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VIII

THE NEW MARK VIII AUTOMATIC COLOUR CAMERA

THE CHOICE FOR THE 70'S

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INTRODUCTION

In 1966 an appraisal of the factors which led to the design of the Marconi Mark VII colour television camera was published[1]. First were listed the "Factors Governing The Choice" and these are as true today as they were then. In the order of priority in which they then appeared, they are

Performance and Reliability
Operational Flexibility
Cost (Capital and Running)
Sensitivity
Size and Weight
Immunity to Environmental Conditions

Next followed a discussion of the "Available Choices" which centred mainly around the type and number of camera tubes to be employed. Before describing the successor to the Mark VII, a brief discussion on this particular question may be of interest, since it is in this area that the door has now been opened to many techniques which could not then have been seriously considered.

THE TYPE AND NUMBER OF CAMERA TUBES

There have been no serious contenders to the lead-oxide camera tube and concern is therefore not with the choice of a new tube but with the number it is necessary to use. It has been well known, almost since colour was first introduced, that three-tube cameras must be accurately registered if errors are not to be visible in the final picture. The use of a fourth tube eased the problem since errors of greater magnitude can be tolerated for equal visibility as compared with the three-tube arrangement. If the fourth tube is to be omitted the performance of the deflexion yokes must be improved so that the absolute registration is adequate, and the stability must be improved so that this improved level of performance can be maintained indefinitely. The way in which both these requirements can now be met is described.

Another factor has emerged more recently. Circuit techniques have reached the stage where the limiting factor on sensitivity is no longer signal-to-noise ratio but lag, a function of the camera tube. Lag has of course always been a feature of television cameras and is not particularly offensive to the eye provided there is no associated colour change. Differential lag, on the other hand, is objectionable. Thus, to a reasonable degree, a neutral smear following a white or black object, or a red smear following a red object can be tolerated. The eye will not however tolerate a green or magenta smear, for instance, associated with a white object.

The cause of differential lag is fundamental, and stems from the relatively large amount of usable energy in the green part of the visible spectrum as compared to that present in the blue and red regions. The green signal current of a three-tube camera is thus typically at least twice the blue or red signal currents. Using a fourth tube, it is possible to reduce the green signal current to match the red and blue currents without prejudice to the signal-to-noise ratio. This solution is not possible using three tubes, but fortunately there is another and better way of dealing with the problem. Lag is not a function of signal current but of the charge pattern on the photocathode. The magnitude of the charge pattern is a function of the image brightness which, for a given light input to the camera, is inversely proportional to the image size. If therefore the size of the image is reduced 2:1 in area, the brightness will be doubled and the lag will be reduced to a value equivalent to that associated with the larger image and twice the light input to the camera. Since red and blue are the channels involved, any small sacrifice to resolution is offset by the relatively smaller contributions made by these channels to the detail in the final picture. The degree of lag in the three channels of a three-tube camera can thus be made approximately equal by using smaller image sizes in the red and blue channels as compared to that in the green channel. In providing these reduced image sizes it is of course important that little or no sacrifice is made to optical efficiency by the introduction, for instance, of re-imaging systems which would significantly detract from the potential improvement.

Having eliminated the fourth tube the question of size remains and this is closely related to the optical arrangement adopted. Basically the smallest image is required which is permissible for red and blue on grounds of resolution, and the size of the tube must then be adequate for the larger image in green. The 30mm tube allowing an image diagonal of up to 21·4mm proves ideal.

THE MARK VIII COLOUR CAMERA

The design has two aims :—

1) To eliminate the relatively complicated setting-up and operating procedures which have come to be associated with colour cameras.
2) To eliminate the fourth tube and produce the smallest possible camera without any sacrifice to performance.

Three key factors have contributed to the achievement of these aims :—

1) Automation
2) Minifiers
3) Precision Yokes

What these headings mean, and how they have contributed to the design of what is effectively a three-tube camera with the controls of a single-tube camera, is described.

THE OPTICAL SYSTEM

The optical system is designed to operate with zoom lenses providing 21·4mm diagonal images, and having rear conjugates of sufficient length to accommodate the light-splitting prism system. To obtain the reduced image size required in red and blue, a minifying lens is placed immediately in front of the camera tube. The successful design of suitable minifiers allows primary images to be employed in each channel, avoiding the disadvantages of a field lens and copying system. The quality of the minified images is substantially the same as that of the full-size image and there is no significant loss in resolution.

From figures 1 and 2 it will be seen that the entire system falls within a single quadrant of an X,Y,Z space system. Thus if the zoom lens be considered to lie along the X axis, the axes of the green and blue yokes lie in the X,Y plane while the red tube is turned through 90° to lie along the Z axis. The viewfinder and camera electronics are then fitted into the one quadrant to produce a minimum size camera head. The overall length from the front of a 10:1 zoom to the viewfinder screen has been reduced to under 600mm. The overall weight, including the 180mm viewfinder but excluding the zoom lens, has been reduced to less than 34kg.

Although the zoom objectives are readily removable, being held in place by a single screw, they are mounted integrally with the prism block in such a way that any zoom may be fitted to any camera and provide immediate zoom tracking without any preliminary focus adjustment. Similarly, the three yokes may be easily removed and relocated without any need for mechanical adjustments, each of the three exit ports being provided with a reference face which is accurately related to the image position in that channel. The complete elimination of mechanical adjustments is a major factor in achieving stability and immunity to mechanical shock.

The input port is provided with an automatic dust cover which excludes dust when the zoom is removed. Behind this is fitted a remotely controlled 4-port filter turret for the insertion of neutral density filters in the main optical path. Behind this again is mounted a remotely operated shutter running on precision slides and on the rear face of which is fitted a small mirror which, when in the capped position, injects light from a built-in diascope.

SPECTRAL RESPONSE

For perfect colorimetry, the taking characterisitcs of a colour camera must include regions where the response of one or more of the three primary transducers is negative. Whilst it is possible to compensate for the absence of the negative lobes in the spectral taking characteristics by using positive lobes of reduced width, this course leads to a reduction in the overall sensitivity of the camera. A preferable solution is to use relatively broad taking characteristics and to correct for the absence of the negative lobes by means of an electronic matrix.[2] The actual choice of the characteristics used in the Mark VIII is based on the colour fidelity obtained with a set of 26 test colours, the actual optical response curves being as broad as possible consistent with the use of matrix coefficients which are not in excess of 1·5, a value above which some forms of distortion tend to be exaggerated. The effective response curves after correction are shown in figure 3. Facilities are provided on the colour correction matrix whereby the precise values of the matrix coefficients may be adjusted to suit the spectral characteristics of the particular optical system fitted to the camera. Small differences between individual optical systems are thus eliminated. Alternative matrix values are provided for indoor and outdoor conditions. In addition a variable matrix may be selected by which the colour may be varied in discrete parts of the spectrum

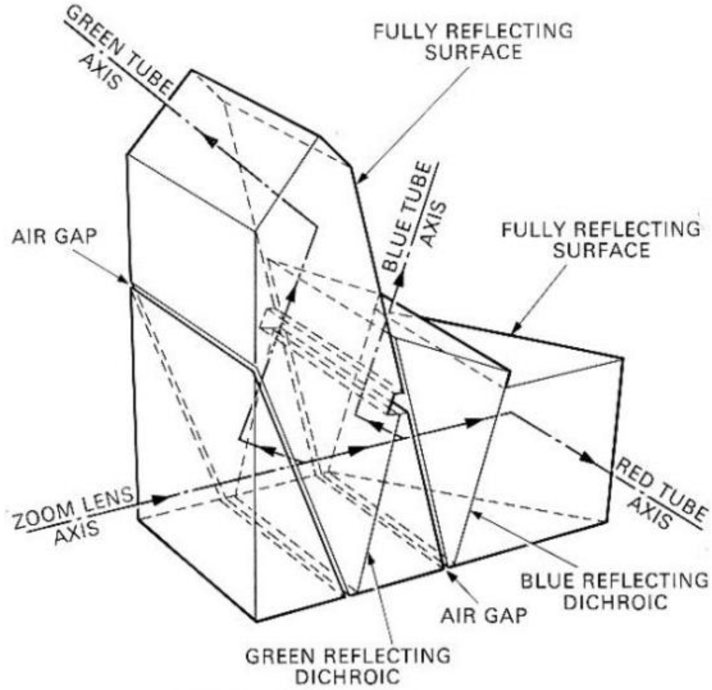

Fig.1 Simplified diagram of prism system.

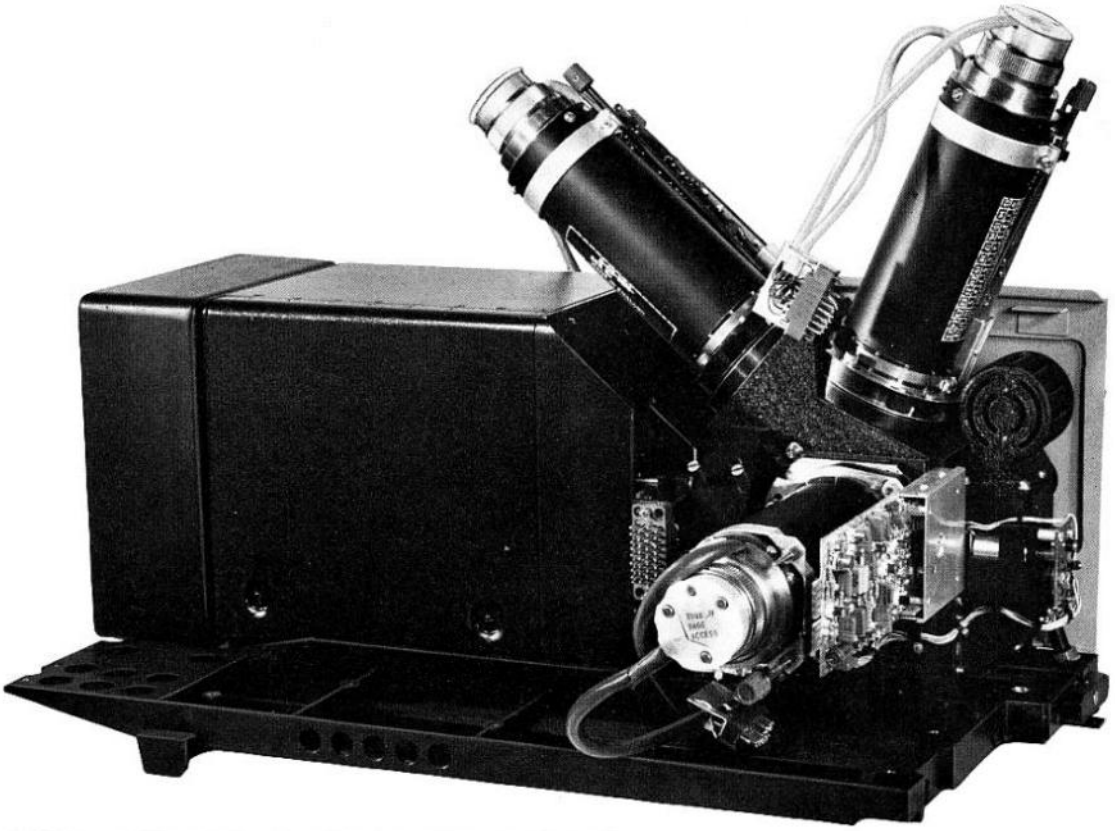

Fig.2 The complete optical system with yokes and zoom lens in position.

without affecting the gray scale or introducing significant changes in other parts of the spectrum[3].

DEFLEXION YOKES

The accuracy with which it is possible to register the three primary images of a colour camera depends on the accuracy of the optical splitting system and of the camera tube deflexion system. Optical components can be made with great and consistent accuracy, a claim which cannot be made for wound components such as conventional deflexion coils. To eliminate the inaccuracies due to the use of wound coils it was decided to print the deflexion coils, and although a significant improvement over wound coils can be achieved by the use of conventional copper coated flexible laminates which are etched in the flat and then formed round a cylindrical former, the long-term stability of such an arrangement was not considered adequate. Ideally the coils should be etched directly in cylindrical form. In the interests both of initial accuracy and long-term stability it was decided to use glass tubes. After grinding to size, the tubes are coated with copper and treated with a suitable photoresist. The single-layer coil is printed in two operations, a master pattern on a flexible base being jig located over one half and exposed, and the same pattern then being moved to the opposite side and the process repeated. By arranging that the join occurs at the point of minimum field where there are only ends and no longitudinal conductors, any slight discrepancy between the diameter of the former and the size of the pattern is removed, – the degree to which the conductors overlap at this point being unimportant. Due to the fineness of the pattern, the etching has to be relatively deep and a special spray-type bath has been developed for this purpose.

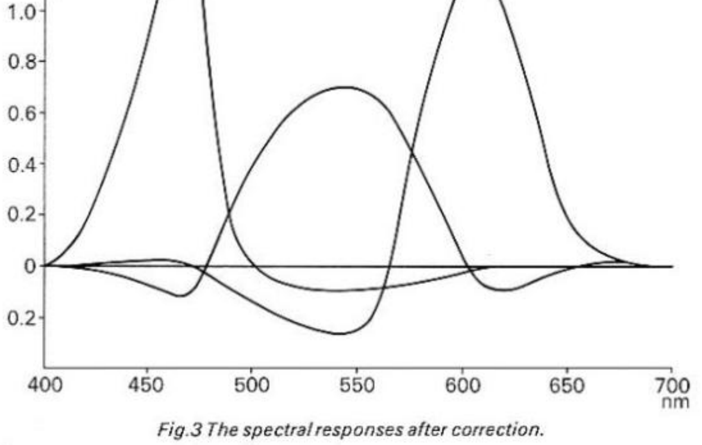

Fig.3 The spectral responses after correction.

The two glass tubes, (Fig. 4), one for the line and one for the field deflexion system, are mounted coaxially with the camera tube, the larger diameter tube being the line coil. True concentricity is maintained by end-support rings. The electron-optical deflexion system thus employs similar materials and techniques to those used in the optical system, not only with respect to initial accuracy, but also with respect to long-term stability and consistency of manufacture.

Having described two of the essential developments leading to the production of a high performance three-tube camera, there is the last, but by no means the least, of the three key factors stated above.

AUTOMATIC LINE-UP SYSTEM

Apart from improving performance, a prime objective of the design has been to reduce the need for skilled and delicate operations in the field. By its very nature a multi-tube colour camera must be accurately adjusted if errors are not to be visible in the final picture. Experience has shown that considerable time and skill must be spent on routine lining-up, and that however carefully carried out the accuracy required is such that the settings must be rechecked at maximum intervals of a few days, especially when the environment is constantly changing as in the case of mobile conditions.

In the Mark VIII, the line-up routine has been completely automated and the overall procedure can be split into three separate functions.

Automatic Colour Balance
Automatic Beam Alignment
Automatic Registration

The complete routine may be initiated by pressing the sequential Line-Up button, (Fig. 5). The sequence commences with the insertion of the capping shutter which also introduces a special pattern from the diascope. The order of events is as follows:

1) Introduction of line up pattern, (Fig. 6).
2) Automatic lamp adjustment bringing the green channel output to a preset level.
3) Gain adjustment in red and blue channels to match red and blue signal levels to green.
4) Automatic Beam Alignment of the green, red and blue tubes in turn. The top left-hand corner of the central white area is used for this purpose, this corner being in the centre of the chart. The focus voltage of each tube is varied and the displacement of the centre point is measured both vertically and horizontally, in the vertical direction by counting lines and in the horizontal direction by counting cycles of a 5·5MHz oscillation. In both cases the appropriate alignments are corrected to bring the difference in count at the two extremes of the focus variation to zero.
5) Automatic registration of the red and blue images with the green image. The eight diagonal edges of the four triangles on the chart are used to examine the relative timings in the three channels. Both horizontal and vertical errors are thus both detected from horizontal information only. Correction is applied to horizontal and vertical centring, width, height, twist, skew and horizontal linearity in the two slave channels, red and blue. The system is arranged to minimize the errors detected at all eight inspection points.

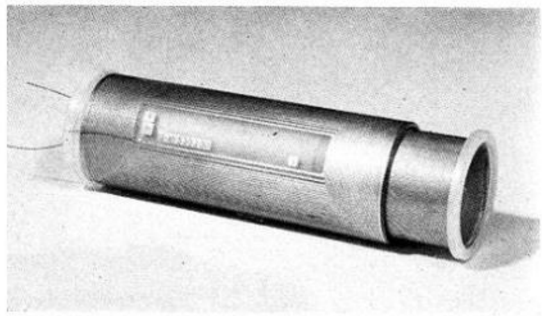

Fig.4 The Line and Field deflexion coils shown partly withdrawn.

Each successive step is monitored by a series of indicator lamps, (Fig. 5), the lighting up of which signifies the beginning of a particular function, and extinction indicates completion. Upon completion of the last phase, the diascope is switched off and the capping shutter withdrawn. The complete sequence as described takes from two to three minutes according to the initial condition of the channel. The majority of this time is occupied by the tube alignment procedure and, if these have not been touched, an overide switch can be used to by-pass one, two or all of the tube alignments. A routine check of the registration can then be performed in about thirty seconds. It will be noted that there is no need for a second operator at the camera, for instance to focus on a test chart, nor is there any need for the operator to remain in attendance at the CCU. Several channels may thus be lined-up simultaneously by a single operator.

All the above operations are performed using the diascope so that one further operation is necessary before the camera is ready to go on air, namely colour balance. In this case a suitable reference white must be included in the camera picture and the lens zoomed so that it occupies a reasonable area of the picture. The Colour Balance button is then pushed, whereupon the iris is automatically adjusted to bring green to a preset level, and the red and blue gains are adjusted to match. This process may be repeated at will should the colour temperature of the illuminant be changed.

An important feature of all the automatic line-up circuits is the use of motor-driven potentiometers for the various adjustments involved (Fig. 7). Because of this it is possible to inhibit all the con-

Fig.5 The CCU showing the Automatic Line Up controls.

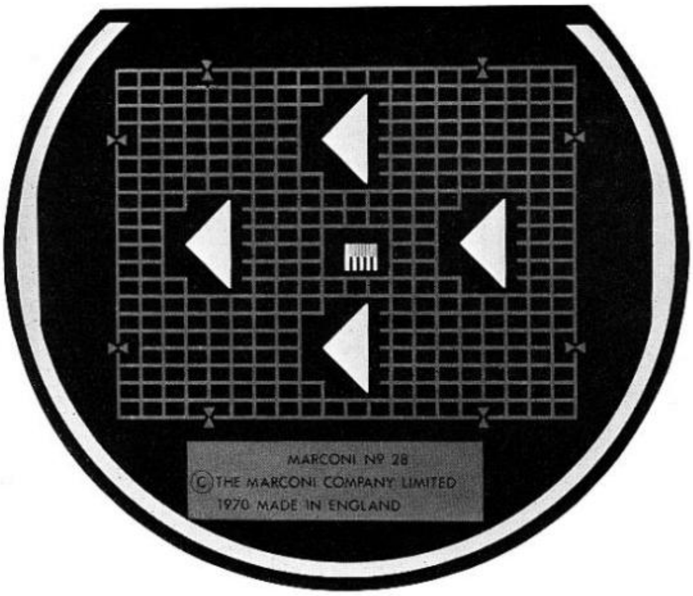

Fig.6 The Automatic Line Up Pattern.

trol functions except when the line-up sequence is specifically initiated by the operator, and, furthermore, the system is immune to the effects of interruptions to the mains supply or power surges.

The provision of an automatic line-up system not only saves time, but introduces a standard method of lining-up which will always be repeated, thus eliminating the differences which always occur between individual operators. Another advantage lies in the ease with which a number of different camera tubes can be fitted and assessed in relation to others in a particular camera.

DYNAMIC CENTRING

The automatic line-up procedure is based on the use of a special test chart requiring that the camera be taken off the air, if only for a few seconds. To insure further against the possibility of registration errors the horizontal and vertical centring circuits are also arranged to operate from normal picture information. The Dynamic Centring system is intended to eliminate the effect of small mechanical movements in the optical system under extreme environmental conditions, either of temperature or shock. It should be remembered that a relative movement of only 10 μm at the image plane represents a registration error of 1 part in 1000. Fortunately any such errors are likely to be of a simple nature which can be corrected by centring adjustments only.

The picture information is sampled along horizontal and vertical lines which cross in the centre of the picture and are about 20% of the width and height. Edges appearing in a narrow window centred about mid grey are used to detect errors between red and green or between blue and green. To avoid misinterpretation due to unrelated transitions in close proximity, any error signals which exceed ± 360ns horizontally or 4 lines vertically are ignored. In addition, action is only taken when an apparent error in a positive (or negative) going transition is confirmed in an associated negative (or positive) going transition on the same field and at a distance equivalent to at least 1·8μs horizontally or 20 lines vertically.

It may be argued that despite these precautions no automatic registration system operating from normal picture information can be completely free from the possibility of misoperation with certain types of picture detail. This objection is largely overcome by applying the correction slowly so that the overall effect is beneficial provided that the correction is applied in the right direction for most of the time. The risk of misoperation is thus reduced to the unlikely case that the particular pattern in question remains the centre of interest in the picture for a prolonged time. In practice such occurrences have not been a problem.

THE CAMERA CABLE

An essential component of a modern light-weight camera channel is a light-weight camera cable to match. As the number of ways in the cable is reduced, the complexity of the multiplexing equipment required increases. It was decided that the optimum compromise resulted when the number of conductors in the cable approximated to those in the standard Mark IV cable, and this type of cable was therefore adopted in principle. Even this black-and-white camera cable is rather heavy and a special Mark VIII cable has been designed which is the light-weight equivalent of Mark IV cable. The outer diameter of the Mark VIII cable is 12mm and it weighs only 220 kg/km. The camera may operate over lengths of up to 900m of this cable, or of Mark IV cable should this be desired. To facilitate use where Mark IV cable may be installed, standard Mark IV couplers have been used.

Because of the relatively smaller number of conductors available, as compared for instance with the Mark VII colour camera cable, multiplexing has been used for many of the auxiliary functions including the viewfinder signal. To eliminate any

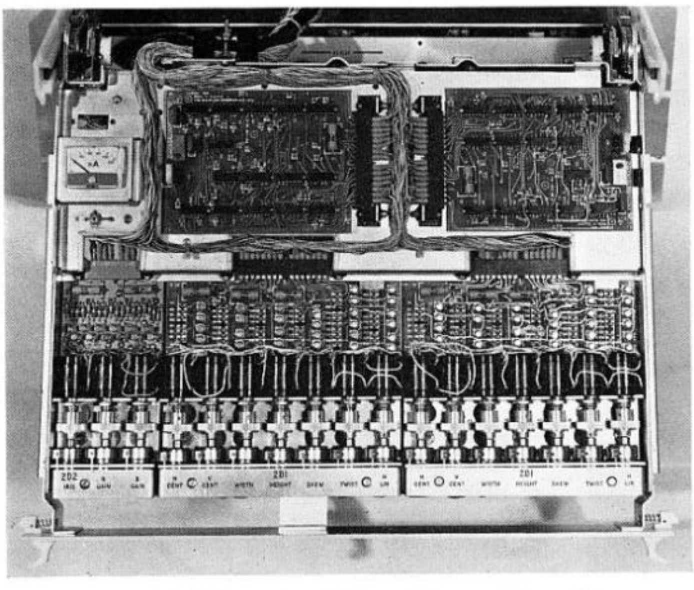

Fig.7 The motor unit shown in the servicing position.

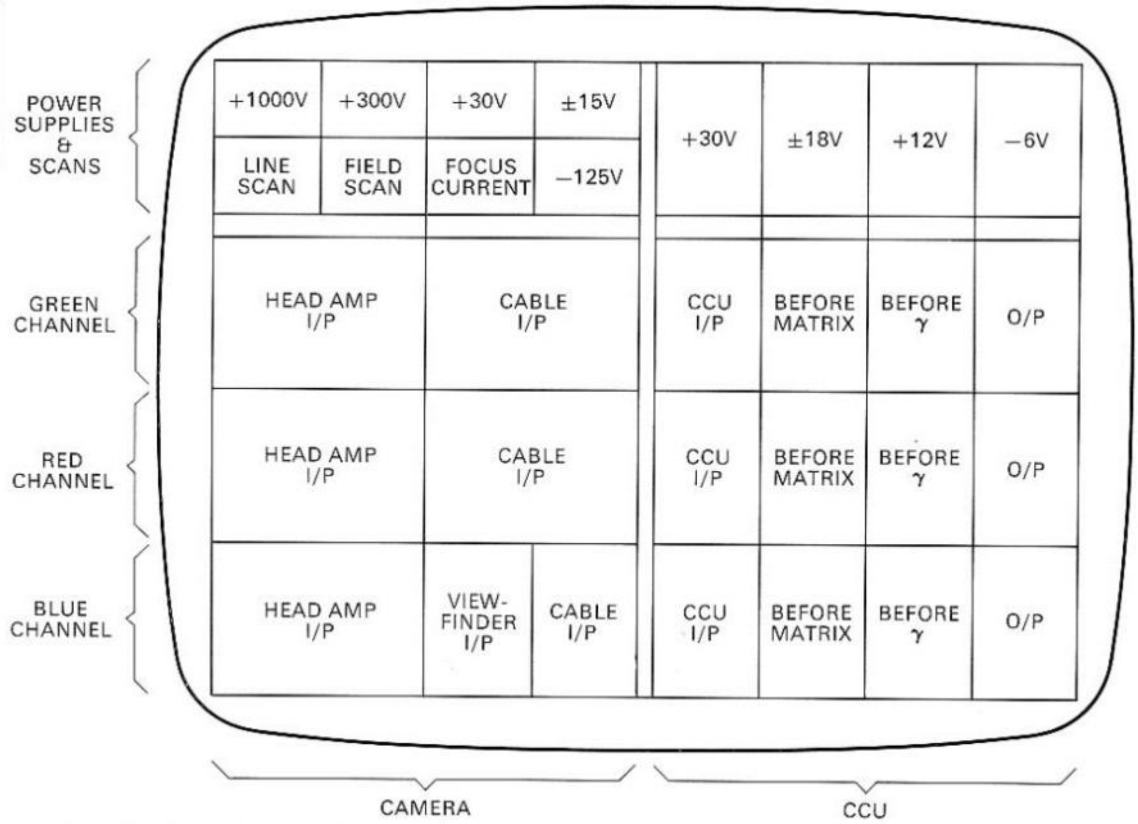

Fig.8 Auto Test Display. Each area is normally white except when there is a fault condition. The particular function associated with each area is indicated on the diagram.

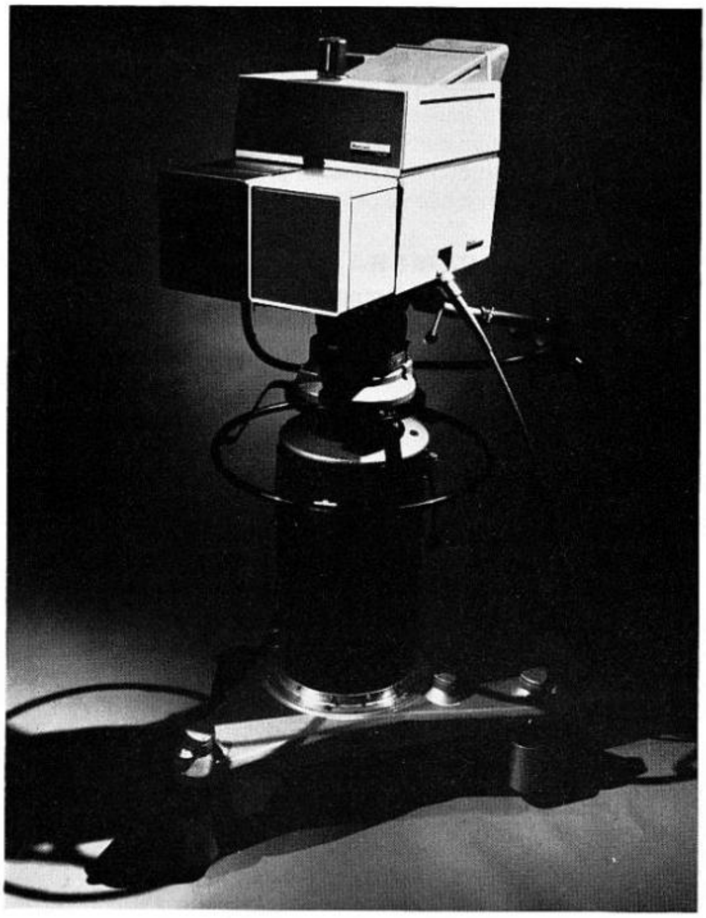

Fig.9 The Marconi Mark VIII Colour Camera

possibility of distortion to the three primary signals from the camera, these are simply transmitted as video-frequency signals along the three 75 Ω coaxial conductors in the cable. The cable carrying the blue signal is additionally used to transmit the viewfinder signal from the CCU to the camera using the band of frequencies 10 to 20MHz. The maximum attenuation using 900m of cable is 63dB, and frequency modulation is used to avoid the necessity for cable equalization.

Time-division multiplexing is used to transmit the line and field timing information for the deflexion circuits together with seventeen on/off control signals from the CCU to the camera, and three from the camera to the CCU. The control inputs are sampled every field, one input being sampled per line. The first 24 lines of each field are used for this purpose, so that the possibility of crosstalk from the multiplex system to the vision circuits only exists during blanking and the one or two lines immediately following. The sampled data is combined with the line and field timing information and, after shaping in a sine-squared filter, transmitted along a single pair of wires.

BLACK LEVEL STABILITY

However stable the vision amplifiers are made, black level instability can arise due to the presence of dark current under low light-level conditions. Again, it is almost impossible to eliminate completely effects due to line scan fly-back pulses which may be present at the input to the head amplifier due to imperfect screening. Both these

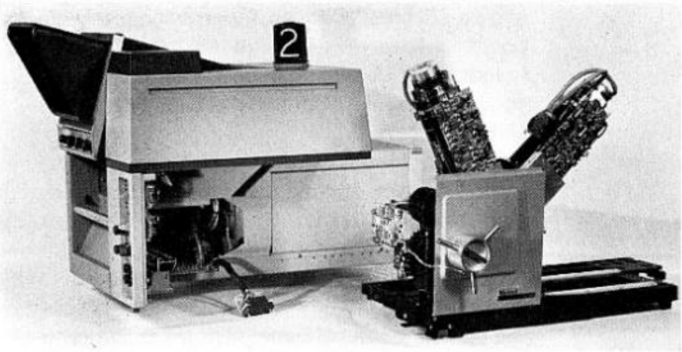

Fig.10 The Camera, showing the optical and electronic components separated.

problems are solved by clamping to true optical black. Each camera tube is fitted with an optical mask which excludes light from the region of the photocathode outside the normal image format. Due to the impossibility of placing this in the actual image plane, the mask is not in focus, and true black is only established several lines away from the normally scanned area. For this reason a step is added to the field scan current immediately after flyback, and this displaces the first few lines some 10% above the normal position. Since no video information is present during these lines, a sample can be taken of this level and used to control the subsequent clamps in the amplifier chain.

GAMMA

A choice of four gamma laws is provided, namely 0·4, 0·45, 0·5, 0·55. Any two of these may be chosen for selection by a switch, a third position of which provides a linear condition. The function generator is maintained at constant temperature in an oven, tracking between channels being accurate to within 0·25% with respect to the peak white signal. A pure power law is generated over a contrast range of at least 60:1 within an accuracy of 10%. Below this level the gain is constant to give an overall contrast ratio of 80:1.

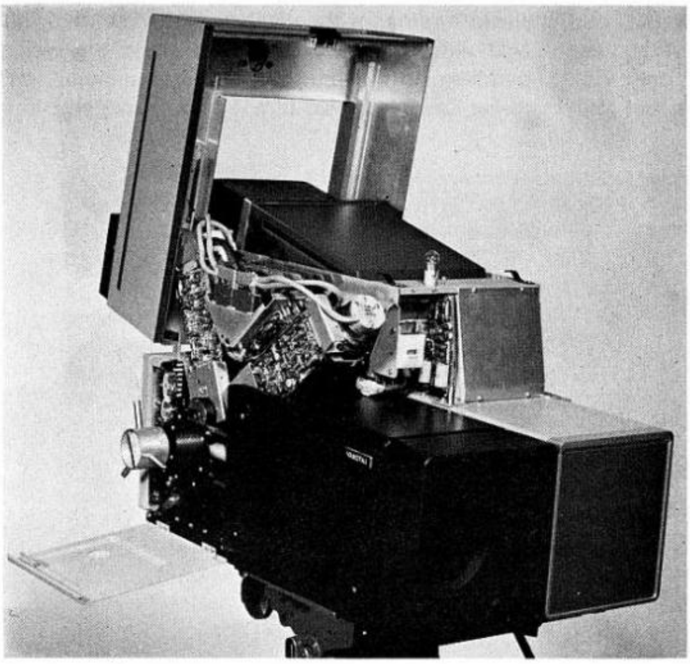

Fig.11 The Camera with the top opened to provide access for servicing.

SIGNAL PROCESSING AND APERTURE CORRECTION

The use of a relatively wide lobe for the spectral response of the green channel allows this signal to be used to provide the high frequency detail for the composite colour signal and this is dealt with in a separate article.[2] Both horizontal and vertical aperture correction is performed in a single aperture corrector employing two glass delay lines. The horizontal corrector has a theoretical peak boost frequency of 10MHz. In addition, an in-band corrector with a 3·6MHz peak frequency is provided and the resultant signal added to the vertical correction signal to provide symmetrical in-band correction. The combined correction signal is added to the mixed highs signal. The resultant signal is given a combed response with maxima corresponding to the line-frequency harmonics and minima corresponding with frequencies shifted by half the line frequency from these. In this way high-frequency noise is reduced whether aperture correction is used or not.

STANDBY IRIS SYSTEM

Although it is not possible to provide automatic iris control which would truly match the performance of manual control under all conditions, an automatic iris control suitable for stand-by operation has been provided. When in use, reasonable pictures can be obtained from widely differing scenes at times when the operator is not immediately available.

AUTO TEST

The camera channel is provided with an Autotest facility which provides an immediate visual check of the operational state. A series of pulses are injected at suitable points along each video path, the output being viewed on the picture monitor. (Fig. 8). The pulses are so gated and timed that each occupies a small rectangular patch on the screen. If all pulses are present, all the rectangular patches are white, indicating that all sections of the video path are functioning correctly. Apart from the video channels, other squares are allocated to monitoring the supply rails and the outputs of the scanning generators. Any defect is immediately indicated by a black square, the position of which indicates the area of the fault and which unit should be changed.

GENERAL FEATURES

To complete this brief outline of the Mark VIII colour camera, it may be of interest to look at a few of the mechanical features. The camera head, (Fig. 9), 600mm in length over the lens, by 400mm high and 360mm wide, is made in two separate parts, the optical component including yokes and head amplifiers, and the electronics component (Fig.10).

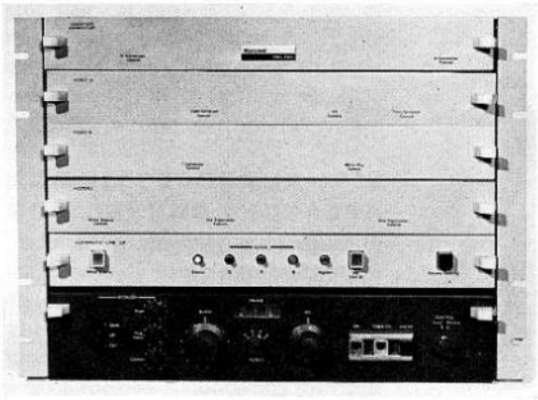

Fig.12 The CCU.

The only electrical connexions to the optical component are to the yokes and amplifiers and for the optical system itself. These are all via removable connectors so that the two components may be separated in a matter of minutes. The servo amplifier for the zoom lens is housed in the electronics component, and is common to all lenses of a given manufacture. All zooms are normally provided with manual focus and one of two gear ratios can be selected, offering a choice for the total number of turns of the focus control. Zoom control may be either manual or servo, the iris servo always being included. As already stated, no zoom tracking adjustment is necessary, any individual zoom being preadjusted to fit any camera.

Access for servicing is via the top hinging cover and the left hand side cover, tube changing being particularly easy to accomplish. (Fig. 11). The majority of printed boards are of the card type, and are grouped together at the front of the camera alongside the lens.

The CCU is 350mm high, (Fig. 12), the circuit boards being mounted horizontally in pull-out trays fitted with flexible cable forms so that they may be withdrawn on power. This not only dispenses with the need for extender boards, but also allows all presets to be mounted directly on the boards where they can be adjusted if necessary without first switching off the channel. The power supply occupies a further 133mm of rack height, (Fig. 13).

The operational control panel is conventional and carries the iris control. In addition the Automatic Line Up and Colour Balance push-buttons are remoted to this panel so that the registration and colour balance sequences can be carried out by the remote operator. The colour balance trim control on the auxiliary control panel also takes the form of a quadrant control, and operates over a single colour axis, that along which colour temperature changes may be expected to occur. To meet the unusual situation, the knob on the control arm may also be rotated to provide colour trim along the axis at 90°. With this form of control, the positions may be readily logged. A central locked position is provided. This control may be used when it is desired to depart from the formal colour balance point, or when it is impracticable to carry out the automatic colour balance process.

CODER

A new colour coder for use with PAL or NTSC is available for use with the Mark VIII. This has been constructed in the same style as the CCU, and occupies 45mm of rack height, (Fig. 14). Setting-up has been reduced to a minimum, there being no such controls on the front. An internal colour bar generator is provided and the coder may be set-up entirely by observation of the output waveform on an oscilloscope.

CAMERA TUBES

Finally, the Mark VIII camera channel has been designed to use camera tubes incorporating both light bias for the reduction of lag, and special electron guns for the discharge of scene highlight overloads which can otherwise cause the typical puddling or blooming effects encountered with earlier camera tubes. It will be remembered from

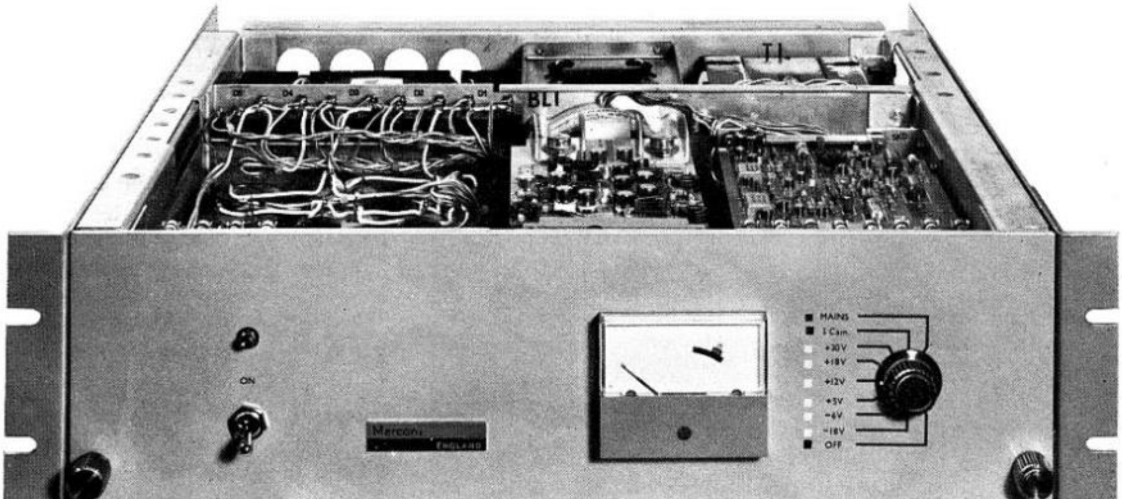

Fig.13 The Channel Power Supply.

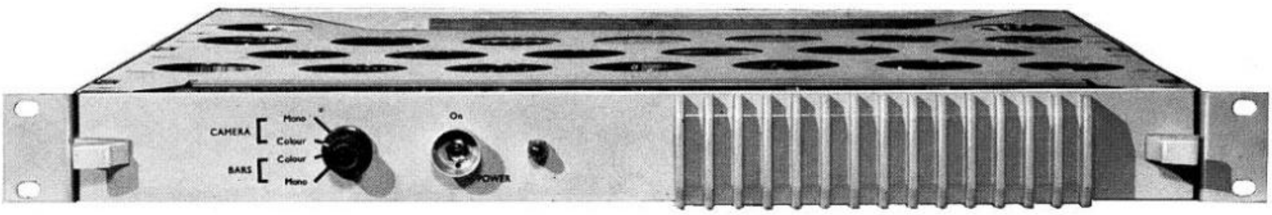

Fig.14 The Coder.

the description of the optical black clamping system that this circuit automatically compensates for any change of the dark current. No special arrangements are thus required for the removal of the light-bias pedestal, and indeed the light-bias may be switched on and off in practice without affecting the black level. The high-light discharge is accomplished during the line fly-back, the beam current being simultaneously increased and defocussed during this period, and the cathode potential being raised by some 5V at the same time. The retrace beam thus reduces the highlight charge to a level just above that corresponding to a normal highlight, and within the capacity of the forward scanning beam.

DESIGN DETAILS

This brief survey has attempted to summarize the more innovative features of the Mark VIII. The design set out to advance in several areas of camera technology in parallel and has been the united effort of a large team of engineers co-ordinated by Mr. A. N. Heightman and Mr. W. T. Underhill. Further papers will be published shortly dealing in greater detail with various aspects of the design. Thanks are also due to the English Electric Valve Company for their co-operation in the development of new camera tubes, and to Rank Precision Industries Ltd. who carried out the detail design of the optical system including the minifiers.

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