

THE MARK IV AND THE FOUR-AND-A-HALF

VIDEOTAPE CENTER, New York, is making much of its new Marconi cameras, imported from England', recorded America's **Advertising Age** in January, 1961.

'This new camera is claimed to increase the gray-scale cut down on flare and permit one extra generation of tape duping without loss of quality. In their demonstration reels are at least three items which seem to bear out the claims: tests for Campbell soups appear to increase appetite appeal in food shots, as seen side-by-side with older cameras. Tests for Toni for Miss America show improvements in rendition of hair texture. . .'

Well, since then the Marconi Mark IV has been established across the world's TV studios for three years. Recently in **INTERNATIONAL TV TECHNICAL REVIEW I** quoted from Mayer and Partington's paper in **Sound and Vision** telling how as long ago as 1951 the Marconi organisation decided to adopt the 4½-in tube as a contender for top picture quality.

Before giving a detailed description of the Mark IV as it is today, it is interesting to learn from Mr B. M. Poole, AMBrit.IRE, a Marconi man since 1935, and who graduated from being the Company's Senior Development Engineer working on television to the position of Chief of Camera Development Section.

'The "design philosophy" behind the Mark IV image orthicon camera', explains Mr Poole, 'has been to produce a channel with the following characteristics.

(a) Performance and stability of circuits to exploit fully the 4½-in tube with some margin for development.

(b) A camera as simple to control as a high-grade photographic camera.

(c) The minimum number of valves at operational positions.

(d) All electronics easily replaceable in blocks with a high degree of interchangeability.

(e) Line-up procedure to be possible from the camera control panel along without a cameraman being employed.

(f) Facility for conversion from one standard to another by switching or by simple linking.'

Says Mr Poole:¹ 'Some very interesting experimental work was carried out by the BBC at their Riverside studios using four Marconi Mk III cameras which had been slightly modified. The gain, lift and light-filter controls were remoted to a common panel at which one engineer could control all four cameras, all other CCU controls being left untouched.'²

'Several programmes were transmitted using this "hands-off" technique, and it was fairly obvious that provided the lighting was consistent, one man could handle all camera controls and maintain very close picture matching.

'With the experience of these trials and the extra stability inherent in the Mark IV channel, the extension of camera control functions to a single position becomes highly practicable, and the camera control panel contains a switch to extend the gain, lift and iris controls to a remote point.

'Thus the interesting possibility of centralised equipment rooms with vision control in the production control room becomes technically possible with the Marconi Mark IV channel. . .'

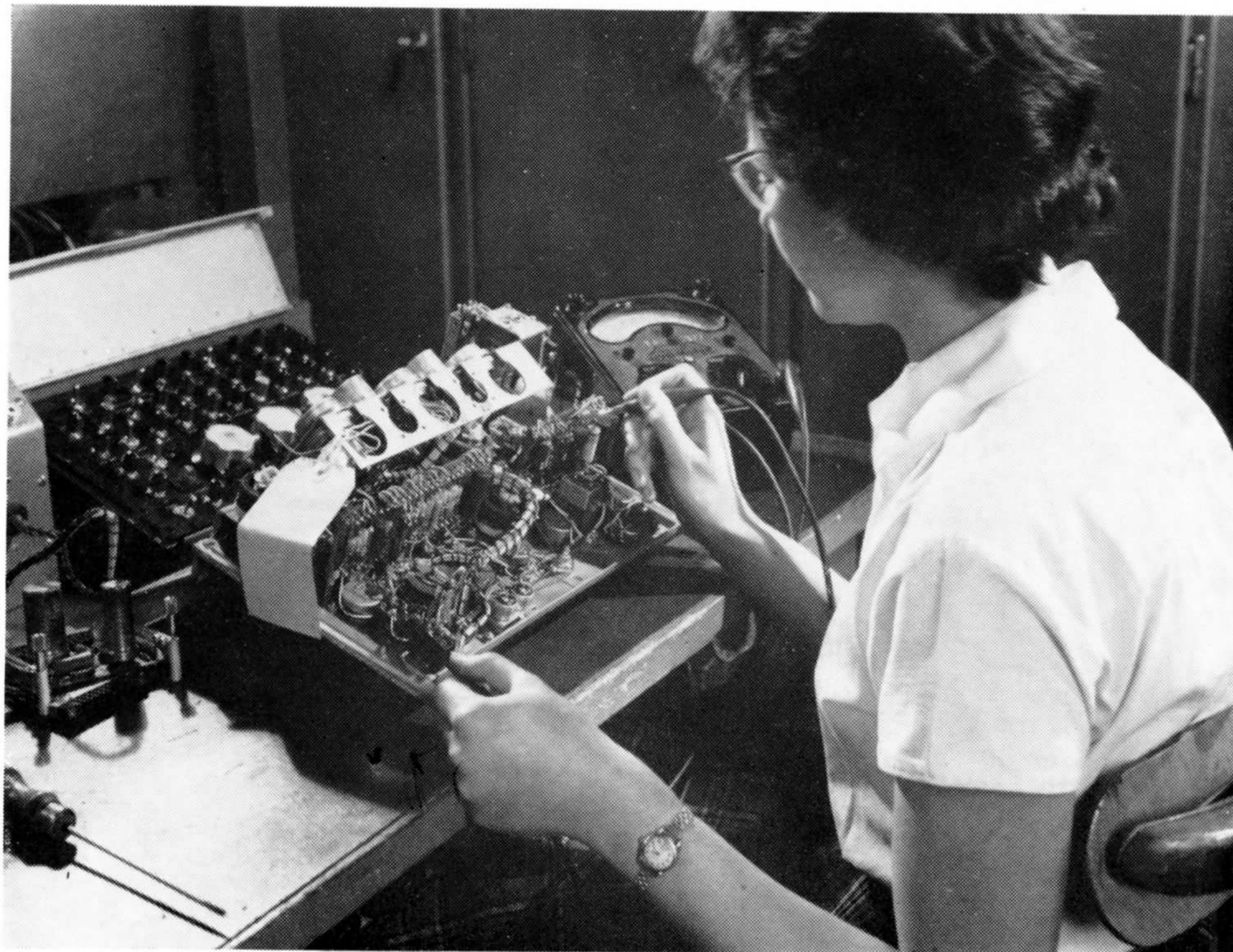
How was this 'hands-off' reliability achieved. As Mr Poole explains, in order to achieve a higher degree of operational stability it is essential to use components with closer tolerances and reduced temperature drifts, to use rugged valves of the E88CC family, and to ensure that components and wiring layouts are mechanically rigid. These facts may tend to increase cost, although Marconi's found that by careful circuit design some reduction in the number of components is possible.

¹**Sound & Vision**, Vol 1, No 1.

²G. E. Partington, The Design of a 4½-in 10 Camera Channel, **Journal SMPTE**, Vol 69, No 2, and **Sound & Vision**.

► The Mark IV and the 4½"

Marconi Mk IV camera channel.
A Camera Control Unit chassis
on test (circuit checking)



In view of the controversy over printed-circuit-board techniques, it is interesting to have the views of the Marconi Chief of Camera Development section.

'Domestic-receiver manufacturers had begun to change over to printed wiring techniques to reduce their costs', he explains, 'and this appeared to offer a means of achieving the rigidity, stability and interchangeability which was sought.

'Within the scale of production of studio and OB equipment, printed wiring techniques are attractive because of the consistency of performance, ability to produce plug-in sub-units, and the relative simplicity of access to components. **Normal mass-production receiver methods of printed wiring proved inadequate for professional equipment. . . .**

'A great deal of engineering development had to be applied to the problem of producing reliable boards which would withstand the extreme climate conditions, permit components to be replaced easily and which would not be damaged by component fault conditions. A glass-fibre-based material is used which is virtually fire-proof and extremely strong. The boards are flow-soldered and then coated with an epoxy resin varnish for protection. . . '

Camera Construction

Minor differences are to be found in Mark IV's in use in various parts of the globe. It has been pointed out to us by Mr Poole that for the BBC's Television Centre a variation in the original Mk IV connector construction is employed. This uses multi-pin plugs at the rear of the cases which mate with fixed sockets in the racking. A special locking and releasing mechanism gives the mechanical pressure necessary for making and breaking the many contacts. This enables 'electronic cassettes' to be quickly interchanged without touching the connectors.

On the other hand, for the Australian ABC, mobile

cases complete with cowl and skids are rack-mounted, providing complete and rapid interchangeability between studio and mobile equipment.

In addition to the six 'design-philosophy' points enumerated by Mr Poole, the major features of the Mark IV are:

- (1) Small size, low weight and low power consumption
- (2) Suitable both for the 4½ and the 3-in image orthicon.
- (3) Simplified circuitry providing stable operation. Short warm-up time.
- (4) As an optional extra, integral orbiting device to extend the image orthicon tube life.
- (5) Large-diameter turret with simplified change mechanism, and control of iris from CCU.
- (6) 7-in viewfinder.
- (7) Plug-in printed-wiring circuits, and rugged, long-life valves.
- (8) Both power supply and camera control electronics in small draw-out units which can be rack-mounted or mobile.
- (9) Very easy access to all circuits, and to yoke for tube changing.
- (10) Passive control panel for camera control with all operational controls. Size permits grouping CCU's.
- (11) Transistor communication circuits built into the camera channels.
- (12) 14-in picture and 5-in waveform monitor tubes with line-strobe facilities.

Mechanical Details

The framework is formed from magnesium alloy castings with a light alloy top. The bottom tray carries the wedge-base on the underside and the yoke carriage on the top. Hinged light-alloy side covers carry the sub-chassis. This gives easy access to circuit elements.

A standard Vinten pin-and-slot wedge-base is used, which is also suitable for the Debie head; and this base

may be moved fore and aft to give balance adjustment. An alternative baseplate is available to give secure fixing on American-type friction heads. The camera cable entry and headphone jacks are positioned to give full up-and-down tilt with the Vinten Type-III head or equivalent. The top of the camera base carries a socket into which may be plugged either a 'Transmission' cue light, or an indicator showing the camera number on three faces and also incorporating the cue light.

A four-position turret is carried by a large-diameter tube running in self-aligning bearings at back and front of the camera, with a most elegant indexing mechanism at the rear. A single turn of a handle on the right-hand side of the camera moves the turret one position with a non-linear rotation law permitting a heavy set of lenses to be accelerated from rest and smoothly halted at the end of this travel.

The lenses have the same type of flange and clamping that have proved so successful with the Mark III camera (and which have been adopted as a standard by the BBC), but are mounted on an 8-in diameter pitch circle. With normal hoods, lenses of 5-in or less focal length can be mounted next to a 2-in lens, or 8-in or less next to a 3-in lens without interference. Lenses of up to 40-in focal length can be mounted opposite a 2-in lens.

Iris Control and Diascope

As I have already mentioned, full positional **servo** control of the iris from the remote CCU position is optionally available for all lenses, both in the studio and the OB range. And of course there are the latest zooms which are rotatable with the turret, and have full controls available at the remote position. This servo amplifier (an optional extra) uses transducer circuits, and it is mounted in the power supply unit draw-out case. With no servo control of iris, a $\frac{1}{2}$ -in diameter hole is provided through the turret shaft for zoom lens control.

The optional orbiting device prolongs the useful life of the tube, and prevents 'sticking' when used on static pictures. This orbiting facility consists of an electrical shift circuit connected to small deflection coils incorporated in the tube yoke. A simple diascope (video analyser) can be fitted in one lens position, and obtains the projector lamp supply from a socket on the turret, thus obviating the need for flying leads which must be broken to enable the turret to rotate. A slide-holder for two standard 2×2 miniature slides (picture area 28-mm by 21-mm) is fitted.

Yoke and Focus Control

A new design of yoke (somewhat smaller in diameter and of course lighter in weight) is used in the Mark IV, and precautions are taken to ensure the tube works at its optimum temperature. Remotely-controlled 'capping' of the tube is provided from the camera control panel. The yoke carriage slides on self-aligning PTFE bearings running on chromium-plated guides. A simple focus mechanism is used, operated from a three-spoke capstan on the right-hand side of the camera, giving approximately two turns for full travel.

On the Mark IV there are sockets for a headset for the cameraman, and three additional headphones for dolly-pushers and others of the team. The cameraman's headset carries a small microphone by which he can talk to the

CCU operator, and the earpieces normally receive producer's talk-back, camera-control talk-back, and programme sound. The other headphones normally receive only producer and programme sound. Separate volume controls are provided for all sources. The amplifiers for the cameraman's mike and the other talk-back inputs are carried in the CCU power unit and, as mentioned in Point 11 of the Marconi specification, are transistorised.

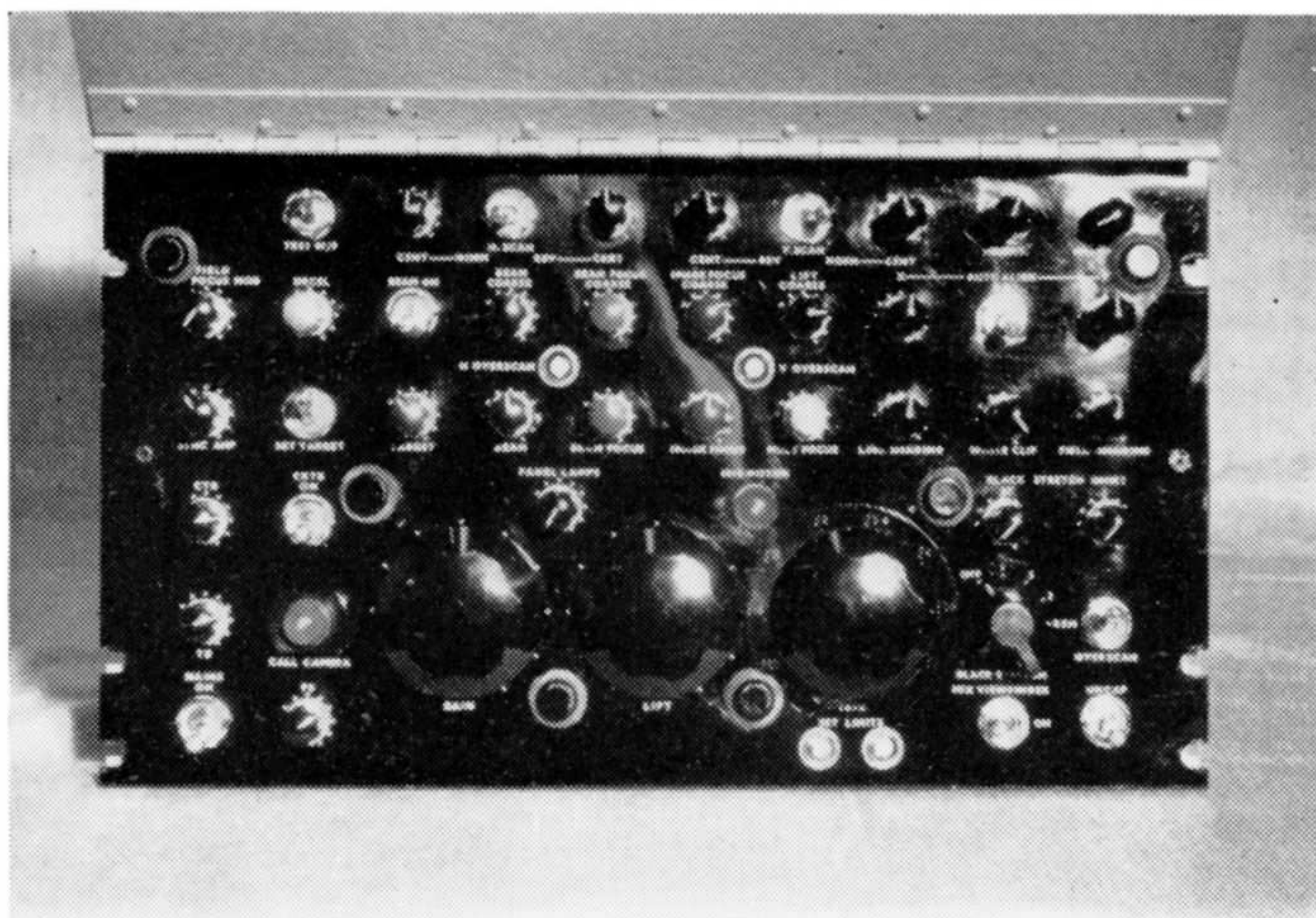
Camera Control Unit

Printed-wiring boards tend to occupy more surface area than the equivalent wired chassis, so in the Mark IV a new type of rack-mounted unit has been developed to make the best use of rack space. The CCU electronics and the power supply are two separate units which can be placed side-by-side across a standard 19-in rack. At Chelmsford they have devised quite an ingenious layout. And each unit consists of a central vertical panel carried at top and bottom by ball-bearing slides. On each side of this panel are mounted printed boards connected by plugs and sockets. A swan-neck of cables joins the external connectors with the boards, and allows of inspecting 'under power'. Normally no controls appear on the front panel: all pre-sets are sited where most convenient on the boards themselves, but of course are quite accessible with the unit withdrawn.

I am told at Chelmsford that when rack-mounted in stacks it may be necessary to provide forced ventilation, particularly if units have to be arranged one above the other, or when ambient temperatures are high. For mobile channels, the same printed-wiring cases are provided with top cowls and base runners, and there are handles fitted to produce compact 'suitcase' units.

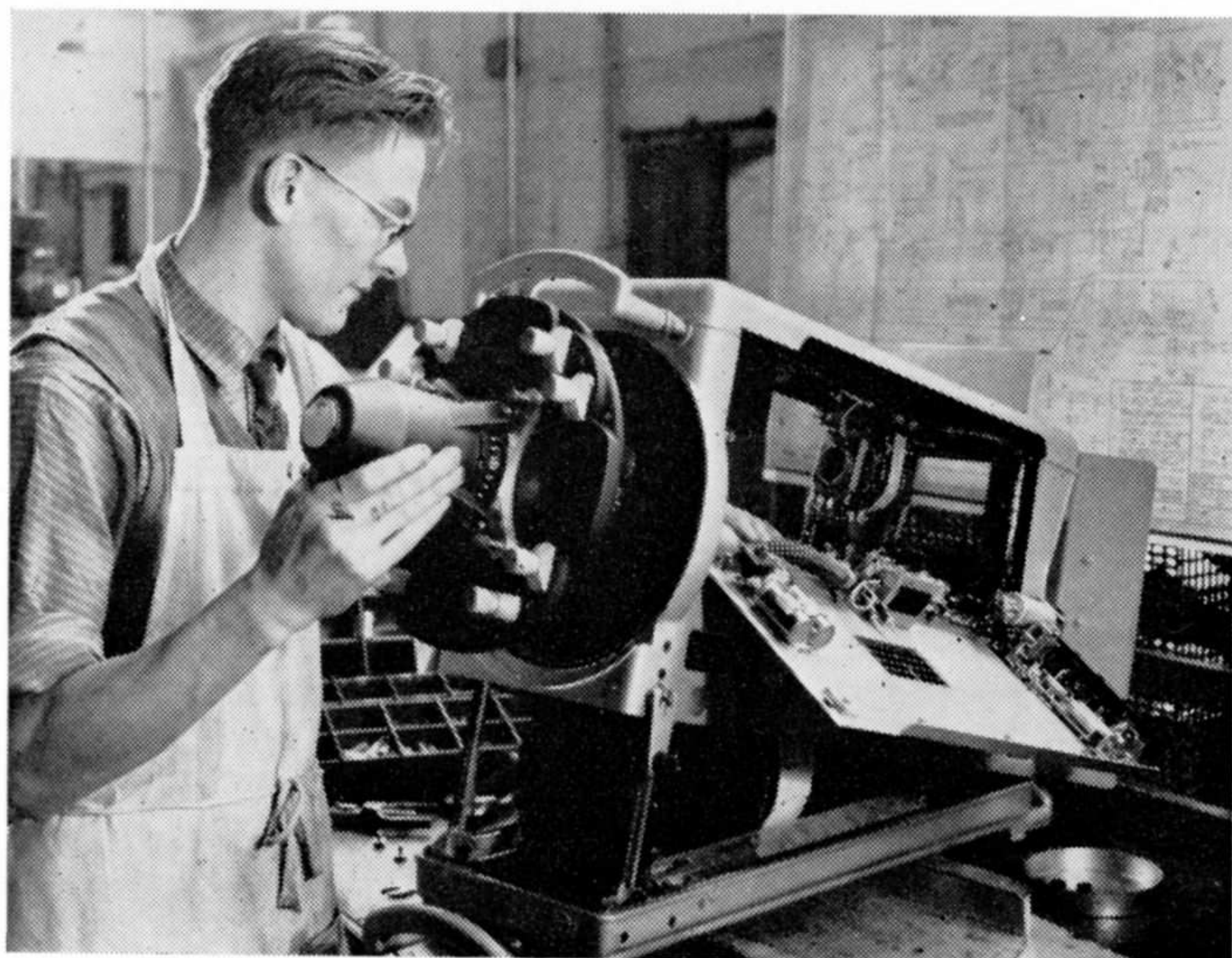
The standard camera-control position consists of the studio console housing for the Mark IV equipment, containing a BD 873 picture and waveform monitor, and in the desk position beneath this monitor is the camera control panel for the rack-mounted CCU. This panel has the main operating controls on the edge close to the operator, and the rest of the presets are normally covered by a hinged lid. This entire panel is only 8-in from front to back, and 14-in wide, so it is perfectly possible to place two or even more control panels under the care of one operator.

For OB work, the picture and waveform monitor is



A Mark IV camera control panel

► The Mark IV and the 4½"



Production of the Marconi Mark IV TV camera—fitting a turret shaft assembly. The body of the camera hinges upwards, giving access to the image-orthicon tube

carried in the mobile case, and the camera control panel is housed in a small unit mounted conveniently beneath the monitor in the OB vehicle racking. Where the equipment has to be de-rigged, this can be placed on any convenient flat surface in front of the monitor.

In some studio layouts, due to the inherent stability of the Mark IV channel, it is considered desirable to have the control of all cameras in the hands of one senior engineer. For this technique a remote control panel can be provided at Chelmsford, bringing the main operating controls of the CCU in a form suitable for grouping together.

Circuit Details

In the last article we briefly considered the characteristics of the 4½-in image-orthicon tube, and now we can see what happens to the signal after it has been dealt with and created in the pick-up tube.

As a first step, the signal from the image orthicon is passed into a low-noise cascode input stage in the camera's head amplifier. Feedback is used to reduce the input impedance and correct for capacity losses across the load resistance. This eliminates the need for the otherwise conventional 'high-peaker' stage, and I am told it makes for a considerable improvement in the LF response. Additionally, it stabilises the amplifier and makes it much less prone to microphony.

The dynode supply is stabilised by a corona regulator. To reduce noise, the signal input and dynode decoupling capacitors are selected for freedom from current leakage. A phase-splitter provides picture polarity reversal and, after amplification, a cathode-follower matches the signal into the 75-ohm camera cable line.

At the input of the camera control unit, shading waveforms correct the camera signal. The signal is then passed through a cable correction circuit which is continuously variable over the range of zero to 1,000 feet—and incidentally this control requires adjustment only when the length of cable in use is changed.

Gain of the video processing amplifier is remotely controlled from the panel. A continuously-variable phaseless aperture corrector permits accurate compensation for any loss of resolution in the image orthicon; the phaseless

nature of this correction, coupled with the low noise of the image orthicon itself, allows over-correction to be used when high-frequency emphasis is required.

The clamp stage is very carefully designed to eliminate set-up drift. Clamp pulses are supplied from a split transformer winding, and are always balanced. Pulses are derived from line drive which is returned from the camera after initiating camera scan. Thus, when long cables are used, the clamp pulses are equally delayed and remain correctly timed with respect to the camera video signal. This eliminates 'shutter bar' problems when scan amplitudes or centering are altered. The clamp pulse widths are very wide to reduce the possibility of clamping on spurious signals. Inserted blanking amplitude is fixed by clamping between two DC references. The set-up clipper is controlled by feed-back; the clamp bias is produced from an amplified pulse, the size of which is proportional to the set-up.

Gamma Correction

Gamma correction is provided by reducing the current feed-back to the cathode of the clamped valve. The circuit is such that reduction of the current feedback does not affect frequency response.

After DC insertion, the signal passes to a stage where synchronising pulses are added if required. Three parallel 75-ohm output stages follow, one of which provides the feed to the viewfinder. The other two outputs are for the mixer and monitor. By slight alteration of the circuit, these two outputs may be composite or non-composite, or one of each.

The viewfinder amplifier terminates the 75-ohms line from the camera control unit, with a transformer network providing a high-frequency boost. This permits cable correction, and produces additional boost which is a valuable aid to focusing.

A shunt-regulated output stage provides a large linear swing to the grid of the viewfinder tube, producing a wide-band response. The DC component is maintained by a DC restorer.

Field-scan generators for both camera and viewfinder are housed in the camera control unit. Negative feedback circuits prevent any change in linearity or amplitude when camera cable lengths are changed. A line drive pulse is fed to a clipper on the line-scan chassis. Separate discharge circuits are provided to drive the independent high-efficiency output stages for the camera and viewfinder scanning. The viewfinder output stage provides the 12-Kv for the viewfinder tube, and the -600 volts for the image orthicon. The latter voltage is regulated by a corona stabiliser.

To diverge for one moment from the circuit details, it may be noted that on the Mark IV the 7-in diagonal rectangular tube is used for the viewfinder, and this is recessed into the camera back. A built-in hood, open at the bottom, keeps stray light from the tube face, but a deeper tilter hood is available where preferred. The viewfinder is larger than that used on previous Marconi cameras, and dispenses with magnifying lenses. Special attention has been paid to the interlace and linearity of display. The brightness, contrast and timebase controls are easily located in small recessed panels on each side at the rear, while other controls appear as presets under the side cover.

An 'On Air' cue light shows in the hood, and the turret

(continued on page 104)

position is shown by an illuminated number in the usual way. The viewfinder input is from the CCU, as we have seen, and the cable feeding it can be switched at both ends to route a test signal to the camera head amplifier, enabling tests to be made from the CCU position.

Normally the viewfinder has an output from the CCU, but an external signal can be mixed with this for superimposition effects and so forth. In order to set the gamma correctly between panels after alignment of cameras has taken place, the test signal switch is arranged to switch out shading so that a test saw-tooth can be inserted.

The camera line-scan provides the image orthicon dynode supply. This is used as a bias to safeguard the tube against line-scan failures. The field-scan current is sampled by a transformer which produces the bias for the camera line-scan discharge tube. Hence, if the field-scan fails, the line-scan is switched off, and the image orthicon is biased off. This forms a very reliable scan-protection circuit which safeguards the tube against synchronising generator failures or scanning failures, without recourse to the use of relays.

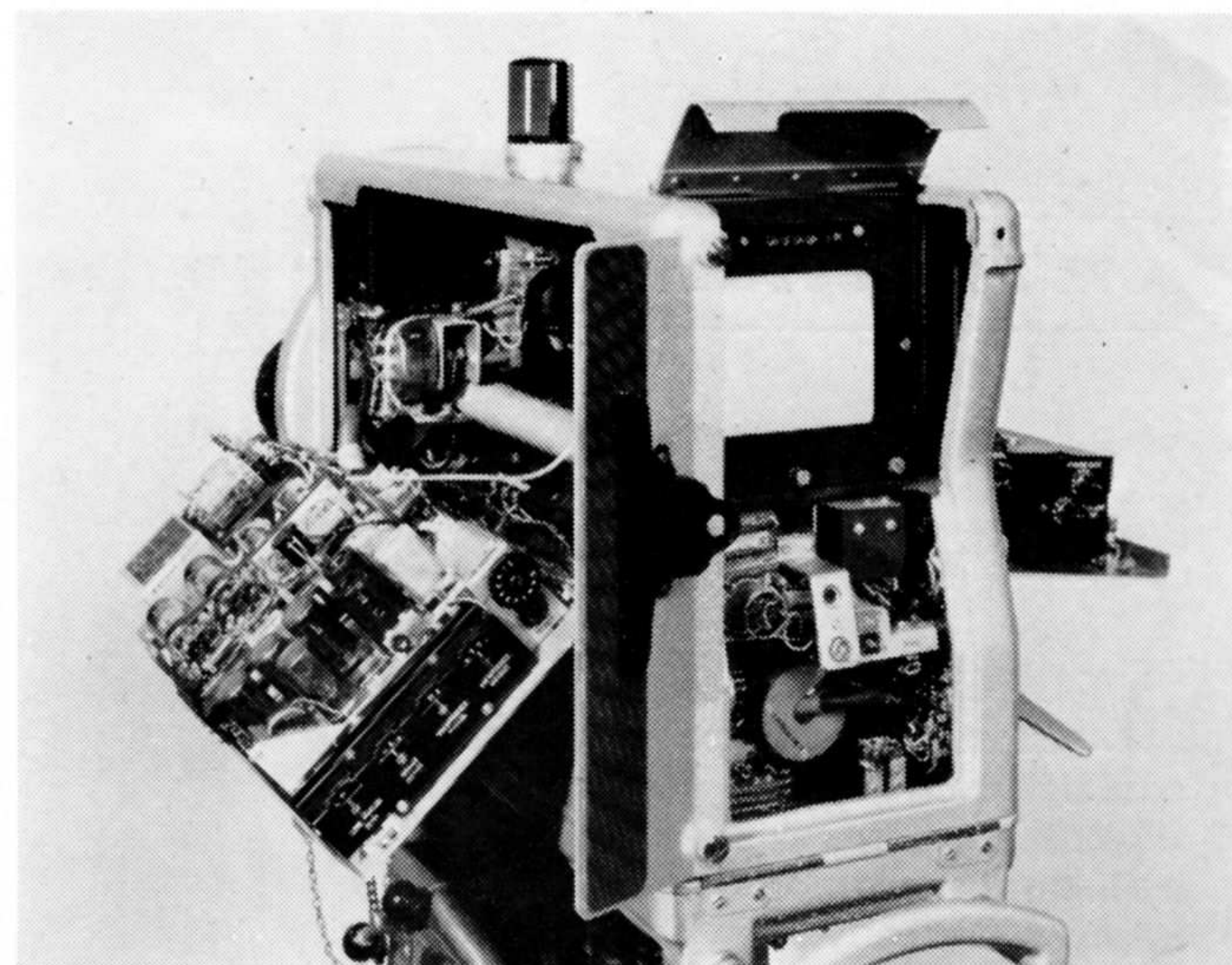
The HT regulator utilises a transducer to control the amount of rectified current flowing into the smoothing system. This gives half-cycle by half-cycle regulation of HT voltage, which compensates for changes in AC input or output load. High-frequency control is established by a type of shunt regulator stage of very high efficiency, without the use of banks of series regulator valves.

The power supply unit also contains the electronic circuits associated with the remote iris control. In action, the voltage on the slider of the iris control is compared with the voltage on the slider of a potentiometer attached to the iris gear-ring; any difference-voltage is amplified and fed to the magnetic amplifier. This latter causes the iris motor to turn, so rotating the iris ring potentiometer until the difference-voltage is cancelled out.

Even a brief examination of the Mark IV shows that a considerable amount of development has gone into the production of reliable and compact printed-wiring boards, which have the unique feature of two screened bus-bars running along the edges of the boards, providing low-impedance HT points, earth points and heater supplies. In addition, these bus-bar systems add considerably to the mechanical rigidity of the board, and are used to provide a means of fixing.

The camera contains a total of only twelve valves, seven of which are the long-life, close-tolerance E88CC. The circuits are carried on small printed sub-assemblies, which are plugged into the main frame, giving very easy access for rapid maintenance. A number of features which have been found convenient in earlier designs have been retained in spite of the slight extra weight and bulk introduced, for example, the camera cable connector tails are soldered to a tag-block joining them to the internal circuits of the camera, enabling the connector to be replaced if necessary without great disturbance of the internal wiring. Other modifications in this connection have already been noted.

Although the channel stability is such that acceptable pictures are normally available as soon as the rapid warm-up of the image orthicon is complete, as a measure of day-to-day 'preventive maintenance', a useful test facility is provided. By using the Test switch on the CCP, a test



The side cover is here dropped down, revealing the Mk. IV's line-scan unit. The rear cover of the camera is also removed, showing the tube base.

signal is routed to the head amplifier test input, via the viewfinder cathode-follower and its coaxial conductor in the camera cable, to appear as the channel output. Reference has already been made to this facility, but this signal can be seen on the waveform display Type BD 873 (which is itself easily checked against a standard calibration signal looped through all channel monitors), and by using the line strobing facility frequency response can be quickly checked from a test pattern.

In these days of 405, 525 and 625-line working, and the current need in Britain to produce programmes simultaneously on two standards, multi-standard switching is most important in any camera channel.

The position of the Mark IV in this connection is clearly stated by Mr Poole: 'The increasing use of magnetic tape for the international exchange of programmes has brought with it the need for quickly changing the line standard of studios, as an alternative to the use of standards converters, and the Mark IV channel caters for this requirement very effectively.

'Where several cameras are used together, a communication unit is provided for the production talk-back, programme sound and so forth, and therefore provides a central point with access to all channels. Into this unit switching circuits are fed which are routed to all the cameras and their monitors, and operate relays to make the necessary changes to scanning and signal circuits.

'For permanent or long-term alteration of line standard, internal links and shorting plugs can be used to provide a cheaper alternative to the relays'.

I recall that when Marconi's Chief of Camera Development Section spoke about the new channel, in 1960, he said: 'In designing the Marconi Mark IV camera, every effort was made to achieve the ideal. A mass of informed opinion was considered to find what users really wanted, putting aside all technical considerations such as size of camera tube or previous practice'.

Present outstanding results being obtained with this channel at television centres across the world show that the high hopes engendered by this design-philosophy have certainly not been misplaced.

Next month the concluding section of this paper will deal with operational notes on the 4½-in image orthicon itself, with particular reference to lighting, staging and set design.

(To be concluded)

The Mark IV and the Four-and-a-half

by E. P. L. Fisher

The largest single order for 4½ in. image orthicon television cameras in the world has been awarded to Marconi's by Columbia Broadcasting System. This, allied with the world success of the English Electric 4½ in. tube makes a true saga of British industrial achievement recorded here in a major series of articles by E. P. L. Fisher, with official co-operation from the television companies concerned

THE largest single order for 4½ in. image orthicon TV cameras ever to be placed in the world has been awarded to us,' I was told by Marconi's Wireless Telegraph Co.'s Dan Boyle, 'by Columbia Broadcasting System TV Network.

'Twenty-nine of our Mk. IV camera channels—the latest type fitted with a transistorised pre-amplifier—are being delivered before November this year for the new CBS broadcast centre in New York City. Six others are going to the CBS News Facility in Washington, and nine more Mk. IVs to the CBS Network Television City in Hollywood. . . .'

At this juncture in world television, the 'four-and-a-half', that amazing version of the image orthicon which in actual fact has an image section of 4.6 in. diameter (117 mm.) has completely changed our techniques. Programme coverage which previously would just not have been possible is now given with cameras such as MWT's Mk. IV, and OB as well as studio television is developing virtually a new art form which could not have been, but for the development of the 'four-and-a-half'.

It seems only yesterday (but in fact was in May 1961) when the Oscar of the television industry crossed the Atlantic for the first time and, as has already been recorded in these columns, 'Emmy', the USA National Academy of Television Arts and Sciences Engineering Award (given annually in recognition of an outstanding engineering or technical achievement) was conferred jointly on Marconi's, English Electric Valve Company and the Radio Corporation of America, in recognition of the independent development of the 4½ in. image-orthicon camera and pick-up tube.

As a tribute to English Electric and to MWT, I have been invited by INTERNATIONAL TV TECHNICAL REVIEW to compile a summary of the history and development of the 'four-and-a-half' and of the Marconi Mk. IV camera, giving test and operational data to assist users the world over.

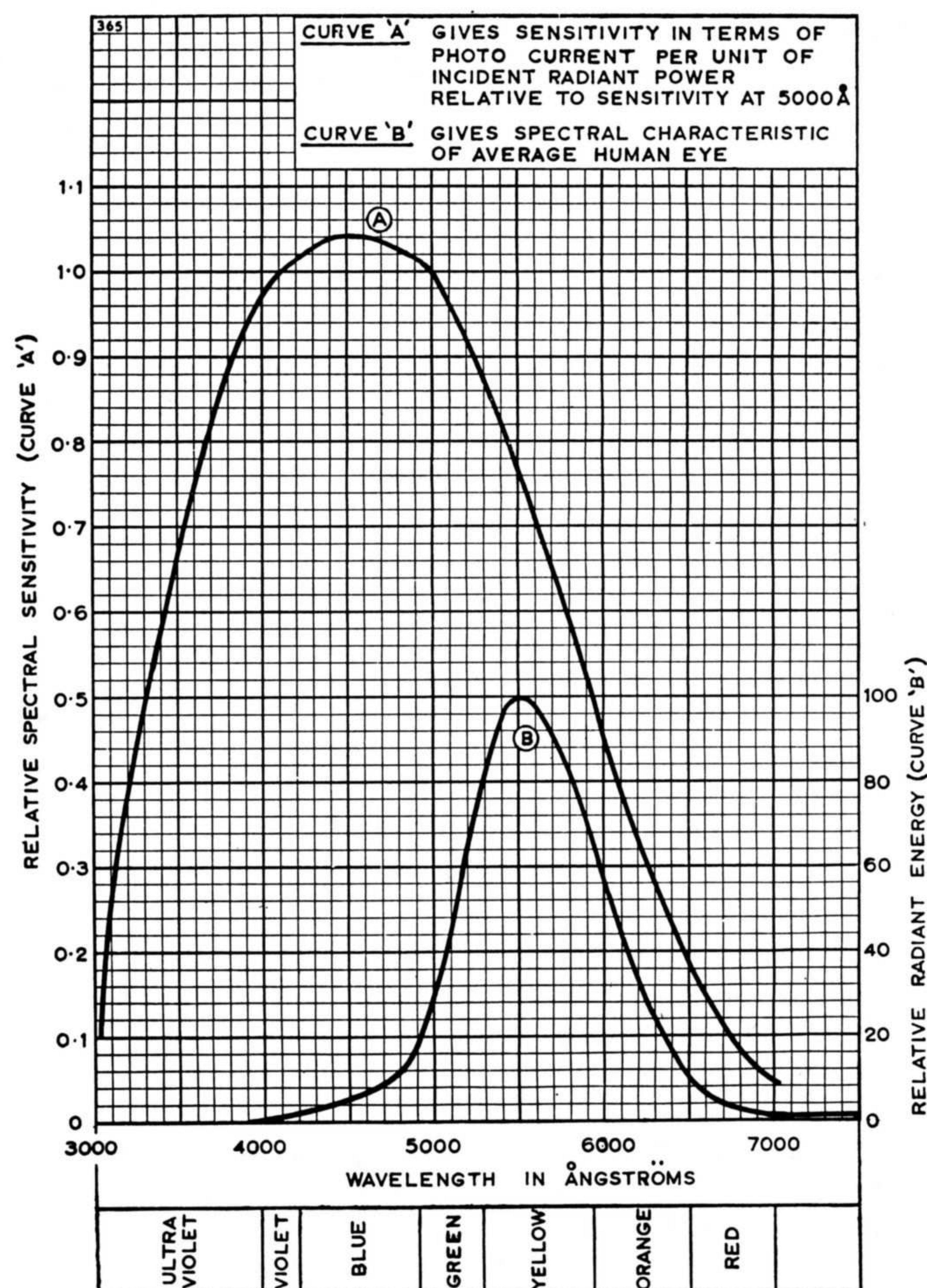
In professional circles, the English Electric 'four-and-a-half' is the 7295 or 7389, between which, as we shall see, there are a few differences, the later tube having a higher target capacitance and giving a better signal-to-noise ratio. In addition there are 'four-and-a-halves' such as the P812, which has an extremely high signal-to-noise ratio and is used almost solely for standards-conversion equipment; there are also the P815 medical and P825 X-ray 4½ in. image orthicons, which are not suitable for entertainment TV applications. Just as 7295 was the first in the range of 'four-and-a-halves', so the 5820 3 in. image orthicon was a pioneer in its field.

'For some twenty years the 5820 3 in. image orthicon was almost the only tube used for television pick-up in the USA,' says Mr. W. E. Turk, BSc, AMIEE, of the English Electric Valve Co. Ltd., 'and in the greater part of the rest of the world as well. Yet the tube was never used in the operational sense in Britain, in spite of a very serious attempt being made immediately after the war to introduce it to the BBC.

'Whereas the US rejected the image iconoscope very early in its television history, British television clung to it steadfastly until 1958. Many authors have said, somewhat patriotically, that the reason for this contradictory state of affairs was that each country was sure that its tube produced the best picture. . . .'

RCA's contribution

It is now popular history that the 4½ in. image orthicon pick-up was originally developed experimentally by Mr. Otto H. Schade for laboratory use by the Radio Corporation of America. It was not commercially exploited. However, in 1950 Mr. G. E. Partington, later Chief Engineer of Marconi's Broadcasting Division, saw the possibilities of this tube, and development work on a new camera was started at MWT, Chelmsford. Research on the tube was



Spectral sensitivity characteristic of typical English Electric Types 7295 and 7389 4½ in. tubes

put into the hands of Mr. G. B. Banks of the English Electric Valve Company.

Mr. Turk (by then Manager of the Photo-Electric Tube Division of the EEV Co., and who with Mr. J. F. James, the Chief Development Engineer of Marconi's, was at the Ziegfield Theatre, New York, in May 1961, to receive the Oscar) has summarised accurately this chapter in the transition to the new technique.

'When immediately after the war' (he explained) 'it was sought to re-establish the television service in Britain, one was very conscious of the American wartime development and, most notably, the elegant solution by RCA of the particularly awkward problem of a double-sided mosaic and its use as a storage target in the image orthicon.'

'However, the violent difference between this tube and the image iconoscope (and, later, the CPS Emitron) rather prevented its immediate adoption; and the CPS Emitron, or orthicon, was soon accepted as the preferred tube.'

'Its advantages over the iconoscope were enthusiastically welcomed. Among its desirable features were constant gamma and black level, greater sensitivity (mainly due to a novel British method of making antimony photo-sensitive mosaics) straight-through optics, and simplicity of operation. Probably the main points against it were inadequate

sensitivity for OBs and its lack of stability at high light-levels. These objections were, of course, well satisfied by the image orthicon, and it was to this tube that English Electric Valve Company turned its attention early in 1949, with a view to adapting it to the British taste.

'On examining the mechanism of the discharge scanning process in the 5820 (that is, the 3 in.) it was found some improvement would result from the straightening and the strengthening of the field immediately in front of the target—that is, rendering it more uniform and strictly parallel to the target surface, and with a higher beam decelerating rate. This was achieved by fitting a fine, highly transparent copper mesh at wall anode potential across the tube on the scanned side of the target. It is important to realise the requirements of this mesh. Firstly, it should be 100 per cent transparent so as not to absorb any of the scanning beam, and secondly it should not be seen or have any effect on the viewed picture. The first is clearly impossible; but in practice a transmission of about 75 per cent is fairly easily achieved; higher values than this result in very weak meshes.

'Invisibility is a bigger problem. The scanning beam passes through this mesh twice, the return beam being slightly displaced with respect to its forward path. This has the effect of emphasising any defects in the mesh (blemishes are seen twice, or magnified in size, and errors in the pitch of the mesh appear as check patterns) either regular or not. The axial position of the mesh affects its visibility critically. As is well known, the path of the beam from gun to target is in the form of a series of varying diameter helices, and care must be taken to arrange the mesh at a point of maximum helix diameter in order that it be least in focus when the beam is focused on the target.

'One serious drawback of this field mesh, as it has been named, results directly from its interception of the beam. At the voltage of incidence appreciable secondary emission occurs, and the secondary electrons emerge with the picture-producing beam on its return journey, and produce an out-of-phase signal, sometimes known as the second image. Resolution and noise are both impaired by this unwanted signal, but a solution due to Hendry (incorporating a suppressor electrode on the gun) eliminates them.

'This field-mesh 3 in. image orthicon was introduced to British television about 1951, and it has enjoyed an increasing popularity throughout Britain and the world since that time. Its improved geometry has proved invaluable in colour cameras where three tubes have to be accurately matched and their pictures superimposed.'

How it works

The 2¼ lb. of 4½ in. tube contain some of the highest precision electronics ever devised by man, and at this stage it is advisable to make a brief run-through of the principles of an image orthicon's operation.

In the classic description given by EEV Co. themselves, the tube is separated into three sections, the image section, scanning section, and multiplier section. You can see the whole layout in an accompanying diagram.

The image section contains a semi-transparent photocathode on the inside of the face plate, and electrodes to provide an accelerating electrostatic field to the target. This latter consists of a thin glass disc with a fine mesh screen

mounted very closely to it on the photo-cathode side.

An image of the scene to be televised is focused by an optical lens system on to the photo-cathode and causes photo-electrons to be emitted. This photo-electron emission is proportional to the intensity of the optical image at any particular point. The photo-electrons are focused on to the target by the combined action of the electrostatic field and a longitudinal magnetic field, the latter being produced by an external coil. The magnetic field is so graded that the image formed at the target covers approximately three times the area of the image at the photo-cathode.

Secondary electrons are produced by the impact of the photo-electrons on the target, and these are collected by the fine mesh screen which is held at a small positive potential with respect to the target. The screen potential limits the excursion of the target and ensures complete stability at all light levels. The secondary emission at the target produces a pattern of positive charges corresponding point by point with the light distribution of the original scene, and the thinness of the target allows the charge pattern to be reproduced immediately on the reverse (that is, the scanned) side.

Scanning Section

The face of the target remote from the photo-cathode is scanned by an electron beam emanating from a triode electron gun, the potentials being so adjusted that the beam approaches the target with a substantially zero velocity and is, therefore, unable to produce unwanted secondary electrons.

In areas of the target corresponding to the dark areas of the image, the beam electrons are unable to land and are reflected towards the gun. In areas corresponding to the illuminated regions of the image, the target will be positively charged and electrons will be deposited until the target potential is restored to its original value. That fraction of the beam not required for neutralisation of the target charge pattern will return towards the gun. The return beam will be thus amplitude modulated, its intensity being inversely proportional to the brightness of the original image.

All beam electrons can be prevented from landing on the target, whatever the photo-cathode illumination, if the target mesh is made more negative than a certain potential termed 'cut-off potential'. For normal operation the target mesh potential is set a few volts above this value.

The beam is focused at the target by the magnetic field of the external focusing coil and the electrostatic field of the wall coating (Grid No. 4 in the diagram), and deflection is accomplished by transverse magnetic fields produced by external deflection coils. The beam is aligned with the focusing magnetic field by means of a small transverse magnetic field produced by outside coils located at the gun end of the focusing arrangement.

The target end of the wall coating (grid No. 4) is closed by this fine mesh known as the field correcting mesh, and it is maintained at a potential a few volts positive with respect to the wall coating. In addition to improving the landing characteristics of the beam at the target, the presence of the field correcting mesh reduces the intensity of the white edging which bedevilled pictures produced by earlier versions of the image orthicon.

Edge field at the end of the beam focusing electrode is controlled by adjusting the potential of the decelerator

(grid No. 5) which is situated between grid No. 4 and the mesh, this adjustment helping to improve the landing characteristics of the beam. Finally, as a precaution against light leakage, which in the past used to cause puzzling, spurious results, the gun end of the tube is coated with an opaque enamel.

Multiplier Section

The return beam, comprising electrons which are not required for neutralising the charge on the target, travels back along approximately the same path as the outgoing electron beam and is directed into a five-stage electron multiplier where it is amplified to become the output video signal. To reduce the intensity of the image of the first dynode which will be superimposed on the transmitted picture, the whole of the multiplier section assembly is mounted off-centre.

This multiplier gives an overall multiplication from the five stages of between 500 and 2,000. This is sufficiently high to bring the random noise of the electron beam well above that of the input stage of the camera head amplifier and is, therefore, the limiting noise factor in the use of such a 'four-and-a-half' tube. Incidentally, the multiplier also permits the use of an external amplifier of lower gain.

It will be appreciated that when the beam moves from a *less* positive portion of the target to a *more* positive part, the signal output voltage across the load resistance changes in the positive direction. Hence, for highlights in the scene, the grid of the first video amplifier valve swings in the positive direction.

Camera Design

So much for the essential functioning of the 'four-and-a-half'. A detailed specification is given in an accompanying chart.

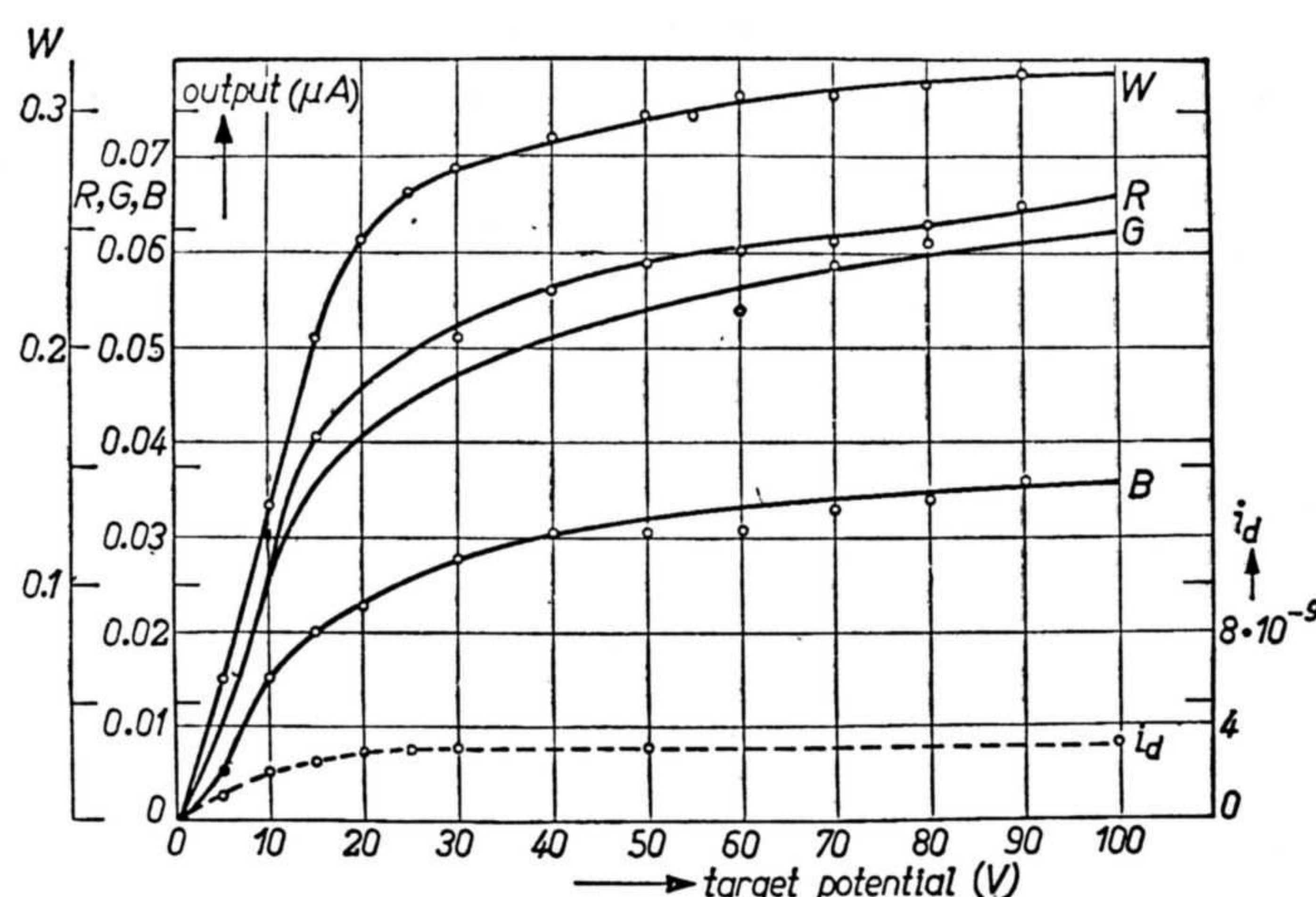
Now right from the start there has been very close working between EEV Co. and MWT. The first outcome was the Mk. III camera, which had a world-wide sale before being superseded by the Mk. IV. Tubes of this type are used by other producers of cameras, and before considering the MWT Mk. IV in detail it is instructive to see what type of camera equipment English Electric themselves advise. I have been fortunate in being given information from the Chelmsford laboratories of EEV which will be of assistance to design teams in other parts of the world anxious to incorporate a 'four-and-a-half' into their specification.

Focusing, Scanning and Alignment Coils

The focusing tube for the 'four-and-a-half' should be so designed as to provide the correct relation between the magnetic field at the photo-cathode and that at the target. The electron lens so formed magnifies the electron image from a diagonal of 1.6 in. at the photo-cathode to a diagonal of 2.4 in. at the target. The field in the scanning section has to be substantially uniform.

The image cross-section of the coil should be well shielded to prevent cross-talk from the scanning coils, and if this is not done EEV find the electron image tends to oscillate at scanning frequency, of course, with a consequent loss in resolution.

(continued on page 402)



Schematic arrangement of the 4½ in. image orthicon tube

Alignment coils are usually a pair of mutually perpendicular saddle coils arranged with their magnetic centre about $\frac{1}{4}$ in. in front of the first dynode of the gun, and the magnetic axes vertical and horizontal. The resultant field should be not less than 3 gauss. If the heat generated by the focusing and scanning coils is sufficient to raise the tube temperature above the maximum permitted level of 60°C., provision has to be made for forced-air cooling. Most manufacturers use a small blower, but care has to be taken to prevent mechanical vibration of the tube and its amplifier.

In the event of there being insufficient heat generated to maintain the temperature within the recommended range, a heater has to be provided surrounding the image section, and naturally this is controlled by a thermostat.

The 'four-and-a-half' has two guides for inserting it correctly in the focusing coil; they are the location contact No. 3 on the shoulder base and the short radial line in the corresponding position on the face-plate. Focusing and deflection coil assembly should be so positioned that the key-way for the location contact is at the bottom of the image coil. Orientation of the scanning coils has to be such that the vertical scan is essentially parallel to the plane passing through the location contact and the centre of the face-plate, and provision has to be made to allow a slight rotation of the shoulder socket and deflection coils to permit correction of any image rotation introduced between the photo-cathode and the target. The tube is installed in the camera by inserting the diheptal base end of it through the coil, the orientation of the tube being such as to ensure registration of the two locating bushes on the shoulder where fitted, and also the shoulder contacts with their correct slots in the yoke. The radial line is thus at the bottom of the face-plate.

Power supplies

The DC voltages required by the 'four-and-a-half' are as shown in the specification table. The field mesh should be maintained at a potential of 15 to 25 volts above that of the wall coating forming grid No. 4. It is usually convenient to derive both supplies from a common source, and independent adjustment of the field mesh potential is not necessary.

In designing a voltage-divider for the multiplier section of the tube, it should be recognised that the DC output of individual tubes of any one type may have a range of ten to one. The range, therefore, must be considered in the choice of bleeder resistor values. If these values are too high, the distribution of voltages applied to the dynodes will be upset by a tube with a DC output at the upper end of the range. As a result, there will be an abrupt drop in the AC output of the tube as the beam current is increased. When this drop occurs before the beam is at its optimum value, the ratio of signal to noise will be lessened.

Even with satisfactory bleeder resistor values it is possible to overload the tube itself. For tubes having high DC outputs, a current reversal can occur at the fifth dynode stage of the multiplier as the beam current is increased. This current reversal will also produce a sharp drop in the AC output of the tube. To prevent such a current reversal it is recommended that the provision be made to reduce the overall multiplier voltage for tubes with DC outputs at the upper end of the range. A reduction to 1,000 volts should be adequate for most tubes, provided that the anode voltage relative to dynode No. 5 is maintained. A preferable alternative is to adjust the potential of dynode No. 3 relative to dynode No. 2 and No. 4.

Video Amplifier

The video amplifier should be designed to cover a range of AC signal voltages relative to the possible range of signal output currents flowing in the load resistor. To utilise fully the resolution capability of the tube in the horizontal direction, it is necessary to use a video amplifier with an adequate bandwidth. For 405 line working a bandwidth of at least 6 Mc/s is necessary, and for 525 and 625, 10 Mc/s.

Shading correction

The provision of shading correction signals is recommended. A sawtooth signal with a frequency equal to the line frequency, and an amplitude approximately twice that of the video signal should be provided. Provision should be made for varying the amplitude and polarity of the signal, and field shading correction should also be provided.

Target Blanking

A blanking signal must be applied to the target to prevent the electron beam from striking the target during the return portions of the horizontal and vertical deflection cycles, and unless this is done the camera tube return lines will appear in the received picture.

The blanking signal is a series of negative voltage pulses. Voltage between pulses must be constant to prevent fluctuation of the target voltage; during the blanking periods, the full beam current without video signal modulation is returned to the multiplier, and its multiplied output flows through the load resistor.

To avoid damage to the target of the tube, provision should be made to bias off the electron beam in the event of failure of either of the deflection circuits.

Finally, the lens system used with a 'four-and-a-half' should be designed in accordance with standard optical practice, and an iris or other mechanism must be incor-

porated to control the amount of light falling on the photo-cathode. To prevent entrance of stray light, all internal surfaces of the lens holder have to be finished in matt black.

Progress summary

To summarise the development of the 'four-and-a-half' I cannot do better than quote Mr. T. Mayer, BSc, AMIEE and Mr. G. E. Partington, BSc, AMIEE, who recently surveyed simplified image orthicon operation in the Marconi publication *Sound & Vision*.

'By the time our development was initiated,' say these two 'godfathers' of the 'four-and-a-half', 'the classic work of Otto Schade had already demonstrated the exceptional picture quality potentially available in the 4½ in. image orthicon. For this he used some RCA experimental 4½ in. tubes made in the mid-1940s, but never commercialised. These were virtually scaled versions of the 3 in. tube. In our development, two major innovations were made. The field mesh first introduced in 3 in. tubes in 1950 was used to ensure more uniform beam landing and to reduce beam-bending. In the 4½ in. tube, fuller advantage was taken by separating the field mesh from the focusing electrode, and operating it at a potential to suppress secondary emission introduced at the mesh by the scanning beam.

'Secondly, the photo-cathode image size was retained at 1.6 in. (40 mm.) diagonal as in the 3 in. tube, so that larger lenses are not required.

'Since the charge pattern from the photo-cathode is then expanded three times in area on the larger target, it might be thought that the operational sensitivity would be reduced by a factor of three. Fortunately this has not proved to be so, because the optimum exposure for a 4½ in. tube is only about half a stop above the knee compared with say two stops for a 3 in. tube, which makes them of about the same operational sensitivity. This has allowed the 4½ in. to gain full acceptance for outside broadcasts where it has probably made an even greater contribution to improved picture quality than in the studio.

'In low light conditions it is actually more sensitive than the 3 in. tube, in that it will give an acceptable picture at lower light levels due to the greater margin for deterioration.'

Development of Mk. IV

In 1951 the Marconi Company decided to adopt the 4½ in. tube as a contender for top picture quality, in competition with the other types of pick-up tube then available. Development then continued in co-operation with EEV until 1955, when the 4½ in. image orthicon was introduced with the Marconi Mk. III camera channel. Hundreds were sold, to TV chains around the world.

Stability of operation proved to be a prime feature of the new tube, and prior to the development of the Mk. IV camera T. Mayer and G. E. Partington, in the survey already mentioned, disclosed how the BBC aided tests to demonstrate the possibility of simplified operation.

'In England,' they said, 'we were fortunate in having the British Broadcasting Corporation, who were quick to realise this point, and therefore carried out exhaustive tests on a set of Marconi Mk. III 4½ in. cameras installed at their Riverside studios. These tests showed that with little improvement it was possible to set up a 4½ in. camera

channel when a new tube was put in and then only a brief check, say once a day, would be required. . . .

'The improvements ensured that all image orthicon electrode potentials were stable after a warming-up period, which operators required to be as brief as possible. Scan amplitudes, centering voltages and the subsequent signal processing must also be stable under all conditions, including changes of line voltage, ambient temperature and pulse variation.

'Having modified the cameras to achieve this, the BBC felt it was now possible to let one camera control operator handle a complete production on his own by regarding the majority of the controls as pre-set, and only giving him access to exposure, lift and gain controls, and possibly black stretch. Several one- and one-and-a-half-hour dramas were successfully transmitted with this method of operation as long as four years ago.'

From such tests and, of course, from development at their own Chelmsford laboratories by MWT, came the Mk. IV camera. A Marconi spokesman told me that the use of some 300 of the Mk. IIIs in many parts of the world, especially Italy, Canada and Australia, helped when it was decided to embark on the design of the Mk. IV.

It was decided (I was told at Chelmsford) to minimise the circuitry in the new camera to make it small and light, and to improve stability, reliability and maintenance. Also the Mk. III variable neutral filter exposure control, switch operated, was replaced by a full positional servo control of lens iris.

This has gained about a stop in operational sensitivity since it was found that operators always wanted at least this amount of filter *in*, just in case they later wanted to take it *out*. Naturally this loss is significant when related to studio lighting, say the difference between 100 kW and 200 kW.

In a future article I will give a detailed account of the Mk. IV as subsequently developed, and will follow with operational notes on the English Electric tube which will be of practical help to all users of cameras of which the 4½ in. image orthicon is the heart.

(To be continued)

Bibliography

- ZWORYKIN AND MORTON. *Television*. John Wiley & Sons.
- ROSE, WEIMER AND LAW. 'The Image Orthicon, a Sensitive Television Pick-up Tube'. *P.I.R.E.*, July 1946.
- JANES, JOHNSON AND MOORE. Design and Performance of TV Camera Tubes. *RCA Review*, June 1949.
- JANES, JOHNSON AND HANDEL. A New Image Orthicon. *RCA Review*, December 1949.
- JANES AND ROTOW. Light Transfer Characteristics of Image Orthicons. *RCA Review*, September 1950.
- BANKS, FRANK AND HENDRY. Image Orthicon Camera Tubes. *Journ. Television Soc.*, September 1953.
- TURK AND HENDRY. An Improved Image Orthicon. *J.S.M.P.T.E.*, February 1960.
- THEILE. Recent Investigations into the Operation of Image Orthicon Camera Tubes. *Journ. Television Soc.*
- ROTOW. Image Orthicon for Low Light Levels. *RCA Review*, 1956.
- PARTINGTON. The Design of a 4½ in. Image Orthicon Camera Channel. *J.S.M.P.T.E.*, February 1960.
- MAYER AND PARTINGTON. A Survey of Simplified Image Orthicon Operation. *Sound & Vision*, Vol. 2, No. 1.