obtained from a single tube, this is unaffected by image misregistration. Further, since the signals from the colour tubes do not contribute to the luminance signal, the registration of the colour images is not required to be as precise as in a three-tube camera. Even with this relaxation the accuracy of registration necessary in a four-tube camera is still very high. It is desirable, in fact, for the relative image displacement to be no greater than 0·1% of the picture width. In the Mark VII Camera a registration accuracy of 0·05% can be achieved in Zone I (the central area covered by a circle of diameter 0·8 of picture height). No readjustment of controls to restore registration should be necessary during the course of a day's operation, and probably longer, during which time there may be changes in ambient temperature and in the voltage of the a.c mains supply.

It will be clear that this performance demands a very high standard of design and manufacture. On considering the many factors on which correct image registration is dependent, it will be appreciated that the permissible variation of any one of them is extremely small. To illustrate this, the following are some of the factors which can contribute to a relative movement of a point in the image from a pick-up tube:

1. Scanning current amplitude
2. Scanning current linearity
3. Centring current
4. Beam alignment current
5. Focus coil current
6. Focusing potential.

Unwanted variations of each of the currents listed above may occur as a result of changes, due to temperature or other causes, in the following:

1. Resistance of the coil
2. Resistance of the camera cable
3. Resistance of the adjusting controls
4. Source voltage.

Since the centring and beam alignment currents may be of either polarity in each yoke, the absolute stability must be very high because any change that affects the currents similarly will cause the images to move in opposite directions.

These factors have been studied in great detail and some of the methods adopted to ensure the necessary circuit stability are described later. Amongst other factors which can adversely affect registration are unwanted movement in the optical system and the effects of stray external magnetic fields. Thus to ensure stability of the optical system both the fixed optical components and the deflexion yokes are rigidly attached to a substantial aluminium plate, mounted vertically in the camera (Fig. 5). The pick-up tubes are in turn firmly supported within the yokes. To prevent external magnetic fields from causing spurious deflexion of the camera tube beams the yokes are doubly screened. In addition, the optical system has been designed so that the longitudinal axes of the camera tubes are substantially parallel to each other, and at the same time the orientation of the images is similar. With this arrangement any residual deflexion caused by external magnetic fields tends to be in the same direction in each tube, thus preserving registration.

Colour Balance

Particular care has been taken in design to ensure that correct colour balance can be obtained and maintained for long periods without the need for readjustment. This requires that the four channels are matched very closely and stably in amplitude characteristic, and the design objective has been to match the characteristics to within 1% over the greater part of the dynamic range. Since all the video amplifiers and particularly the gamma-correctors in each video chain can influence the amplitude characteristic, special circuit techniques have been employed throughout. Some of these are referred to later.

Geometry

The achievement of good picture geometry (the correct placing of points in the two-dimensional picture plane) requires good deflexion and focusing yoke

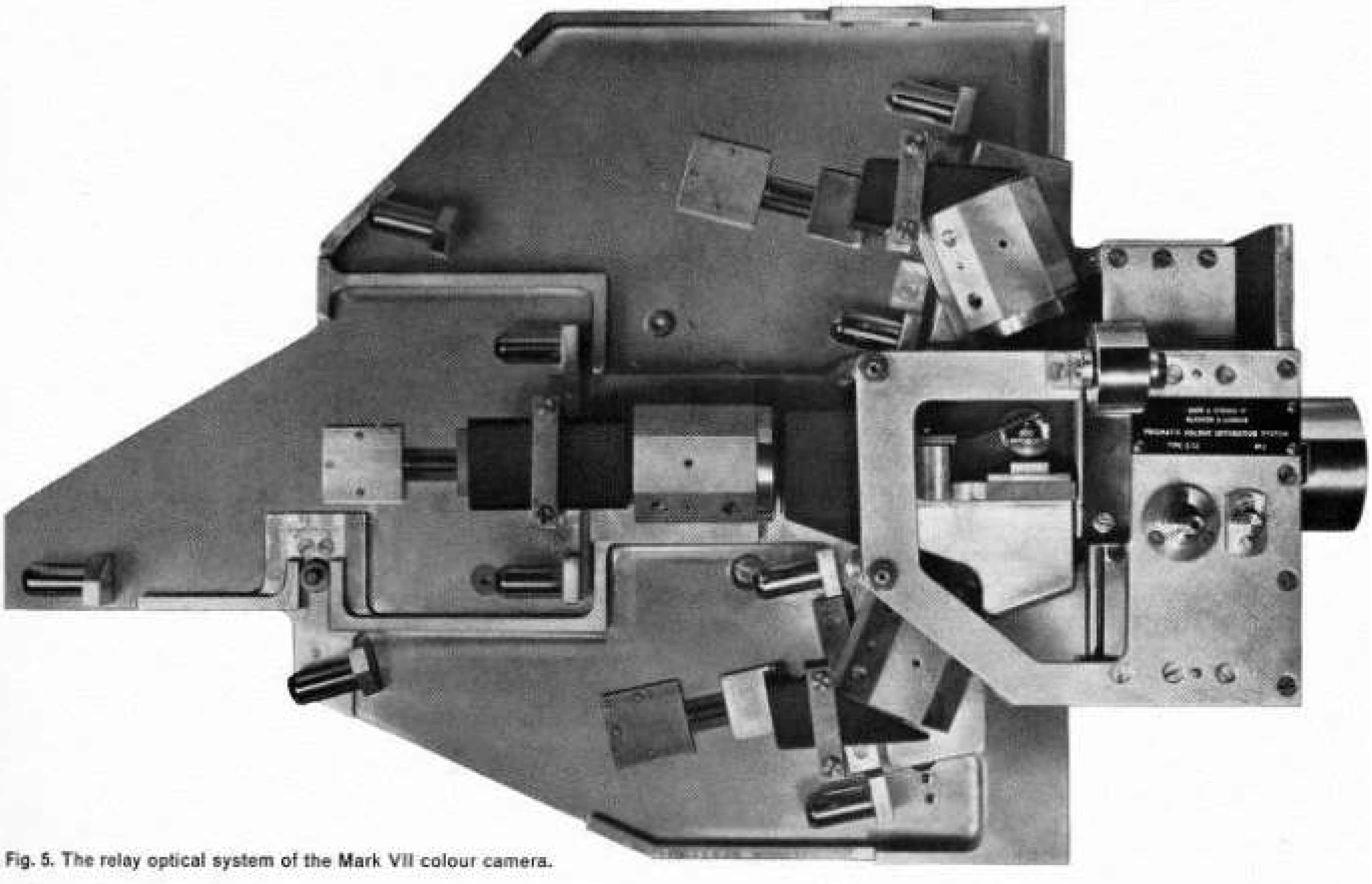

Fig. 5. The relay optical system of the Mark VII colour camera.

design in order to obtain a truly rectangular image. A high degree of linearity of the line and field scanning currents is also needed, in order that points within the rectangle shall be correctly placed. Both these aspects have received close attention in the camera design.

Amongst the many details of yoke design that could be mentioned is the need to eliminate coupling between the field and line deflector coils. Such coupling can cause spurious deflexion which makes good geometry very difficult to achieve. Having satisfied this requirement there remains the skew, or uniform non-rectilinearity, of the raster due to the unequal effective axial lengths of the two deflecting fields. This is satisfactorily corrected in the Mark VII camera by controlled injection of field-scanning current into the line deflector coils.

Whilst geometry is not necessarily required to be better in a colour camera than in a black-and-white one, good geometry must be achieved in a fundamentally sound manner that ensures a closely identical and unchanging performance in each of the four images, otherwise image registration will be adversely affected. The geometry in fact achieved in the Mark VII camera is such that, over the greater part of the picture area, the location of picture points is within 1% of picture height of their correct positions, and any errors do not occur abruptly.

CONSTRUCTION

Camera

The main structural framework of the camera, consisting of base, front, middle and rear sections, is made from milled magnesium alloy plates. The basic case can be adapted for both live and telecine operation by using one of two different front sections, which are bolted directly to the front of the camera. In the case of the live camera the front section, which is also made from magnesium alloy, provides the mounting surface for the zoom lens or single lens adaptor and contains the two filter-wheels for colour and neutral density filters. There are also mounting holes provided in the front for accessories such as prompting devices, etc. The front section for telecine operation provides a mounting surface for an optical multiplexer if required, and also carries two of the three adjustable feet by which the camera is attached to the telecine pedestal, the third being at the rear of the camera.

Sheet-metal side-covers, which are pivoted at the top and bottom of the camera, open out to give complete side-access to the interior. The lower covers also incorporate sturdy lifting handles which run the full length of the camera body.

The complete optical assembly of prisms and relay lenses, together with the four camera tube deflexion yokes, are mounted on a substantial aluminium alloy plate. This whole assembly is enclosed in a dustproof cover and is mounted upon two stainless-steel tubes which run from the front to the rear of the camera and are rigidly attached to the main framework. A lead screw provides longitudinal movement of the optical assembly along the stainless-steel tubes to provide the necessary focusing movement. It is possible to adjust focus from outside the camera. In the case of the zoom lens this is used for presetting of focus, but when a single-lens adaptor is fitted the lead screw can be driven by a Teleflex flexible control cable, with an operating wheel fitted to the camera panning handle.

The viewfinder is fitted at the rear right-hand side and is quickly removable to give access to one of the colouring yokes for tube changing. To the left of the viewfinder is fitted a small control panel carrying the talkback controls, and underneath this is a large door which provides access to the line-scan and power-supply units and the remaining three yokes.

The weight of the camera, without the zoom lens but including the viewfinder, is 160 lb (72 kg). The overall dimensions of the camera body are 26¾ in. (67 cm) long, 19¾ in. (50 cm) high by 13 $\frac{7}{16}$ in. (34 cm) wide.

Camera Control Unit

The C.C.U (Fig. 2) is designed for mounting in either 19-in. (48-cm) standard equipment racks or consoles and occupies 19¼ in. (49 cm) of rack height. It consists of two frames, containing the plug-in circuit modules, mounted one upon the other. The upper frame is 7 in. (17·8 cm) high and the lower 10½ in. (26·6 cm) high. Both are set back from the rack front mounting surfaces so as to accommodate the control panel, which occupies the full frontal area of the C.C.U. The control panel is hinged at its lower edge so that it may be opened downwards to give access to the circuit modules. Mechanical restrictions are incorporated to prevent the panel from opening accidentally and causing damage. Behind the module frames a rear panel carries all the connectors for the interconnecting cables. This panel can be lowered, giving access to the internal wiring of the C.C.U.

Power Supply Unit

The P.S.U is designed for mounting in a standard 19-in. (48-cm) equipment rack and occupies 8¾ in. (22 cm) of rack height. The chassis construction allows a reasonably free path for ventilating air. This

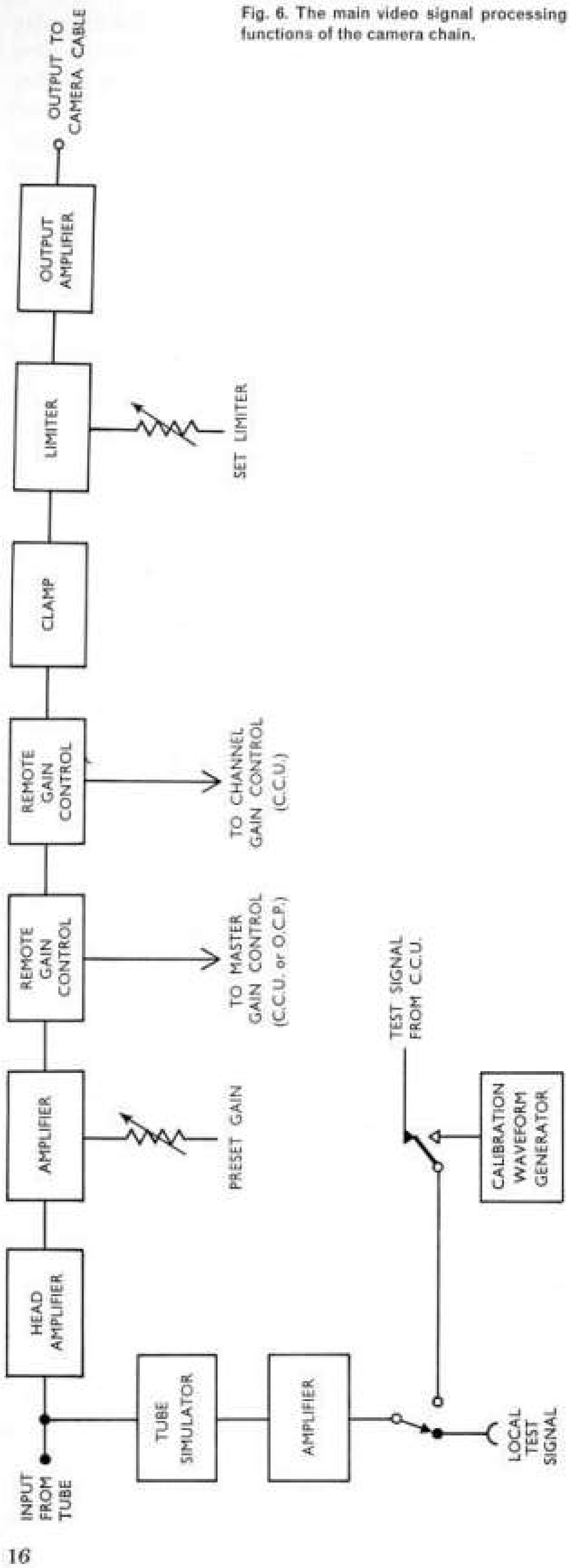

Fig. 6. The main video signal processing functions of the camera chain.

chassis is supported in the rack by a subframe serving as a runner on which the chassis may be slid during insertion and removal from the rack. The power supply main controls are mounted on the front of the unit. The remainder of the front consists of a removable cover behind which plug-in printed-wiring boards and preset controls are located.

THE VIDEO PROCESSING CHAIN

The block diagrams in Fig. 6 and Fig. 7 show the sequence of the main video signal processing functions in the camera and the C.C.U respectively. The positions in the chain of the major operational and preset video controls, and test signal injection points and monitoring and bridging points are also shown. The camera channel has, of course, four separate video chains, and the block diagram is that of the luminance channel. However, the differences between the video circuits for the luminance and colour channels are not very great, and these are shown in Fig. 7.

Camera

Referring to Fig. 6, the signal current from the pick-up tube is initially amplified by the head amplifier, mounted directly on each deflexion yoke, where it is raised to a sufficient level to be passed on to a further amplifier. This includes a preset gain control for setting the sensitivity of the channel. The following two units each contain a special remote gain control arrangement by means of which the gain of the unit can be controlled from the C.C.U or O.C.P. The first of these is for the main operational control of gain by the Master Gain control which is connected to the corresponding unit in all four channels. Operation of the Master Gain control thus simultaneously varies the gain in the four channels. The second is for individual control of the channel gains.

The variation of gain within the remote gain control stages is by means of a photo-sensitive resistor and lamp combination, the resistor forming part of a video attenuator. Current for the lamp is derived from a d.c control signal originating from the remotely located gain control potentiometer. Because the photo-sensitive resistor is also extremely temperature-sensitive, a technique of d.c feedback stabilization is employed which ensures a highly stable and linear control of video gains. In the case of the Master Gain control this also ensures that the gain variation produced in all four channels is the same.

The second remote gain control stage is followed by a first clamping stage which establishes the signal d.c level necessary for proper operation of the limiter stage

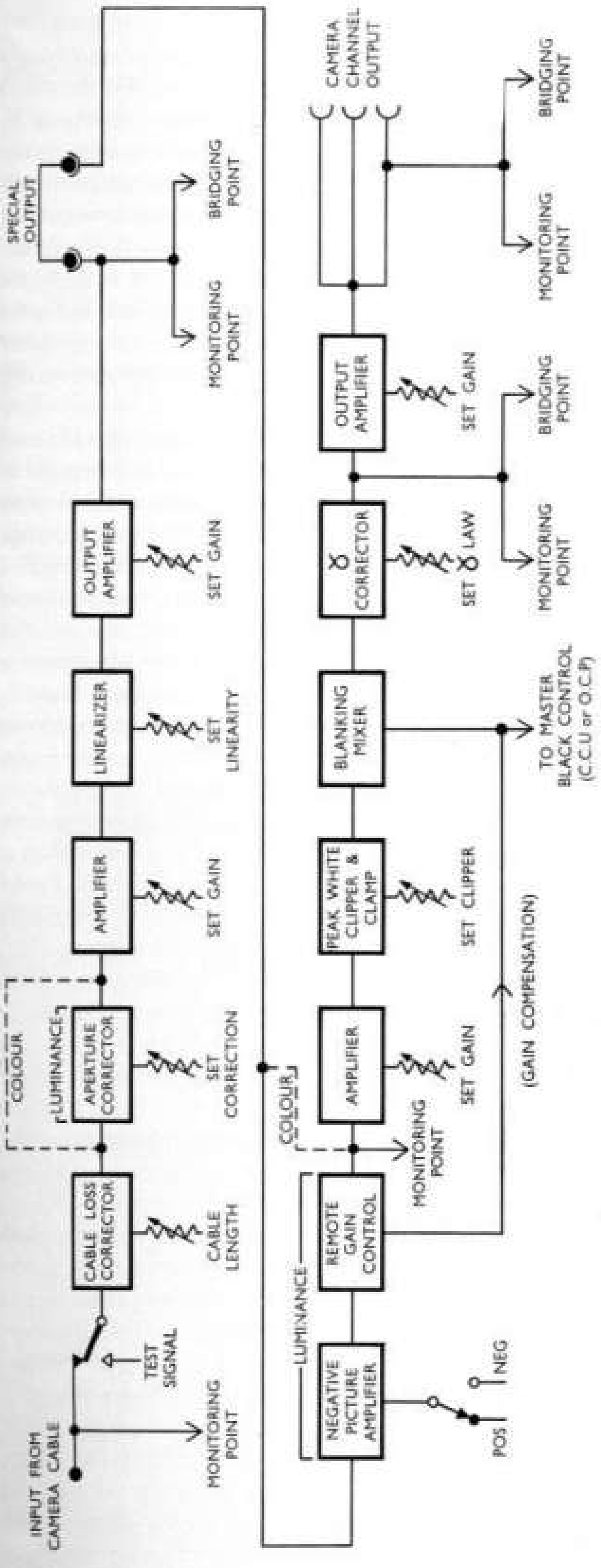

Fig. 7. The C.C.U. video processing functions.

which follows. It also removes spurious low-frequency components of the video signal that might otherwise cause overloading or intermodulation in later stages. The limiter stage is similarly included to protect later stages from signal components of excessive amplitude. Such a limiter is especially necessary when Plumbicon tubes are employed, since the Plumbicon does not have the inherent self-limiting characteristic of other types of tube, and can produce large-amplitude signals from scene highlights.

The final video stage in the camera in each of the four channels is an amplifier of 75 Ω output impedance for feeding the video coaxial in the camera cable. It will be noted that the operational control of gain is effected at an early point in the video chain. This, of course, has the advantage that all the following stages operate at a substantially constant signal level, and no compromise is necessary between the choice of a high level to override spurious signals or of a low level to avoid over-loading. Thus the signals fed from the camera to the C.C.U are at a constant level of 0·7 V peak to peak.

Camera Control Unit

At the C.C.U video input from the camera cable is the first of the several waveform monitoring points (Fig. 7). Signals from these points may be fed to the external waveform monitor under control of the Monitor Wave-form push-button selector switch on the C.C.U control panel. Following the monitoring point is the change-over arrangement for injection of test signals. This enables the C.C.U performance to be checked independently of that of the camera.

The first C.C.U stage is the camera cable corrector, which corrects for the frequency-amplitude characteristic of the cable, and is adjustable to suit the length of cable in use. This is followed by the aperture corrector, a stage giving an adjustable and substantially phaseless accentuation of the higher video frequencies, as is necessary to compensate for the finite scanning aperture of the pick-up tube. This stage is not included in the colour channels as the tube aperture loss within the narrower chrominance band is negligible.

The next block is an amplifier, including a preset gain control, whose purpose is to provide the correct signal level for the 'Linearizer' stage which follows. The linearizer is a non-linear amplifier that can be adjusted so as to have an amplitude transfer characteristic complementary to that of the pick-up tube so that the overall transfer characteristic is linear. This facility is included for two reasons. The first is the need to provide the linear camera channel output that is necessary for certain proposed methods of processing four-tube camera signals for transmission. The linear signal is available at the Special Output Socket, for which an output amplifier of 75-Ω impedance is provided. The second reason for including the linearizer is that the linear signal makes it possible to use a particularly convenient type of gamma-corrector which is described later.

The next two circuit blocks are included only in the luminance channel. First is a negative picture amplifier which provides the facility of reversing picture polarity and is intended for use in black-and-white operation of the camera. This is followed by a remote gain control stage, of the type already described, whose purpose is to vary the video gain as the Master Black control is adjusted, so as to maintain the total video signal excursion constant. This is achieved by deriving the d.c control signal from the Master Black control potentiometer. The remote gain control stage is only required in the luminance channel because the Master Black control adjusts the black level of the luminance channel only. Because of the small range of black level adjustment that is required, and the dominating influence of the black level of the luminance signal in the reproduced picture, it is not necessary simultaneously to vary the black levels of the colour channels.

An amplifier stage is next in the chain with a preset gain control for setting the correct video level for the following stages, the first of which is the peak white clipper, including the main clamp, serving the usual purpose of preventing the signal excursions from exceeding peak video level. This is followed by the blanking mixer, in which the correct black level is established and the system standard blanking durations introduced.

The final processing stage is the gamma-corrector, a non-linear amplifier that gives the outgoing video signal the desired gamma characteristic. The special circuit arrangement employed has considerable operational advantages in that the gamma exponent can be continuously varied by means of a single control and, at the same time, the peak video signal amplitude remains constant. In addition, for greater precision, the non-linear characteristic is approximated by four linear segments, instead of three as are commonly employed. A switch on the C.C.U control panel enables a choice to be made between two different gamma characteristics. A preset control is provided for each characteristic, one having a gamma range of 0·4 to 0·6 and the other 0·6 to 1·0.

The output amplifiers in each of the four channels provide three outputs at standard level into 75-Ω impedance.

CIRCUIT DESIGN FEATURES

Line Scanning

The line-scanning generator is of the type employing a transistor as a switch, with a diode to recover the stored energy. The scanning current is made very linear by two ferrite-cored non-linear inductors. In order to ensure identical scanning currents in the deflector coils of the four tubes it would appear advisable to connect these all in series, but this is not, however, a practicable solution. In particular it is very difficult to apply the individual d.c centring currents to each coil, and in the present instance a higher scanning current is required for the luminance tube, it having a higher focusing potential.

The output of the line-scanning generator is therefore applied to the four deflexion coils connected in parallel. To reduce the effect of variations of inductance of the deflexion coils on the individual scanning current amplitudes, an inductor is connected in series with each coil. Part of each inductor is variable for adjustment of scanning current. Variable resistors are also included in series with each deflexion coil for the adjustment of the inductance–resistance ratio to minimize linearity differences. The effect of temperature on the resistance of the deflector coils is compensated by negative temperature-coefficient resistors contained in the yoke.

A problem encountered in the design of transistor line-scan generators is that of the delay in the decay of current in the output transistor when it is switched off by the driving pulse. The ultimate effect of this delay is a corresponding delay in the video outputs of the camera, relative to the timing of the television system. The delay is temperature-dependent and so cannot be simply compensated. Another problem is the further delay caused by the camera cable, affecting both the driving pulses sent to the camera from the C.C.U and also the returning video signal. This total delay is also variable, depending on the length of camera cable in use.

A novel solution to these problems, successfully employed in the Mark V black-and-white camera, is also used for the Mark VII colour camera. The effect of both the variable delays is eliminated automatically and the camera channel video outputs are always correctly timed. This is achieved by sending a sample of the flyback pulse from the line-scanning generator in the camera to a phase-comparator circuit in the C.C.U. The television system line-drive pulses are also applied to the comparator whose output is a signal whose amplitude is proportional to the timing difference between the two sets of pulses. This signal is fed to a circuit which changes the timing of the line-driving pulses sent to the camera so as to reduce automatically the timing error to zero.

Field Scanning

With parallel-connected line deflector coils it is the circuit inductance, relatively stable with temperature, that determines the current flowing in each coil; in parallel-connected field coils it is the circuit resistance that determines the current flow. This resistance, being largely that of the copper wire forming the deflector coil, has a large temperature coefficient, and, as a result, it is very difficult to maintain equality of deflexion amplitude in the four tubes. In addition, each deflexion coil circuit must include electrolytic capacitors of large value for isolation of the individual d.c centring currents. These capacitors are temperature-dependent, both in capacitance and in series resistance, and affect amplitude and linearity adversely.

These difficulties are overcome in the Mark VII camera by providing an individual generator for each deflector coil to produce both scanning and centring currents. This method, of course, demands a very high differential stability in the generators, and this is achieved by the use of 'twin' silicon transistors and thin-film resistors. Each deflector coil is fed by a constant-current push-pull d.c amplifier with a large amount of negative feedback which stabilizes both the scanning and centring currents. The field-scanning generators are located in the C.C.U and their outputs are fed to the deflexion coils over the camera cable.

Power Supplies

Since the stability of performance of most of the electronic circuits in a camera channel depends to a large degree on the stability of the d.c supplies serving them, the power supply circuits have to be engineered with great care and precision.

Altogether eleven different d.c supplies are provided by the power supply unit for the C.C.U and camera, ranging in voltage from +1,000 to −150, all of which, except the +1,000 V supply, are stabilized and closely

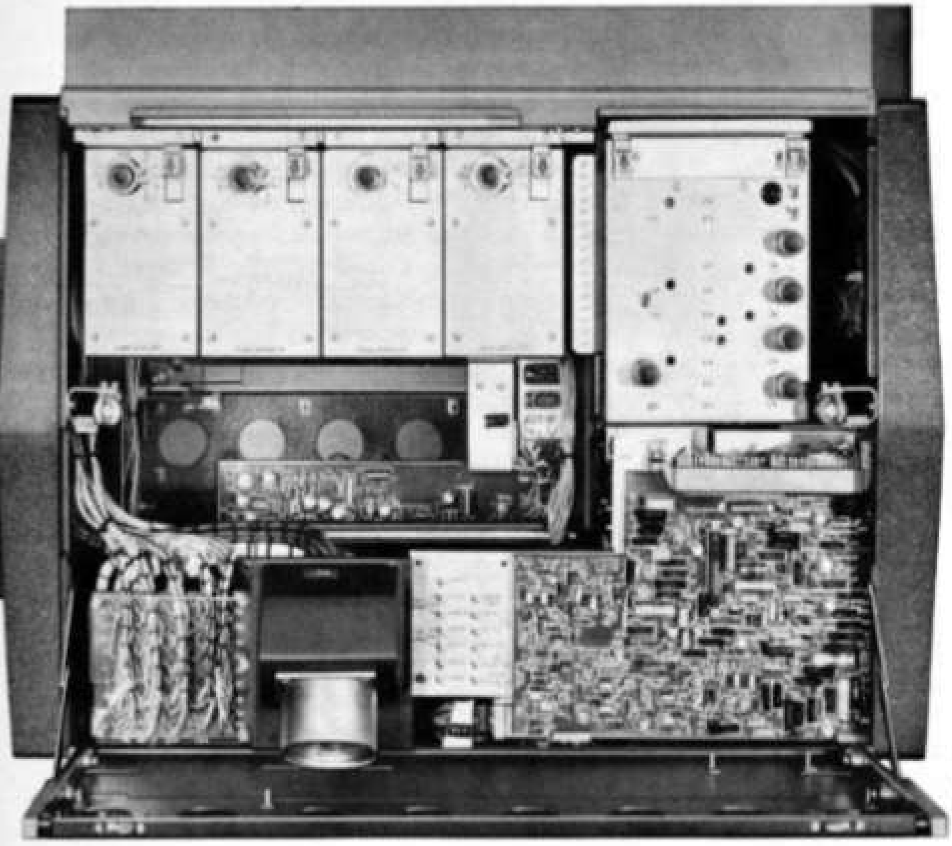

Fig. 8. The Mark VII Colour Television Camera with covers opened and the optics removed to show the construction.

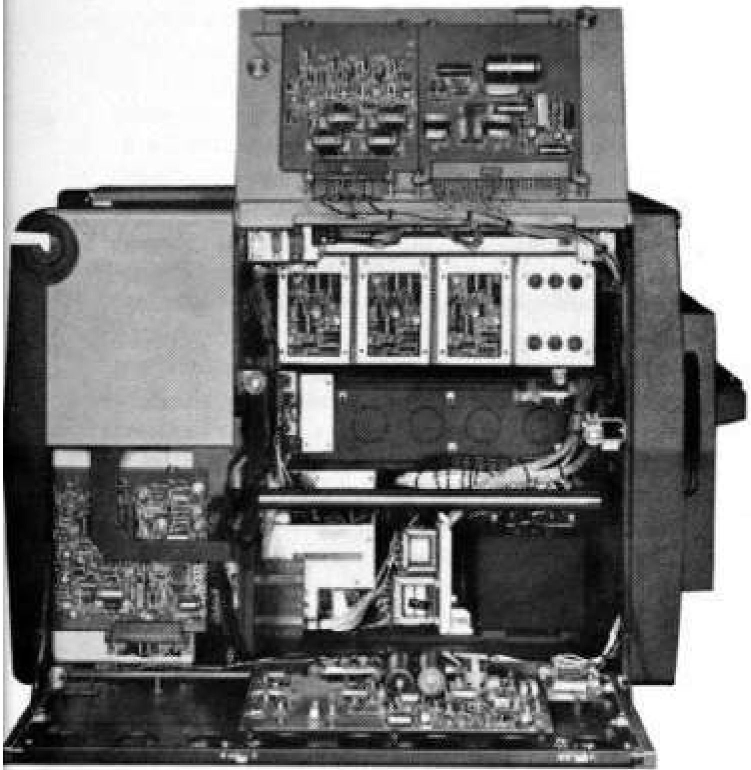

Fig. 9. A view of the camera from the other side.

regulated by means of transistor regulator units. The +1,000 V supply is stabilized by means of a corona regulator tube. For the more critical supplies the zener diodes providing the reference voltages for the regulators are enclosed in a thermostatically controlled oven.

The main d.c supply required by the camera itself is 5 A at 30 V. It is, of course, not practicable to pass such a high current down the camera cable, which may be 2,000 ft (600 m) long, because of the excessive voltage loss that would occur. An alternative is to supply a.c at mains voltage, but this has two disadvantages; one being the increase in weight of the camera caused by the mains transformer, rectifiers and smoothing components which would have to be incorporated, and the other is the risk of spurious deflexion of the pick-up tubes by the stray magnetic field of the transformer.

The method adopted is to supply d.c to the camera at approximately 130 V and to transform this to 30 V by means of a d.c-to-d.c converter. A novel converter has been developed for this purpose which is particularly suited for use in a camera in that it is silent and employs no transformers or chokes.

The heaters of the four camera tubes and of the four head-amplifier valves are fed from a smooth stabilized d.c supply, both to ensure stable operation and to avoid the injection into the head amplifiers of a.c from the heater supply.

The power-supply unit can be located at a distance up to 100 ft (30 m) from the C.C.U.

GENERAL CIRCUIT DESIGN TECHNIQUES

The extensive use of silicon transistor amplifiers with large amounts of negative feedback has enabled a performance and stability to be obtained considerably better than is possible with thermionic valves. In most cases the loop gain existing is sufficient for the net gain to be almost solely determined by the resistors forming the feedback network. This emphasizes the need to employ resistors having stable characteristics.

In critical circuit positions of this kind it is essential to use resistors with a low temperature coefficient of resistivity, in order to achieve adequate absolute stability. Where it is also necessary to achieve a high relative stability, as for example in the relative amplification of the four camera video channels, the variation in temperature coefficient between individual resistors must be small. In many circuit positions high-grade metal-film resistors are used, having temperature coefficients of about ±20 parts per million per °C.

Considerable use is made in the camera and C.C.U of small circuit modules in which the circuit is formed by the thin-film deposition technique on a glass substrate.[3] The process developed by The Marconi Company yields highly stable resistors having a temperature coefficient of ±10 parts per million per °C. All the resistors on a substrate are made simultaneously and hence tend to acquire identical characteristics. Capacitors can also be made by this process. Transistors or other devices required to complete the circuit are attached to the substrate, and the complete assembly is enclosed in a small metal case measuring 1·6 by 1·1 by 0·6 in. (4·1 by 2·8 by 1·4 cm). Sixty-seven of these modules are used in the Mark VII channel, 40 of which are of one type, a multi-purpose video amplifier.

Variable control resistors, particularly those associated with image registration, must be both electrically and mechanically stable and of adequate resolution. Therefore helical multi-turn potentiometers of low temperature coefficient are used for a number of the more critical setting-up controls.

Since the camera channel is required to provide full performance at ambient temperatures from $-10°C$ to $+40°C$ it has been necessary to employ tantalum electrolytic capacitors in many circuits. The common and less expensive aluminium electrolytic capacitors suffer from a loss in capacitance and a considerable increase in series resistance at the lower temperatures. These are used in less-demanding positions, however, particularly where large values of capacitance are necessary.

Except for a few special cases, all the electronic circuits in the camera, C.C.U and P.S.U are constructed on printed-wiring boards. This form of construction has been used in Marconi equipment for a number of years and has proved stable, reliable and convenient for maintenance. The physical disposition of conductors and components is fixed in the original design, and this is helpful in achieving stable circuit performance, particularly at the higher video frequencies.

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