TECHNICAL DESCRIPTION
MARCONI-E.M.I. SYSTEM OF TELEVISION

PART 10. PICTURE MONITORS
THE PICTURE MONITOR

The Picture Monitor is an apparatus for converting the picture signals derived from the Distribution Amplifier into a picture. A cathode ray tube, known as a 12" diameter spherical enmoscope, is employed for the purpose and, since its characteristics determine the design of all the apparatus in the Picture Monitor unit, it will be described first.

The Cathode Ray Tube

The tube is illustrated in Fig. 1, and it will be seen that it contains a series of electrodes designated in succession Heater, Cathode, Cathode Screen, Accelerator, Grid, First Anode, Second Anode. An understanding of the functions of these electrodes may be approached in two ways.

In the first place the tube may be compared with a multi-electrode valve, and both as regards the disposition of its electrodes and in its electrical characteristics it resembles a hexode. There exists a relationship between the electrodes of the latter and those of the tube, which may be represented in the following table.

<table>
<thead>
<tr>
<th>Cathode Ray Tube Electrode</th>
<th>Valve Electrode</th>
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<tr>
<td>Cathode</td>
<td>Cathode</td>
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<tr>
<td>Cathode screen</td>
<td>Inner control grid</td>
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<tr>
<td>Accelerator</td>
<td>Inner screen grid</td>
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<tr>
<td>Grid</td>
<td>Outer control grid</td>
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<tr>
<td>First anode</td>
<td>Outer screen grid</td>
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<tr>
<td>Second anode</td>
<td>Anode</td>
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The beam current of the cathode ray tube corresponds, of course, to the anode current of the equivalent hexode, and the relationship between the beam current and the potentials of the various tube electrodes is similar to that existing between the anode current of a hexode and the potentials of the valve electrodes. The comparison between the tube and a hexode is chiefly of importance in considering the modulation characteristic.

We may secondly examine the functioning of the electrodes from the point of view of the tube as a device for generating a picture, and in this connection it is convenient to divide them into two groups. The cathode, the cathode screen, the accelerator and the grid form collectively an electron gun, the intensity of the emergent beam from which is under control. The first and second anodes may be considered as a separate electrode system, and together constitute an electronic double convex lens, which focuses the beam emerging from the electron gun to a small spot on the fluorescent screen. As usual the focal length of the equivalent lens is dependent upon the ratio of the potentials of the first and second anodes. It will be seen, therefore, that the operating potentials of all the electrodes are determined from a combination of the requirements of the electrodes (a) operating as an equivalent hexode, and (b) operating as an electron gun together with an electronic lens system.

It is now necessary to consider the question of how the beam current shall be modulated by the vision signals. Remembering the equivalence with a hexode, it is clearly possible to modulate either the cathode screen or the grid, corresponding respectively to the inner or outer control grids of the equivalent hexode. It is found that if modulation is applied to the grid alone, the modulation characteristic flattens off at the higher amplitudes so that the white parts of the picture are not well reproduced. On the other hand, if the modulation is applied solely to the cathode screen the modulation characteristic is too steep, that is to say, it is not linear but tends to conform to a square law curve, the effect of which is to give an over-contrasted picture. It is found, however, that if modulation is applied simultaneously to the grid and cathode screen, almost any shape of modulation characteristic can be obtained, depending upon the proportions in which modulation is relatively...
The Cathode Ray Tube (Cont’d)

applied to the two grids. Individual biases are, of course, applied to these
two electrodes, and it happens that the modulation characteristic is linear
when the amplitudes of modulation applied to the two grids are equal.
The modulation may accordingly be directly applied in equal proportions
to the two grids, or it may be applied in reversed sense to the cathode alone,
in which case the two grids are energised with respect to the cathode at equal
amplitudes. The latter scheme, that is to say, cathode injection, is adopted
in practice, and the grids are each tied to earth via condensers.

The amplitude of the vision signal which is required fully to modulate
the tube is of the order of 15 V. The amplitude, however, of the emergent
vision signal from the Distribution Amplifier is approximately 8 V, and
therefore it is necessary to provide means for amplifying the vision signal
in the Picture Monitor unit. This amplification is carried out in a panel
known as the Monitor Amplifier and Focus Unit.

We must now consider the requirements of the various electrodes of the
tube as regards their fixed operating conditions. The heater consumes
1.5 A at 4 V A.C., and this is provided by means of a transformer located
in the Amplifier and Focus unit. The cathode shield and the grid require
negative biases of −15 V and −24 V, respectively, with respect to the
cathode. The accelerator, first anode and second anode are maintained
at steady positive potentials of +300 V, +1,300 V† and +7,000 V respec-
tively. These two negative and three positive potentials are all obtained
from potential dividers in the Amplifier and Focus unit. Connection to the
various output electrodes of the tube, with the exception of the second anode,
is made by means of a 7-pin socket shown in Fig. 1. The second anode,
however, has a connecting stub, shown at B in Fig. 1, so that it is well removed
and insulated from all other electrodes and cables.

The system of electrodes described above, therefore, is what is required
to produce a finely-focused spot on the fluorescent screen and modulate it
with vision signals. The spot must now be made to scan the screen, and this
is carried out electro-magnetically. For this purpose two pairs of coils are
mounted mutually at right angles round the neck of the tube and are fed
with currents of saw-toothed waveform from a further unit known as the
Separating and Scanning Unit. These waveforms are timed from the
synchronising signals, which are contained in the vision input. It is lastly
necessary to ensure that the picture shall be centrally located on the
fluorescent screen.

There is fundamentally no reason why this should not automatically
be so, the requirements being that the tube electrodes must be accurately
in line, and the beam must not be influenced by any external field. In tube
manufacture, however, the requisite degree of accuracy cannot usually be
obtained, and the picture is liable to be off centre. Behind the scanning
coils, therefore, are provided a further pair of coils mounted upon an iron core,
connected in series and fed with steady D.C. from the Amplifier and Focus
unit. These coils produce a steady field which effects a permanent displace-
ment of the scanning beam. By properly orientating the shift coil assembly,
the steady deflection due to these coils may be so adjusted as to oppose the
natural deviation of the beam from the central axis, and by means of a control
on the Amplifier and Focus unit the intensity of the permanent deflection
can be so regulated as to bring the raster to a central location on the screen.

A panel known as the Supply Unit provides two H.T. supplies at 300 V
for the Amplifier and Focus unit and the Separating and Scanning Unit,
and a further panel known as the 7,000 V Unit provides r.f. at this voltage
for the second anode and other tube electrodes.

The Picture Monitor unit therefore comprises the following individual
sub-units:

- The Cathode Ray Tube Assembly
- The Amplifier and Focus Unit
- The Separating and Scanning Unit
- The Supply Unit
- The 7,000 V Unit

Of these the Cathode Ray Tube has been described, and the necessity for
the other units has been shown. The four remaining units will now be
described in the above order.

The Amplifier and Focus Unit

The circuit of this unit is shown in Fig. 2††. It has been explained that a
gain of the order of 2:1 is required between the vision input and the cathode
ray tube, and also that the vision input is applied to the cathode of the tube.
Since, however, the application of a negative potential to the cathode will
increase the tube beam current and increase the brightness of the spot, the
sense of the picture input to the cathode must be negative. The sense of the
picture input from the Distribution Amplifier is positive. It will be seen there-
fore that a single amplifying stage will both provide the necessary reversal
and the very moderate degree of gain required. Accordingly the input to the
Distribution Amplifier is applied to the control grid of the valve V1, which
amplifies and reverses the signals. But the signals cannot conveniently
be applied to the cathode of the tube direct from the anode of V1, as the
capacity of the cathode to earth via the tube heater is such that it must be
fed from a low impedance source. The cathode follower V2 is therefore
interposed between V1 and the cathode of the cathode ray tube.

The input which is to be applied to this unit will be derived from a
Distribution Amplifier and will in general be taken from a 140 ohm output,
in which case it will have a black level of +3.5 V, a white level of +10.0 V,
and a rough sync level of 0 V, all with respect to earth. The unit is, however,
designed so that if desired an input derived from a 110 ohm output of the
Distribution Amplifier may be employed, in which case black level will be at

†Subject to fine adjustment for focusing, see p. 5

††Figure 2 attached to p. 5
+10.0 V, white level at +16.5 V, and through sync level at +3.5 V, all with respect to earth. The input is applied to the Amplifier and Focus Unit via terminal A. The input circuit has been so designed that if desired a further picture monitor can be fed from the same Distribution Amplifier output by plugging the monitor into a concentric socket located on the first monitor. This concentric socket is connected to the terminal C in Fig. 2. It is, of course, necessary to terminate the incoming line in its own impedance of 140 or 110 ohms. No permanent termination is provided in the Amplifier and Focus unit, but the following method is employed. Assuming that only one monitor is to be fed from the Distribution Amplifier output, for example at 140 ohms, then a special plug containing a 140 ohm resistance is plugged into the concentric socket C, and the desired matching is effected by this impedance of 140 ohms in conjunction with the small resistances $R_s$ and $R_t$, and the input impedance of the unit, which is effectively 2,000 ohms, viz., the impedance of a potentiometer $R_p$. It will be seen that the impedance between the point D and earth is composed of the terminating plug resistance of 140 ohms and $R_s$ (5 ohms) in parallel with $R_t$ (2,000 ohms). The resulting impedance is 135 ohms. This impedance at the point D is increased by the resistance $R_t$ (5 ohms) to 140 ohms, thus presenting at the input terminal A the correct impedance to terminate the incoming cable. Where it is desired to feed a second monitor from the terminal C, then the 140 ohm terminating plug is removed, but it must be plugged into the corresponding terminal C of the second monitor. The second monitor is now arranged as has just been described above, and therefore shows an input impedance of 140 ohms, which substitutes completely for the 140 ohm termination plug formerly plugged into terminal C of the first monitor. The whole system for two monitors therefore continues to terminate the line exactly.

The Separating and Scanning Unit, to be described later, also requires an input of mixed picture and sync signals, and that is taken from the point D via the 5,000 ohm resistance $R_p$.

An important feature of the design of this monitor must now be considered. In all picture monitors the quality of the picture is determined by two adjustments. There is firstly a control which determines the overall brightness, or standing illumination, of the picture, and which, of course, determines the absolute brightness corresponding to black level. This control is variously designated brightness, brilliance, or background. This adjustment usually operates by establishing a correct standing voltage corresponding to the desired black level at the modulated electrode of the cathode ray tube. Secondly, there is the contrast control, which determines the relative brightness of the different areas of the picture. This operates by regulating the amplitude of the vision input to the modulated electrode of the tube. It is frequently the case that manipulation of the Contrast control will modify the setting of black level previously established on the

**Brightness control,** with the result that considerable inter-manipulation of the controls becomes necessary before the optimum picture quality can be obtained. This is an inconvenient state of affairs and has been eliminated in these monitors.

Referring to Fig. 2, the contrast control is the potentiometer $R_p$, which, being the gain control of the amplifier, is consequently designated Gain. If the lower end of this potentiometer were returned to earth, in the standard manner, it would regulate the amplitude of the signals applied to the control grid of $V_1$ with reference to earth potential. That is to say, if it were set to a minimum the control grid would receive 0 V, if it were set to a maximum, the control grid would receive the full input and the black level would be 3.5 V, whilst at intermediate settings the black level would vary between 3.5 V and 0 V. This is precisely the effect which it is desired to eliminate, as variation of the gain setting at black level would result in a variation of the overall brightness of the picture. We desire that the control of black level should be entirely performed by the picture brightness control, and should be in no way influenced by the gain setting. To effect this the lower end of the potentiometer $R_p$ must be returned to a point at which a potential of 3.5 V, corresponding to black level, may be found. It might be connected to the positive end of a 3.5 V battery, or it might be connected to a suitable point on a potentiometer across the H.T. supply; but in this case a suitable point at 3.5 V can be found on the cathode impedance of $V_1$, which will remain perfectly steady at 3.5 V, even though $V_1$ is a vision frequency amplifier and in the ordinary way its cathode impedance would be carrying varying potentials due to the passage of vision frequency current through it. The point in question on the cathode impedance of $V_1$ is the point B in Fig. 2, and the reason for the absolute steadiness of potential here will be explained later. The potentiometer $R_p$, designated Amp. Preset will clearly enable the standing voltage at B to be varied, and it is in practice until the voltage at B is 3.5 V, the same figure as the input black level. Assuming that the correct adjustment of $R_p$ has been found, then when $R_p$ is at a minimum the control grid of $V_1$ will receive black level and no picture or synchronising signals, and when $R_p$ is not at a minimum $V_1$ will receive the same black level accompanied by vision and synchronising signals having amplitudes determined by the setting of $R_p$ and retaining their incoming picture/sync ratio.

$V_1$ has a finite input capacity, which in conjunction with the input resistances would cause a certain amount of loss of the upper frequencies. This loss is corrected by the condenser $C_1$, which shunts the upper portion of the potentiometer $R_p$, and by-passes the upper frequencies direct from the input on to the control grid.

The valve $V_1$ is a straightforward vision frequency amplifying stage having a maximum gain of 10, and the usual elements will be recognised in
The Amplifier and Focus Unit (Contd)

The intervalve coupling circuit. The inductance \( L_2 \) gives the coupling the configuration of a prototype low pass filter, the resistance \( R_3 \), being added to improve the phase characteristic at the upper frequencies. The filter is terminated at the sending end by the elements \( L_4 \) and \( R_{1b} \) in series. The potentiometer \( R_{1a}, R_{1b}, R_{1c} \) reduces the standing positive potential applied to the grid of \( V_p \), but the condenser \( C_4 \) by-passes the vision frequency components. The elements \( R_{1b}, R_{1c} \) and \( C_5 \) decouple the anode circuit of \( V_1 \), and as usual the time constant \( C_5 (R_{1b} + R_{1c}) \) is made equal to the time constant \( C_4 (R_{1a} + R_{1c}) \), so that the frequency characteristic at low frequencies, down to and including zero frequency (the D.C. component), is perfectly straight. The cathode resistance \( R_4 \), straightens the working characteristic of \( V_1 \) while \( R_2 \) and \( R_3 \) together provide the correct working grid bias of the control grid of \( V_1 \) with respect to its cathode. \( R_2 \) and, as has been seen, \( R_3 \) together determine the black level potential at \( B \). The condenser \( C_4 \) eliminates \( R_4 \) at the upper frequencies, a provision which was found necessary in design owing to requirements in connection with the complex input circuit.

The anode output of \( V_1 \) is applied to the control grid of the cathode follower, \( V_2 \), which is of straightforward design. The usual cathode impedance \( R_{1a} \) is provided to generate the required feed-back, while the anode circuit, which must contain no impedance, is shunted to earth by the condenser \( C_4 \). The screen grids of both \( V_1 \) and \( V_2 \) are fed normally. The suppressor grid of each valve must be given a small negative bias with respect to the cathode. In the case of \( V_1 \), the correct bias is secured by connecting the suppressor directly to earth. In the case of \( V_2 \), however, a similar connection would result in the application of an excessive bias, accordingly the suppressor is connected to the junction of \( R_{1b} \) and \( R_{1c} \) where a small positive potential exists, which in conjunction with the automatic bias of \( V_1 \) results in the suppressor grid of this valve taking up an appropriate negative potential with respect to the cathode. The sense of the vision signals is positive at the control grid of \( V_1 \), and accordingly negative at its anode. \( V_2 \) does not, of course, effect a phase reversal, and negative picture signals emerge from its cathode and are applied to the cathode of the emiscope, where they effect modulation of the beam. It will be realised, of course, that the modulation to be applied to the grid of the emiscope, the sense of the applied signals would have to be positive, but since we are modulating the cathode the sense must be reversed, i.e. negative.

We must now consider an important feature in the design of this amplifier, which is desirable for more than one reason. It will be remembered that in all vision amplifying circuits working under D.C. conditions, as is the case in this unit, considerable importance attaches to good regulation of the H.T. supply, and to that end throughout the television system it is customary to ensure H.T. supplies of low internal impedance by means of stabilisers. If, however, it could be arranged that no vision frequency current were required to flow in the H.T. supply to a vision frequency amplifier, then the requirements for regulation could be somewhat relaxed. Expressing this another way, if the amplifier were to be internally balanced within itself so that a constant current were taken from the H.T. supply, then good regulation would be of negligible importance. This technique has been applied to the unit under consideration, with the result that it is found possible to dispense with stabilisers in the H.T. supply. It is arranged that whenever the current effectively drawn by \( V_1 \) increases due to the presence of a white picture signal, then that drawn by \( V_2 \) correspondingly decreases and the total H.T. current remains unchanged.

In the Amplifier and Focus Unit this condition of balance is secured in the following manner. In the first place the magnitude of the feed-back associated with \( V_2 \) is so chosen that the voltage excursions existing between the grid and cathode of this valve are equal in amplitude to the corresponding excursions between the grid and cathode of \( V_1 \). This does not, of course, mean that we have suppressed in \( V_p \) by means of feed-back, all the gain we secured in \( V_1 \), for it must be remembered that a much larger current will flow in \( V_2 \) than will flow in \( V_1 \) for the same grid-cathode excitation, and this larger cathode current will develop across the cathode impedance a voltage nearly equal to that emerging from the anode of \( V_1 \). Even though we impose this condition, therefore, \( V_2 \) behaves like an ordinary cathode follower, that is to say, passes on nearly all the amplitude received from \( V_1 \). The second point is that identical valves are used for \( V_1 \) and \( V_2 \). Since both valves are pentodes, their internal impedance is very high. It follows therefore that provided there is no very wide divergence between the values of the external impedances through which the respective anode currents of the two valves flow, the magnitude of these two currents will be equal and opposite, and there will be no residual current due to this cause in the H.T. supply. It is interesting to note that the circuit must be so designed as to take account of the effect of the screened grid of \( V_1 \). The cathode currents and grid-cathode excursions of the two valves are to be made equal, but in both valves some 20 per cent of the cathode current flows in the screened grid circuit, leaving only 80 per cent for the anode. Since \( V_1 \) is a pentode, the voltage excursion at its anode will be only 80 per cent of the desired value. This excursion, of course, the grid excursion of \( V_p \), which will therefore be too low, and the condition of equality between the amplitude of the grid of this valve and that of the grid of \( V_1 \) will not have been obtained. Compensation is therefore effected by making the external anode impedance of \( V_1 \) 5/4ths of the value which would be obtained by ignoring the effect of the screened grid, the value in practice being 2,000 ohms.
We see therefore that vision frequency components of the anode currents of the two valves are balanced, being equal and opposite at all times. This condition also applies to the screen currents. Consequently the cathode currents, which include both anode and screen currents, are balanced.

Since this state of balance exists, it is possible to make part of the cathode circuits of $V_1$ and $V_2$ common, the portion in question including $R_{14}$, $R_{16}$ and $R_{19}$. By doing this, advantage is taken of the steady drop due to the steady common cathode current through $R_{14}$ and $R_{16}$ to establish the fixed black level potential of $S_1^V$, to which reference has already been made. In practice, the balance, though very good at the lower and medium frequencies, becomes imperfect at the upper frequencies owing to the fact that the input capacity of the cathode of the emiscope shunts the cathode impedance $R_{14}$ of $V_2$ and shunts away some of the higher frequencies which should be contributed by $V_2$ to the common cathode resistances $R_{14}$ and $R_{16}$. In addition there is some phase shift in the coupling between $V_1$ and $V_2$. As a result of these two causes the loss of balance will give rise to the presence of upper frequency components across $R_{14}$, $R_{16}$ and $R_{19}$ and there will be upper frequency loss and other undesirables effects. These components are therefore removed by the condenser $C_4$.

It will be noticed that a further vision current flows to the common cathode circuit from $R_{16}$, $L_4$, $R_{11}$, $R_{13}$, $C_6$, $R_{123}$ but this is very minute and is insufficient to upset the balance.

Under conditions of black level the anode current of $V_1$ is small, and its anode potential high, the absolute value being 224 V. The D.C. intervalve coupling circuit involving $R_{11}$, $R_{12}$ and $R_{14}$ imposes a quarter of this potential, or 56 V, on the grid of $V_2$ at black level. The cathode resistance $R_{14}$ of $V_2$, apart from its function as a feed-back impedance, imposes a permanent standing bias on this valve so that under all working conditions its cathode potential will be somewhat greater than that of the grid, and at black level this potential is 60 V. For a full white vision signal this potential will be lowered to 47.5 V, and this voltage excursion is applied by direct connection to the cathode of the emiscope. The emiscope cathode screen receives a positive potential of $+45$ V from the junction of $R_{14}$ and $R_{19}$ in the potentiometer $R_{17}$, $R_{18}$, $R_{19}$, $R_{16}$ so that at black level it is negative by $-15$ V with respect to the cathode. The emiscope grid receives a positive potential of $+30$ V from the junction of $R_{14}$ and $R_{19}$ so that at black level it is at $-24$ V with respect to the cathode. A white signal, by imposing an excursion of $-12.5$ V on the cathode, will set the cathode screen at $-2.5$ V and the grid at $-11.5$ V both with respect to the cathode.

The emiscope accelerator receives a steady potential of $+300$ V, from the junction of the resistances $R_{17}$ and $R_{18}$. The capacities $C_7$, $C_8$ and $C_9$ remove any trace of vision frequency potentials from the junctions on the potentiometer $R_{14}$, $R_{16}$, $R_{16}$, $R_{19}$.

The standing potentials on the cathode screen and grid may be simultaneously adjusted by variation of the potentiometer $R_{19}$. This therefore controls the standing brightness of the picture and the absolute illumination corresponding to black level. It is consequently designated Background.

A supply of current is also taken from the H.T. line via the resistances $R_{16}$, $R_{27}$, $R_{28}$, $R_{29}$ and $R_{30}$ for the shift coil already described. The resistance $R_{16}$, being in the form of a potentiometer, enables the shift current to be adjusted and, assuming that the shift coil has been correctly orientated, thus enables the raster to be accurately centred upon the end of the tube. The potentiometer $R_{19}$ is accordingly designated Shift.

The supplies for the first and second anodes are derived initially from the 7,000 V H.T. supply, the output from which is taken to the potentiometer $R_{24}$ to $R_{25}$, which is also located in the Amplifier and Focus Unit, and shown in Fig. 2. The second anode receives a potential of almost 7,000 V, and is decoupled from the 7,000 V supply by $R_{26}$, $C_9$ and $C_{11}$. In view of the high value of the voltage involved, it is desirable from practical considerations to employ in this position two condensers in series. It does not follow that the voltage will divide itself evenly between them, since the ratio of potentials across them will not depend upon their relative capacities but upon their relative insulation. It might well happen that the greater part of the applied voltage will exist across one condenser and the remainder across the other, and consequently if each condenser is rated at a working voltage of 3,500 V there will be a liability to breakdown. It is desirable specifically to locate the junction of these condensers at 3,500 V. This is done by connecting this junction via the resistance $R_{25}$ to the junction of the resistances $R_{26}$ and $R_{27}$, where there exists the required potential.

The first anode requires a potential of 1,200 V, which is found on the potentiometer $R_{19}$. Since the focusing of the spot depends upon the ratio of the first and second anode potentials, and since the second anode potential is fixed, a variation of first anode potential by means of $R_{19}$ enables the focus to be finely adjusted. This potentiometer is therefore brought out to a manual control, and designated Focus. A tapping on the resistances $R_{21}$, $R_{22}$ and $R_{23}$ enables the first anode voltage to be varied in considerable steps should any variation in the design of emisscopes require this.

Access to the 7,000 V circuit by personnel is prevented by means of the shorting switch shown in Fig. 2, which operates when the back of the monitor is removed.

The emiscope heater is supplied from the transformer $T_E$, whose primary is fed from a 13 V secondary on a transformer in the Supply Unit, and whose secondary delivers 1.5 A at 4 V. To avoid ripple the cathode screen is connected to the centre point of the secondary.
Figure 2. The Amplifier and Focus Unit
The Separating and Scanning Unit

The function of this unit, as has been already stated, is to generate the line and frame scanning currents, which are, of course, saw-toothed waveforms having frequencies respectively of 10125 and 50 c.p.s., and which must be applied to the deflecting coils situated round the neck of the emiscope. These waveforms must, of course, be kept in step with the line and frame synchronising signals. The required waveforms are illustrated in Figs. 3 and 4.

Figure 3.

Figure 4.

Considering firstly the line scanning waveform (Fig. 3), the current in the line scanning coils must rise linearly during the period A to B and fall as quickly as possible, but not necessarily linearly, in the period B to C, the total time occupied by the complete cycle from A to C being 1/10125 sec. During the part of the cycle AB, known as the forward stroke, the spot will be linearly deflected across the receiving screen from left to right, and during the period BC, known as the fly-back or return stroke, it will return to the left-hand side again ready for a new line. It is important that the period BC should be as short as possible, as this period is so much waste of time. Similar considerations apply to the frame scanning waveform illustrated in Fig. 4, with the difference, of course, that during the forward stroke DE the spot is deflected downwards, and returns during the return stroke EF, the complete period of the cycle being 1/50th sec. In view of the fact that these monitors form the means by which the standard of quality of the transmitted picture is judged, they are considerably more complex in design than standard commercial receivers, and this complexity shows itself chiefly in the Separating and Scanning Unit.

The circuit of the unit is shown in Fig. 15†. The valves V5, V6, V7, V8 and V9 are concerned with the generation of the line scanning waveform, and V1, V2, V3 and V4 provide the frame scanning waveform, so that the circuit really consists of two separate sections energised by a common input. Apart from the fact that the input, H.T. and L.T. power supplies are common, the two sections are entirely separate, and they will accordingly be described individually, commencing with the line scanning circuit.

The Line Scanning Circuit

The line saw-tooth is generated primarily as a voltage by the relaxation oscillator, comprising the resistance R1 and the condenser C1, in co-operation with the valve V4. In order to simplify the description, the right-hand side of the condenser C1 should, for the time being, be considered as connected to earth. The fundamental action is that, assuming that the potential of both sides of the condenser C1 is initially zero, and H.T. is applied to the top of the resistance R1, the condenser C1 will slowly charge, the rate of charge being governed by the time constant C1 R1, and accordingly the potential of the left-hand side of C1 will rise. While this is happening, the valve V4 is entirely non-conductive, but at a certain point it becomes highly conductive and therefore constitutes almost a short circuit to earth from the left-hand side of the condenser C1, which is accordingly discharged. The valve V4 is now made non-conductive, and the cycle of operations repeats itself. The portion AB of Fig. 3 corresponds to the charging period of C1 when V4 is non-conductive, and the period BC to the discharging period of C1 when V4 is conductive.

We must now consider the means by which V5 becomes alternately conductive and non-conductive and it will be desirable to commence a study of this cycle of operations from that point of the cycle corresponding to the point A of Fig. 3, i.e. the beginning of the forward stroke. At this moment the potential on the left-hand side of C1, which is connected to the anode of V4, is zero, and at the same time, due to a reason which will appear later, the grid of V4 is at a strong negative potential sufficient to carry the valve well beyond its cut-off point. Starting from the point A, the H.T. voltage slowly proceeds to charge C1 via the high resistance R1, so that the anode voltage of V4 rises steadily. At the same time, as an entirely separate effect, the large negative potential on the grid of V4 leaks away via the grid resistances R4, R5 and R6 at a rate determined for practical purposes by the time constant C1 (R4 + R5 + R6). At one and the same time, therefore,
we have the anode potential of $V_e$ rising in the positive direction and the grid potential approaching zero from a large initial negative potential, and though the valve was initially non-conductive due to this negative potential, a state of affairs is clearly being approached in which the valve will have sufficient anode potential together with a small enough grid bias to become conductive. Apart, however, from conductivity between anode and cathode, it will be observed that the screen and suppressor grids of $V_e$ are both connected to a positive voltage derived from the potentiometer $R_3$, $R_4$, $R_5$, so that when the negative bias on the control grid becomes sufficiently reduced there will be conductivity between the screen grid and cathode, and current will flow. This occurs at the point $B$ of Fig. 3, at which point the screen grid begins to draw a small current, which passes through the primary winding of the transformer $TR_1$ and induces a voltage in the secondary. This latter winding is connected to the control grid in such a sense that the voltage across it will tend to drive the grid more positive. This increases the current drawn by the screen grid, which in turn increases the positive voltage applied to the control grid. The effect is therefore cumulative, and when the screen begins to conduct the screen current will immediately be driven to a very high peak value. At the same time the anode-cathode path becomes highly conductive, and the condenser $C_1$ is discharged. A finite time is, of course, necessary for the discharging operation, and this is the period $EC$ of Fig. 3. The cathode of $V_e$ is connected directly to earth, and the control grid can therefore readily draw grid current. The amplitude of the positive pulse delivered to the control grid from the secondary of the transformer $TR_1$ is sufficiently great as to attempt to drive the grid strongly positive, but restoration of D.C. occurs and the control grid does not succeed in becoming more positive than zero potential. Therefore at the moment during the return stroke when the maximum screen current is being drawn, and the maximum positive potential is being applied to the control grid, there co-exists on the control grid, due to D.C. restoration, a negative charge equal in value to the amplitude of the induced positive pulse. When the positive pulse has driven the grid as far positive as the restoration of D.C. will permit, the screen current can increase no further, and it is for the moment stationary. There is now no flux in the transformer, and the positive pulse is withdrawn, leaving a negative charge due to D.C. restoration on the grid, which accordingly cuts off screen and anode current. The screen current in falling will induce a flux in the opposite direction to the transformer $TR_1$, which will momentarily drive the grid more negative than the potential due only to D.C. restoration. But when the screen current finally ceases the flux in the transformer $TR_1$ will again be zero. The negative pulse will therefore cease, and the negative potential of the grid becomes that due to D.C. restoration alone. This last effect, involving a negative pulse on the control grid, however, has no bearing on the action of the circuit since the valve is already cut off by the potential due to D.C. restoration, and is a purely subsidiary effect which must result from the action of the transformer $TR_1$. The cycle of operations has now arrived at the point $C$ in Fig. 3, which corresponds to the end of the first saw-toothed cycle and the beginning of the next one, and the cycle repeats itself indefinitely. It will be seen that though it is the action of the screen and control grids which result in the alternate non-conductivity and conductivity of the valve, conductivity of the screen-cathode path is, of course, accompanied by conductivity of the anode-cathode path, and it is this latter path that is utilised to discharge $C_1$, across which there now must appear a waveform of the type illustrated in Fig. 3.

The potential applied to $R_1$ and $C_1$ for the purpose of generating the saw-toothed waveform is supplied from the H.T. line via the potentiometer $R_3$, $R_4$, and the decoupling circuit $R_5$, $C_5$. The specific voltage corresponding to the point $B$ in Fig. 3, that is to say, the maximum amplitude of the saw-toothed waveform, will depend upon the potential applied to $R_1$. This potential may be controlled within limits by adjustment of the potentiometer $R_3$, which therefore acts as a control of the amplitude of the line scanning, and thus of the width of the received picture. The potentiometer $R_3$ is accordingly designated Width.

The frequency of the generated waveform will clearly depend upon the value of the time constant $C_1$ $(R_1 + R_2 + R_5)$, for if any of these resistances is reduced the negative potential which holds $V_e$ non-conductive will leak away from the control grid more rapidly and the frequency will increase, and vice versa. Further, the application of a positive potential to the lower end of $R_3$, $R_4$ will also increase the frequency by accelerating the leakage of the negative potential from the grid. Variation of such a positive potential forms a convenient means of frequency control, and this latter method is used for the normal fine frequency adjustment under operating conditions.

To effect this, $R_4$ is made part of the potentiometer $R_3$, $R_5$, $R_6$, which is connected across the H.T. supply and so carries a positive potential. It is accordingly brought out to a manual control designated Line Frequency. For normal operation $R_4$ is held shorted by the switch $S_1$, but it is convenient for test purposes to be able to run the line scanning at half frequency, and the insertion of $R_4$ by opening $S_1$ effects this.

It is now necessary to synchronise the line frequency generated by $V_e$ with the line synchronising signals incoming from the transmission. This may be done by arranging to apply the line synchronising signals in the positive sense to the control grid of $V_e$. Assuming that at the instant of application of a line synchronising signal the control grid is still sufficiently negative to render $V_e$ non-conductive, the application of a synchronising signal will overcome the remaining negative charge on the grid and render the valve conductive. The leading edge of the synchronising signal will therefore coincide in time with the point $B$ of Fig. 3, that is to say, the synchronising signal will initiate the return stroke and not, of course, the
The Line Scanning Circuit (Contd)

forward stroke. The monitor has to be supplied from a Distribution Amplifier, and at the monitor output of such an amplifier the vision waveform has the characteristics given in Fig. 5. The troughs of the synchronising signals correspond to 0 V, black level to +3.5 V, and white level to +10.0 V, all with respect to earth. The synchronising signal incoming is therefore in the negative sense, but \( V_g \) requires it in the positive sense. The signal must therefore be reversed by a valve, and this is the function of \( V_s \). At the same time it is, of course, necessary to separate the signal from the incoming picture and synchronising waveform, as the synchronising signal only is required by \( V_c \). This separation is also performed by \( V_c \).

![Figure 5](image)

Figure 5.

It will be seen that the cathode of \( V_c \) is returned to the potentiometer \( R_{14} \), which is a portion of a potentiometer system \( R_{16}, R_{11}, R_{12}, R_{13}, R_{14} \) connected across the H.T. line. These resistances are so proportioned that on \( R_{14} \) may be found a potential of +3.5 V. This potentiometer is brought out to a manual control designated Sep. Bias. At black level, therefore, the potential of the control grid of \( V_c \) with respect to its cathode is zero; the synchronising signals will drive the grid 3.5 V negative, but the vision signals will attempt to make it positive. At black level, however, when the control grid is at zero potential with respect to its cathode, the potential of the anode, due to the high anode resistance \( R_{14} \), is already so low (about +5 V) that it would scarcely be influenced by any movement of the grid potential in the positive direction. Expressing this another way, the resistance \( R_{14} \) and the anode-cathode path of the valve \( V_c \) are together constituting a potentiometer, in which at black level the impedance of the anode-cathode path is very small compared with \( R_{14} \) so that the standing D.C. potential at the junction of \( R_{14} \) and \( V_c \) has already been reduced to 5/300ths, i.e. 1/60th, of that of the H.T. line. Accordingly if the picture signals render the control grid slightly positive, the impedance of the anode-cathode path will be reduced, but as it was previously very low compared with \( R_{14} \) the percentage change, as it were, in the setting of the potentiometer consisting of \( R_{14} \) and \( V_c \) will be so small that there will be a negligible change in the absolute anode potential, so that picture signals will have little effect on the grid of \( V_c \). Very considerable suppression of the picture signals is effected in this manner. In addition, however, the resistance \( R_{17} \) is inserted having a value, 10,000 ohms, much higher than is normal were it placed there purely for anti-parasitic purposes. If the potential of the control grid with respect to the cathode attempts to become more positive than zero upon the application of picture signals, the impedance of the grid cathode path will be very much less than \( R_{17} \); the greater part of the voltage due to the picture signals will be dropped across \( R_{17} \) and only a small proportion will appear between the grid and cathode. On the other hand, when the synchronising signals drive the grid negative with respect to the cathode no grid current will be drawn, and the impedance of the grid-cathode path will be very high with respect to \( R_{17} \), the effect of which will now be negligible, as nearly all the input voltage due to the synchronising signals will appear between the grid and cathode and energise the valve. The presence of \( R_{17} \) therefore constitutes a second method of suppressing the picture signals. The two methods of suppression operate together, and whereas neither acting alone would provide the requisite degree of suppression, the two together ensure that the waveform appearing at the anode of \( V_c \) consists almost entirely of pure synchronising signals. Due to the reversing action of \( V_c \), the sense of the signals on the anode is positive, and they are therefore applied directly to the grid of \( V_g \) via the blocking condenser \( C_4 \).

The screen grid potential of \( V_g \) is fixed at the unusually low value of 28 V, from the junction of \( R_{18} \) and \( R_{19} \) in the potentiometer \( R_{18}, R_{19}, R_{12}, R_{13}, R_{14}, R_{15} \). This gives the valve \( V_g \) a very short grid base, so short in fact that a synchronising signal of some 3.5 V input will drive the control grid to the bottom end of its characteristic, and the anode current will be cut off. Employing once more our former analogy in which we compared the resistance \( R_{14} \) and the anode-cathode path of \( V_c \) to a potentiometer, we can say that in the presence of a synchronising signal, since the impedance of the anode-cathode path becomes nearly infinite, the impedance of the upper limb of the potentiometer, \( R_{14} \) is very small compared with that of the lower limb, the anode-cathode path of \( V_c \), and consequently the anode potential will be approximately that of the H.T. line. Such a signal therefore causes the anode potential to rise from -5 V to +300 V. Therefore a very strong synchronising signal, having an amplitude of some 295 V, is delivered to the grid of \( V_g \), and clearly the control exerted by it on the blocking oscillator \( V_g \) will be very firm.

It will be noticed that the complete synchronising waveform is applied to the grid of \( V_g \), and that is to say, although the circuit associated with \( V_g \) is concerned solely with the generation of the line scanning waveform, both line and frame synchronising signals are applied to its grid. This is done for a reason which has been explained in my note on the Signal Waveform (Item 1.1). It is desired that the line scanning waveform should be smoothly maintained throughout the frame synchronising period, and therefore the line scanning generator \( V_g \) must be synchronised at line frequency during
this period. In my note on the Signal Waveform it is explained that the frame synchronising waveform is so designed as to contain line synchronising components, and it is therefore suitable to maintain generation of line scanning waveform during the frame synchronising period. For this reason therefore both the line and frame synchronising signals are applied to the grid of \(V_s\), and no attempt is made to separate them.

\[E = \frac{dL}{dt}\]

That is to say, the voltage across an inductance is given by the first differential with respect to time of the current through the inductance. Therefore to produce in an inductance a current having the waveform of Fig. 3, we should have to apply across the inductance a voltage having the waveform illustrated in Fig. 6, which is the first differential of the waveform of Fig. 3. The points \(GHI\) in Fig. 6 occur at the same times as the points \(ABC\) in Fig. 3 respectively. Expressing this physically, upon the application of a voltage across an inductance, the current does not rise to its full value immediately, but takes time to do so. In order to produce the desired current \((AB\) in Fig. 3) in the inductance it will be necessary to hold across it a steady voltage, \(GH\) of Fig. 6, whilst to effect the fly-back \((BC\) in Fig. 3) the voltage will have to be reduced to a negative standing value, as shown in Fig. 6, over the time \(HI\). If we have to produce a saw-toothed current in a circuit containing both inductance and resistance in series, which is the practical case, the necessary voltage waveform will be a combination of Figs. 3 and 6, and will be on the lines of that indicated in Fig. 7. If on the other hand we wished to drive a saw-toothed current through a pure resistance, we should, of course, apply an identical saw-toothed voltage waveform, as in Fig. 3.

In the practical case there are two courses open to us, either we may apply to the deflection coils, which consist of inductance and resistance in series, the waveform of Fig. 7, which must consist of a properly proportioned mixture of the saw-toothed waveform of Fig. 3 and its first differential shown in Fig. 6, or we must add in series with the deflection coil a comparatively high resistance so as to swamp the effect of the coil inductance, in which case we may apply a saw-toothed waveform. In the present case we employ the second of these alternatives, simply by making the output valve \(V_s\), a pentode. The high internal impedance of the valve then overcomes the distortion of the current waveform which would otherwise be produced by the presence of the effective inductance of .108 H in its anode circuit.

This cannot be done by applying a saw-toothed voltage across the inductance for the reason that the voltage \(E\) across an inductance \(L\) is given by the expression \[E = \frac{dL}{dt}\]. The points \(GHI\) in Fig. 6 occur at the same times as the points \(ABC\) in Fig. 3 respectively. Expressing this physically, upon the application of a voltage across an inductance, the current does not rise to its full value immediately, but takes time to do so. In order to produce the desired current \((AB\) in Fig. 3) in the inductance it will be necessary to hold across it a steady voltage, \(GH\) of Fig. 6, whilst to effect the fly-back \((BC\) in Fig. 3) the voltage will have to be reduced to a negative standing value, as shown in Fig. 6, over the time \(HI\). If we have to produce a saw-toothed current in a circuit containing both inductance and resistance in series, which is the practical case, the necessary voltage waveform will be a combination of Figs. 3 and 6, and will be on the lines of that indicated in Fig. 7. If on the other hand we wished to drive a saw-toothed current through a pure resistance, we should, of course, apply an identical saw-toothed voltage waveform, as in Fig. 3.

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In theory, the circuit as so far described contains the essential features necessary to provide a saw-toothed current at line frequency in the line deflection coils of the tube and having a peak value of 1 ampere. Unfortunately, however, a complication is introduced owing to the presence of self-capacity in the line deflection coils and transformer windings, the total value of which, when referred to the primary of the transformer \(T_{RP}\), is .0001 \(\mu F\). To understand its action, let us imagine we have arrived at the point of the scanning cycle corresponding to \(B\) in Fig. 3, where the scanning current is at its maximum value of 1 ampere and the return stroke is about to commence. The grid potential of \(V_s\) having attained its maximum positive value falls suddenly, and \(V_s\) attempts to cut off the current flowing through
The Line Scanning Circuit (Contd)

the primary of TR4. The effective inductance in the anode circuit of V7, however, does not permit a sudden reduction of the current to zero, but endeavours to maintain the current flowing, and it flows into the self-capacity. In effect, the tuned circuit comprising the effective anode inductance and self-capacity is excited, by the sharp transient formed by the return stroke, into oscillation at its natural frequency, which is of the order of 50,000 c/s. Instead, therefore, of the spot making a smooth return to the left-hand side of the picture, it will return in an oscillatory manner and take as much as 160 micro-seconds, or the time of one line to do so. Obviously, the spot must be made to return much more quickly, and certainly within the period of 15 micro-seconds during which black level is maintained by the line suppression pulse. In commercial receivers the difficulty is overcome by placing across the circuit a resistance of value such as to give critical damping. This is quite in order where the requirements of the tube and the design of the scanning circuit as a whole are more moderate than in the present case, and where therefore the effective inductance in the anode circuit of the output valve has a smaller value. The more advanced type of cathode ray tube employed in the Picture Monitor, however, demands a greater amplitude of scanning current, which in practice entails scanning coils and an output transformer whose constants give the comparatively high value of effective inductance of .106 H already quoted. With critical damping, the return stroke is effectively completed, that is to say, the spot will have traversed 99 per cent. of its path, after a period equal to 1.3 times the periodic time of the resonant oscillation. In this case, the return time would therefore be

\[ 1.3 \times 10^8 \mu \text{sec} = 26 \mu \text{sec} \]

which is too long, being nearly twice as great as the duration of the line suppression period. To decrease this it would be necessary to design the circuit so that less effective inductance was present to the anode of V7, but we would not then be able to get an adequate scanning amplitude.

The difficulty is, of course, that any damping applied to the transformer TR4 is present all the time. What we really desire is for the transformer to be undamped during the forward stroke, but to be damped during the return stroke so that the oscillation at 50,000 c/s may be suppressed. In practice the problem is dealt with in this manner by the inclusion of the valve V8 and its associated circuit. The circuit is an example of a case where the adoption of a certain technique with a particular end in view, which in this case is the suppression of the resonance at 50,000 c/s, brings in its train one or more further advantage. In this case the inclusion of V8 also has the effect of increasing the output which is possible to obtain from V7. Were it not for this feature, this valve would have to be of a larger type than is actually used.

In order to study the action of the complete circuit, including V7, it will be convenient to commence with a consideration of the saw-tooth cycle from the beginning of the forward stroke, that is to say, from the point A in Fig. 3. At this moment the grid voltage of V7 commences to rise in the positive sense, and a steadily increasing anode current is forced through the effective inductance L of .106 H. The voltage E across the inductance is given by the equation

\[ E = \frac{L \int i \, dt}{dt} \]

Since this equation indicates, as we have seen, that the voltage across the inductance is proportional to the first differential of the current, and since the current has the saw-toothed configuration of Fig. 3, the voltage across the inductance will have a constant value during the whole of the forward stroke AB. By substitution in the above equation we can compute this voltage.

Thus, we have

\[ L = .106 \text{ H} \]

\[ \frac{d}{dt} \], taken over the duration of the forward stroke (AB of Fig. 3) is, as already stated, 140 mA.

\[ \frac{d}{dt} \], the duration of the forward stroke (AB of Fig. 3) is 90 \mu ms, i.e. the difference between the complete time of a line, 100 \mu ms, and the fly-back period, which will be shown later to be 10 \mu ms.

Therefore,\[ E = \frac{L \int i \, dt}{dt} = .106 \times \frac{140}{1,000} \times 10^8 = 165 \text{ V} \]

The anode voltage of V7 will remain steady at a voltage equal to the H.T. voltage less E, or 135 V. An anode current, which will be shown later to be = 100 mA, will be built up by the time the end of the forward stroke is reached. At B of Fig. 3, the grid potential of V7 drops suddenly to zero and endeavours to cut off the anode current. As we have seen, however, the inductance maintains a current flow into the self-capacity, and an oscillation of 50,000 c/s commences, one cycle of which is illustrated in Fig. 8. During the first quarter cycle (MN of Fig. 8) the current maintained by the inductance flows into the self-capacity and produces a back voltage across it, which rises to the very high figure of some 3,000 V. At the point N in Fig. 8, which in time occurs, of course, shortly after the point B of Fig. 3, the absolute anode potential of V7 is approximately 3,000 V and, owing to opposition from the back voltage across the self-capacity, the current in the inductance has fallen to zero. We are now about to begin the second quarter (NO in Fig. 8) of the 50,000 c/s oscillation. The self-capacity begins to discharge through the inductance L, producing a current in the reverse direction which, neglecting losses for the moment, rises to the end of the second quarter of the cycle, that is to say at the point O of Fig. 8, to = 100 milliamperes. The self-capacity will now be completely discharged, and therefore the high anode voltage of 3,000 V will have disappeared from the anode of V7, which will be at the potential of the H.T. line, i.e. 300 V. We are now about to
commence the third quarter (OP of Fig. 8) of the 50,000 c/s oscillation, during which it will be clear, that unless we take preventive measures the anode voltage of $V_2$ will become negative and, neglecting losses, will attain a potential of $-3,000$ V at the point $P$ of Fig. 8. It is, however, prevented from doing so by the action of the diode $V_6$, which has so far been inoperative.

In order to understand the action of $V_6$ we must return once more to the beginning of the forward stroke (the point $A$ in Fig. 3). It will be seen that the diode is connected across the primary of the transformer $TR_1$, that is to say, across the effective inductance $L$ of $106$ H. In series with its anode are the elements $R_{16}, R_{13}$ and $C_5$. During the forward stroke there is, as has already been stated, a steady voltage drop of $165$ V across the primary of the transformer $TR_1$, so that during this time the absolute potential of the anode of $V_6$ will remain steady at $+135$ V. For a reason which will appear later, there is a similar drop of $165$ V across the elements $R_{16}, R_{13}$ and $C_5$, so that during the forward stroke the absolute anode potential of $V_6$ is also steady at $+135$ V. But the cathode of $V_6$, being connected to the anode of $V_6$, is also at $+135$ V. There is therefore no difference of potential between the anode and cathode of $V_6$, so that during the forward stroke it does not conduct. Actually this statement is not strictly true, but for the moment we will assume that $V_6$ does not conduct during the forward stroke. It will also be of assistance to imagine for the moment that the elements $R_{16}, R_{13}$ and $C_5$ are simulating a battery of $165$ V with its positive end connected to the H.T. line and its negative terminal to the anode of $V_6$.

In point of fact such a battery could perfectly well be substituted for these elements.

Transferring our attention to Fig. 8, during the period $MN$ the anode voltage of $V_2$ rises to $+3,000$ V, and during the whole of this period therefore the cathode of $V_6$ is more positive than its anode. Similarly, during the period $NO$ of Fig. 8, when the anode voltage of $V_6$ falls from $+3,000$ to $+300$, $V_6$ still does not conduct. After a short portion, however, of the period $OP$ of Fig. 8, the anode voltage of $V_6$ will have fallen to $+135$ V, at which point the anode and cathode potentials of $V_6$ are equal, and subsequently attempts to move off to $-3,000$ V. But the moment it falls below $+135$ V the diode $V_6$ becomes conductive. The impedance of the diode is 100 ohms, so that the circuit of $V_6$ effectively short-circuits the primary, the short circuit, however, being in series with the voltage of $165$ at present across $C_5$. The oscillation is therefore completely damped out by the sudden imposition of the short circuit, and its continuance beyond the point $O$ of Fig. 8 is impossible. At the point $O$, the current in the effective inductance $L$ has reached its maximum negative value, that is to say, the spot is fully deflected to the left from the point of view of an observer facing the picture, and in fact the return stroke is complete. In practice, due to losses, the reverse current only rises to $-40$ mA, so that the complete current change is to $-40$ mA to $+100$ mA, i.e. the desired change of $140$ mA. It is evident therefore that the return stroke has been accomplished during the time occupied by the half cycle $MNO$ of Fig. 8. The duration of this, namely, $\frac{1}{4} \times 1/100,000$, or 10 micro-seconds, is a very satisfactory fly-back time, since it is only 10 per cent of the time of a line, and is thus well covered by the standard line suppression pulse, which has a duration of 15 per cent of the time of a line. In view of the fact that the circuit is allowed to make one undamped half-cycle of oscillation, that is to say, the circuit resonates for half a cycle, the circuit is said to be of the resonant return type.

It has already been observed that the inclusion of the resonant return circuit confers the advantage of increasing the deflection output which it is possible to obtain from $V_7$ for a given excursion of anode current, and we are now in a position to see why this is so. Without the resonant return circuit the anode current of $V_7$ would have to vary between zero, corresponding to the commencement of the forward stroke, and $+140$ mA at the end of the forward stroke. With the inclusion of the resonant return circuit, however, the necessary scanning excursion of $140$ mA is obtained with a maximum anode current of only $100$ mA, since the resonant anode circuit derives from this a scanning excursion of approx. 1.5 times this value. The beam deflection, or width of picture available from a given size of valve at $V_7$, is therefore increased by 1.5 times by the use of the resonant return circuit, and the width of scanning necessary for the 12" cathode ray tube can therefore be obtained without recourse to a power amplifier, $V_7$, of fundamentally greater capacity.
The Line Scanning Circuit (Contd)

We must now consider the action of the elements $E_{15}$, $R_{18}$ and $C_{18}$, and ascertain why there is a steady voltage drop of 165 V across them during the forward stroke. This feature is somewhat bound up with the operating conditions of the valve $V_T$. It is clearly a necessary feature of the working of the circuit that during the forward stroke there should be a steady drop of 165 V across $E_{15}$, $R_{18}$ and $C_{18}$, and this can only be possible if an appropriate current is flowing through $R_{18}$ and $R_{19}$. This current is provided by arranging that $V_s$ will conduct slightly during the forward stroke. For this to happen the circuit must endeavour to reduce the potential of the cathode of $F_a$, and consequently of the anode of $V_T$, slightly below +15 V during the forward stroke. This will occur if it is arranged that the rising anode current of $V_T$, due to the application of the forward stroke saw-tooth from $V_a$, is always slightly greater than the current required by the primary of $T_{R_3}$. This will obviously be the case if the amplitude of the saw-tooth applied to the grid of $V_T$ is made slightly greater than the theoretically exact figure. This is done, and the result is that the excess of the anode current of $V_T$, over and above that required to produce 165 V across the primary of $T_{R_3}$, flows through the diode $V_a$. This excess current will vary somewhat during the forward stroke, and accordingly the values of $R_{18}$ and $R_{19}$ are chosen so that the mean current through the diode during the forward stroke will produce a voltage of 165 V across these resistances. The function of $C_{18}$ is purely as a smoothing condenser to eliminate from the steady voltage across $R_{18}$ and $R_{19}$ the variations which normally obtain due to the fact that the current in $V_s$ is not constant during the forward stroke. The voltage will be substantially constant if the time constant $C_{18}(R_{18} + R_{19})$ is made much longer than the time of a line, and it will be seen that the figure employed in practice is 2,000 $\mu$s, or the duration of 20 lines.

If the resonant return circuit were not used, the current in the primary of $T_{R_3}$ would be zero at the beginning of the forward stroke, and the commencement of the latter would coincide with the commencement of the application of the saw-tooth from $V_a$. With the present circuit, however, the current in the primary of $T_{R_3}$ is $-40$ mA at the beginning of the forward stroke, and it is not only unnecessary, but is undesirable, to apply the saw-tooth from $V_a$ at this moment, since until the $-40$ mA has fallen substantially to zero it is unnecessary for $V_T$ to deliver any current. In these circumstances the application of the saw-tooth from $V_a$ would make $V_T$ deliver unnecessary current, all of which would pass through the diode $V_a$, in the manner just described. Such a current would produce a voltage drop sufficient to disturb the standing potentials of +135 V and mar the linearity of scanned. Accordingly the circuit is arranged so that $V_T$ is not, as it were, turned on until the $-40$ mA has dropped nearly to zero. This is done by the simple expedient of arranging that the amplitude of the saw-tooth delivered from $V_a$ is greater than the grid base of $V_T$, by the appropriate amount, which is about 1.5 times, so that during the first part of the saw-tooth the operating characteristic of $V_T$ is beyond the cut-off point and the valve delivers no current. It will be observed that the condenser $C_{18}$ is returned not, as would be expected, to earth, but to the cathode of $V_T$. This is because no feedback is required on this valve, and since the cathode resistance $R_{18}$ of $V_T$ is required for grid bias purposes, the grid of this valve must be returned to its cathode with respect to A.C. in order to avoid feed back.

It is found that certain unavoidable losses in the coils of the transformer $T_{R_3}$ tend to make themselves apparent towards the end of the line in the shape of a slowing up of the scanning. To overcome this it is desirable that the current in $V_T$ should rise a little more rapidly than is required in theory. However, the natural curvature of the characteristic of $V_T$ compensates for this very closely.

It is found that with the circuit as so far described a number of black and white vertical bars will be observed on the left-hand side of the reproduced picture, decreasing in intensity from left to right. This is due to the fact that the leakage inductance of the transformer $T_{R_3}$ is in series with the self-capacity of the line scanning coils forming a tuned circuit. The transient due to the sudden cessation of current at the time of the return stroke will excite this tuned circuit into oscillation at about 500,000 c/s, and the duration of the oscillation is such that it extends beyond the period of the return stroke and continues for the first portion of the line scan. The line scanning voltage applied to the line scanning coils is therefore modulated at 500,000 c/s and the velocity of the long scan across the tube will vary at this frequency. Since the brightness of the trace on a cathode ray tube is affected not only by the intensity of the scanning beam, but also the speed at which the beam traverses the fluorescent screen, these variations in velocity will produce variations in brightness on the screen which will be superimposed upon any picture that may be there. The effect is, of course, well known as velocity modulation, and it is imperative that this variation in line scan velocity should be removed. This is effected by the circuit involving $V_a$, $R_{18}$ and $C_{13}$, which operates so as to damp out the oscillation in precisely the same manner as the circuit involving $V_a$, $R_{18}$ and $C_{13}$, operated suppression of the other oscillation at 50,000 c/s. The effect could, of course, be alternatively suppressed by the connection of a resistance of several thousand ohms across the secondary of the transformer $T_{R_3}$, but this would result in a diminution of the line scanning amplitude which the circuit could provide, and it is therefore considered preferable to effect the suppression by means of a circuit which does not apply damping during the line scanning period. Since the operation of this type of circuit has been very fully described in connection with the elements $V_a$, $R_{18}$, $R_{19}$ and $C_{18}$, it will not be repeated in connection with $V_a$, $R_{19}$ and $C_{18}$.
The Frame Scanning Circuit

The frame scanning circuit comprises the valves $V_1$, $V_2$, $V_3$ and $V_4$ (see Fig. 15).

Considering the circuit in detail, we may conveniently commence with the action of the valve $V_2$. The resistance $R_{23}$ and the condenser $C_{12}$ form a relaxation oscillator in which the condenser is charged slowly from the H.T. line via the resistance $R_{23}$, thus generating the fundamental saw-toothed excursion for the forward stroke of the scanning, and at the appropriate moment is discharged by the valve $V_2$, which becomes conductive for the purpose. The alternate conductivity and non-conductivity of the valve $V_2$ is obtained by a circuit which is very similar to that associated with $V_3$ and already described for the line scanning. It is therefore unnecessary to describe the circuit associated with $V_3$ in detail. The components $R_{34}$, $C_{13}$, $V_3$, $T_{34}$, $R_{34}$, $R_{24}$, $R_{14}$, $R_{15}$, $R_{16}$ and $R_{17}$ associated with the valve $V_3$ correspond respectively in their functions with the components $R_1$, $C_1$, $V_e$, $T_{12}$, $R_2$, $R_4$, $R_5$, $R_6$, $R_7$, $R_8$, and $R_9$ associated with the valve $V_4$. The potentiometer $R_{24}$ controls the amplitude of the generated saw-tooth and therefore the height of the received picture, and it is consequently designated Height. The potentiometer $R_{24}$ controls the frequency of the frame saw-tooth, and is consequently designated Frame Frequency.

It is, of course, necessary to synchronise the frequency of the frame scanning waveform generated by $V_4$ with the incoming frame synchronising signals. It has been explained that in the case of the line scanning generator it is unnecessary, and in fact quite wrong, to separate the line synchronising signals from the frame synchronising signals. Both are required for the proper operation of the line scanning generator. The converse, however, does not apply. It is necessary to apply to the circuit of $V_3$ only the frame synchronising signals, since when $V_3$ is nearing the end of the forward stroke of the frame scanning it is in a state where it can easily be tripped by a synchronising signal, and a line synchronising signal occurring several lines before the end of the frame would trip this valve. Not only would this be quite wrong from the point of view of the normal operation of the circuit, but interlacing would be impossible. The essentials of good interlacing lie in ensuring that the frame scanning generator $V_3$ shall be tripped with precision at the end of every 252.5 lines. No synchronising signal of any sort must be allowed to influence the valve before the correct moment of tripping. Furthermore, when the trip occurs it must be sharp, that is to say, a strong positive pulse must be impressed upon the grid of $V_3$, and this pulse must rise to its full amplitude in the shortest possible time. This is achieved in the following manner.

The valve $V_4$, which corresponds exactly in its functions to the valve $V_2$, in the line scanning circuit, separates from the complete vision waveform applied to its grid, mixed line and frame synchronising signals, which are delivered in the positive sense from its anode. The method and conditions of operation of this valve are the same as that of $V_4$, and need not be described again. The anode of $V_4$ contains the high resistance $R_{10}$, and in shunt to earth is the condenser $C_{11}$, the time constant of the combination $R_{10}$, $C_{11}$ being 170 micro-seconds, which is long compared with the duration of the line synchronising signal. As in the case of the valve $V_4$, the application of line or frame synchronising signals to the grid of $V_4$ results in its anode current falling to zero, and if the condenser $C_{11}$ were not present, the anode potential would at these times rise to the same value as the H.T. The condenser $C_{11}$, however, materially alters this state of affairs, and we must now examine what happens to the anode potential of $V_4$, firstly during line and then during frame synchronising signals.

During the forward stroke of each line, that is to say, the picture period, $V_4$ is conductive and its impedance is much less than the value of the resistance $R_{10}$. The value of the valve impedance remains stationary, as explained above, the circuit suppresses the picture components, which therefore cannot influence the valve impedance nor consequently the anode potential. We must say, therefore, that the resistance $R_{10}$ and the impedance of $V_4$ form a simple potentiometer in which the impedance of the lower arm, $R_{10}$, is so much less than that of the upper arm, $R_{11}$, that the potential at the junction is very low. It is in fact less than 0.5 V. Approaching the matter in another way, we may say that the low impedance of $V_4$ effectively short-circuits the condenser $C_{11}$. When a line synchronising signal arrives, the impedance of $V_4$ becomes very high, and the short circuit is removed. During the period of synchronising signals we can in fact imagine that $V_4$ is not in circuit at all, and we may disregard it. Now that the short circuit across $C_{11}$ is removed, this condenser will begin to be charged from the H.T. supply via the high resistance $R_{10}$, and this charging process continues for the duration of the line synchronising signal, which is 10 micro-seconds, after which the short circuit is reapplied as $V_4$ becomes conductive. In order to understand the working of the circuit properly, it is essential to know the exact value of the voltage which exists across the condenser at the end of the line synchronising pulse.

As is well known, the charging of a condenser is governed by an exponential law which may be expressed as follows. If a voltage $E$ is applied across a condenser and resistance in series, as shown in Fig. 9, the voltage $E$, existing across the condenser at a time $t$, after the initial application of the voltage $E$, will be given by the formula

$$E_t = E(1 - e^{-\frac{t}{R C}})$$

$E_t$ is the voltage across the condenser at a time $t$, $E$ is the applied voltage, $R$ is the resistance, and $C$ is the capacitance of the condenser.
The Frame Scanning Circuit (Contd)

We may calculate the value of \( E_t \) at the end of the line synchronising pulse. Thus we have \( E = \) the value of the H.T. supply = 300 V.

\[
CR = \text{the time constant} = \frac{0.00005 \times 10^8 \times 5 \times 10^4}{175} \text{ sec.} = 175 \mu \text{sec.}
\]

\( t \) = the duration of the line sync. signal = 10 \( \mu \) sec.

Therefore

\[
\frac{-t}{CR} = -\frac{10}{175} = -0.057
\]

From tables we find \( e^{-0.057} = 0.944 \)

Therefore

\[
E_t = 300(1 - 0.944) = 16.8 \text{ V}
\]

This value, namely 16.8 V, therefore exists across the condenser at the end of the line synchronising pulse.

In Fig. 10 has been plotted a curve showing the increase of voltage \( E_t \) across the condenser \( C_{1a} \), as it is charged from the H.T. supply, the curve being determined by a number of points calculated in the above manner, and it will be seen that the point \( A \) on the curve represents the state of affairs at the end of a line synchronising signal, \( t \) being 10 \( \mu \) sec. and \( E_t \) 16.8 V at this point.

To the upper side of \( C_{1a} \) is connected the anode of the diode \( V_2 \), whose cathode is returned via the tertiary of \( T_h \) to the point \( x \) on the potentiometer \( R_{2a} \) to \( R_{1a} \), where there is a potential of 25 to 30 V. It is a coincidence that this is also the correct potential required for the screen grid of \( V_1 \), so that the cathode of \( V_2 \) appears to be returned to the screen. The line \( CD \) has been drawn in the graph of Fig. 10 to indicate a steady value of 28 V, and it will be seen that at the end of a line synchronising signal the upper side of the condenser and the anode of \( V_2 \) reach a maximum potential of 16.8 V, which is 11.2 V negative with respect to the cathode of the diode, so that no current can pass through \( V_2 \).

Let us now consider what will happen when a frame synchronising signal occurs. The first part of such a signal to arrive will be the first broad pulse, having a duration of 40 micro-seconds. As before, during the half or whole line preceding the first broad pulse, depending upon whether we are at the end of an odd or an even frame, \( V_1 \) is conductive and \( C_{1a} \) is held discharged. On the arrival of the first broad pulse \( V_1 \) becomes non-conductive and the charging of \( C_{1a} \) commences, as in the case of the line synchronising signal. But this time it is continued for 40 micro-seconds, the duration of the broad pulse, at the end of which the potential of the upper side of \( C_{1a} \) corresponds to point \( B \) in Fig. 10, which is seen to be 61.5 V. The moment the potential rises beyond the point \( P \) in Fig. 10, so that the anode of the diode becomes more positive than its cathode, the diode will pass current and a pulse corresponding with the portion \( PB \) of the curve of Fig. 10 will flow through this valve. Via the tertiary of \( T_h \), this pulse will be communicated in the positive sense to the grid of \( V_2 \), and this valve is accordingly tripped. It will be seen that the above arrangement effectively precludes any possibility of the frame scanning circuits being influenced by line synchronising signals, and ensures that the pulse delivered to \( V_2 \) is reasonably sharp. It is obvious that this method of separation is much superior to any method of frequency separation depending upon the fundamental difference of the frequencies of the line and frame synchronising signals. An ideal synchronising signal should have a steep wave front, that is to say, it should rise to its maximum amplitude in the shortest possible time, and it will be seen, that the wave front \( PB \) of Fig. 10 which attains its maximum amplitude in 22\( \frac{1}{2} \) \( \mu \) sec., although not as steep as that of the transmitted broad pulse, is nevertheless good.
A study of the curve of Fig. 10 will explain another effect which will be noticed in monitors having this scanning circuit. From an examination of the transmitted waveform it would be supposed that the frame scanning generator at the receiver would be tripped precisely half way along a line, and that the interface would be observed to begin from such a point, but it is the point $O$ of Fig. 10 which corresponds to the beginning of a broad pulse, and it is not until at least the point $P$ is reached that the frame scanning generator will be tripped. Accordingly the interface does not begin physically from a point half-way along the line but from a point to the right of centre and corresponding to the interval $t_1$ in Fig. 10. It might be thought that this would be irreconcilable with the process of interlacing, but it is not so since interlacing will be perfect if the next frame is tripped off precisely 1/50th of a second after the first one, and so on. This, of course, must be the case as the tripping of the frame scanning generator will occur at the end of each frame at a time corresponding to the point $P$ in Fig. 10, and the occurrences in time of the points $P$ must therefore be spaced by 1/50th of a second precisely.

The portion of the circuit so far described involving $V_1$, $V_2$ and $V_3$ produces a saw-toothed voltage at frame frequency, and as in the case of the line scanning we must derive from this a saw-toothed current which will flow in the frame deflection coils. In this case we are confronted with the same pair of problems as in the case of the line scanning circuit, namely, we must see that the inductance of the circuits neither prevents us from getting a truly saw-toothed current during the forward stroke, nor prevents us from obtaining a fast fly-back time. Whereas in the case of the line scanning circuit the major problem was the fly-back time, in this case the difficulty lies largely in obtaining a good scanning waveform on the forward stroke. This difference arises because the range of frequencies with which we are concerned for frame scanning is very much lower than that for line scanning. It extends from 50 to some 6,000 c/s, and is thus comparable with that which has to be considered in audio frequency circuits. The scanning coils must clearly be fed by an output transformer, and it will be remembered that in sound circuits the main source of distortion which output transformers are liable to produce is a loss of low frequencies. This loss arises because the impedance presented to the anode circuit of the output valve by the effective inductance of the transformer may at the lower frequencies be insufficiently low as to shunt away some of these frequencies. This source of distortion applies also in a frame scanning output circuit, but the requirements for linear frame scanning are much more stringent. With the constants that obtain in such circuits it would be necessary to provide an output transformer with a secondary resistance of only 1 or 2 ohms but an inductance of 1 H. It is not possible to provide a transformer having these properties which will be satisfactory in other respects, and it is owing to this difficulty that the necessity arises for the somewhat complex circuit associated with $V_4$.

The transformer $TR_1$ has a ratio of 30:1, a primary inductance when there is a D.C. current of 30 mA superimposed of 80 H, and a secondary leakage inductance and resistance of 2 mH and 2 ohms respectively. The inductance and resistance of the deflection coils are also 2 mH and 2 ohms. The total inductance and resistance in the secondary circuit are therefore 4 mH and 4 ohms. Transferring this impedance to the primary side, we have, $4 \times 30^2 = 3,600$ ohms, and $0.04 \times 30^2 = 3.6$ H. The primary resistance of the transformer is 3,600 ohms. Having these figures, we can draw the equivalent circuit of the network and impedance which the output valve $V_4$ actually sees in its anode. In Fig. 11, $L_1$ is the primary inductance, which shunts the secondary inductance and resistance $L_2$ and $R_2$, and in series with these three elements is the primary resistance $R_1$. The fly-back is created by suddenly stopping the saw-toothed current which flows through $L_2$ and $R_2$, and $L_4$ will tend to make the current die away gradually and thus to slow up the fly-back. On the other hand, the inductance $L_4$ will be responsible for bad waveform during the forward stroke, by shunting away the lower frequencies, and thus preventing them from building up a linear saw-toothed current through $L_4$ and $R_4$. Arrangements are made in the circuit to compensate for both these effects.

Dealing first with the effect of $L_1$, it is evident that if the source of supply feeding the saw-toothed current in the network of Fig. 11 can be given a very low impedance compared both with $L_2$ and $R_2$, and with $L_4$, the shunting effect of $L_1$ would be negligible because, instead of robbing current from the other branch, $L_4$, $R_4$, it would simply draw more current from the source which would be able to supply it without loss of output voltage. The source is, of course, the valve $V_4$, plus $R_1$, the effective primary resistance, and therefore this valve must be given a very low effective impedance, and $R_1$ must be
The Frame Scanning Circuit (Contd)

effectively eliminated. This is done by providing \( V_F \) with very heavy feedback to the extent of some 20 times. Ordinarily the grid excursion required for \( V_F \) would be 5 V. To effect the feedback the condenser \( C_{12} \) (Fig. 11) is reduced to 1/20th of the value which would be required were there no feedback present, so that the voltage across it, and hence the input grid excursion, rises to 20 times the normal value, or 100 V. Then, feedback to the extent of 95 V is applied in series with \( C_{12} \) by means of the tertiary of the transformer \( T_{R1} \), so that the resultant grid to cathode excursion is equal to \((100 - 95) = 5\) V, or the required amount.

The use of the tertiary winding to provide feedback is of special interest, as it is by its use that \( R_1 \) is effectively eliminated. The tertiary is wound with the same number of turns as the primary, and the volts across it must be equal to those across the effective primary inductance \( L_{R1} \), and are not influenced by any considerations of primary resistance. The resistance \( R_1 \), therefore, appears as if it is lumped with the internal impedance of the output valve \( V_F \).

The degree of feedback employed is effective to reduce the impedance of \( V_4 \) and \( R_1 \) from 100 ohms, and such a low impedance source can easily supply the demands of \( L_{R2} \) at the lower frame scanning frequencies, and the deleterious effect of this shunt inductance is thereby eliminated.

It would seem from the foregoing that we shall be faced with considerable non-linearity of scanning owing to the fact that we are allowing the output from the relaxation oscillator \( R_{22} C_{12} \) to be no less than 1/3 of the steady applied voltage, for it will be seen that the output has been raised to 100 V by reducing \( C_{12} \) some 20 times from the normal figure and yet the steady applied voltage of the H.T. is still only 300 V. This is not so, however, for the following reason. Non-linearity in any relaxation oscillator only arises because the charging cycle is accompanied by a progressive decrease of the current flowing into the condenser. If, however, the voltage applied across the combination were to increase appropriately during the charging process the current into the condenser would be maintained constant and the saw-toothed voltage across it would be linear with time. This method of compensation is used to prevent non-linearity in the present circuit. It will be seen that the feedback from the tertiary is applied to the condenser \( C_{14} \), which is in series with the relaxation oscillator condenser \( C_{12} \), and during the forward stroke the potential of the lower end of \( C_{14} \) is drawn down by the feed-back to the extent of nearly 95 V, the junction of \( C_{14} \) and \( C_{12} \) being about \(-95\) V negative to earth at the end of the forward stroke. In effect we have steadily raised the value of the applied H.T. during the forward stroke to a maximum value of 395 V so as to maintain an unvarying supply of current into the relaxation oscillator condenser \( C_{12} \), and this artifice is very largely effective in removing non-linearity.

The distortion factor cannot be more than 5 per cent as the grid-cathode excursion is only 5 per cent of the saw-toothed input, but even this small residuum of distortion is compensated for by means to be described later.

We have still to compensate for the effect of \( L_{R2} \) (Fig. 11), which will now be considerably greater as a result of giving \( V_F \) a low effective impedance.

The time constant \( \frac{L_{R2}}{R_{22}} \) is 1 millisecond, which is comparatively short. It will, however, introduce some non-linearity into the beginning of the forward stroke, i.e. the top of the picture, and it will slow up the return stroke. The non-linearity of the beginning of the scan will clearly manifest itself as a bunching together of the lines at the top of the picture. The effect of \( L_{R2} \), of course, is to reduce the amplitude of the upper frequencies of the scanning current flowing in the \( L_{R4} R_{22} \) branch, so that if we can include a circuit giving an upper frequency boost to the saw-toothed waveform, we shall be able to eliminate the effect. We can obviously do this by introducing elements into the feed-back circuit which will introduce an upper frequency loss into the feed-back, which will appear as an upper frequency gain in the output. The feed-back circuit already includes the condenser \( C_{14} \) so that the loss may satisfactorily be provided by including the resistance \( R_{40} \). Compensation will be exact if the time constant \( C_{14} R_{40} \) is equal to the time constant \( \frac{L_{R2}}{R_{22}} \) which is 1 millisecond. It is convenient to make \( R_{40} \) manually adjustable, and it is accordingly designated Waveform. When the correct setting of this control has been found, the bunched lines at the top of the picture will be spread out until their spacing is equal to that over the remainder of the picture.

The elements \( C_{15} \) and \( R_{31} \) are provided to compensate for the small amount of residual distortion in the frame saw-tooth which is applied to the grid of \( V_F \) and which, as was mentioned above, exists to the extent of some 5 per cent. The distortion manifests itself effectively as a loss of lower frequencies in the output waveform. Hence, an effective gain at low frequencies must be provided, which may be conveniently done by introducing a low frequency loss into the feed-back circuits, and this is the function of the elements \( C_{15} \) and \( R_{31} \). It is also found desirable to compensate for the leakage inductance in the coupling between the primary and the tertiary. This is effected by the elements \( C_{14} \) and \( R_{31} \), the technique in this case being similar to that adopted in many other parts of the system.

In addition to the above essential compensations, a refinement is added in the shape of means for extinguishing the cathode ray beam during the frame fly-back period. It may appear strange that this should be desirable because in theory the beam is already extinguished, since during the frame return period when nothing but frame and line synchronising signals are being radiated there can be no signal of greater amplitude than black. It
would appear, therefore, that we are attempting to extinguish a beam which is already non-existent. In practice, however, the monitor will rarely be set up exactly in accordance with the dictates of theory for the following reason. In Fig. 12 is given a typical curve showing the variation of brilliance of the scanning spot of a cathode ray tube against the modulating voltage applied to one or more of its grids. It will be observed that, as is usual in all thermionic devices, the curve, which ideally should be the straight line \(ABC\), has the usual bottom bend \(DB\). If the curve had the ideal shape \(ABC\), the Background control would be so set that black level corresponded to the point \(A\), the beam would be completely extinguished at black level, and the setting of the monitor would correspond exactly with theoretical considerations. Owing to the existence of the bottom bend \(DB\), the beam is not completely extinguished until adjustment of the Background control has increased the negative grid bias to that corresponding with the point \(D\). If such a setting is employed, however, the bottom bend will clearly mar the reproduction of detail in the lower greys, since these tones will be darker than they should be. Consequently the background will in general be set to correspond with the point \(B\), at which the blacks will look very dark indeed, and the modulation will occur over the part \(BC\) of the characteristic, which is reasonably linear. Individual operators will in practice choose various settings between the points \(D\) and \(B\), and at any of these settings there is, of course, a small but finite beam current which corresponds to black level.

Let us assume for the moment that no picture is being radiated but only black level and synchronising signals. During the forward stroke of the frame scanning the fluorescent screen will be showing a very faint degree of illumination owing to the fact that black level corresponds to a finite scanning beam albeit so faint as to be considered by the operator effectively to produce black in any received picture. During the frame fly-back the beam traces a zig-zag path up the screen, being impelled vertically by the voltage corresponding to the frame fly-back and horizontally due to the continuance of the line scanning. During those portions of the fly-back period corresponding to the troughs of the synchronising signals the beam intensity will be very low indeed, if not actually zero, but during the intervals between the broad pulses comprising the frame synchronising signals, the beam intensity will correspond to black level, and since this corresponds to a finite scanning beam the fluorescent screen will again be faintly illuminated. Thus during the complete cycle of the frame scan, including both the downward picture scan and upward fly-back, all the elements of the screen area will receive one traversal of the beam at black level, whilst those elements which lie in the path of the zig-zag frame return stroke in the positions corresponding to the intervals between the broad pulses will receive two traversals at black level. Remembering that owing to persistence of vision the eye will integrate the effect of repeated traversals of successive scans over the same element, it will be expected that those parts of the scanned area which in a complete cycle receive two traversals at black level will stand out more brightly than the remainder of the area which in the same period has undergone only one such traversal. We should accordingly expect to see a trace on the screen consisting of a small number of broken diagonal lines corresponding to the black level periods of the frame return stroke, while if the Background control is turned up so that the beam current has a finite value even in the troughs of the synchronising pulses, the diagonal lines will become continuous, as illustrated in Fig. 13. The portions in the fly-back trace corresponding to the 10 \(\mu\) second intervals between the broad pulses will stand out more brightly than the 40 \(\mu\) second periods of the broad pulses themselves, although this effect is not shown in Fig. 13. It will be observed that there is a total of six lines which, since the fly-back must be interlaced like the forward stroke, indicates that each fly-back is accomplished in the short time of three lines.
The Frame Scanning Circuit (Cont'd)

That is to say, since the fly-back commences during the first broad pulse and the broad pulses extend over four lines, the fly-back is completed within the period of the complete frame synchronising signal and well within the duration of the frame suppression pulse, which is the maximum allowable period.

Although in general such traces will only appear if the Background adjustment has been set at the point B of Fig. 12, or even higher, it has been considered that means should be included for suppressing them. Clearly the obvious solution is to make sure that the beam current is truly zero during the whole of the frame return time, and this is what is done in practice. To effect this we must apply a large negative pulse to one of the modulation electrodes of the tube during the frame return time. It will be seen that we need not specially generate a pulse for the purpose as a convenient one exists and is so far unused in the circuits already provided.

Referring to Fig. 15, we already know the nature of the current which is flowing in the secondary of the frame output transformer TR. It is a linear frame saw-tooth. If we examine the voltage across the secondary, which occurs as a result of such current, we find that it has the form shown in Fig. 14, and, as we would expect, it consists of a frame saw-tooth due to the passage of the scanning current through the resistive components of the circuit, upon which is superimposed an impulse component due to the rapid change of flux through the effective inductance of the transformer, generated according to the familiar relation \( E = L \frac{di}{dt} \). During the forward stroke AB of Fig. 14, the amplitude of the waveform is some 2 V, but during the return stroke, BCDE of Fig. 14, owing to the rapid collapse of the scanning current through the inductance, the amplitude of the waveform is some 20 V. If the pulse BCDE be added in the negative sense to the modulation applied to one of the modulating electrodes, it will completely extinguish the beam during the return stroke. Unfortunately, if we add the waveform of Fig. 14 to the modulation, we shall include not only the required pulse BCDE, but the additional portion AB occurring during the forward stroke, which will have the effect of imposing a frame tilt upon the received picture. We must therefore seek means of eliminating from the waveform of Fig. 14 the portion AB, while retaining the portion BCDE. This is performed by the elements \( R_{32}, R_{33}, C_{17} \) and \( C_{14} \) in Fig. 15. When the voltages corresponding to the waveform in Fig. 14 are applied to \( C_{17} \) and \( R_{32}, R_{33} \) in series, the condenser starts to charge during the time AB. Now, if the voltage during AB were constant, the current into the condenser \( C_{17} \) would gradually fall off, an effect which we know is responsible for distortion in a badly designed relaxation oscillator, but as the voltage AB is rising, it tends to offset the falling off of current into \( C_{17} \) and to maintain a constant current flowing into this condenser. The constant current flowing into \( C_{17} \) will produce a steady drop of voltage across \( R_{33}, R_{34} \) so that the voltage appearing across these resistances will be constant, and will not have the rising characteristics AB of Fig. 14. The same argument applies to the saw-tooth component CD shown in Fig. 14, and occurring during the return time. Whereas it is not important to eliminate CD, it is, as has been observed, of first importance to eliminate AB. Clearly the maintenance of a constant current flow into \( C_{17} \), and consequently the exact degree of the elimination of the saw-toothed components AB and CD from the waveform of Fig. 14 will depend upon the relative values of the condenser \( C_{17} \) and the resistances \( R_{32} + R_{33} \) but the elimination will be exact if the time constant \( C_{17}(R_{32} + R_{33}) \) is equal to the time constant of the scanning coils. The time constant of the scanning coils, for which \( L = 2 \) mH and \( R = 2 \) ohms, is 1,600 usec and the time constant \( C_{17}(R_{32} + R_{33}) \) has been given approximately the same figure, the error \( (R_{32} + R_{33} \text{ should be } 0.9 \text{ instead of } 1 \text{ megohm) being due to the necessity of using standard components and being inappreciable in practice. } \)

Owing to the fact that the extinguishing voltage need only be some 10 per cent of the amplitude of the pulse BCDE, the total resistance is divided into two parts, \( R_{33} \) and \( R_{34} \) which form a potentiometer giving at the junction the correct amplification. The pulse BCDE, known as the black-out voltage, which exists across \( R_{34} \), is applied to the grid of the receiving cathode ray tube. \( C_{18} \) removes a last trace of non-linearity. Since the normal modulation is applied to the cathode of this tube, both the control grids will normally be returned to earth, but in order to pick up the black-out voltage the grid of the emissor is returned to the top of \( R_{32} \).
The Supply Unit, Type 2a

This unit provides the L.T. and H.T. power supplies which are required by the Amplifier and Focus Unit, the Separating and Scanning Unit, and the Emscope Heater. These supplies are three in number:

1. An A.C. L.T. supply of 13 Volts, 5 Amperes for all valves except the three diodes \( V_7, V_8 \) and \( V_9 \) of the Separating and Scanning Unit.
2. An A.C. L.T. supply of 4 Volts, 2.6 Amperes for the above three diodes and the emscopec heater.
3. A D.C. H.T. supply of 300 Volts, 190 Milliamperes for the Amplifier and Focus Unit and the Separating and Scanning Unit.

The circuit of the Supply Unit is shown in Fig. 16. The mains at 230 Volts are applied to the terminals \( T_1 \) and \( T_2 \), and proceed via the switches \( AA \) to the transformer \( TR_1 \). The secondary \( S_1 \) of this transformer provides A.C. L.T. at 4 Volts for the three diodes and the emscopec heater. The secondary \( S_3 \) provides A.C. L.T. at 13 Volts for the other valves in the Amplifier and Focus Unit and in the Separating and Scanning Unit. The secondary \( S_3 \) supplies the heater of the rectifier \( V \), which will provide the 300 Volts H.T. It is desirable to allow all the valves in the monitor and the heater of the emscopec to warm up for a minute before either the 300 Volts H.T. supply for the valves or the 7,000 Volts E.H.T. supply for the emscopec gun are switched on. In order to effect this the anodes of the rectifier \( V \) are separately supplied from the transformer \( TR_2 \), and the mains input to the primary of this transformer are not taken from the mains directly but from the contactor \( G \), which is closed by the thermal delay switch \( TD \) after this has been heated for one minute from the secondary \( S_3 \) of the transformer \( TR_3 \). To apply the delay also to the 7,000 Volts E.H.T. supply which is generated in a separate unit, the mains input to this unit is also taken from the contactor \( G \) via the switches \( BB \) and the terminals \( T_3, T_4 \). The operation therefore is as follows. The switches \( AA \) and \( BB \) are closed, the transformer \( TR_3 \) is energised and the heaters of all the valves in the monitor, the emscopec heater, the heater of the valve \( V \) in the Supply Unit, and the heater of the thermal delay unit are all energised. After one minute the contacts \( K_1 \) of the thermal delay switch close, and operate the contactor \( G \) from 230 Volts A.C. derived in parallel with the primary of the transformer \( TR_2 \). The contactor \( G \) operates, and the contacts \( K_2 \) apply the mains to the primary of the transformer \( TR_2 \) to the 7,000 Volts E.H.T. unit, and to the operating coil of the contactor \( G \) so that by this last operation they short circuit the contacts \( K_1 \). If now the thermal delay switch \( TD \) were allowed to remain heated from the secondary \( S_3 \) of the transformer \( TR_1 \), it would not be ready to apply the delay again in the event of the mains becoming accidentally switched off. To assure that in such circumstances the delay would be reapplied, the contacts \( K_2 \) of the contactor \( G \) remove the secondary \( S_3 \) from the thermal coil of the thermal delay switch \( TD \), allowing it to cool. The contacts \( K_1 \) will now open, but the contactor \( G \) will remain operated, since the contacts \( K_2 \) have already short-circuited the contacts \( K_1 \). On the other hand, should the mains supply fail, the contactor \( G \) will open and will not re-close.

The switches \( AA \) and \( BB \) are provided to allow the monitor to be energised with the exception of the 7,000 Volts E.H.T., a state of affairs which will frequently be required during testing. The operation of these switches is interlocked for the following reason. If the switches \( AA \) were opened before \( BB \), then all the supplies would be withdrawn, since the switches \( AA \) would break the primary of \( TR_1 \) directly, and the contactor \( G \) would fall out and break the primary of \( TR_2 \) and the supply to the 7,000 Volts unit. The scanning would therefore collapse and the emscopec beam would fade away. The tube, however, would be liable to damage because the scanning would collapse considerably in advance of the cessation of the beam owing to the storage of the smoothing condensers of the 7,000 Volts unit. By the time the scanning had collapsed there would still be a considerable residual beam intensity directed in the form of a small spot against the centre of the emscopec screen, which would cause a photo-electric burn. It is essential therefore that the 7,000 Volts unit should be switched off before the scanning. To effect this the switches \( AA \) and \( BB \) are interlocked so that \( AA \) cannot be opened until \( BB \) has been opened. The design of the interlock further brings about the feature that when both switches are open it is impossible to close \( BB \) until \( AA \) has been closed, this feature not, however, being strictly necessary.

The output from the rectifier \( V \) is followed by a normal type of smoothing circuit involving the inductances \( L_4 \) and \( L_5 \), and the condensers \( C_1, C_2, C_3 \) and \( C_4 \). The output voltage is measured by the voltmeter \( M_1 \), and the total output fed by the milliammeter \( M_2 \).
Figure 15. The Separating and Scanning Unit
The 7,000 V Unit

A 7,000 V E.H.T. supply is, as has been explained, required for the first and second anodes of the cathode ray tube. and this is generated by a 7,000 V Unit, the circuit of which is given in Fig. 17.

Figure 17.

This is a straightforward voltage doubler rectifier, which will be self explanatory from the circuit. It is provided with an automatic shorting switch, also shown in the diagram, which operates when the cover is removed and thus prevents danger of shock.

Operation

Assuming that the apparatus has not in any way been adjusted, the full procedure for this will be as follows.

The mains connection should be plugged into the mains at 230 V 50 C[230V 50C], and the earthing terminal connected to earth. The input should be connected to the output of the Distribution Amplifier at 140 ohms, and the concentric terminating plug should be inserted in its socket. The mains having been switched on, the switches AA and BB should be closed. The valves and cathode heater will now warm up, and after a minute the thermal delay switch will close the contactor G and the scanning and beam will be established. A camera should be set up and a picture obtained on the system.

The Background and Gain controls should be set in any convenient positions which will give a picture on the screen. In all probability the picture will not be synchronised, and the Frame Frequency and Line Frequency controls should be adjusted until the picture is in synchronism. Should it be found impossible to synchronise the picture, then the control designated Sep. Bias should be rotated to a new position, and further adjustments made to the Frame and Line Frequency controls.

The Focus control should be adjusted until the lines are as sharply defined on the screen as possible.

It is likely that the scanning field will not be centrally located on the end of the tube, and the next operation is to effect this adjustment by means of the Shift control and the position of the shift coils. The Height and Width controls should now be adjusted so that the width and height of the picture are somewhat less than the dimensions of the mask, and the Waveform control should be adjusted so that the spacing of the lines at the top of the field is as even as the spacing at the bottom. The Shift control should be adjusted and the effect on the picture noted. If the shift coils are properly orientated, adjustment of the Shift control will be all that is necessary to centralise the picture. If, however, the shift coils are not properly set, then adjustment of the Shift control will clearly not move the picture back to the centre from its displaced position. In this case the monitor should be switched off and withdrawn from the cabinet, when the Shift coils may be orientated to a new position. After switching on again, a further adjustment should be made to the Shift control, and if its action is still not satisfactory the monitor must be switched off and further adjustments made to the position of the shift coils. This procedure should be repeated until operation of the Shift control will bring the scanning field exactly to the centre of the screen. The Height and Width controls may now be adjusted until the scanning field exactly fits the limits of the mask, which are designed so as to demarcate a picture having an aspect ratio of 5:4.

The next adjustment which should be fixed is that of the control designated Sep. Bias. This control should be rotated in either direction from the existing setting, and it will be observed that at certain limits in either direction the synchronising will fail. If the control is rotated too far in the anti-clockwise direction synchronising will be impossible, but if it is adjusted too far in the clockwise direction the synchronising will not be impossible, but will be unsteady and there will be distortion of the position of detail in the picture, the latter having a peculiarly jagged appearance. This is, of course, due to the fact that vision signals are now present in the scanning circuits and have not been properly eliminated by the separating valves in the Separating and Scanning Unit. The Sep. Bias control should be set approximately halfway between these two extremes, in which circumstances a good interface should be obtained. Since the ultimate criterion by which the setting of the Sep. Bias control is judged is the interlacing, this control should be further finely adjusted until the operator considers that the interlacing is the best which can be obtained.

The Line and Frame Frequency controls should now be further checked, and in each case an optimum position between two extremes can be found. The line hold is particularly firm, and there is no doubt whatever as to its setting. Care should be taken, however, with the Frame Frequency control as the final adjustment of this will affect the interlacing. The hold is quite strong, but it will be observed that towards the extremes of the
range on which synchronising is obtained interlacing will disappear and the picture will be scanned in 282 lines. This is particularly the case at the setting which tends to make the picture float downwards. Again, the final adjustment is that which gives the most even interlacing.

Now that an interlace has been secured, the Waveform and Focus controls should both be finely adjusted, the former to make the spacing between the lines at the top of the picture the same as that at the bottom, and the latter to define the lines as sharply as possible.

The final operations of adjustment are concerned with the Amp. Preset, Gain, and Background controls. The Amp. Preset control may be accurately set in the following manner. The monitor is switched on normally, but the input from the Distribution Amplifier and the concentric terminating plug are both removed. A high resistance voltmeter should be connected across either the picture input socket or the concentric terminating socket, and the Amp. Preset control adjusted until a reading of 2 is obtained. This is the most accurate method of setting this control, but should it become mis-set and it be desirable to reset it without the aid of a voltmeter, then the following method may be adopted. The Picture Monitor should be switched on and supplied normally from the Distribution Amplifier and an input of black level and sync should be obtained. The Background control should be rotated until a visible field is obtained, and the Gain control rotated backwards and forwards. If the Amp. Preset control is properly set, this operation of the Gain control should make no difference to the brightness of the field, but if the Amp. Preset control is mis-set in one direction or the other, then an increase of gain will either increase or reduce the brightness of the field. The Amp. Preset control should accordingly be adjusted until rotation of the Gain control makes no difference to the brightness of the field.

The final operation is the adjustment of the Gain and Background controls. Assuming that the monitor is being fed with normal picture, the Gain should be rotated fully anti-clockwise, and the Background control set until the scanning field is almost invisible when viewed from a normal distance. The Gain control may now be turned up until the picture is fully modulating the oscilloscope. Care should be taken to avoid an excessively contrasted picture, which may be produced on the one hand by excessive gain which will over-emphasise the white parts of the picture and in the limit lead to defocusing of the spot and blurring, and on the other hand by too low a setting of the Background, which tends to spoil the detail in the darker parts of the picture by rendering them at unnecessarily dark tones. The Background should in general be set so that the blacks are of an agreeable tone in respect of the standing illumination in the room.

Testing

The following measurements should be made periodically to ensure that the apparatus is behaving normally. For this purpose the unit may be withdrawn from its case and the switches BB closed, thus energising the Separating and Scanning Unit and the Amplifier and Focus Unit, but the switches A4 should remain open as it is both unnecessary and unsafe to energise the 7,000 V Unit with the chassis withdrawn from the case.

The Separating and Scanning Unit. The following voltage measurements should be made with a high resistance voltmeter.

<table>
<thead>
<tr>
<th>Value</th>
<th>Screen Voltage</th>
<th>Cathode Voltage</th>
<th>Value of $V_1$</th>
<th>Value of $V_2$</th>
<th>Value of $V_3$</th>
<th>Value of $V_4$</th>
<th>Value of $V_5$</th>
<th>Value of $V_6$</th>
<th>Value of $V_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25–30</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_2$</td>
<td>150</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_4$</td>
<td>250</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_5$</td>
<td>25–30</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_6$</td>
<td>130</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_7$</td>
<td>140</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For convenience in measurement, the cathodes of $V_4$ and $V_7$ are each brought out to red studs at adjacent points on the chassis. The black studs adjoining each red stud are earthed.

The Amplifier and Focus Unit. The input from the Distribution Amplifier and the concentric terminating plug should both be removed, and a high resistance voltmeter should be connected between the inner of one of the input sockets and earth, when a reading of 3.5 V should be obtained. If the reading differs from 3.5 V, adjust the Amp. Preset control until the correct reading is obtained. Having done this, the following series of voltage measurements may be made with the high resistance voltmeter to ascertain if the performance of the circuit is correct.

<table>
<thead>
<tr>
<th>Point of Measurement</th>
<th>Value of $V_1$</th>
<th>Value of $V_2$</th>
<th>Value of $V_3$</th>
<th>Value of $V_4$</th>
<th>Value of $V_5$</th>
<th>Value of $V_6$</th>
<th>Voltage across $C_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anode of $V_1$</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Cathode of $V_1$</td>
<td></td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cathode of $V_2$</td>
<td></td>
<td></td>
<td>69</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screen of $V_1$</td>
<td></td>
<td></td>
<td></td>
<td>250</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screen of $V_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage across $C_4$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

Three of the above measuring points have been brought out to studs on the side of the chassis. The upper red stud is connected to the cathode of $V_1$. The centre blue stud is connected to the top of $C_4$. The lower red stud is connected to the cathode of $V_2$.

Supply Unit. The following outputs should be obtained from the various terminals of the Supply Unit.

- Between terminals 21 ... ... ... ... 13 V A.C.
- Between terminals 22 ... ... ... ... 4 V A.C.
- Between terminal 4 and earth ... ... ... ... 300 V D.C.