

# A High-Performance Automatic Color Camera

A. N. HEIGHTMAN

**Abstract**—To meet the requirements of broadcasters the Marconi Mark VIII color television camera has improved performance and new automatic facilities.

A new method of image size reduction increases sensitivity by reducing lag. Using three tubes, the camera has spectral responses and a signal processing method giving a four-tube quality luminance signal. Separate color correction matrices for studio and daylight are included, individually computed for each camera, giving high-quality standard colorimetry. Deflection coils printed on borosilicate glass tubes aid registration stability.

A push-button operated automatic setting up sequence aligns each tube and registers the images, using a built-in diascope pattern. Another automatic system can be switched in to maintain registration from picture information. Push-button automatic color balance is also provided. Other aids include a fault location monitor display.

## INTRODUCTION

WHILE COLOR television cameras have generally reached a high standard in performance and facilities, there are areas in which most broadcasting organizations would benefit from some improvements, and what are probably the most important are listed as follows.

- 1) An improvement in sensitivity of about 2:1 or one lens stop would enable usable pictures to be obtained in 5 to 10 foot candles illumination, a level at which it often seems necessary to operate in broadcasts outdoors. This would also allow a useful reduction in studio lighting load, or a greater depth of focus.
- 2) Increased accuracy and stability of image registration is a common requirement.
- 3) A reduction in setting up time, necessary for adjustment of registration, color balance, and color matching, camera-to-camera would increase utilization and reduce operating costs.
- 4) Better color analysis and greater uniformity in colorimetry amongst cameras is another common requirement.
- 5) Extension to 60:1 or more of the contrast range over which accurate gamma correction is provided.
- 6) Some reduction in camera size and weight would generally be advantageous, particularly in remote operations.

These advances should be accompanied by minimal increase in cost, and no worsening of reliability. In fact, increased reliability and also greater ease of maintenance are themselves important.

To meet the broadcasters' needs, listed above, was the

objective in the design of the Marconi Mark VIII camera, the subject of this paper. The description is not exhaustive but deals principally with the novel features of the camera, which include such automatic functions as are likely to be of practical value to the operator.

## PICKUP TUBES

Among the first decisions that have to be made in starting a color camera design are the type and number of pickup tubes to be used. In the present case the high standard of performance aimed at dictated the choice of the standard 30-mm lead oxide photoconductive tube, such as the Philips Plumbicon® or the similar Leddicon® made by the English Electric Valve Company.

It was decided that worthwhile reductions in size and weight could only be achieved if three rather than four tubes were employed. This was a difficult decision because of the advantages of the four-tube camera, such as the high quality of the luminance signal and somewhat less critical image registration. Nevertheless, it was desirable that the performance of the camera in both these respects should exceed that of existing four-tube cameras, and some of the means adopted to achieve this are described later. It should be added, perhaps, that one-tube or two-tube configurations were rejected as not being capable of a sufficiently high performance.

## SENSITIVITY

The limiting sensitivity of color cameras using photoconductive tubes is at the present time determined by lag because high signal-to-noise ratios can now be obtained, so that noise alone no longer sets the limit to sensitivity. This improvement in noise is due to the use of field-effect transistors in the head amplifiers, and in addition, nonlinear circuits in the aperture correctors reduce the visibility of noise.

It is known that the subjective effect of lag is less serious if it is neutral in color, as may be achieved by making the lag from each of the pickup tubes of the same amount. In a four-tube camera, for example, this may be done by reducing the light to the green tube, which normally receives a greater light energy than the red and blue tubes. This will increase the lag in the green tube to the same value as in the red and blue tubes, and is permissible because the luminance tube continues to give a good signal.

Such a method is not, however, possible in a three-tube camera, where the luminance signal is obtained

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The author is with Marconi Communications Systems, Ltd., Chelmsford, England.

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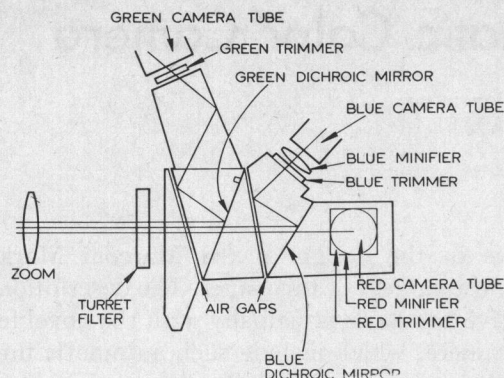


Fig. 1. Color-splitting optical system.

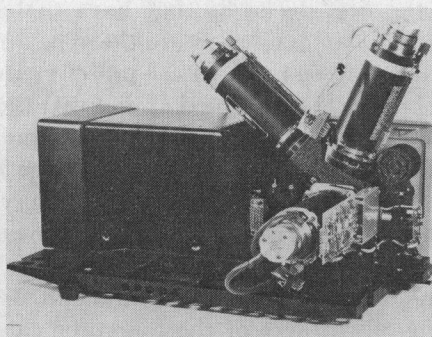


Fig. 2. Optics assembly with a zoom lens and the deflection yokes in position.

principally from the green tube, because of the serious loss of sensitivity. A new solution has, therefore, been found, and this depends on the fact that lag is reduced, not simply by the increasing signal current, but by increasing image brightness. Thus the lag in the red and blue tubes can be reduced by reducing their image size and so increasing their image brightness. Not only is the absolute amount of lag in these tubes reduced, but it is also made more nearly equal to the lag in the green tube, so that the lag that remains in the displayed picture is more neutral in color and its subjective effect much less serious.

### Optical System

To reduce the image sizes a relay type of optical system may be used, but the extra field lens and relay lenses will cause a loss of light. A new method has, therefore, been employed in which specially designed "minifier" lenses are placed close to the front of the red and blue tubes. The green tube receives a normal 21.4-mm diagonal image directly.

Also in the interest of sensitivity optical losses have been kept low by reducing the number of air-to-glass surfaces to a minimum, and by using high-efficiency dichroic and antireflection coatings.

The sensitivity that has been achieved allows normal operation at 75-fc illumination at an aperture of  $f/4$  with a signal-to-noise ratio of 47 dB in 5.5-MHz bandwidth. So that pictures may be obtained at low light levels

there is additional amplifier gain available of 12 dB. This gives a usable signal down to 5 fc.

Fig. 1 shows the form of the color-splitting optical system. It can be seen that the system is also different from the normal type used for three-tube cameras in the position of the red pickup tube, laying horizontally at right angles to the zoom lens axis, and this arrangement helps to keep the camera body small. Fig. 2 shows the complete optical assembly, with zoom lens and the deflection yokes in position.

Lenses available for the camera from Rank Taylor Hobson and from Angenieux range from a small  $f/2.9$ , 10:1 zoom to one at  $f/2.2$  and 16:1. The optical path behind the zoom lens includes a four-section filter wheel, having a clear glass and three neutral filters giving a light loss equal to 2, 4, and 6 lens stops. The filter wheel is remotely controlled from the operational control position. Also built into the optical system is a remotely controlled diascope for projecting a special pattern for lineup purposes, referred to later.

### Spectral Responses and Colorimetry

The choice of the optical spectral response characteristics used was based on a computer optimization program, as has been described by Jones [2] in which the best reproduction of a set of 26 test colors is the objective. The optical responses in each channel have been made as broad as possible in the interest of camera sensitivity, as shown by dotted lines in Fig. 3, and electrical correction matrices are employed in the video circuits to give the correct final responses, as shown by solid lines. The spectral response of the green channel has been further extended so that the green tube can adequately provide the fine detail for the composite color signal. The camera is provided with separate matrices for studio or daylight illumination, which are simply switched in as required. This method replaces the use of optical correction filters and has the advantages that no light is lost and the result is more accurate. The computer program is used in camera manufacture to calculate ideal matrix values for each individual

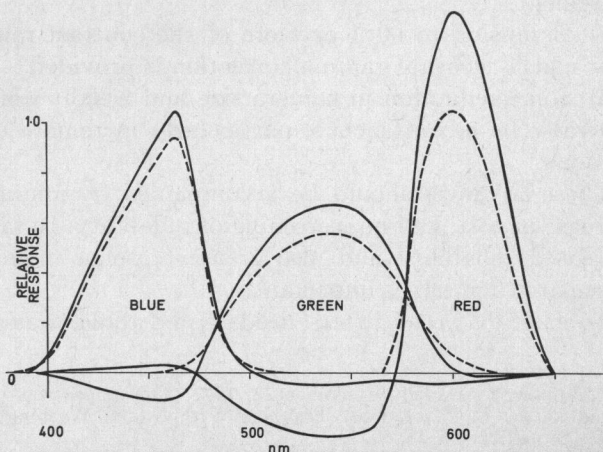


Fig. 3. Spectral responses (before matrix in dotted lines).

optical system. In this way the effect of the small differences which exist in the dichroic systems due to manufacturing tolerances can be substantially eliminated.

The display phosphor coordinates which have been used in the colorimetric calculations are those representing modern color display tubes [3] and which are in process of adoption internationally.

### IMAGE REGISTRATION

A particular object of the design was to achieve very good effective image registration, and this has been approached in three main ways. First, a method of video signal processing is used which allows some relaxation of registration accuracy. Second, special care has been taken in the mechanical and electrical design of all parts that can affect registration, including the development of a new type of deflection coil. Thirdly, a new dynamic centering system is included which automatically maintains registration during operation.

### Video Signal Processing

It has been noted that the spectral response of the green channel has been made as wide as possible. This permits the green channel to serve in the same way as the luminance channel of a four-tube camera. The fine detail of the picture is, therefore, similarly provided by only one tube of the camera and is, consequently, not affected by errors in registration, permitting a small relaxation in registration accuracy.

The system of signal processing employed is shown in functional form in Fig. 4 where the main green, red, and blue signal paths are shown in heavy lines.

Horizontal and vertical aperture correction for the camera is obtained from the green tube signal, and is introduced into the "highs" signal path. Two horizontal correction characteristics are included, one to compensate the aperture loss of the pickup tube and another peaking at a frequency within the videoband to complement the vertical correction characteristic. The correcting signal from the vertical and complementary hori-

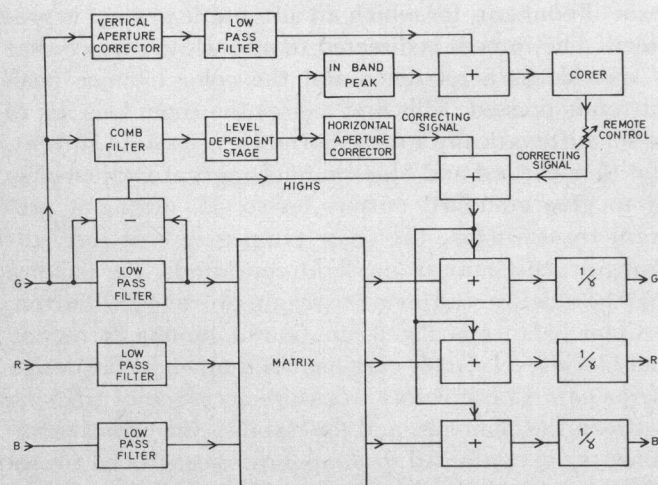


Fig. 4. Method of signal processing.

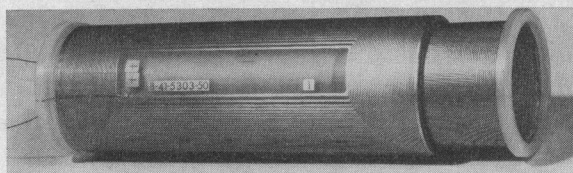


Fig. 5. Deflection coils printed on borosilicate glass tubes.

zontal correctors is passed through a "corer" stage which blocks low-level signals and thereby reduces the enhancement of noise by the correctors. In addition, a level dependent stage allows the high-frequency correcting signals to pass only above a certain level near to the picture black level and in this way noise in the darker parts of the picture is reduced.

A new feature of the camera is an operational control of the aperture correction which makes it possible to adjust the sharpness of the picture as an artistic variable. The aperture correctors also include a comb-type filter to reduce noise in the higher frequency part of the videoband, and in particular, to reduce noise injection into the chrominance signal. Although shown for clarity as a separate block in Fig. 4, the comb filter makes use of the two one-line ultrasonic delays of the vertical aperture corrector.

### Deflection Coils

A new type of deflection coil [4] for the pickup tubes has been designed because of the difficulties of achieving and maintaining good registration with conventional wound coils. The new coils are made by a process similar to that used for printed wiring and are therefore very accurate and uniform in manufacture. The mechanical support is given by two concentric borosilicate glass tubes, the outer tube carrying the horizontal deflection coil and the inner tube the vertical deflection coil. Each is made by first coating the tube with a layer of copper. This is then covered with a photoresist, which is exposed through a photographic master coil pattern, and the tube is finally etched to remove the unwanted copper.

The deflection coils are shown in Fig. 5 where the inner tube is shown partly withdrawn. The coils are assembled together with electrostatic and magnetic screens, and the focus and alignment coils to form a complete deflection yoke. In the interest of registration stability, close mechanical tolerances are observed in production of the yoke, and the substantial outer screening can form a rigid main structural member, solidly attached to the optical assembly.

### Dynamic Centering

Having taken care of the more obvious causes of misregistration there remain the long-term effects of temperature and the possibility of mechanical shock, which may disturb the optical system. It is to deal with these that "dynamic centering" has been included in the camera. In this system the picture information during normal operation is continuously sampled in the hori-

zontal and vertical directions in the central part of the picture. Positional errors, detected in the red or blue signals, relative to the green, automatically adjust the centering circuits of the red and blue channels so as to correct the errors.

It is, of course, necessary to design such a system so that the probability of incorrect operation is very small. In the Mark VIII system, the following precautions are taken.

1) Only signal transitions in a narrow amplitude range centered at half maximum signal level are sampled.

2) Red or blue transitions separated from green transitions by more than 360 ns horizontally, or 4 television lines vertically are not used.

3) Each apparent error must have a complementary apparent error, but separated by more than  $1.8 \mu\text{s}$  horizontally or 20 television lines vertically.

4) The control system operates slowly, so that short periods of confusing picture information will not have a serious effect, and the whole system therefore tends always to improve the registration accuracy.

The dynamic centering system is put into operation by a push-button switch at the main camera control or remote operational control positions.

#### AUTOMATIC LINEUP SYSTEMS

Significant in the economics of television operations is the time needed to set up color cameras ready for use. Thus in the Mark VIII camera automatic systems have been included both to reduce the time, which previously had to be spent in manual adjustment, and to improve the accuracy and consistency of the result. Setting up of the green channel deflection is not automated, being a simple operation and especially as it is aided by the built-in diascope, and not requiring readjustment except on tube replacement.

##### *Sequential Lineup*

The main automatic setting-up operations follow each other in a sequence that is started by pressing a push button on the camera control unit, or a similar button on a remote operational control panel. The following events then occur automatically.

1) A built-in diascope pattern (Fig. 6) is presented to the camera tube, and the light from the zoom lens is shut off.

2) The brightness of the diascope lamp is adjusted to give normal signal current in the green pickup tube.

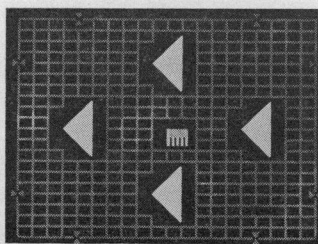


Fig. 6. Diascope pattern.

3) The gain of the red and blue channels is adjusted to match their signal levels to the green.

4) The beams in the green, red, and blue tubes are aligned in turn.

5) The red and blue images are simultaneously registered with the green image.

6) When registration is complete, the diascope pattern is removed, and light from the zoom lens is again admitted.

At each stage of the sequence a series of indicator lamps light individually to show the event that is proceeding, and are extinguished when the event is finished. The complete sequence occupies between 2 and 3 min. However, if the pickup tubes have not been changed, the beam alignment operation may be omitted by means of an override switch, and the sequence will then occupy only 30 s. Furthermore, in a studio installation having a number of cameras, all the cameras can be automatically set up at the same time by one operator. No operator is required at the camera head during the setting-up period.

The method adopted for the automatic beam alignment is to change the tube focus voltage cyclically, then to measure the movement of the center of the diascope pattern, and to adjust the current in each alignment coil until the movement is zero. The position of the center of the pattern is found by counting lines vertically, and by counting cycles of an oscillation of 5.5-MHz signal horizontally. The difference in the counts at the limits of the focus voltage change is a measure of the movement.

In the operation of registering the red and blue images to the green, which serves as reference, adjustment is made so as to align the three images along the eight diagonal edges of the four white triangles of the diascope pattern. The variables that are controlled are horizontal and vertical centering, width, height, twist (rotation), skew, and horizontal linearity.

##### *Automatic Color Balance*

The next adjustment necessary before using the camera is to color balance for the color temperature of the scene illuminant, for which an automatic system is provided. The camera is directed to any white surface that is suitable as a reference and the color balance push button is pressed. This first causes the zoom lens iris to be set automatically to give normal green signal current, and then the red and blue channel gains are adjusted so as to give standard output levels. If, during a program transmission, the color temperature of the light changes, as it may in daylight conditions, the balance may be quickly readjusted by again pressing the button.

Color balance is also a function of gamma correction and black level. Great care has been taken in the design of the gamma correctors to ensure accuracy of tracking between the channels, and for stability the critical components are contained in temperature-controlled ovens. Black level stability has also received careful attention, a black reference optical mask being fitted in front of

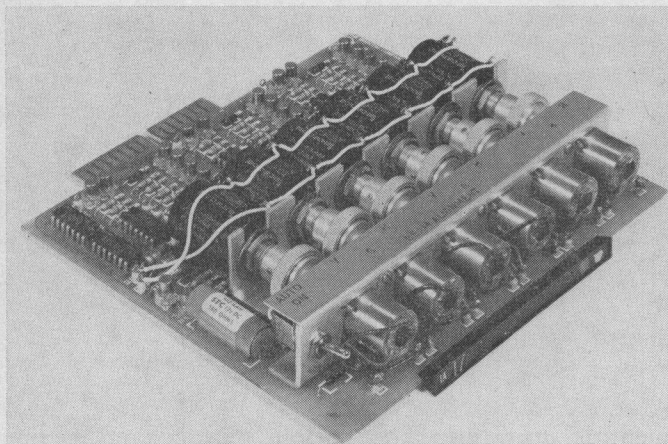


Fig. 7. Camera alignment module showing some of the motor-driven potentiometers.

each pickup tube, and the unlit area of the target is sampled by an extension of the normal field scan excursion. Black level is affected by optical flare, and so flare correction is provided in each channel, adjustable for the differing characteristics of zoom lens types.

The picture area examined during the balancing operation is confined to a central square patch, indicated to the cameraman by a white frame in his viewfinder picture. This makes it possible to avoid bright objects in the scene that might otherwise cause a false balance.

Apart from initial simple analog-to-digital conversions from the video signals, the automatic systems operate digitally, using reliable standard integrated circuits. The systems must of course have some method of storage of setting information, and after a careful study of various methods the use of motor-driven potentiometers has been adopted, thereby combining the storage medium and the control element. This has the advantage that the automatic systems can be completely switched off during camera operation except when required to function, and interruption of the power supply does not destroy the stored information. Furthermore, the provision of slipping clutches between each potentiometer and its motor permits manual adjustment for test purposes or in an emergency. A group of the motor-driven potentiometers can be seen in Fig. 7, which shows the beam alignment plug-in module, located in the camera head.

#### Auto Test

Another detail of the camera design is a facility, called Auto Test, which gives an indication of correct operation of the camera by a visible display on the picture monitor, obtained by pressing a button. This display is in the form of a number of rectangular areas which are normally white, but change to black to indicate a fault. The area in which the fault has occurred can be seen from a corresponding chart, shown in Fig. 8. The video signal paths are checked by injecting pulses at various points, while supply voltages are checked by voltage comparator circuits.

Power Supplies and Scans	+950V (1A11)	+300V (1A11)	+30V (1A11)	±15V (1A11)				
	Line Scan (1A9)	Field Scan (1A8)	Focus Current (1A11)	-125V (1A11)	+30V (3A)	±18V (3A)	+12V (3A)	-6V (3A)
Green	Head Amp Input (1B1)		Cable Input (1B1)		Control Unit Input (2F1)	Before Gain Comp (2F1)	Before Matrix (2F4)	Before 1/γ (2E1)
	Head Amp Input (1B2)		Cable Input (1B2)		Control Unit Input (2F2)	Before Gain Comp (2F2)	Before Matrix (2F4)	Before 1/γ (2E1)
Blue	Head Amp Input (1B2)	V/F Decoder Input (1B2)	Cable Input (1A4)		Control Unit Input (2F2)	Before Gain Comp (2F2)	Before Matrix (2F4)	Before 1/γ (2E1)
Camera				Control Unit				

Fig. 8. Auto-test display identification chart.

#### Automatic Standby Iris

A simple automatic control of the zoom lens iris as a function of video signal level is incorporated in the camera, and may be brought into use by a switch at the control position. This makes it possible to expose the camera correctly during times when the operator is not available so that reasonable pictures can be obtained, for example, in outdoor situations where the light may change suddenly.

#### Camera Cable

A small lightweight camera cable is an advantage generally and particularly in remote operations, aiding mobility and speed in running out, and for the Mark VIII camera a new 34-way cable only 0.47 in (12 mm) in diameter has been developed. This has the same conductor configuration and well-tried connectors as the Mark IV monochrome camera cable, which can also be used. The camera will operate on up to 3000 ft (900 m) of the new cable.

The number of conductors was chosen to be near optimum, as increasingly complex multiplexing electronics are required as the number is reduced. In the Mark VIII cable the primary green, red, and blue signals are sent down separate coaxial cables to avoid any distortions that might be caused by a multiplexing technique, and the video for the viewfinder is sent to the camera on the blue signal coaxial as an FM signal in the band 10 to 20 MHz. Driving signals for the horizontal and vertical scanning circuits and a number of switching functions are carried by simple time-division multiplex.

#### CONSTRUCTION

A general view of the camera is given in Fig. 9, here fitted with an Angenieux  $f/2.4$ , 15:1 zoom lens with built-in range extender turret. The camera dimensions are 16 in (400 mm) high by 14 $\frac{1}{4}$  in (360 mm) wide and 22 $\frac{3}{4}$  in (580 mm) long, and it weighs 80 lb (36 kg) without lens, but including the viewfinder. Lens weights range from 25 lb to 48 lb (11 to 22 kg).

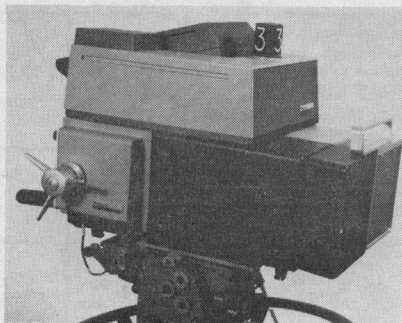


Fig. 9. The Mark VIII camera.

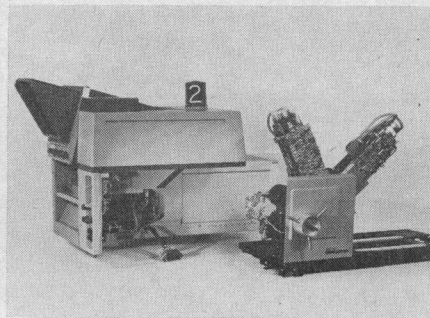


Fig. 10. Optics and camera body assemblies.

The optical system together with the camera base are a solidly constructed assembly separate from the camera body, which forms another assembly, as shown in Fig. 10. This is primarily intended to isolate the optical system from mechanical forces that could cause misregistration, but the ability to separate the camera in this way is also useful in manufacture and maintenance.

The camera control unit (CCU) is designed for standard rack mounting and occupies 14 in (356 mm) of rack height (Fig. 11). As can be seen from Fig. 12, the CCU is constructed in the form of a series of drawers that may be pulled out for servicing while the equip-

ment is operating. The bottom dark-colored section carries on its front panel the major operational controls, iris, and black level, and the section above this carries the push-button switches and indicator lamps for the automatic lineup system. The power supply (Fig. 13) is a separate unit taking  $5\frac{1}{4}$ -in (133-mm) rack height and can also be pulled out on runners for servicing.

Two small remote control panels have been designed containing only essential operational controls, for mounting in a vision control position, Fig. 14. The operational control panel (left) has iris and black level controls, and camera on-off switches, as well as remote push buttons

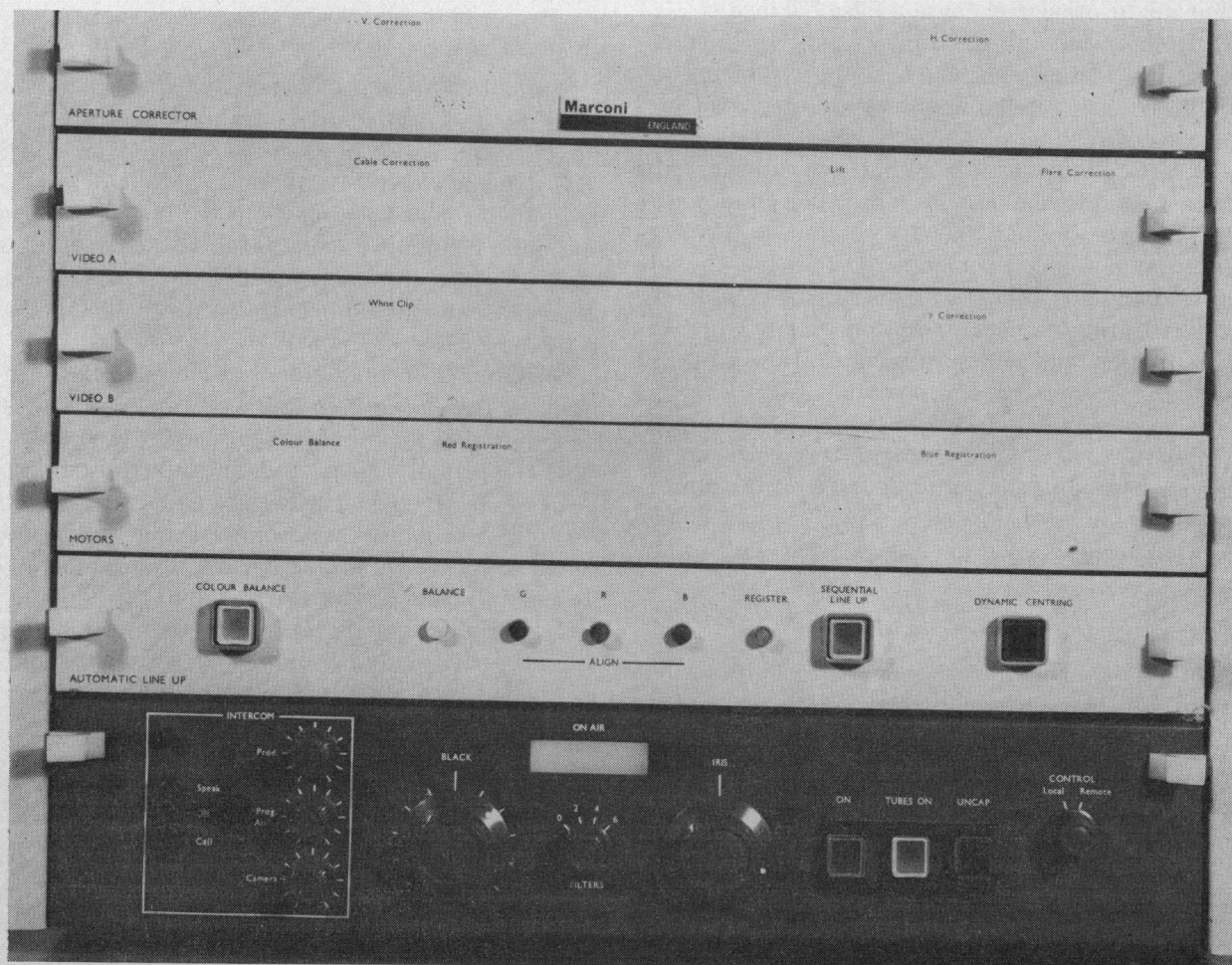


Fig. 11. Camera control unit.

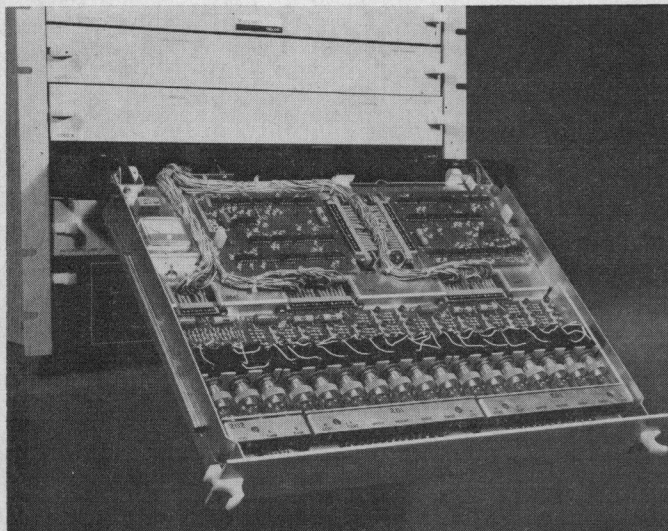


Fig. 12. Drawer construction of CCU.

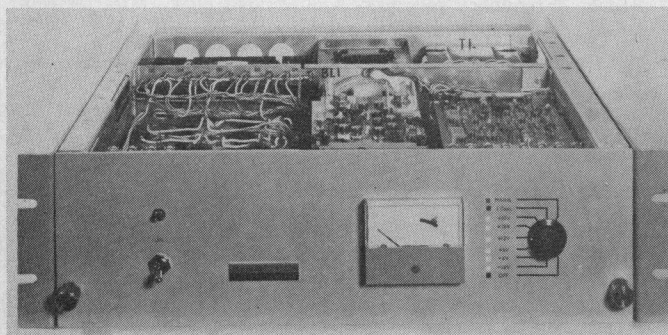


Fig. 13. Power supply unit.

for automatic lineup and color balance. The auxiliary control panel (right) is optional and carries color trim controls, operating over the red-blue and green-magenta axes. This is intended to compensate for changes in illumination color, due for example to daylight variations or the presence of colored reflecting surfaces.

#### CONCLUSIONS

In conclusion it may be of interest to note that since its introduction in the fall of 1970 the camera has been operated in many countries under varying climatic conditions in the course of evaluation trials.

Notable in these trials has been the reliability of the camera, considerably exceeding calculated figures, and the automatic systems have proved particularly dependable.

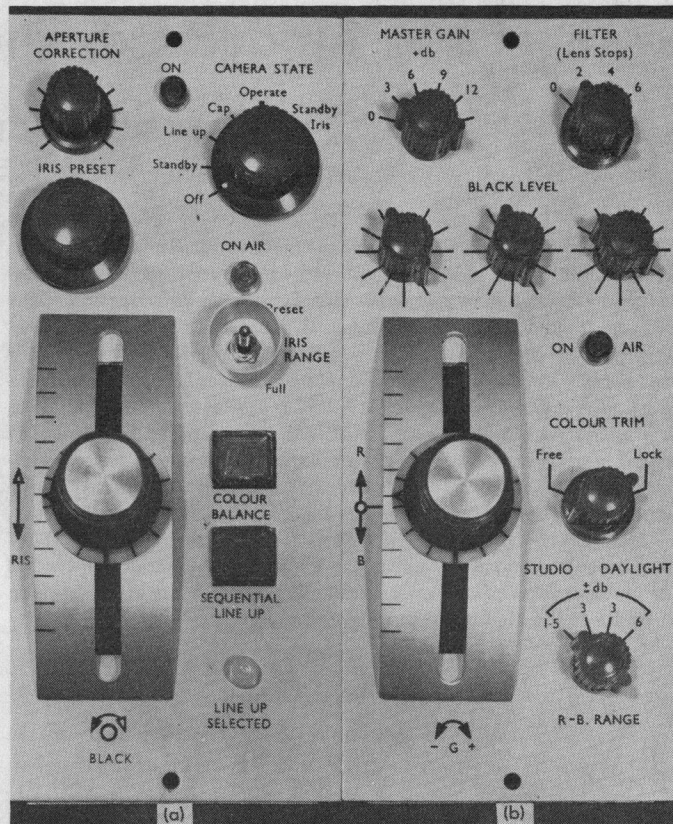


Fig. 14. (a) Operational control panel with iris and black level controls. (b) Auxiliary control panel with color trim controls.

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