DESIGN FEATURES* OF A TELEVISION CAMERA WITH A SINGLE-LENS OPTICAL VIEW-FINDER

By T. WORSWICK, M.Sc., and J. L. BLISS, Associate Members.

SUMMARY

Some of the problems of television-camera design are considered. A description is given of a design for a high-velocity-tube camera in which an optical view-finder and a servo focusing-control are incorporated.

LIST OF SYMBOLS

u = Distance of object from lens.

v = Distance of image from lens.

f = Focal length of lens.

D = Diameter of photo-cathode.

c = Diameter of maximum permissible circle of confusion.

$\left.\begin{array}{l} u_1 \\ u_2 \end{array}\right\}$ = Inner and outer limits of u for objects in acceptable focus.

u_H = Hyperfocal distance.

(All in similar units.)

k = Stop number (f-no.) of lens.

Subscripts F, C, indicate that a symbol relates to the view-finder lens or the camera lens respectively, e.g. f_F, u_C.

(1) INTRODUCTION

In 1948, the British Broadcasting Corporation undertook the design of a television camera based on a small Super-Emitron camera-tube available at that time. This camera was not required to meet a specific programme or operational commitment, and therefore considerable latitude in design was afforded for incorporating various ideas which had developed from time to time since the inauguration of the television service. Attention was paid to the designs offered by manufacturers, and considerable thought was given to methods of overcoming any disadvantages that were apparent. For example, there was at that time a general trend towards greater size, weight and complexity in television cameras. One aim, therefore, was to keep these qualities to a minimum. At the same time, satisfactory performance had to be maintained and adequate operational convenience offered. Reliability and consistency of operation were considered of prime importance.

The problems involved in the project will be discussed.

(2) OBJECTIVES OF DESIGN

The broad objectives can be tabulated as follows:

(a) Weight to be as small as possible (say 50 lb max.).

(b) Size to be as small as possible.

(c) Camera circuits to be kept to a minimum for simplicity of maintenance and operation.

(d) All electronic units to be rapidly changeable.

(e) Lens-changing to be facilitated so that various angles of view may be used.

(f) Performance based on a high standard of picture quality.

Needless to say, most of the requirements conflict and compromises must be made at nearly every stage in the design. However,

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* Patent Applications: 4726/49, 30785/49, 1372/50.

Mr. Worswick and Mr. Bliss are with the British Broadcasting Corporation.

one decision is all important and must be taken before anything else need be considered; that is the method of view-finding to be adopted. This is discussed in Section 5, and, as will be seen, it was decided to use a view-finder of optical type and of novel design.

(3) CAMERA LENSES

In order to have a choice of different angles of view, a number of lenses of different focal length must be available. The range of focal lengths called for in practice is from about 1¼ in to 6 in in the case of the midget Super-Emitron tube. The conventional method of lens changing on television cameras is to mount the lenses on a turret. If it is to be possible to put lenses of widely different focal lengths on the same turret the turret has to be so large and heavy that it becomes the dominant factor in the size and weight of the camera. Further, the fitting of adequate lens hoods to lenses on a turret is very difficult. For these reasons a mechanism which holds one lens at a time was devised and the mode of changing adopted was that of removing one lens and replacing it by another. A skilled operator can change lenses in 10 sec. The lens hood takes the form of a light sheet-metal trumpet attached to the front of the lens.

(3.1) Iris Control

Experience in service had shown the need for rapid and easy adjustment of the iris diaphragm of the lens to take account of varying lighting conditions. It was therefore thought that a small motor and a suitable gear train incorporated in the camera for controlling the lens iris were justified. The motor is operated by the control-equipment operator, who also has all electrical adjustments under his control, so that he can make the best of any particular set of conditions. A simple remote-indicating circuit shows the f-number on a meter at the control position.

(3.2) Camera Lens Mounting

Each camera lens is mounted on a circular flange plate which fits into a circular recess on the front of the camera. Contact is made between three flat hardened-steel bosses on the flange and the hard steel spherical surfaces on the camera front. The circular flange is held in the recess by six phosphor-bronze spring fingers which swivel to grip it. Each lens is aligned on its flange plate so that when mounted in the camera it is at the correct distance from the photo-cathode for focusing.

(4) THE CAMERA TUBE

A description of the tube itself is contained in another paper.[1] There are, however, certain features which have a direct influence on the camera design. Perhaps the most important of these is the unusually small size of the photo-cathode (approximately 20 mm in diameter). Since the focal length of lens required to secure a given viewing angle is proportional to the photo-cathode diameter, it follows that the optical equipment required is considerably smaller, lighter and cheaper than is necessary with larger photo-cathodes. It can also be shown (see Section 13.1) that the focusing motion necessary to cover a given variation in

object distance is proportional to the square of the photo-cathode diameter. The small-movement required by a 20 mm photo-cathode facilitates the design of the servo focusing-system adopted in the camera, because adequate power can be obtained from a relatively small motor.

From an operational point of view, the small photo-cathode introduces an important feature. It is well known that the depth of focus given by a camera can be increased by stopping down the lens, if adequate light is available, and, conversely, that insufficiency of light can be compensated at the expense of depth of focus by opening up the iris. Now it can be shown (Section 13.2) that the aperture (expressed by the stop number or f-number) required to give a prescribed depth of focus is proportional to the photo-cathode diameter. The camera described gives acceptable depth of focus with an aperture of $f/2 \cdot 8$, while the maximum available aperture is $f/1 \cdot 9$. It follows that inadequate lighting can be compensated over a range of about 2 : 1, whereas with a photo-cathode of twice the diameter the working aperture would be $f/5 \cdot 6$, and by operating at $f/1 \cdot 9$ the camera would give pictures satisfactory in respect of everything except depth of focus with only one-eighth of the normal lighting. These considerations are of little importance in studios, where it is easy to provide enough light, but for outside broadcasts the usefulness of the camera is limited to occasions of fairly bright daylight in spite of a high intrinsic sensitivity for a tube of the high-velocity type.

(4.1) The Camera-Tube Mounting

The methods of mounting the camera tube in the correct position in the camera and of supporting the necessary scanning and focusing coils are important. To facilitate rapid interchange the tubes are mounted in cradles designed with a view to quick and accurate location in the camera and so formed that the tubes with their scanning and focusing coils can be pre-aligned.

The design of a suitable cradle was simplified by the close mechanical limits to which the glass envelopes of the tubes are manufactured. In particular, accurately formed dimples permit the scanning and focus assemblies to be centred on the tube by the device of building the assemblies on cylindrical formers which slide over the dimples. The scanning and focusing coils are fairly heavy. They are carried on the cradle instead of on the glass of the tube in order to prevent breakage of the tube by mechanical shock to the camera.

It is necessary to protect the tube from external magnetic fields, which could cause displacement and distortion of the image; it is also necessary to reduce to a minimum the degree of penetration of the scanning fields into the image section of the tube. Unless this is done there is a serious loss of resolution since the image of the photo-cathode formed on the target will not be stationary but will be deflected in accordance with the scanning, resulting in a blurring of fine detail in the image. These requirements are met by extensive Mumetal screening for the tube. The screening is so far effective that no loss of resolution due to unwanted fields can be detected in a 405-line system, and it would seem to be adequate for a system of at least 625 lines. Mumetal is subject to dimensional changes when it is finally annealed after working. The cradle has therefore been designed so that correct alignment of the tube is independent of any distortion of the screens. The construction of part of the cradle is shown in Fig. 1.

Because it is magnetically focused the image section of the tube causes a rotation of about 45° in the image of the photo-cathode formed on the target. To compensate for this the tube is rotated about its axis and provision is made for adjusting its position between about 40° and 50° when setting up the tube in its cradle.
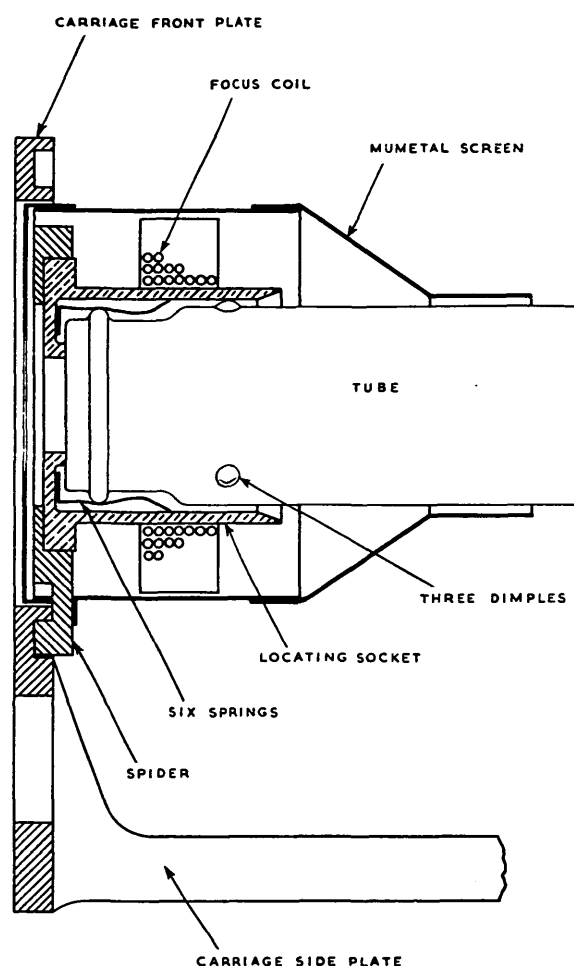

Fig. 1.—Forward mounting of camera tube.

Attention has been paid in the design of the cradle to keeping the photo-cathode as near the front of the cradle as possible, so that lenses with focal lengths as low as 1 in can be used. The tube cradle fits on to a focusing carriage by means of dowels.

(5) THE VIEW-FINDER

The functions of a view-finder are to indicate to the camera operator the content of the picture and whether the camera is correctly focused.

A detailed study of view-finder requirements has been made by G. L. Beers.[2] Insufficient emphasis was given in that contribution to the need for the finder to present an image which can be seen comfortably with both eyes without accurate positioning of the head. A monocular finder suitable for a ciné-camera causes intolerable eyestrain if it is used for long periods, and a binocular finder is little better.

From time to time suggestions have been made that control of focus might be taken away from the camera operator and operated remotely, leaving the camera operator responsible only for the picture content and composition. Such a step would certainly simplify the view-finder design, but, although it might be occasionally useful, it could not be generally satisfactory for the following reason. It often happens that the camera must be panned from a distant object to a closer one or vice versa, or that a figure enters the picture nearer to the camera than the plane of focus. In such cases a skilful camera-man anticipates the focus

adjustment, making the change as the camera moves or the actor enters, so that the new object of interest is seen sharply as soon as it is seen at all. This anticipation would be almost impossible if part of the operation were controlled remotely. In the camera described, provision is made for remote focusing where appropriate.

It is useful, but not essential, for the camera operator to see not only the transmitted picture but also a margin around it. A small margin assists the operator to prevent unwanted objects, such as microphones or lamps, from appearing in the picture, and for certain subjects, such as a narrow-angle shot of a fast-moving game, a large margin is very desirable. In such conditions the centre of interest, e.g. the ball in a football match, moves too rapidly to be followed perfectly. With an adequate margin the ball may still remain in view in the finder, and the camera can be quickly re-centred. Without a margin it is surprisingly difficult to find such an object once it has been lost.

The view-finder to be described was designed, not in the belief that it would solve all view-finder problems, but with the intention of testing in practice the many factors which were already largely known and had been assessed in theory.

(5.1) Existing Types of View-finder

The cameras used by the B.B.C. before the war were fitted with optical view-finders of a very simple type. A pair of matched lenses were mounted side by side, one forming an image on the mosaic of the camera tube whilst the other produced an image, which was of course inverted, on a ground-glass screen coplanar with the mosaic. The ground-glass screen was a little larger than the scanned area of the mosaic, which was approximately $4\frac{1}{2} \times 3\frac{1}{2}$ in, and the limits of the transmitted picture were defined on the screen by pencilled lines. The two lenses moved together as the camera was focused, and the view-finder lens was traversed simultaneously to correct for parallax in the focal plane. The cameras were normally used with lighting levels high enough to give a fairly bright view-finder image.

The chief disadvantages of these view-finders were:

(a) The image was inverted, so that practice was required before an operator could use a finder effectively.

(b) It was difficult to maintain the view-finder screen and camera mosaic in alignment. The tube was mounted in resilient supports which permitted some movement, and any slight change in size or position of the scanned area of the mosaic from any cause introduced errors. In particular, when a camera tube was changed the view-finder had to be completely re-aligned.

(c) Lens changing took a long time. It involved two changes and the parallax compensator had to be reset.

In spite of these drawbacks the view-finders served well enough, but serious difficulties were encountered when similar finders were used with tubes of the Super-Emitron type which were introduced for outside broadcasts in 1937. These tubes had a useful photo-cathode diameter of about 35 mm, and were used with lenses some of which covered an area little greater. The view-finder picture was so small that camera operation became very difficult and tiring. It was soon evident that the simple twin-lens finder could never be satisfactory in combination with tubes having such small photo-cathodes. Optical magnification between the finder screen and the operator's eye does not help, because of the loss of image brightness it involves. Indeed, the increased sensitivity of camera tubes already permitted operation of the camera tube under conditions which gave very dim view-finder images even without magnification.

In the post-war period, pick-up tubes of higher sensitivity than pre-war types were available to designers and they all had relatively small photo-cathodes. The view-finder problem was invariably solved by fitting electronic view-finders which consisted of a small cathode-ray tube displaying the transmitted picture. These finders have many advantages, some of which are obvious, but they also have a number of serious drawbacks.

The outstanding advantage of the electronic view-finder is that no alignment problem arises. The finder can only show the transmitted picture, and the designer is not concerned with questions of alignment of different lenses, whether different pick-up tubes fit precisely into the same position in the camera, or even whether the relative position of lens and tube can change during operation. It is difficult to appreciate this point fully without having experienced the problem of designing and constructing an optical finder which will maintain alignment with any combination of lenses and pick-up tubes. Electronic view-finders simplify lens changing because there is only the camera objective to be considered.

On the other hand, electronic finders present problems of their own. They are necessarily heavy and relatively complicated devices which affect reliability adversely. More serious is the difficulty of producing a small picture capable of resolving all the detail of which the system is capable—the minimum requirement to monitor focus properly. Moreover, a number of electrical defects can produce a de-focused picture in the view-finder, and this can be confusing to the camera-man. Experience has revealed an unexpected difficulty in the form of a strong tendency to concentrate on the sharpness of the raster rather than on that of detail in the picture, and to accept a slightly soft picture as satisfactory as long as the raster is perfectly sharp.

It is possible, with electronic view-finders, to show a narrow margin around the transmitted picture by using narrower blanking pulses in the finder than are used in the main channel. This margin is much too small to be useful.

With all these factors known it was decided for the camera described to construct an optical view-finder with a minimum of the inevitable disadvantages of the type. The simple twin-lens type was ruled out because the camera-tube photo-cathode was very small, and it was thought that a satisfactory view-finder image should measure about 4×3 in. The camera tube, although fairly sensitive, needed a lighting level which would be sufficient to give a bright image on a suitable finder of the ground-glass-screen type. It was also decided that the image should be erect; an inverted image would prejudice camera-men accustomed to electronic finders.

The design of the camera permits the use of a range of lenses, and it was considered that provision should be made for lenses of focal lengths between $1\frac{1}{4}$ and 6 in, giving viewing angles in the horizontal plane between 30° and 6°, approximately. The finder screen employed is about six times as large in diameter as the photo-cathode, so that it would be necessary to use lenses of focal lengths up to 36 in for the finder if the finder screen were to be filled with an image coinciding precisely with the photo-cathode image. This was regarded as impossible in a small camera, and it was decided to use a single lens of 8-in focal length in the finder.

The field of view of the $1\frac{1}{4}$-in camera lens nearly fills the screen, and rectangles indicating the field of view of this and all other lenses are inscribed on the screen. A 1-in lens can also be used, and there is then no margin. The rectangle corresponding to the 6-in camera lens measures only $0 \cdot 67 \times 0 \cdot 89$ in, which appears at first sight to be much too small. In practice it has been found to be fairly satisfactory. A field lens is fitted behind the screen and magnifies the image to the apparent size of about $1 \times 1 \cdot 3$ in, but a more important factor is that the wide margin of view removes the sensation of having to concentrate on a very small image. It is indeed true to say that the camera operator's task of focusing his view-finder accurately is the same whatever camera lens is in use, except that the reduced depth of focus obtained with long-focus camera lenses demands greater precision in

focusing the finder. The depth of focus of the finder and the resolution of its lens and screen are such that critical focusing of the 6-in camera lens at its maximum aperture of $f/1\cdot9$ is just possible. With smaller focal lengths or apertures the view-finder has less depth of focus than the camera and accurate focusing is therefore easier.

Since the view-finder lens is of longer focal length than the camera lenses it is necessary to provide a suitable coupling between the view-finder focusing motion and that of the camera; the coupling must have as many ratios as there are lenses provided for the camera. To a first approximation the required coupling is linear (see Section 13.3) and the required ratio is that of the squares of the focal lengths of the finder and camera lenses. Two difficulties arise. The first is that lenses as commonly sold have a tolerance of a few per cent on the nominal focal length so that the required ratios cannot be determined in advance and may in any case be very awkward numbers. The second difficulty arises from the extremely severe requirements in respect of backlash in the coupling. With a lens of aperture $f/1\cdot9$ the picture is just visibly de-focused by an error in photo-cathode position of $\pm0\cdot0025$ in. This tolerance has to embrace errors which arise if the photo-cathode is not exactly perpendicular to the optic axis or is not perfectly flat, as well as positional error due to backlash. It was decided that the maximum permissible backlash should be $0\cdot001$ in and should preferably be less. After a number of schemes had been considered and rejected, an electro-mechanical servo coupling was devised which is extremely flexible (giving any reasonable number of adjustable ratios), and meets the requirements in respect of backlash.

The servo coupling is essentially a linear one while the required coupling is only approximately linear. It would be possible to elaborate the servo coupling to give a rigorously accurate relation, but the difficulty of setting it up and maintaining it in adjustment would be excessive. Instead, a device was adopted which makes the coupling accurate for the lens of shortest focus, and gives a better approximation for the lenses of longer focus, so that errors are negligible at the relatively great object distances at which they are used. The device is simply to set the view-finder lens back from the camera lens so that the distance from an object to the front principal foci of the two lenses is the same (Section 13.3). This condition can only be satisfied for one camera lens, and it is most useful to make this the one of shortest focus. A further condition is that the magnification of the two lenses should have a constant ratio at all object distances. Section 13.3 shows that this condition is satisfied to the same approximation as the coupling ratio is linear. The camera lenses are so mounted that the camera and finder alignment is correct for an object distance of infinity, and the coupling ratio is adjusted for correct alignment at twice the shortest object distance at which the lens can be used, because this minimizes "tracking" errors.

(5.2) Detailed Description of View-finder

The view-finder is built as an independent unit, secured to the top of the camera by locating dowels and a screw latch. Some saving of space could have been achieved by building it integrally with the camera, but it was thought that it would be useful to experiment with the camera with remote focusing control in fixed positions, and without view-finder.

Fig. 2 shows the optical system. Four mirrors of surface-aluminized glass are used to re-erect the image. The finder lens, of 8-in focal length and $f/4\cdot5$ aperture, lies between mirrors 2 and 3. This position permits the widest possible viewing angle for the finder. The optical path is the same as that in the Porro prisms used in binoculars. Besides erecting the image the folding of the optical path considerably shortens the overall length of the finder and thereby facilitates the location of the

VIEW—FINDER LENS MIRROR 3

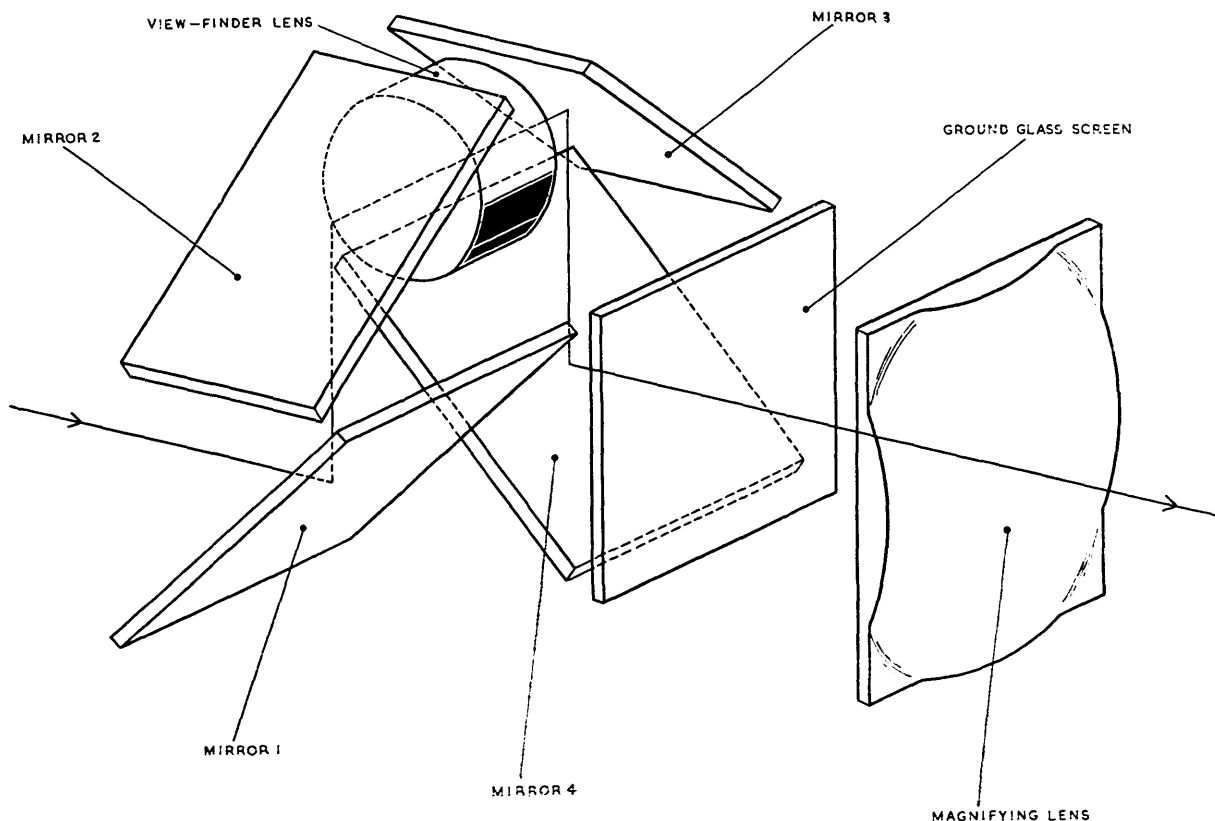MIRROR 2 GROUND GLASS SCREEN

MIRROR 1

MIRROR 4

MAGNIFYING LENS

Fig. 2.—Optical system of view-finder.

finder lens behind the camera lens necessitated by the focus-coupling system.

The image is formed on a ground-glass screen which is moved to and fro for focusing. The focus control is a knob, on the left-hand side of the finder, on a shaft which is coupled to the screen by a pulley and a spring-tensioned wire drive. It is important to keep backlash down, but owing to the effective step-down ratio between finder and camera the tolerance is of the order of $\pm 0\cdot 01$ in, which can be easily met. The field lens fitted behind the focusing screen serves two purposes: it provides a little magnification of the screen image, and—its principal function—it removes "hot spot" from the screen. The brightest possible image is required in the finder. With a given lens the image brightness can be increased by using more finely ground glass, but beyond a certain stage the brightness increases in the centre while remaining constant or even decreasing at the edges, because the more finely ground glass acts progressively less as an ideal diffuser. Such a "hot spot" is reduced by the field lens, which refracts toward the observer's eyes light from the corners of the screen which would otherwise not be effective at his position. Images seen through the lens can be at least twice as bright as when the screen is viewed direct, and the small magnification is also helpful.

Since the optical axis of the view-finder lies above that of the camera lens there is a parallax error. This can be compensated in the focal plane by rocking the front mirror. An alternative and preferred method is to set the guides in which the focusing screen travels at an angle to the horizontal so that the motion of screen has a component in its own plane.

The focus control is coupled direct to a linear potentiometer forming part of the focusing mechanism, which is described in the next Section.

(6) THE FOCUSING MECHANISM

The pick-up-tube cradle is mounted on a carriage driven by a lead-screw and nut. The lead-screw is driven by a worm drive from a 2-phase induction motor. The total travel of the carriage is $\frac{3}{16}$ in, which is sufficient to enable any lens to fill the transmitted picture with the image of an object measuring 15×20 in. The lead-screw is geared to a linear potentiometer similar to that in the view-finder, the ratio being chosen so that the full movement of the carriage corresponds to 270° of rotation of the potentiometer. Backlash between the carriage and potentiometer movements must be kept to a minimum. This has been achieved by careful fitting of the lead-screw and nut and by the use of gears of large diameter and fine pitch for driving the potentiometer. Since the backlash between correctly formed gears is a small fraction of a tooth-pitch the backlash can be kept as small as desired by the choice of a sufficiently fine pitch. The potentiometers in camera and view-finder form part of a bridge circuit (Fig. 3) energized from the mains. One winding of the motor is permanently energized, the other winding being fed from an amplifier whose input is the unbalance voltage of the bridge. Refocusing the view-finder unbalances the bridge, and the motor then drives the tube carriage and camera potentiometer until balance is restored. The bridge is so designed that balance occurs when view-finder and camera are both in focus. The bridge ratio is adjusted by inserting padding resistors in the arms.

The load on the motor consists primarily of friction in the gears and carriage guides, but if the camera is tilted up or down work is done with or against gravity. The relation between speed and load is such that there is little tendency to overshoot or hunt, but, as a safeguard, an induction generator, which is built into the motor carcase. feeds a voltage proportional to the motor speed into the amplifier, this voltage being opposite in phase to the error signal from the bridge. The drive then has velodyne

characteristics, with speed proportional to the bridge error, and overshooting is impossible.

The amplifier has an output of about 10 watts, which is sufficient to move the carriage over its full range in about 1 sec when the camera is level, or about 2 sec at 45° tilt. The lag thus introduced has not been found troublesome, because the speed at which the distance focused can be changed is greater than the speed of any physical object likely to be encountered. Furthermore, the lenses of shorter focus which, in a studio, might be required to swing quickly from distant to nearer objects, use only a fraction of the maximum carriage-travel and no lag is observable.

It was thought to be impossible to arrange that the infinity position on each potentiometer should be exactly at the end of the potentiometer windings; this is the reason for the complication of the double bridge circuit. Unless this could be arranged, the infinity alignment would vary with the setting of the range switch. With the arrangement shown, the auxiliary bridge circuits comprising the main and infinity-setting potentiometers are balanced when the corresponding lenses are focused at infinity, with the result that the main-bridge balance at infinity is not disturbed by the operation of the range switch.

The view-finder infinity potentiometer normally needs adjustment only if the finder has been dismantled for cleaning. The camera infinity potentiometer generally needs adjustment when the camera tube is changed. Although the tubes and their cradles are manufactured to close limits it is impossible to hold the photo-cathode positions with different tubes and cradles to the close tolerance necessary to ensure no perceptible change of focus when tubes are changed. The adjustment is very simple and can be made with any lens in the camera. A fairly close object is focused in the finder, and the camera is then focused by means of its infinity potentiometer.

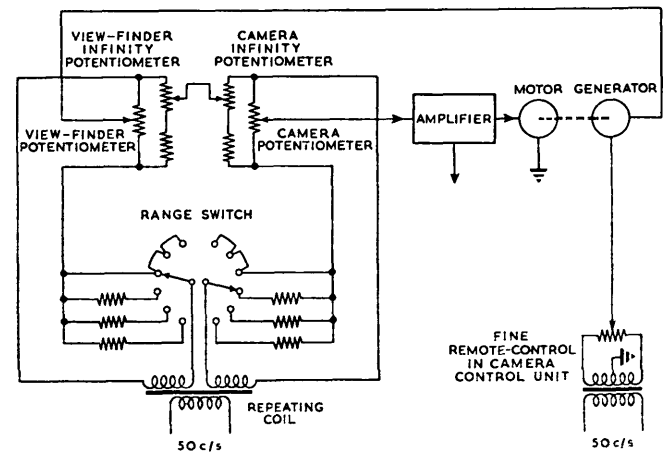The range resistors shown in Fig. 3 consist of fixed resistors in

Fig. 3.—Servo focusing-coupling circuit.

series with adjustable resistors, so that the exact values required can be quickly and easily set up. The remote focus-control is mounted on the camera control unit and as normally arranged gives a control of focus over a small range only. Its main purpose is to compensate for small drifts of alignment that may take place, and occasionally to ensure sharp pictures when the camera operator, owing perhaps to fatigue, is unable to focus sharply. It is also used when critically sharp pictures of test charts are required, such charts being sometimes so close to the camera as to be beyond the range of the coupled focusing mechanism. Alternatively, the remote control can be arranged to cover the
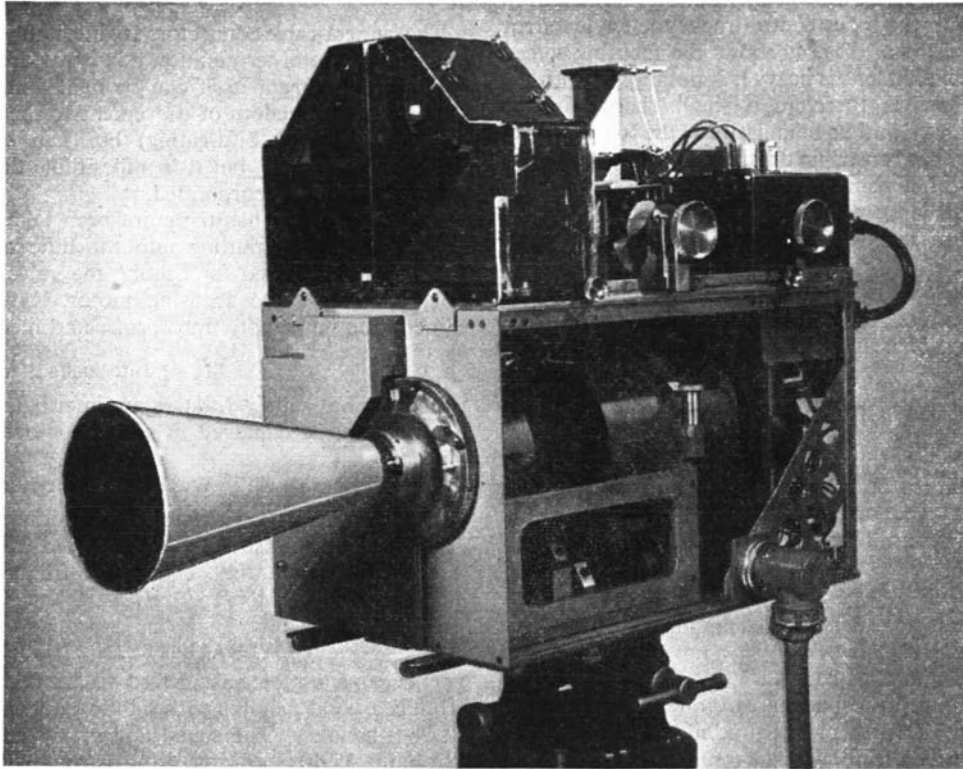
Fig. 4A.—Camera with covers removed: left-side view.

whole focus range, and this facility has enabled the camera to be operated in a fixed position inaccessible to a camera-man, with useful results.

(7) MECHANICAL CONSTRUCTION OF THE CAMERA AND VIEW-FINDER

The arrangement of the component parts of the complete camera is shown in Figs. 4A and 4B.

The base is made from $\frac{3}{8}$-in Duralumin sheet to give a rigid support to the tube-carriage guides, which are visible through the side of the tube cradle (Fig. 4A). The camera body is completed by the front plate, which carries the lens mount, and a framework built of Duralumin angle. The motors for focusing and iris-control, together with the servo amplifier and camera servo-potentiometer are fitted at the back of the camera in a magnetically shielded compartment. This compartment also contains a jack for microphone and headphones enabling the cameraman to communicate with the control unit operator. The servo amplifier slides out and can be quickly replaced in the event of a fault.

In Fig. 4B can be seen the head amplifier, which is carried on resilient supports on the camera front plate, and a scanning-beam-control amplifier which applies a controllable "brightening" pulse to the grid of the pick-up tube. These units can also be quickly removed and replaced.

The dimensions of the camera without the view-finder are $16\frac{1}{4} \times 10\frac{1}{4} \times 10$ in high; the length over all projections is 19 in. The weight of the camera with pick-up tube and all electronic equipment is 45 lb.

The view-finder is built as an independent unit. Fig. 4A shows the tent-like structure housing the four mirrors and the finder lens, and the focus control coupled to the view-finder servo potentiometer. The box at the rear contains six adjustable-ratio
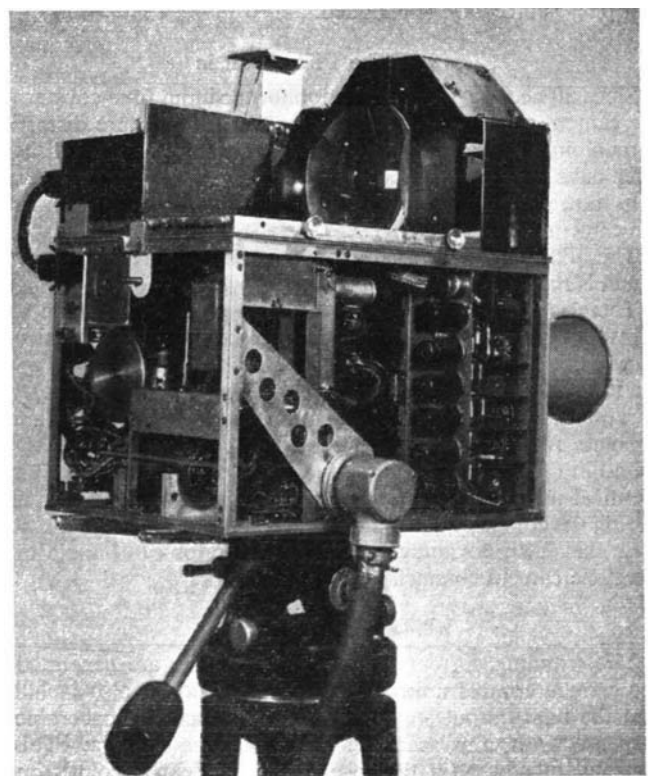

Fig. 4B.—Camera with covers removed: right-side view.

resistors and a switch to select the one appropriate to the lens in use. The cam fitted to the focus control rocks the front mirror to compensate for parallax. Fig. 4B shows the focusing screen and field lens. As the field lens is heavy it is not moved with the focusing screen. There is therefore a small change in the apparent size of the image and its boundaries as the focus control is operated; this effect has caused no difficulty to operators. The view-finder is fitted with a visor to exclude extraneous light from the screen and a small lamp which indicates to the camera-man when his camera is in use. The weight of the complete view-finder is 15 lb.

The photographs also show the cable entries on either side of the camera. Light cables run to a junction box disposed in a convenient position on or near the camera stand.

(8) SOME DETAILS OF AUXILIARY EQUIPMENT

(8.1) The Camera Channel

In step with the camera design the camera control equipment was constructed with the same objectives of small size and weight, simplicity of design, reliability and ease of maintenance.

(8.2) Head Amplifier

The circuit used is a 3-stage d.c.-coupled amplifier with negative feedback applied through a network having a time-constant which compensates for the input time-constant due to the camera tube capacitance, including stray capacitances, and the input resistance of the amplifier. A further stage gives additional top-boost to correct for aperture distortion, with the result that at the output of the head amplifier the signal is completely compensated and no further high- or low-frequency correction is required in the picture chain. This is a convenience from the point of view of maintenance. The amplifier is similar to that described by White and Harker.[3] A low-noise triode is used in the first stage, and phase correction is included.

(8.3) The Picture Chain

Since all necessary compensation for the input time-constant of the camera tube and head amplifier and for aperture distortion is made in the head amplifier itself, the picture chain will thereafter have a flat frequency-characteristic. The only other compensation required is that occasioned by high-frequency losses in the camera cable.

The addition of the shading-compensation waveforms to the signal is made early in the chain.

There is no d.c. restoration of the vision signal. The suppression or blanking mixer is arranged so that for any particular setting there is a fixed relation between black level and the mean picture voltage. The mixer is normally adjusted so that the darkest tone in the picture is just above black level. A limiter prevents any intrusion of picture signals below black level. It is found in practice that a large number of subjects require almost identical mixer settings, and the control needs little adjustment during the course of a programme. From the operating point of view this is an advantage, since one operator can handle more than one camera channel.

(8.4) Camera Scanning

The scanning currents for the camera tube are generated in the camera control unit. Keystone correction is also included, and the final output stage delivers enough power to be able to dispense with any scanning valves in the camera. This is wasteful in power (in the case of the line-scan current), but it leads to a minimum of complication in the camera. The cable may be up to 600 ft in length.

(8.5) Bifurcating Box

The camera-cable connectors are inevitably bulky and awkward, and some form of termination box is required so that the cables entering the camera itself can be light and flexible in order to give complete freedom of movement to the camera-man. Such a termination (or bifurcating) box can conveniently contain passive components, but it is undesirable that circuits involving valves should be incorporated.

The opportunity has therefore been taken to keep down the camera weight by putting into the bifurcating box the mains transformers required for heating the valves in the camera and polarizing the servo focusing motor. Also included are the camera gun h.t.-supply transformer and metal rectifier.

(8.6) Interlocks

The various supply voltages are interlocked so that the equipment cannot be damaged by erroneous operation, or by mains failure.

(8.7) Waveform Generation

The synchronizing waveform is produced in the waveform generator, which also supplies line- and frame-timing pulses to the camera control unit. The frame frequency is locked to the mains by a spongy lock.*

(9) OVERALL TESTS AND RESULTS

The camera tube has proved to be fairly sensitive and has produced good pictures with lighting intensities of the order of 60–70 ft-candles. The signal/noise ratio under such conditions is about 37 db (peak-picture to r.m.s. noise). The overall frequency characteristic measured from a suitable test transparency to the output terminal is 3 db down $\pm$ 1 db, at 3 Mc/s.

(10) CONCLUSIONS

Experience with the prototype camera has shown that it is capable of producing first-class pictures and is easy to operate and maintain. The optical view-finder has proved to be satisfactory, especially for studio work, where there is adequate light and where the range of focal lengths required in the camera lens does not exceed 3 : 1.

Camera-men accustomed to electronic view-finders have reacted favourably to the view-finder image because it is coloured. The presence of colour contrast as well as brightness contrast helps in the focusing of some subjects, and the general effect of the coloured image is appreciably to reduce operating fatigue.

If the camera were rebuilt a number of improvements could be incorporated. It has been found that the view-finder is insufficiently robust and that the position of the mirrors can be changed by mechanical shocks. In a new design the camera and finder would be built as one unit, with a more rigid mirror assembly. This would permit a much more compact construction, and would enable the parallax error to be reduced to rather less than half the present amount. A range of lenses having focal lengths of from 1¼ to 4 in would be mounted in a small turret, and the servo-focusing range switch would be coupled direct to the turret.

Such a camera should weigh not more than 50 lb and should measure about 18 × 10 × 12 in high. Small weight and bulk contribute substantial operating advantage especially when they can be obtained without sacrifice of other necessary features.

(11) ACKNOWLEDGMENTS

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* A spongy lock responds to an abrupt change of phase of the reference voltage by an exponential approach to the new phase with a time-constant of the order of several periods of the reference voltage.

Industries, Ltd., for their helpful co-operation in the supply of camera tubes and information. They wish to thank their colleagues for loyal and unstinting help, particularly the staffs of the Drawing Office and Model Shop.

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(13) APPENDICES

(13.1) Range of Focusing Movement as a Function of Photo-Cathode Diameter

The relation between object distance and image distance for a lens of focal length f is

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \quad or \quad v = \frac{uf}{u - f} \quad \ldots \quad (1)$$

as $u \to \infty$ $v \to f$.

If the object distance varies between infinity and some finite distance u the change in image distance is given by

$$v - f = \frac{f^2}{u - f} \quad \ldots \ldots \quad (2)$$

If $u \gg f$, which is the usual condition,

$$v - f \propto f^2 \quad \ldots \ldots \quad (3)$$

For a given viewing angle $f \propto D$ so that $v - f \propto D^2$

(13.2) Relations between Aperture, Depth of Focus and Photo-Cathode Size

The distances u_1, u_2 defining a zone within which all objects are in apparently sharp focus, when the lens is focused critically at a distance u, are given by the expressions

$$u_1 = \frac{uu_H}{u_H + u} \qquad u_2 = \frac{uu_H}{u_H - u} \quad \ldots \quad (4)$$

At a given object distance the depth of focus depends only on the hyperfocal distance u_H, which is related to aperture by the equation

$$u_H = \frac{f^2}{ck} \quad \ldots \ldots \quad (5)$$

For a given viewing angle, $f \propto D$.

For a given degradation of focus, $c \propto D$, so that $u \propto \frac{D}{k}$.

If the f-number, k, is made proportional to D, the hyperfocal distance u_H depends only on the viewing angle and the permitted degradation of focus. Cameras having different photo-cathode sizes therefore have equal depths of focus when used at equal object distances and with equal viewing angles, if k is made proportional to D.

(13.3) Coupling Ratio between Camera and View-Finder

Consider an object moving from infinity to a distance u. From eqn. (2) the image moves a distance $\frac{f^2}{u - f}$

For $u \gg f$ the coupling ratio is given by $\frac{f_F^2}{f_C^2}$

If the finder lens is set back from the camera lens so that the object distances are u_C, u_F the ratio required is

$$\frac{f_F^2}{f_C^2} \frac{u_C - f_C}{u_F - f_F}$$

If $u_C - f_C = u_F - f_F$ the ratio is precisely $\frac{f_F^2}{f_C^2}$ for all object distances.

The magnification of a lens, from eqn. (1), is

$$\frac{v}{u} = \frac{f}{u - f} \quad \ldots \ldots \quad (7)$$

The ratio between finder and camera magnifications is

$$\frac{f_F}{f_C} \frac{u_C - f_C}{u_F - f_F} \quad \ldots \ldots \quad (8)$$

The condition that $u_C - f_C = u_F - f_F$ thus gives a linear coupling ratio and constant ratio between camera and finder magnifications.

[The discussion on "Programme Origination" will be found overleaf.]