TECHNICAL DESCRIPTION

MARCONI-E.M.I. SYSTEM OF TELEVISION

PART 7. THE VISION MODULATOR

CONTENTS

THE MODULATORS

The design of this apparatus is very complex as the problems to be faced are technically severe. The function of the modulator is to receive a vision input with a swing of about 15 volts and deliver to the modulated amplifier a magnified vision signal having a swing of about 2000 volts. The output power required in view of the grid dissipation of the modulated amplifier will be between 2 and 3 kW. Lastly, the greatest problem of all is that the modulator must show a linear frequency and phase characteristic between 0 and 3 mc/s. A further requirement is that apparatus must be provided by which the D.C. may finally be restored. Although the problem of maintaining a level frequency and phase characteristic does not present undue difficulty at low power, it is altogether a different matter when high power and consequently large valves and apparatus generally are required. Nevertheless in this modulator the above requirements have been satisfied.

The modulator consists fundamentally of four stages of amplification known respectively as the Line Amplifier, the Sub-Sub-Modulator, the Sub-Modulator and the Modulator. The Line Amplifier receives the input at a swing of about 15 volts and delivers it to the Sub-Sub-Modulator with a swing of about 60 volts. The Sub-Sub-Modulator raises this level to about 200 volts, the Sub-Modulator to about 600 volts and finally the Modulator delivers the required 2000 volts.

Before describing the modulator in detail it would be as well to survey the general principles involved in building amplifiers of wide band width as most of the known principles are simultaneously employed in this modulator in an effort to produce the required response.

Method 1. Inductances are placed in anode circuits in order to offset the rise in capacitative susceptance. (This method is generally known as *Robinson* correction.)

Method 2. An inductance is inserted between the anode of one stage and the grid of the next stage in order that the intervalve coupling inclusive of valve capacities may simulate a low-pass filter.

Method 3. An appropriate reactance is placed across the cathode impedance of a valve stage, thereby modifying the cathode-grid reaction and consequently the response characteristic.

Method 4. A cathode follower is connected between two amplifying stages, thereby preserving the response at the upper frequencies, because the cathode follower presents a minimum of capacity to the previous amplifying stage and at the same time presents a low impedance to face the inevitable input capacity of the succeeding amplifier stage.

The modulator consists of four stages, each of which comprises an amplifying stage followed by a cathode follower, thus making use of the fourth principle enumerated above. In addition the anode circuits of the amplifying stages are made inductive where necessary, applying *method* 1, while anode to grid couplings simulating low-pass filters, as covered in *method* 2, are also used. We shall now consider the stages in order.

THE LINE AMPLIFIER

The line amplifier consists of two stages, the first an amplifier and the second a cathode follower, each comprising two pentodes in parallel. The mixed picture and sync waveforms, both in the form of D.C. operating mutually on the opposite sides of a fixed black level datum line, are delivered from the Control Room down a line of characteristic impedance 110 ohms. This line feeds the grid of the first stage V_1 V_2, and there is also provided a connection to the transmitter waveform monitor, by means of which the waveform incoming from the Control Room line may be examined. It is arranged that the impedance presented by the complex circuit associated with the grids of V_1 and V_2, in parallel with that leading to the waveform monitor via the resistance R_1, shall have the value of 110 ohms, and so terminate the line correctly in its characteristic impedance.

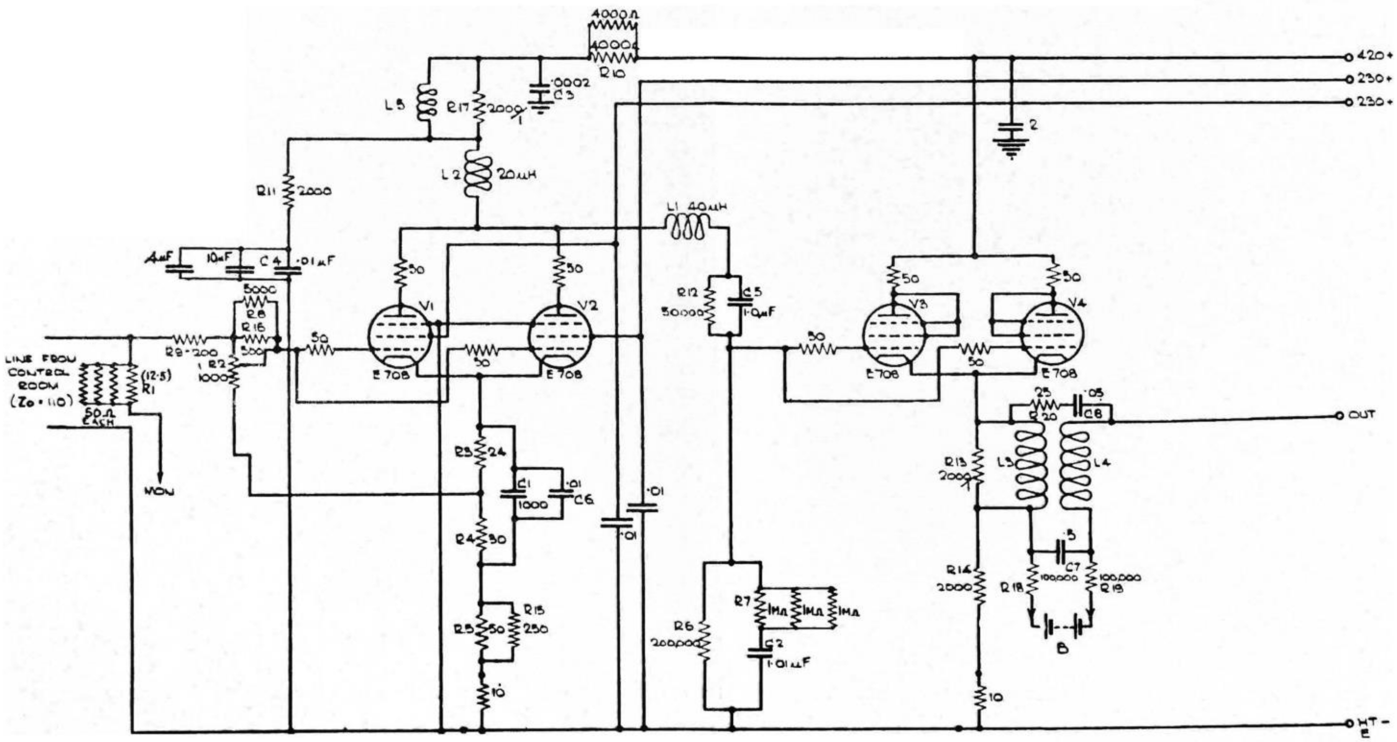
An input potentiometer R_2 is provided so that the correct level can be applied to the grids of the amplifying stage V_1 V_2. Unfortunately the D.C. input, if adjusted in amplitude straightforwardly by the potentiometer R_2, will take up various positions upon the working characteristic of the valves V_1 V_2, whereas it is required that the point on the characteristic corresponding to the black level should remain fixed, and that the potentiometer R_2 should adjust the vision and synchronising amplitudes extending from either side of the black level point without disturbing the point itself. The black level voltage, as delivered from the Control Room, is about 10 volts above earth, and it is consequently necessary to connect the lower end of the potentiometer R_2 to a point which is 10 volts positive above earth. By this means D.C. coupling and economy of valve characteristic will be obtained and the black level operating point of V_1 V_2 will not be disturbed by adjustment of the potentiometer R_2. The simplest way, of course, would be to use a battery, but this is undesirable.

It is also necessary to develop automatic grid bias for the valves V_1 V_2. Cathode resistances R_3, R_4 and R_5 are therefore provided, such that the drop of volts across R_4 and R_5 will be approximately 10, as required to offset the Control Room D.C. component. The drop across R_3 will give the correct bias required for V_1 V_2. There will now be signal feed-back from the cathode circuit of V_1 V_2 to the grid circuit, which will result in loss of gain and the large condenser C_1 is provided to shunt the signal components and reduce the feed-back. As usual, the condenser C_1, being of large capacity, possesses some inductance at high frequencies, and the additional condenser C_6 of small capacity is connected in parallel. The condensers C_1 and C_6 are not, however, connected so as to shunt the whole of the cathode impedance of the valves V_1 and V_2; they shunt only R_3 and R_4, leaving unshunted the resistances R_5 and R_{15} in parallel, and the small degree of feed-back produced by these unshunted resistances results in the characteristic of the valves V_1
187 and V_2 being rendered more straight.

Unfortunately the shunting effect of C_1 C_6 is incomplete on the lowest frequencies, and there is a consequent increase in feed-back and decrease in gain as the frequency becomes lower. This effect is corrected in the output circuit of V_1 V_2 by the elements R_6 R_7 and C_2, which raise the gain at low frequencies in the inverse proportion to the loss occasioned by C_1, C_6, R_3 and R_4. The resistances R_8 and R_{16} are fitted to improve the linearity of control of the potentiometer R_2.

Turning to the output circuit of V_1 V_2, the anode earth capacities of these valves, together with the input capacity of valves V_3 and V_4 co-operate with the inductance L_1 to form a low-pass filter as indicated above in *method* 2. This filter may clearly be terminated at either end and an attempt is made to terminate it as correctly as possible at the input end. Since the filter is a π-section, this characteristic impedance will not be constant, but will rise as the frequency increases. The inductance L_2 is therefore inserted as a half-section series-arm in order to maintain the characteristic impedance more constant, and although L_2 is not M-derived, the characteristic impedance will be satisfactory up to half the cut-off frequency. To obtain an adequate frequency response, the cut-off frequency must be so situated that a characteristic impedance no greater than 1000 ohms can be obtained. We require therefore to terminate the input end of the filter, i.e. to connect the top end of L_2 to earth with 1000 ohms. The connection will actually be made to $H.T.+$ so that the terminating resistance may serve as the anode resistance of the valves V_1 V_2. However, the operating conditions of these valves require that with the H.T. value provided the anode resistance should be 2000 ohms. Accordingly an anode resistance R_{10} of 2000 ohms is provided, but the elements R_{11} C_4 are provided so that over the greater part of the band of signal frequencies the terminating impedance consists of R_{10} and R_{11} in parallel giving 1000 ohms. As in the case of C_1, however, the circuit R_{11} C_4 fails to comply with the conditions, the impedance being greater than 2000 ohms at low frequencies, giving an excessive gain. This is corrected for by the elements R_{12} C_5, which tend to diminish the gain at low frequencies.

The resistance R_{10}, which is carrying nearly the whole of the dissipation of the anode circuit of V_1 V_2, has to be of such a size that it possesses self-capacity and appears therefore at a lower value than 2000 ohms at the upper frequencies, whereas it is essential that this value should remain constant. This is achieved by the addition of the elements L_5 and R_{17}, which co-operate with R_{10} and its self-capacity to form a constant impedance circuit. In order that the circuit will require a suitable practical value of L_5, the self capacity of R_{10} is brought up to a higher value by the addition of the small capacity C_3.


4000Ω
4000Ω
R10
420+
230+
230+
L3
R17
2000
·0002
C3
2
L2
20μH
R11
2000
L1 40μH
4μF
10μF
C4
·01μF
50
V1
50
V2
R12
50,000
C5
1·0μF
50
V3
50
V4
5000
R8
R16
500
R9·200
R2
1000
50
50
LINE FROM
CONTROL
ROOM
(Zo = 110)
(12·5)
R1
50Ω
E708
E708
50
E708
50
E708
25
R20
·05
C8
OUT
MON
R3
24
C1
1000
·01
C6
·01
·01
R13
2000
L3
L4
R4
30
·5
C7
R14
2000
R18
100,000
100,000
R19
R7
1MΩ
1MΩ
1MΩ
R6
200,000
C2
1·01μF
B
R5
50
R15
250
10
10
HT-
E

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We can now consider the circuits associated with the valves of the second stage, V_3 V_4. The anodes of V_1 and V_2 are D.C. coupled to the grids of V_3 V_4, and unless precautions are taken, the operating conditions of the grids of V_3 V_4 would be unworkable owing to the high positive voltage placed on them by direct connection to the anodes of V_1 and V_2. The coupling involves the elements C_2, C_5, R_6, R_7 and R_{12}, the frequency corrective functions of which have already been described, but in addition the elements R_{12} and R_6 form a potentiometer which reduces somewhat the standing positive voltage applied to the grids of V_3 V_4, the full A.C. component being, however, passed on by C_5. The remainder of the standing positive voltage is automatically offset by the high value of standing positive voltage also obtaining at the cathodes of the stage V_3 V_4, which is operating as a cathode follower. It would clearly be rarely necessary to provide a grid bias supply for a cathode follower following an amplifier stage.

The cathode follower stage V_3 V_4 is D.C. coupled to the Sub-Sub-Modulator, and in this case there must be provision for a grid negative supply for the first stage of the sub-sub-modulator, as this valve will have an anode resistance and it will be impossible to develop sufficient self-bias. Such a voltage, provided in this case by the battery B, is termed a *hold-off* voltage as it holds off the positive voltage across the cathode circuit of V_3 V_4 from influencing the first grid of the Sub-Sub-Modulator. The battery B, being connected to the cathodes of V_3 V_4, will have a capacity to earth across the cathode impedance, which will cause a loss of upper frequencies, in other words, the cathode load of V_3 V_4 is a circuit whose impedance decreases as the frequency increases, whereas it should be a constant impedance over the whole band. It is possible, however, to eliminate the effect of this capacity by introducing the elements R_{13} and L_3, R_{14} being regarded as a cathode resistor proper, as looking across the cathode and earth we see a circuit consisting of R_{13}, R_{14}, L_3 and the capacity to earth of the battery which have the configuration of a constant resistance circuit. We now require to take the hold-off voltage from the negative end of the battery B and yet to take the signal voltage effectively from the top end of R_{13}, i.e. the cathode. This clearly necessitates the insertion of the coil L_4 inductively coupled to L_3. The signal frequencies will then be passed out via the inductive coupling between L_3 L_4 and the hold-off voltage by direct connection at the base of L_4. In practice the upper and middle frequencies proceed via inductive coupling and the hold-off voltage plus signal components as high as about 50,000 cycles proceed via the direct connection. The coils L_3 and L_4 are termed hold-off coils.

Actually it is not considered advisable that the low frequency components up to 50,000 cycles should pass through the battery B, and so it is by-passed by the condenser C_7, and kept out of the battery by means of the resistances R_{18} and R_{19}. Thus, the final position is that the fixed hold-off voltage is applied from the negative end of the battery B, the low frequency components up to 50,000 cycles proceeding via the capacity C_7, and the components from 50,000 cycles or so to $3\frac{1}{2}$ Mc/s being transferred by the inductive coupling between L_3 and L_4.

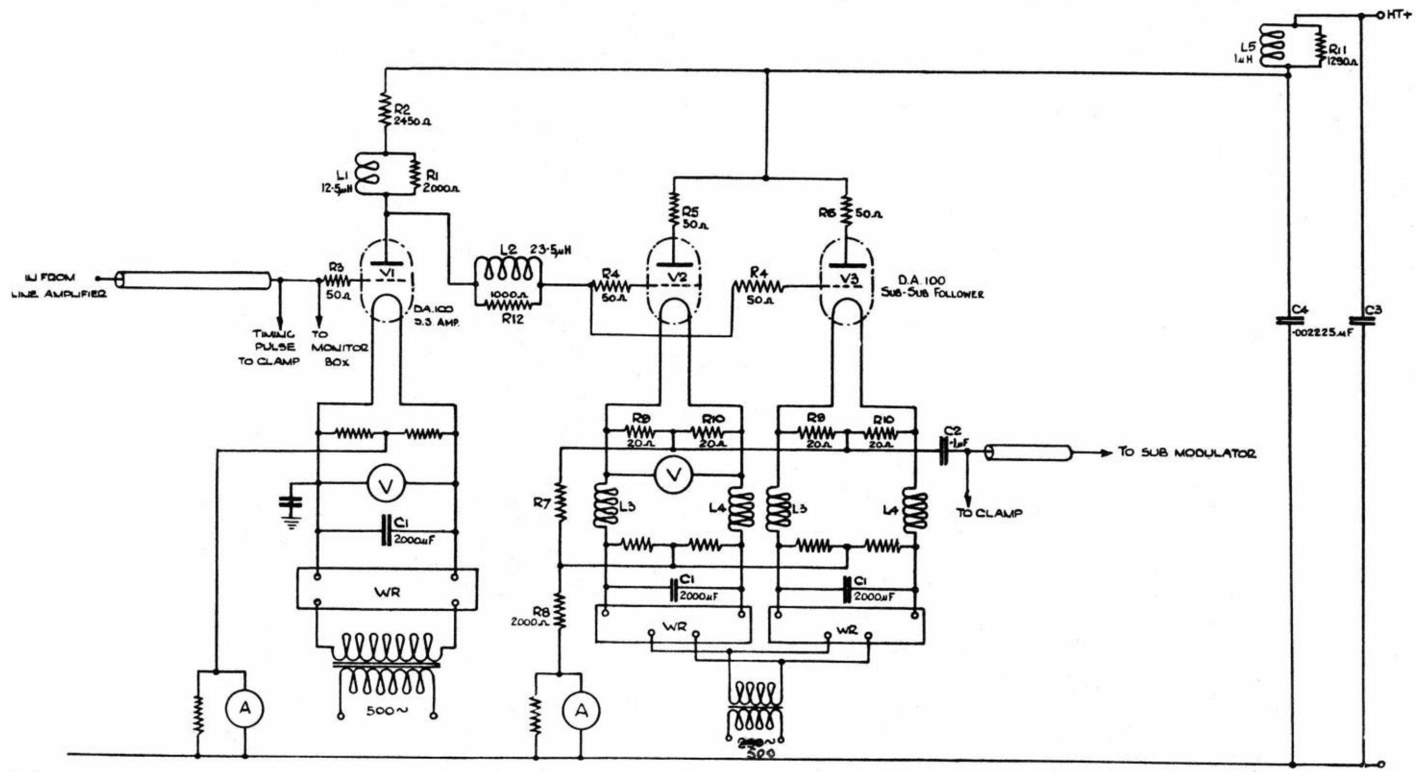
As in the case of all transformers, the coefficient of coupling between L_3 and L_4 is not unity, and in consequence there appears in series with L_4 a leakage inductance, the existence of which prevents the circuit from having a constant impedance at all frequencies. It is possible, however, to eliminate this by the addition of the elements C_8 and R_{20}, which form, in co-operation with the leakage inductance and the series resistance of L_4, a constant impedance circuit. It will be noted that the resistance R_{20} is not connected to the top of L_4, for this would not get outside, as it were, the leakage inductance. It may be found difficult to visualise the arrangement as a constant impedance circuit, because R_{20} appears to be connected back to the separate inductance L_3. The top of this inductance, however, is executing the same potentials as the top of L_4 and the connection of R_{20} to L_3 is the only one which will include the leakage inductance which it is desired to build out. This circuit is also used in the Control Room Distribution Amplifier, and is more fully described there.

The two stages of the line amplifier are fed from a single H.T. supply. It will be noted that, the valves being identical and the anode resistance of the first stage having the same value as the cathode resistance of the second, and further the second stage having no gain, the excursions of the two anode currents upon application of the signal frequencies will be equal but opposite in direction, thus giving a balanced state in which the signal components in the common H.T. supply are small.

THE SUB-SUB MODULATOR

This also consists of two stages, the first an amplifier consisting of one D.A.100 valve, and the second a cathode follower employing two D.A.100 valves. The filaments of all three valves are lit from 500 cycle A.C. rectified in the rectifiers *WR* and smoothed by the condensers C_1. The anode circuit of the amplifier valve V_1 contains the elements R_1, L_1 and R_2, which function more or less according to *method* 1 above. The amplifier is D.C. coupled to the cathode follower valves V_2 and V_3, the elements L_2 and R_2 functioning roughly according to *method* 2 above. The resistances R_3, R_4, R_5 and R_6 are for anti-parasitic purposes. The cathode circuit of the
191 valves V_2 V_3 operates on the general principle already described in the case of the cathode follower stage of the Line Amplifier except that a modification has to be made, because the valves V_2 and V_3 are directly-heated. The rectifiers and associated gear would represent a capacity across the cathode impedance of valves V_2 V_3, and this capacity must be held off.

In each valve, therefore, instead of a single inductance a pair of coupled inductances L_3 L_4 are used, through which the heater currents may be fed. From the point of view of the constant resistance circuit, however, they represent one inductance and, together with the resistances R_7 and R_8 and the capacity of the rectifiers, form a constant resistance circuit.



No hold-off voltage is required for the sub-modulator, and the output is therefore taken from the centre point of the resistances R_9 R_{10}. No hold-off voltage is required because there is placed between the sub-sub-modulator and the sub-modulator a final D.C. restoration circuit, which itself provides the necessary bias for the first stage of the sub-modulator, the positive cathode voltage of the sub-sub-modulator final stage being held off by the condenser C_2.

No reference will be made at this juncture to the final D.C. restoring circuit known as a clamp, which is connected to the end of the Sub-Sub-Modulator. This will be described later.

The high tension arrangements of the Sub-Sub-Modulator are interesting. It will be observed that the stages are balanced, and in general there will be little residual signal current in the common supply. Nevertheless it has been deemed advisable to build out the high tension supply circuits to a constant resistance in order that there shall be no resonances which would feed back from V_2 V_3 to V_1 excessive voltages at one particular frequency. This will be largely dealt with in later descriptions of H.T. supply apparatus, but it must be mentioned now in order to explain the function of the elements L_5, R_{11} and C_3. The high tension supply represents, looking back into it, a constant resistance over the working range, but is shunted by the capacity of the high tension positive lead, so that it ceases to represent a constant resistance. This is corrected by the elements L_5 R_{11}, the condenser C_3 being inserted to build up the capacity to be corrected to a convenient value.

The function of the capacity C_4 is of special interest. In view of the fact that the constant resistance cathode circuit of the valves V_2 V_3 feeds the Sub-Modulator input, the latter throws a capacity across this cathode impedance, with the result that the cathode following action of V_2 and V_3 at high frequencies is disturbed, the cathode grid feed-back is reduced, the stage takes more current than it should do, and the balance of the anode circuit which, as has been mentioned, is sought after is disturbed. Although the anode supply circuits have built up a constant resistance so that no frequency discrimination will be incurred in any out of balance currents occurring in the anode circuit, it is not desirable that such currents should be allowed to be there, as they will give rise to back voltages which will create amplitude distortion, and accordingly the impedance of the anode circuit is made low at the high frequencies at which such out of balance is liable to occur by the insertion of the capacity C_4.

THE SUB-MODULATOR

This consists of two stages, the first an amplifier consisting of one D.E.M.3 valve and the second a cathode follower employing two D.E.M.3 valves. It will be remembered that between the output of the Sub-Sub-Modulator and the input of the Sub-Modulator, D.C. has been finally restored in the combined vision and synchronising signal, and in addition appropriate grid bias has been provided for the first stage of the Sub-Modulator. The D.C. signal and grid bias are therefore applied to the grid of the valve V_1, the filament of which is lit directly from the 500 cycle A.C. supply via the Westinghouse rectifier WR, the filament current being smoothed by the condenser C_1. The filament centre point is found by the resistances R_1 and R_2 The anode is fitted an anti-parasitic resistance R_4.

It is desired that the anode circuit of this stage should consist of an inductance in series with a resistance so as to provide correction according to *method* 1. It was found that a resistance of the size and type necessary for the power to be used had considerable self-capacity and also capacity to its screen, and did not therefore appear to be a pure resistance at all frequencies. It was found necessary to correct this state of affairs by two operations. First the self-capacity of the resistance (R_5 in the diagram) is swamped by the connection of the capacity C_2, and these two elements C_2 R_5 are now built out to constant resistance by means of the elements L_2 R_6. R_5 is, of course, equal to R_6 and the anode circuit of V_1 therefore consists of the inductance L_1 in series with a pure resistance equal to R_5 or R_6, formed by the elements R_5, R_6, L_2, C_2.

The anode circuit of V_1 is direct coupled to the grid circuit of the valves V_2 V_3 by the elements L_3 R_7 which provide correction according to *method* 2. R_8 R_9 and R_{10} are anti-parasitic resistances. The cathode impedance of the valve V_2 V_3 is, as before, such as to render their grids negative with respect to their filaments by the desired amount of grid bias. The filaments of V_2 and V_3 are lit from raw A.C. at 50 cycles, this special method of heating having been found to be most effective in reducing hum. The filament heating transformer throws a capacity across the cathode impedance which would, as usual, upset the cathode following action at high frequencies, and this capacity must be held off by the creation of a constant resistance circuit. The action of the circuit provided in this case will be more readily understood if the circuits provided in the cases of the Line Amplifier and the Sub-Sub-Modulator have been mastered as it is a combination of the two.

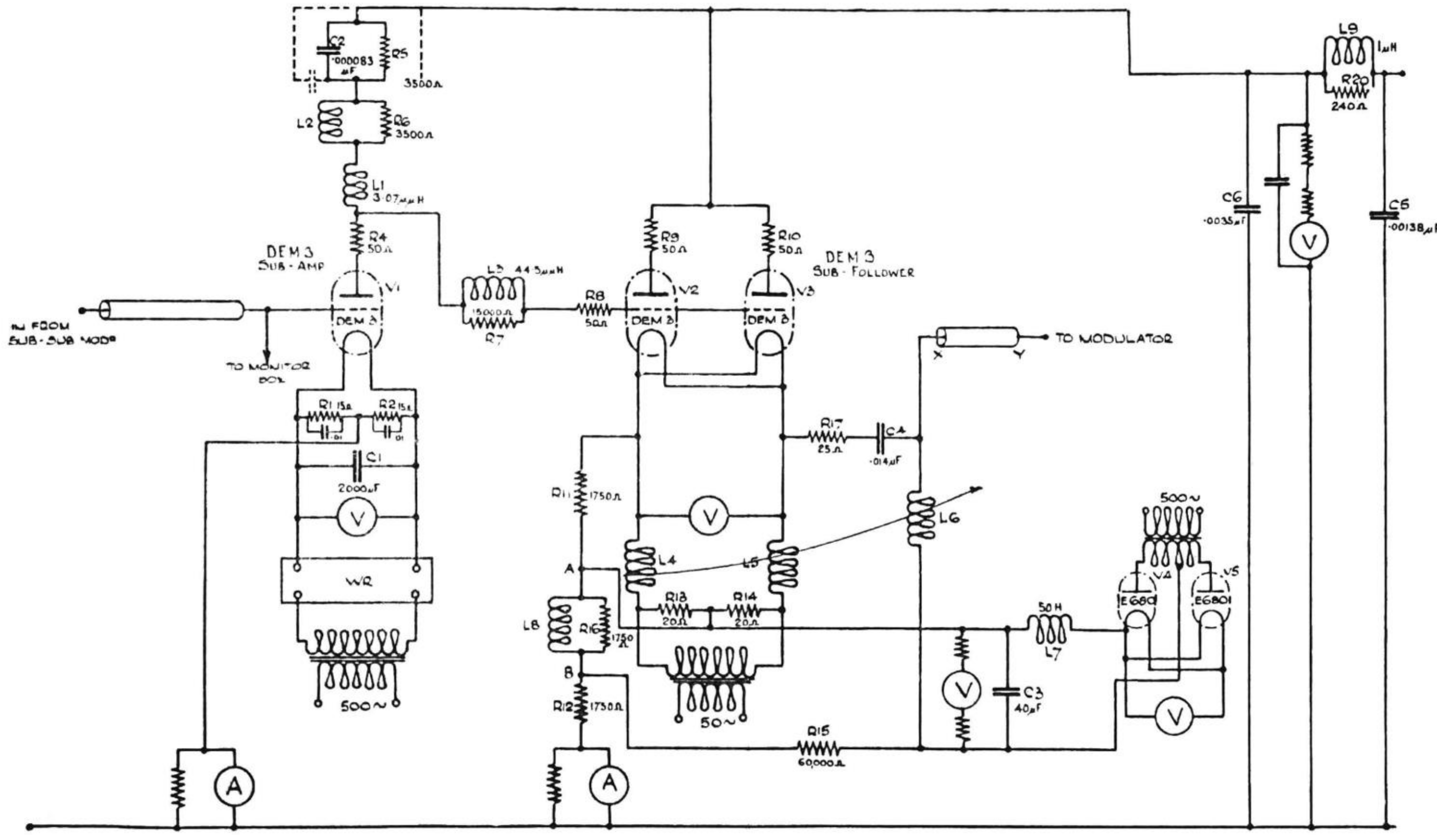
Instead of one cathode resistance there are provided as usual two resistances R_{11} and R_{12} of equal value in series. The centre point of the transformer is consequently found by the resistances R_{13} and R_{14} and is connected to the junction of R_{11} and R_{12}, thereby placing the capacity to earth of the filament heating transformer across R_{12}. There must therefore be placed across R_{11} an appropriate value of inductance. This inductance is provided by three individual inductances L_4, L_5 and L_6, which are tightly coupled and constitute one inductance across R_{11}. The inductances L_4 and L_5 are provided so that a path may be allowed for the filament current, as in the case of the Sub-Sub-Modulator, and as in the case of the Line Amplifier it is necessary to provide a hold-off voltage for the first stage of the Modulator as this will be a triode, and it will be impossible to provide sufficient automatic grid bias. The hold-off generator will have a capacity to earth, and it is therefore undesirable to place it in series between the top end of the cathode impedance of the valve V_2 V_3 and the grid of the first stage of the Modulator, as if we did so this capacity would spoil the constant resistance circuit which we have created for the cathode impedance of V_2 V_3. It must therefore be connected between the junction of R_{11} and R_{12} and the grid of the first stage of the Modulator, so that its capacity to earth will now augment that due to the filament heating transformer and may be cancelled by choosing appropriate values for the constant resistance elements. We require, however, that the vision frequenciès which must also be applied to the grid of the first stage of the modulator should be taken from the top of the constant impedance circuit. This is effected by transferring them by magnetic coupling provided by the inductance L_6. As before, the high and middle frequencies are passed across by magnetic coupling and the lower frequencies and the hold-off voltage by direct connection from the junction of R_{11} and R_{12}.

The hold-off generator is a rectifier incorporating two E.680 valves, V_4 and V_5, the output of which is smoothed by L_7 and C_3, and appears across the load resistance R_{15}.

It was found in practice that the capacity to earth from the point A, which had to be cancelled by the constant resistance circuit, was somewhat high, and as a preliminary measure it was reduced by cancelling all capacity existing from the point B across R_{12} to earth, by means of the elements L_8 and R_{16}.

The coupling between the inductances L_4 and L_5 and the inductance L_6 is not perfect, and there therefore appears in series with L_6 a leakage inductance, which has the effect of reducing the output at high frequencies. This is corrected by the elements R_{17} C_4, which give an increased output at high frequencies. In fact the leakage inductance and the series resistance found in series with it, together with the elements R_{17} and C_4, form another constant resistance circuit. It might be thought that resistances R_{11} and R_{17} should be returned to the centre point of the filament circuit instead of to either leg. The method of connection adopted however is simpler and is found

Circuit Diagram attached



in practice to result in negligible induction from the filament heating supply into the output. Admittedly half the secondary voltage of the filament transformer is applied across L_4 and R_{11} in series, but the current is very small and since L_4 is an air-cored inductance the flux in it is insignificant. Further the amplitude of the vision output at this point is fairly high, of the order of 600 volts. The output finally proceeds via the screened lead XY to the Modulator.

The anode supply circuit very much resembles that of the Sub-Sub-Modulator. The capacity to earth of the positive H.T. lead, which would upset the constant resistance nature of the smoothing circuits, is written off with the elements L_9 R_{20}, having been raised to a convenient value by the capacity C_5. Lastly, the capacity C_6 is provided as before to lower the impedance of the anode supply circuit at the high frequencies at which there will be an out of balance condition, due to the disturbance of the cathode following action of the valves V_2 V_3 by the input capacity of the Modulator acting across the cathode impedance of V_2 V_3.

THE MODULATOR

As has been mentioned, the swing applied to the Modulator is of the order of 600 volts and the output is about 2000 volts, so that the powers are sufficient to call for the use of water-cooled valves. Accordingly the Modulator consists of two stages in which, as before, the first operates as a triode amplifier employing a C.A.M. 3 valve (V_1), and the second operates as a cathode follower and employs a C.A.T.6 valve (V_2).

The grid of V_1 receives by direct coupling the D.C. vision and synchronising signal, together with appropriate hold-off voltage from the output of the Sub-Modulator. Its filament is lit from a filament generator, the centre being found by the resistances R_1 R_2. Having read the description of the Sub-Modulator, the function of the elements in the anode circuit of V_1 will be clear. However, recapitulating, the anode resistance R_3 has capacity to earth, or in practice owing to the action of the screening, to the H.T. supply. This is, as before, swamped by the capacity C_1 and built-out to constant resistance by means of the elements R_4 L_1. The element L_2 in series with a constant resistance formed by the elements, L_1, C_1, R_3 and R_4 gives the correction according to *method* 1. The anode circuit of V_1 is coupled by direct connection to the grid circuit of V_2, the element L_3 giving correction according to *method* 2. The resistance R_5 is anti-parasitic. As usual the correct grid potential for the grid of V_2 is obtained by automatic grid bias from the cathode impedance of V_2.

The cathode circuit of V_2 is very complicated owing to the large number of simultaneously occurring effects which have to be corrected. *Firstly*, the filament heating supply must be above earth potential by the drop of volts across the cathode impedance and an insulated filament generator is accordingly employed. The capacity of this to earth across the cathode impedance must be cancelled. *Secondly*, we must provide a hold-off voltage in order to hold off the positive voltage appearing across the cathode impedance of V_2 from affecting the grids of the Modulated Amplifier to which the output of V_2 will be applied, as these grids cannot well be given adequate automatic grid bias. *Thirdly*, a new problem, peculiar to this stage only, arises in that the internal impedance of the hold-off generator must be low, as considerable grid current will be drawn by the input circuits of the Modulated Amplifier. This will vary with the potential of the vision input, and amplitude distortion would be created if the hold-off voltage varied as would be the case if it had a high internal impedance, i.e. a bad regulation. This problem, of course, is not new, being well known in sound transmitters, but it is more acute in this case owing to the D.C. working employed. *Fourthly*, the corrected elements employed have now become so large in some cases that they do not behave as they are designed to behave and themselves have to be corrected. Bearing these four considerations in mind it is easy to see the reason for the complexity of this circuit.

The hold-off voltage is generated by a rectifier employing two M.R.7.A. valves, V_3 and V_4. The voltage is smoothed by the elements L_4 and C_2 and given a constant resistance by the elements C_3, R_6, L_5 and R_7. The hold-off voltage is now applied to a pair of stabiliser valves V_5 and V_6, a pair of D.E.T.3s, which behave as cathode followers acting under D.C. conditions. A cathode follower will behave as such at any frequency including zero frequency which is D.C., and just as it is used in many cases elsewhere to provide low output impedances for vision signals, it is here used to provide low output impedance for the hold-off source. The output from the stabiliser, of course, constitutes a high value of automatic grid bias for itself, which must be offset by an appropriate positive grid voltage of fixed value. This is generated in the separate rectifier V_7 employing an M.R.1 valve, and is applied to the grids of V_5 and V_6.

The stabilised hold-off voltage therefore now appears across the load resistance R_8, but the effective impedance looking towards this after stabilisation is 200 ohms.

The hold-off apparatus as a whole has a capacity to earth which must be cancelled. If we were to proceed to do this in the same way as has been done in previous stages, we would apply the hold-off voltage between the output and the point E in the diagram, so that its capacity would augment that due to the insulated filament generator. In this case, however, due to the magnitude of the apparatus the capacity so produced would give unmanageable circuit values. It is therefore necessary to make arrangements to cancel the capacity of the hold-off apparatus as a separate matter and not to lump it in with that due to the insulated filament generator.

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In order to understand how this is done, it is necessary to digress, and to consider a constant resistance circuit of the type shown in Fig. 1. Here, if $R_a = R_b = R$, then the circuit will behave as a constant resistance if $L_a/C_a = R^2$. Clearly, the action of the circuit will not be upset if we remove the resistance R_b which, being an ohmic resistance, is a constant resistance

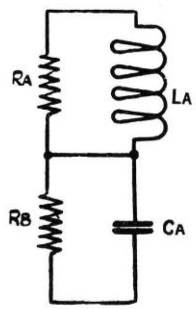


Figure 1

For Constant Resistance

$$\frac{L_A}{C_A} = R_A{}^2 = R_B{}^2$$

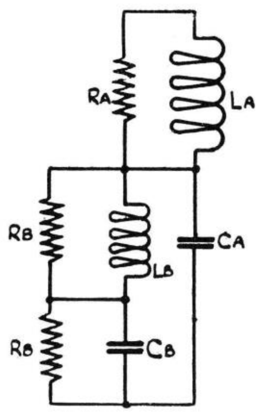


Figure 2

For Constant Resistance

$$\frac{L_A}{C_A} = \frac{L_B}{C_B} = R_A{}^2 = R_B{}^2$$

and substitute for it another constant resistance circuit, as shown in Fig. 2, such that $L_b/C_b = R_b{}^2 =$, of course, R^2. The circuit of Fig. 2 is in fact the theoretical diagram of the cathode circuit of the valve V_2, and the following equivalences hold. C_b is the capacity to earth of the hold-off apparatus and L_b is the hold-off coil which cancels this capacity so that it does not augment the capacity to earth of the insulated filament generator. C_a represents this latter capacity and L_a is the hold-off coil which cancels this capacity. The constant resistance of the whole circuit will, of course, have the value R.

Returning to the modulator circuit diagram, R_9, R_{10} and R_{11} are the three resistances called for by the double constant resistance circuit which has been described and illustrated in Fig. 2. The capacity to earth of the hold-off apparatus exists to earth rather vaguely from the points A and B, and it is desirable that it should be located at B. This is effected by the condenser C_4. But the connection of C_4, in parallel with the constant impedance hold-off apparatus connected across AB, causes the hold-off source no longer to present a constant impedance. The elements L_6 and R_{12} have therefore been added to restore the constant impedance condition which will now obtain across the points CD. It must be remembered that we are dealing with two constant inpedances simultaneously; that of the cathode circuit as a whole, seen between the filament of V_2 and earth, which should be 1000 ohms over the working range, and also that of the hold-off source, seen across such pairs of points as AB, CD, EF and GH, which should not exceed 200 ohms over the working range. The lower constant resistance circuit, which cancels the hold-off source capacity, is now completed by the inductances L_7 and L_8, which are tightly coupled. As before, the hold-off voltage and lower frequencies pass to the output by direct connection from the point A, and the upper frequencies are transferred by magnetic coupling between L_7 and L_8.

Unfortunately it was found that at the higher frequencies the inductances L_7 and L_8 did not behave as pure lumped inductances. These inductances possess considerable self-capacity between each turn and also leakage inductance, so that at the higher frequencies their lumped inductance is entirely swamped and they behave in fact like a short line having a characteristic impedance of 700 ohms. At one particular frequency in the middle of the upper band the inductances appear like a quarter wave line of this characteristic impedance, which is, of course, incorrectly terminated at the lower end, i.e. across the points CD, by the hold-off impedance of 200 ohms. At this frequency therefore a high impedance is thrown up to the points EF, while at frequencies on either side of it the impedance thrown up also contains reactance. In other words the behaviour of the inductances L_7 and L_8 as a short line entirely upsets the impedance of the hold-off source as viewed from the points EF. This effect cannot be eliminated so it has to be accommodated, the first step being to terminate the short line correctly instead of incorrectly at the lower end. It will be clear that it is necessary to raise the impedance at the points CD to 700 ohms at the higher frequencies, while leaving it at 200 ohms at the lower frequencies. This is done by the inclusion of the elements R_{13} and L_9, which, although looking like a typical pair of elements introduced to create a constant impedance, have nothing to do with the creation of a constant impedance, but form a terminating section. It will be seen that L_9 short circuits R_{13} at the lower frequencies, so that the impedance presented to the lower end of L_7 L_8 is 200 ohms, but at the upper frequencies L_9 presents a high impedance and R_{13} is now added in series with the 200 ohms impedance, placing 700 ohms across L_7 L_8. The position is now that we have successfully held off the capacity of the hold-off apparatus, but in doing so have made its internal impedance vary from 200 ohms at low frequencies to 700 ohms at high frequencies, as measured across the points *EF*. This impedance is once more corrected to look like 200 ohms at all frequencies by the connection of a condenser in series with the resistance across the points *EF*. Further reference will be made to this correction later.

We can now proceed to consider the upper constant resistance circuit, whose function is to cancel the capacity of the insulated filament generator. For this purpose, to allow for the supply of filament current to the valve V_2 the inductances L_{10} and L_{11} are connected, as in previous stages, and the third inductance L_{12} is fitted so as to allow the output to be taken off at high frequencies by magnetic transference between L_{10}, L_{11} and L_{12}.

It was again found that the circuit involving L_{10}, L_{11} and L_{12} behaved as a line at the upper frequencies, this time having a characteristic impedance of 155 ohms. This line is therefore incorrectly terminated at the lower end by the impedance of 200 ohms presented to it across the points *EF*, and, as before, very widely varying and complex impedances are presented at the points *GH*. It was therefore similarly necessary to terminate correctly the inadvertently created line. The impedance required for this purpose is one which is 155 ohms at high frequencies, rising to 200 ohms at low frequencies. To this end the impedance of 200 ohms at *EF* is reduced to 155 at high frequencies by means of a resistance and condenser. At *EF*, therefore, two capacity resistance groups are required, viz. a 4 element network. There are, of course, numerous equivalent 4-element networks, all possessing the same characteristics, and in order to obtain convenient values an equivalent was chosen having the constitution shown in the diagram and incorporating C_5, C_6, R_{14} and R_{15}.

The impedance is now correctly matched, and viewed downwards from the points *G* and *H* is 200 ohms at low frequencies and 155 ohms at high frequencies. A final correction must therefore be applied to raise the impedance at high frequencies by 45 ohms so that the impedance will be uniform over the working range at 200 ohms. This is done by the elements R_{16} and L_{13}, which, as can be seen at a glance, look like 45 ohms at high frequencies when the impedance of L_{13} is very big, and appear to be zero at low frequencies when R_{16} is short-circuited by L_{13}. At last looking down from *GH*, the impedance of the hold-off source is 200 ohms at working frequencies. The cathode impedance of V_2 is 1000 ohms over the working frequencies. At *H* we have the vision and synchronising signals with D.C. restored, together with the appropriate hold-off voltage, and the point *H* may therefore be connected to the grids of the modulated amplifier.

We have yet one final correction to perform arising from the fact that the modulated amplifier grids present a capacity across the cathode impedance of V_2. Inclusion of the capacity C_7 gives the circuit the constitution of a capacity resistance potentiometer, and corrects for this factor.

The high tension supply circuit is treated as in previous stages. The elements L_{14} and R_{17} restore to constant resistance the high tension smoothing circuits which have been disturbed by the capacity to earth of the high tension positive lead, and lastly the elements C_8, C_9 and R_{18} are provided as before to lower the impedance of the anode supply circuit at the high frequencies, at which there will be an out of balance condition due to the disturbance of the cathode following action of the valve V_2 by the input capacity of the modulated amplifier acting across the cathode impedance of V_2.

It should be noted that the cathode impedance of 1000 ohms referred to in the above description is the deliberate load placed in the cathode circuit in order that the valve may behave like a cathode follower. The impedance presented at the output, owing to this cathode following action, is much lower, and is 100 ohms. The resultant impedance shown, i.e. 100 in parallel with 1000, is some 90 ohms, and in series with this is added the impedance of the hold-off source which at low frequencies is 200 ohms, but at the high frequencies being largely short-circuited by C_7 is zero. Therefore the impedance finally presented to the grid circuit of the modulated amplifier is about 290 ohms at low frequencies and 90 at high frequencies. This is an excellent result, and ensures good performance of the set in transmitting the brighter parts of the picture in their correct tonal relationship to the darker parts.

Figure 3 Circuit Diagram attached

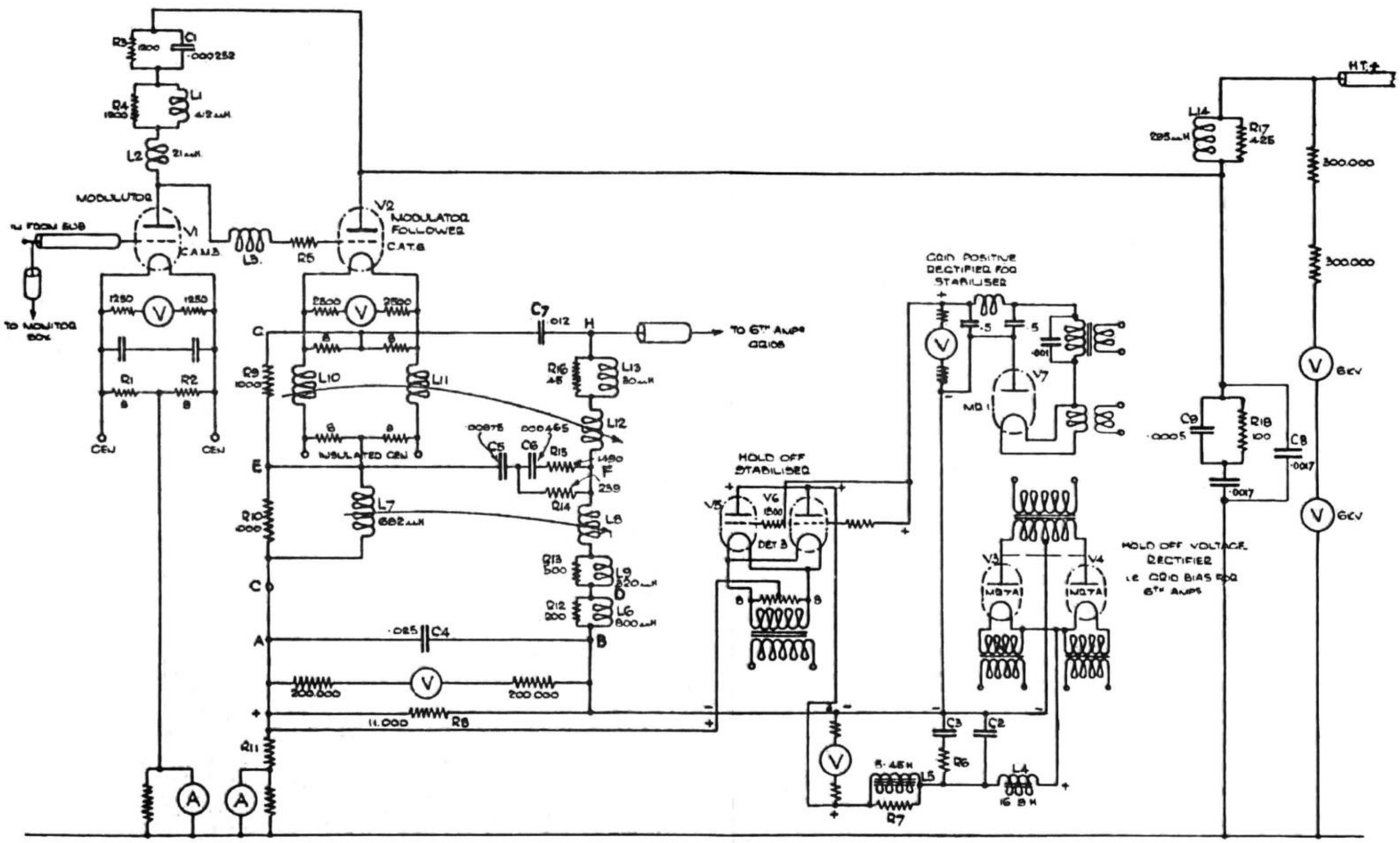


Figure 3. Circuit Diagram

THE BLACK LEVEL PULSE GENERATOR

In my technical note on the Restoration of D.C. (which it is essential should be read and understood before reading this note) it is pointed out (Item 1.2, page 5) that there are imperfections in the simpler method of D.C. restoration as used in the Control Room apparatus, and that although the signal arriving at the transmitter has D.C. restored, it is considered advisable to lose the D.C. and immediately restore it in a more perfect manner. This loss and restoration occurs at the input grid of the Sub-Modulator, and after this point D.C. is not lost again, there being D.C. coupling to the grids of the Modulated Amplifier. This final restoration of D.C. is performed by a unit known as the Black Level Clamp, the essential theoretical circuit of which is given, Item 1.2, Fig. 20, and which requires for its operation a series of pulses at line frequency, as illustrated in Item 1.2, Fig. 21. It is the function of the Black Level Pulse Generator to provide these pulses. They are required to be square-topped pulses at line frequency of some 4 micro-seconds duration.

The straightforward manner of doing this would be to employ a multi-vibrator followed by suitable shaping circuits to generate the required pulses, the multivibrator being timed from the synchronising signals. This has not been done, however, mainly because the time taken to perform the above operations would result in the finished pulse arriving at the clamp unit too late. Accordingly the pulse generator generates the pulses by taking the synchronising signals, separating them from the associated vision signals, and so manipulating the separated sync signals that they are converted without undue delay into pulses of the required shape. Accordingly, the first step is to provide the pulse generator with sync signals free from admixed vision signals.

Considering the circuit diagram, the grid of the valve V_1 is supplied with mixed picture and sync signals so arranged that the vision components are acting in the negative direction below the black level datum line and the synchronising components in the positive direction. Since the grid of the Sub-Sub-Modulator is a point where signals acting in these senses can be found, the input to V_1 is taken from this point. It must be noted that the signals so supplied already have D.C. restored. This was done in the Control Room with reference to black level and it has not been lost in the Line Amplifier.

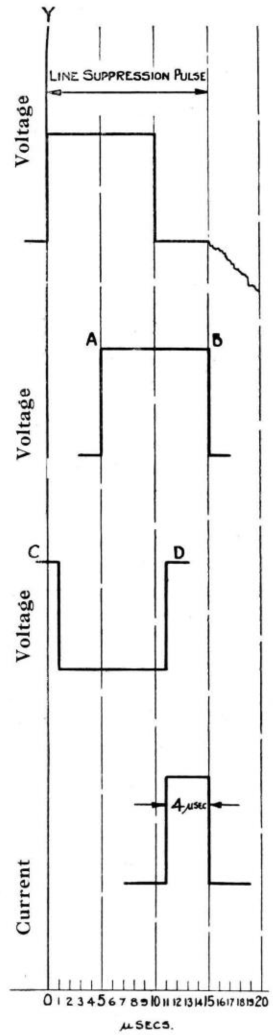
The grid of V_1 is provided with the condenser C_1, which immediately loses the D.C. component of the incoming signals. The grid resistance R_1 is, however, returned to the cathode and so V_1 has no grid bias. V_1, C_1 and R_1 therefore form a circuit in which D.C. is restored to the input signals about a datum line coinciding with the peaks of the synchronising signals. In other words, the grid circuit of V_1 causes a loss of the D.C. which was restored in the Control Room but immediately restores it, but with reference to a new datum line. The only object of this is to ensure that the input signals always act upon the same part of the grid characteristic of V_1. The characteristic of V_1 is arranged to be short in length and the applied amplitude is such that the valve is seriously overloaded. The vision components are thus lost around the bottom bend of the characteristic so that in the anode and cathode circuit of V_1 there appear pure sync signals.

The cathode circuit of V_1 contains the resistance R_0 of 2,500 ohms. There is vigorous feed-back to the grid, and the valve behaves as a cathode follower. Its cathode circuit therefore has a very low impedance, and feeds the filter composed of the inductances L_1, L_2. . . . . L_{10} and C_2, C_3 . . . . . C_{12} inclusive. This filter has an iterative impedance of 2,500 ohms, and is properly terminated in this iterative impedance by the termination resistance R_2. The filter is designed to pass all the component frequencies of the sync pulse and not in fact to act as a filter but as a delay network. It must not impose any phase distortion on the sync pulses and its phase characteristic must be linear up to the highest frequency which it is worth while to reproduce to form a sync pulse. The sync pulse would be well reproduced if 30 harmonics of its fundamental frequency were taken, and the fundamental frequency being 10,125 it is desirable that the filter should exercise no phase distortion up to a frequency of about 300,000 c.p.s. From the well known properties of low-pass filters, the cut-off frequency must not be less than about double this figure, and the filter in this circuit has a cut-off frequency of 640,000 c.p.s. The filter is composed of 10 sections, each of which imposes a delay of half a micro-second on the sync pulse, which at the terminals of R_2 therefore has a total delay of 5 micro-seconds.

An output is also taken from the anode circuit of V_1, the load resistance consisting of the iterative impedance of the filter formed by the elements L_{11}, L_{12}, C_{13}, C_{14} and C_{15}. This impedance is, as before, 2,500 ohms and the filter is properly terminated by the resistance R_3 of 2,500 ohms. The filter has two sections, each of which gives a delay of half a micro-second, and at the terminals of R_3 a total delay of 1 micro-second has been imposed. The sync pulses across R_2 are therefore 4 micro-seconds late with respect to those across R_3. The relative placing in time of these pulses is shown in Fig. 1 attached. Note that the pulse across R_3 is reversed by the normal valve action of V_1.

The pulse across R_2 is applied to the first grid of V_2, which is a triode hexode, via the condenser C_{16}. The grid resistance R_4 is connected to the cathode. D.C. restoration therefore occurs with reference to the datum line situated at AB in Fig. 1. This pulse therefore operates so as to make the first grid of V_2 positive. The pulse across R_3 is applied to the third grid of V_2 via the condenser C_{17}. The grid resistance R_5 is connected directly to the cathode so that as far as the circuit is concerned the conditions are set for D.C. restoration. Unfortunately, however, the third grid, being isolated from the cathode by the first and second grids cannot draw grid current for the purposes of D.C. restoration, and to enable the latter to take place the third grid is connected to the small subsidiary anode and grid forming the triode section of the triode hexode V_2. The use of these subsidiary electrodes in this manner, to form collectively a grid adjacent to the cathode, enables grid current to be drawn as if the third grid were situated adjacent to the cathode, and D.C. restoration is accordingly effected about a datum line shown in Fig. 1 at CD. The potentials of the various electrodes of V_2 are so arranged that anode current can be drawn if the first and third grids are both at zero potential, but that no anode current can be drawn if either or both of these grids are negative by the amount of amplitude of the applied pulses. The datum line AB corresponds to zero potential upon the first grid, and the datum line CD to zero potential on the third grid. During the time of a line therefore the first grid is negative as the long lower part of the sync pulse of Fig. 1b is applied to it and no anode current can be drawn, notwithstanding the fact that during most of this same time the potential of the third grid is zero.

We shall now consider in detail what happens after the time commenced by the line OY in Fig. 1, which is the time of the commencing of the sync signal as applied to the grid of V_1. For the first micro-second afterwards still no anode current can be drawn, owing to the continued action of the pulse of Fig. 1b. At this time the pulse of Fig. 1c appears on the third grid in a negative direction, and makes it even more impossible for anode current to be drawn. 5 micro-seconds after OY the pulse of Fig. 1b drives the first grid to zero potential, but owing to the previously applied pulse of Fig. 1c on the third grid, even now no anode current can be drawn. 11 micro-seconds after OY the pulse of Fig. 1c ceases and the third grid returns to



(a) **Original Sync Pulse at Grid of V_1**

(b) **Sync Pulse across R_2 applied to First Grid V_2**

(c) **Sync Pulse across R_3 applied to Third Grid of V_2**

(d) **Pulse in Anode Circuit of V_2**

Figure 1

zero potential. The first grid, owing to the continued action of the pulse of Fig. 1b, is still at zero potential, and this is the position for the drawing of anode current, which starts as indicated in Fig. 1d. It goes on until 15 micro-seconds after OY, when the pulse of Fig. 1b retreats from the first grid, leaving it strongly negative, and anode current ceases as indicated in Fig. 1d. Anode current is drawn for the time between 11 and 15 micro-seconds after OY, and therefore consists of a pulse 4 micro-seconds wide, and occurring 1 micro-second after the termination of the radiated line sync pulse indicated in Fig. 1a. The line suppression period extends 15 micro-seconds from OY, and the anode pulse of V_2 therefore occupies the last 4 micro-seconds of the line suppression pulse, and it is during this period that the final D.C. restoration is effected at the grids of the Sub-Modulator.

The anode circuit of V_2 contains the resistance R_6, and the 4 micro-second pulse is applied to V_3 and V_4, which are a pair of parallel-connected valves forming a stage of amplication. The elements R_7 and L_{13} are connected to correct the frequency characteristic of the amplifying stage involving V_2 by means of *Method* 1, and accordingly to preserve the upper harmonics of the pulses. No grid bias is applied to the valves V_3 V_4, as, owing to the presence of the condenser C_{18} and the grid resistance R_8 connected to the cathode, D.C. is restored to the pulses and no grid bias is consequently necessary. The pulse at the anode of V_2 is, of course, negative in sense and in the anode circuit of V_3 V_4 it is positive in sense, as is required by the black level clamp, and the output is consequently taken from the anode circuit of V_3 V_4. This anode circuit must contain the high wattage resistance R_9, which has appreciable self-capacity. This would mar the shape of the pulse, and, as is the usual practice, is eliminated by building it out to constant impedance by means of the additional elements R_{10}, L_{14}, the original self-capacity being augmented to a convenient value by means of the condenser C_{19}. The inductance L_{15} holds off the capacity of the output line.

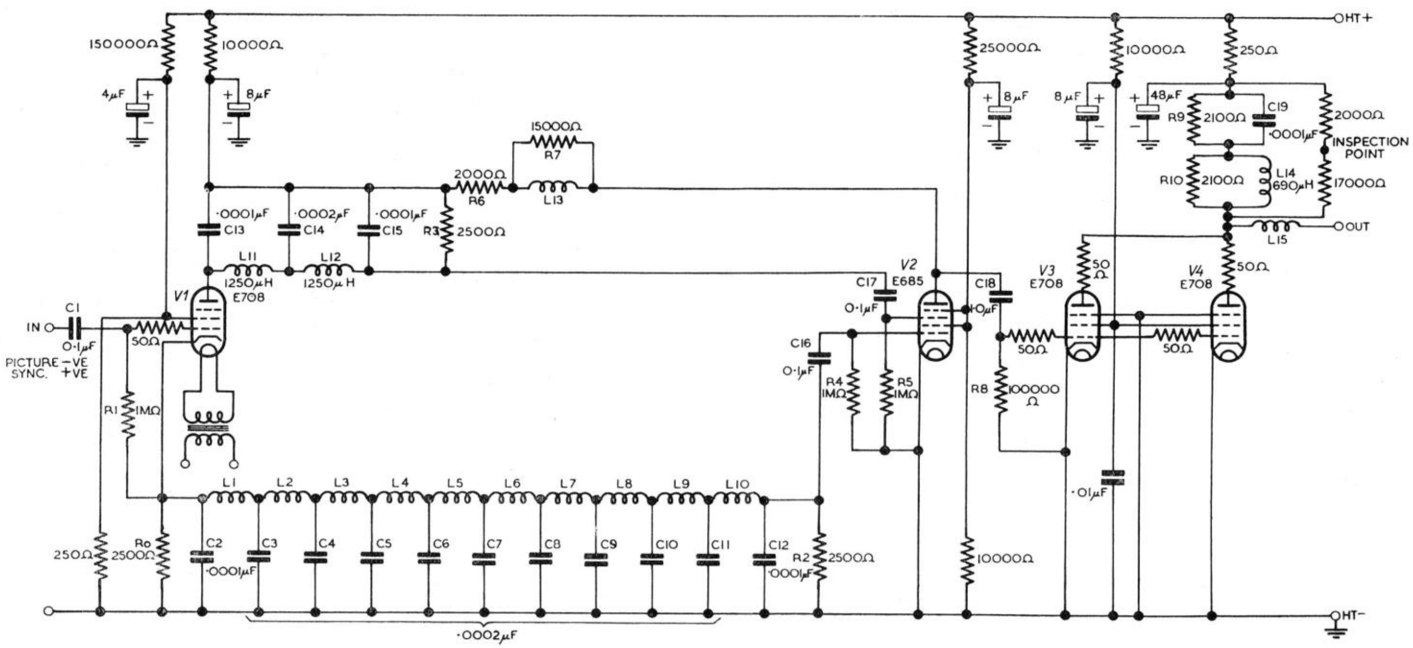
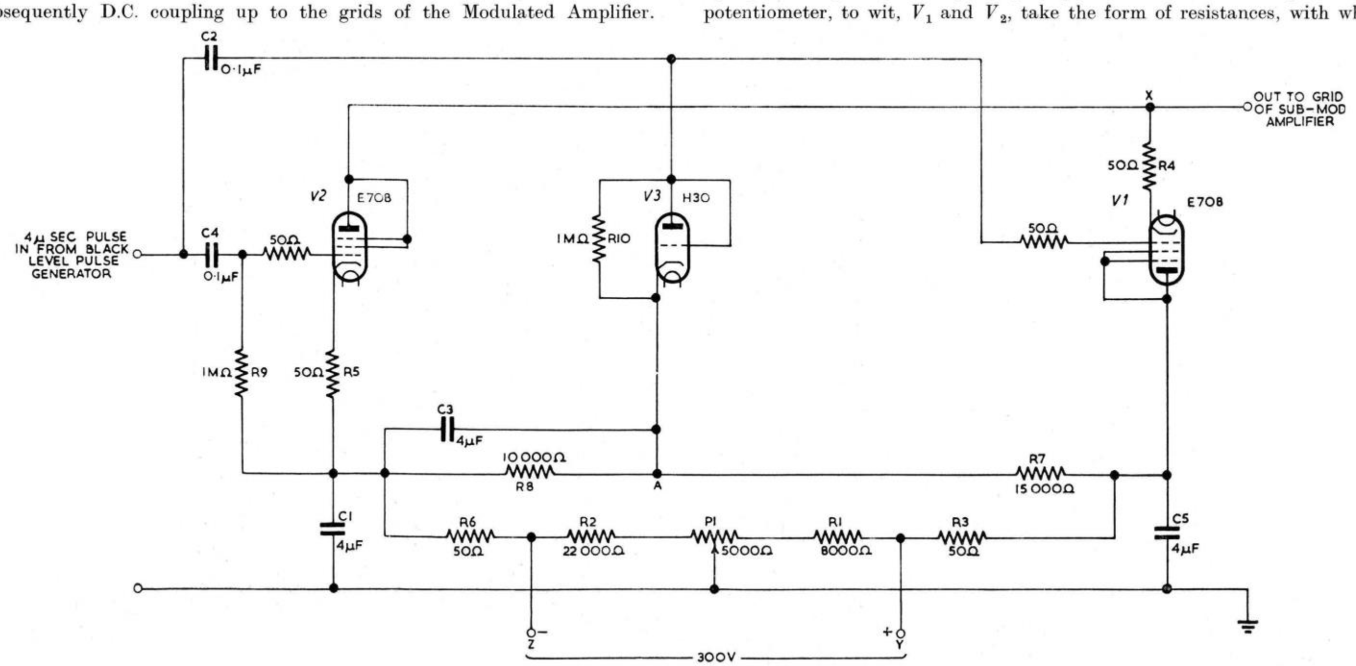


Figure 2. Circuit Diagram

THE BLACK LEVEL CLAMP UNIT

The theoretical working of the Black Level Clamp unit has already been described in my technical note on D.C. Restoration (Item 1.2 page 5), in which it was explained that this unit effects D.C. restoration for the last time and in the most perfect manner yet known at the input grid of the Sub-Modulator, and that the D.C. so restored is not lost again as there is subsequently D.C. coupling up to the grids of the Modulated Amplifier.



In brief, the method is that during that portion of the line suppression pulse which extends after the termination of the line sync pulse the Black Level Clamp unit imposes upon the input grid of the Sub-Modulator a certain potential, afterwards disconnecting itself completely from the grid until the corresponding period comes round again. If the aforementioned theoretical description has been understood, it will be very easy to follow the action of the circuit diagram of the clamp unit.

As will be seen, at Y and Z is provided a source of potential of 300 volts, and assuming that the valves V_1 and V_2 are in a conductive state, current will flow via the path R_3, V_1, R_4, V_2, R_5 and R_6. The point X therefore will take up a potential dependent upon the relative values, on the one hand of R_3 plus the anode impedance of V_1 plus R_2, and on the other hand of the anode impedance of V_2 plus R_5 plus R_6. The elements R_3, V_1, R_4, V_2, R_5 and R_6 really form a single potentiometer across the supply YZ, the point X taking up a potential part of the way along the potentiometer. But two parts of the potentiometer, to wit, V_1 and V_2, take the form of resistances, with which are incorporated what may be described as electronic knife switches. That is to say, by taking V_1 and V_2 off by means of a heavy negative grid potential, the potentiometer can be open-circuited, and being open-circuited in two places, one on either side of the point X, this point together with the Sub-Modulator grid is completely isolated during such time as V_1 and V_2 are so backed off. The relative potential of the point X to earth, however, will be dependent upon where we earth the source YZ. The point X is connected to the grid of the Sub-Modulator, and by choosing the correct point to earth the source YZ, we can determine the operating potential of the Sub-Modulator grid. This working point is largely fixed by the values of the resistances R_1 and R_2, but may be finally adjusted by the potentiometer P_1 which is brought out to the control desk in the form of a control labelled **black level.**

During the whole of the vision period of a line, and during the sync period the valves V_1 V_2 are biassed back and are not in a conductive state, and the Black Level Clamp unit is in effect entirely disconnected from the Sub-Modulator grid. During the last 4 micro-seconds of the line suppression pulse, a separate pulse of the same duration, the generation of which has just been described, is applied to the control grids of V_1 and V_2 so that it drives them both positive, and it is in this short period that they become conductive and the point X takes up a potential determined by the setting of P_1.

Since the line suppression pulse is a period of black, we have established a fixed potential on the grid of the Sub-Modulator corresponding to black, and all subsequent excursions during the vision time of a line must be on the positive side of this level, and therefore D.C. restoration has been effected. The unit, in fact, firmly clamps the Sub-Modulator grid at the chosen black level potential during every 4 micro-second pulse.

It will now be evident that the clamp unit must fail to work if the control room sends a line suppression pulse of insufficient duration, since if any vision signals were applied while the Black Level Clamp was endeavouring to determine the potential of the point X, the actual potential would be modified by the superimposition of the vision signal which is incorrectly coming through, and the correct black level would not be established.

The valves V_1 and V_2, then, are made conductive by application of the 4 micro-second pulse from the pulse generator. A difficulty, however, arises in applying an effective pulse to the control grids of V_1 and V_2 at the same time, and it is the function of the third valve V_3 to remove this difficulty. In order to make this difficulty clear, the essential parts of the circuit have been redrawn in Fig. 2. The cathode of V_2 is, apart from the negligible resistance R_5, earthed by the condenser C_1, and since the pulse is generated with respect to earth it can satisfactorily be applied to the control grid of V_2 by direct connection. Since, however, V_1 and V_2 are in series, it will be found that V_2 is acting as a cathode load for V_1, and if we attempt to apply the pulse also to V_1 without special precautions, V_1 will behave to the pulse as a cathode follower, using V_2 as its cathode impedance. Now the grid of a cathode follower receives considerable feed-back from its cathode impedance, and the effective amplitude of any signal applied thereto is much reduced. In this case, therefore, whereas there would be no difficulty in applying a pulse to the grid of V_2 we should scarcely develop an appreciable amplitude on the grid of V_1. V_1 accordingly would not conduct, and the whole principle of the unit would be negatived. The valve V_3 is therefore inserted so to speak to short-circuit, from the point of view of the pulse, the valve V_2, so that it ceases to act as a cathode impedance to V_1.

Referring again to Figure 1, the pulse is applied to V_3 via the condenser C_2, and the cathode of V_3 is returned to a point on the potentiometer R_7, R_8,

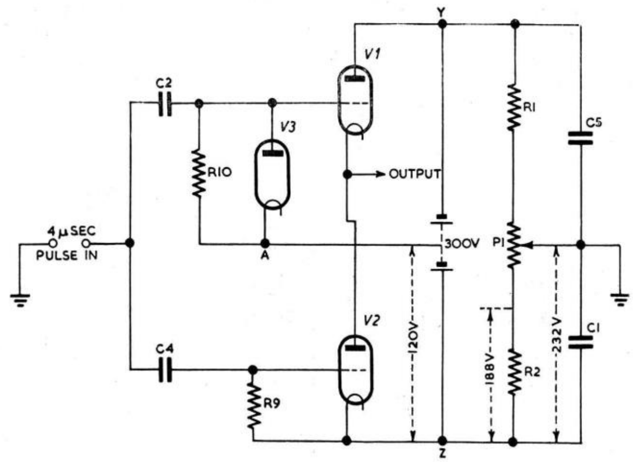


Figure 2

the values of which are so chosen that the point A will always be positive to earth no matter what the setting of the potentiometer P_1. The valve V_3 acts as a diode, its grid and anode being strapped together, and also connected to the control grid of V_1, which therefore has a path to earth via the diode V_3 and the condenser C_3. Thus, the control grid of V_1 receives the full amplitude of the 4 micro-second pulse.

In accordance with the usual technique D.C. is restored at the grids of V_1 and V_2. In the case of V_2 this is effected by the condenser C_4 and the resistance R_9, and in the case of V_1 by the condenser C_2 and the resistance R_{10}. The small resistances R_4, R_5, R_3 and R_6 are for anti-parasitic purposes. The condenser C_5, in co-operation with C_1, decouples the potentiometer P_1 from the pulses.

Finally, the whole of the black level clamp unit may be simply, but not incorrectly, described as a single grid leak which connects the grid of the Sub-Modulator with its source of grid bias during the 4 micro-second periods, but which is otherwise disconnected.

THE TRANSMITTER WAVEFORM MONITORING SYSTEM

It is essential to be able to observe the waveform on a cathode ray oscilloscope as it passes through the Modulator and finally emerges in radio frequency form from the Modulated Amplifier. Arrangements have been made by means of which the waveform may be observed at the following six points, which are termed *monitoring points*.

The line input from the Control Room to the Line Amplifier ;

The output of the Line Amplifier ;

The output of the Sub-Sub-Modulator ;

The output of the Sub-Modulator ;

The output of the Modulator ;

The output of the Modulated Amplifier.

It will be evident that the monitoring system must fulfil a number of special requirements, amongst which may be named the following :—

1. The observation should not be made by means of a number of individual monitors, but by a single monitor, preferably located on the control desk, which may be connected to any one of the above six points.
2. The monitor must be capable of being held in synchronism by means of a signal in either sense, because the signal will be reversed by each stage of the modulator.
3. Special arrangements must be incorporated to enable the widely varying amplitude which will be experienced at the various monitoring points to be adjusted to a constant amplitude before application to the oscilloscope. For instance, whereas the amplitude between white level and sync level at the input to the modulator is 13 V the corresponding amplitude at the end of the Modulator is 1,600 V.
4. The connection of the Waveform Monitor to the above six points must not influence the frequency or phase characteristic of the Modulator.

The system of waveform monitoring which has been applied to the Modulators meets the above requirements in the following manner. At each of the six monitoring points arrangements are made by means of which the amplitude of the vision signals experienced at that point is reduced by a potential divider to a standard figure of approximately 7 V. In the case of the input to the Line Amplifier a simple potentiometer is all that is necessary, but in the case of the other points more elaborate capacity-resistance potentiometers are required, and in the case of the 6th, or radio frequency, point, a rectifier is incorporated so that this point will deliver vision frequency signals to the monitor. In addition, all the monitoring points except that associated with the input to the Line Amplifier incorporates a cathode follower, which isolates the monitor from the modulator circuits so as to avoid any interference with the frequency or phase characteristics.

The Waveform Monitor itself takes the form of a cathode ray oscilloscope mounted in the control desk, and with it is associated a time base adjustable for line or frame frequency, a D.C. amplifier and the necessary H.T. and L.T. supply units, and a selector switch by means of which the output from any of the monitoring points may be applied to the oscilloscope for observation. The oscilloscope is of the electrostatically deflected type, and the output of the time base is applied to the horizontal deflection plates. The output from the various monitoring points is applied via a D.C. amplifier to the vertical deflection points. The time base also receives an input of vision signals from the monitoring point which is being examined, and it is capable of being held in synchronism by signals in either sense. It will be seen, therefore, that in the system to be described the four requirements detailed above are met.

The waveform monitoring system comprises the following apparatus :

1. A potential divider associated with the monitoring point at the input to the Line Amplifier
2. A monitor box associated with the output of the Line Amplifier
3. A monitor box associated with the output of the Sub-Sub-Modulator
4. A monitor box associated with the output of the Sub-Modulator
5. A monitor box associated with the output of the Modulator
6. A monitor box associated with the output of the Modulated Amplifier
7. A power supply for the above monitor boxes
8. A monitoring D.C. amplifier
9. A time base
10. An oscilloscope
11. Power supply units for the tube, amplifier and time base

These various pieces of apparatus will now be described in order.

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Line Amplifier Input Potential Divider for Monitor

This is a simple resistance potentiometer, the circuit of which is illustrated in Fig. 1. The resistances R_1 and R_2 are located in the Line Amplifier, but R_3, R_4, R_5 and R_6 are located in the monitor cubicle in the control desk. At the point x appears the requisite voltage and the requisite

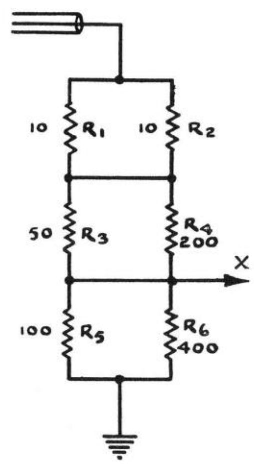

Figure 1.
Waveform Monitoring Point at Line Input to the Line Amplifier.

amplitude of approximately 7 V, which will be applied via the monitoring D.C. amplifier to the vertical plates of the oscilloscope. The resistances R_1 to R_6 are so chosen that together with the remainder of the input circuit to the Line Amplifier the total resultant resistance, as seen by the line from the Control Room, is 110 ohms, so that the line is terminated correctly. In view of the fact that the resistances R_1 to R_6 are all of low value, the capacity at the point x will not influence the frequency characteristic, and this point may be directly connected to the monitoring amplifier.

The Line Amplifier Monitor Box

The monitor box at this point incorporates the apparatus shown in Fig. 2, the whole of which is enclosed by a screen, hence the use of the term *monitor box*. The vision signals at the output of the Line Amplifier are applied to the potentiometer $R_1 R_2$, which reduces them to approximately the value required by the input of the monitoring amplifier. The input of this amplifier might be connected to the point A at the junction of R_1 and R_2, but the total stray capacity from this point to earth, i.e. across R_2, would, in conjunction with R_1 and R_2, attenuate the upper frequencies, and the waveform as illustrated on the monitor oscilloscope would not be representative of that existing at the output of the Line Amplifier. This could be corrected by the connection of a corresponding capacity across R_1, but then the total capacity from the Line Amplifier output to earth would render it impossible to obtain a satisfactory frequency characteristic at the Line Amplifier output. Measures must therefore be applied which will reduce the capacity between the point A and earth. This is achieved by connecting a cathode follower V to the point A by once more making use of the low input capacity which is a property of the cathode follower. The input of the monitor amplifier is taken from the point x in the cathode circuit of the cathode follower. Even so, the input capacity of the cathode follower is sufficient, in conjunction with R_1 and R_2, to attenuate the upper frequencies, so that these will be lacking in the waveform as observed on the oscilloscope. This is corrected, as already suggested, by the addition of a condenser C_1, but owing to the fact that the capacity across R_2 has been greatly reduced by the use of the cathode follower V, the total capacity existing from the Line Amplifier output to earth, when the correcting condenser C_1 has been added, is not now sufficient to influence adversely the frequency characteristic of the Line Amplifier. The values are in fact such that it is possible to add the capacity C_2 across R_2, which is done in order that C_1 may be of a value which can be conveniently provided by an actual variable condenser. The circuit values are so adjusted that $C_1 R_1$ equals the product of R_2 and the total capacity between A and earth, that is to say, C_2, together with all stray capacities in parallel with it.

Since the output of the Line Amplifier is a cathode follower, the vision signals at this point will be situated with reference to a datum line which is positive with respect to earth, consequently a negative bias or hold-off voltage must be applied between the point A and the grid of V in order to overcome the standing positive potential existing at the output of the Line Amplifier and further to provide the control grid of V with a correct negative bias with respect to its cathode. This bias is generated by means of the transformer TR in conjunction with the rectifiers W_6 and the smoothing circuit involving the elements C_3, C_4, R_3, C_5. The resistances R_4 and R_5 form the load resistance of the hold-off rectifier, R_4 being made in the form 206

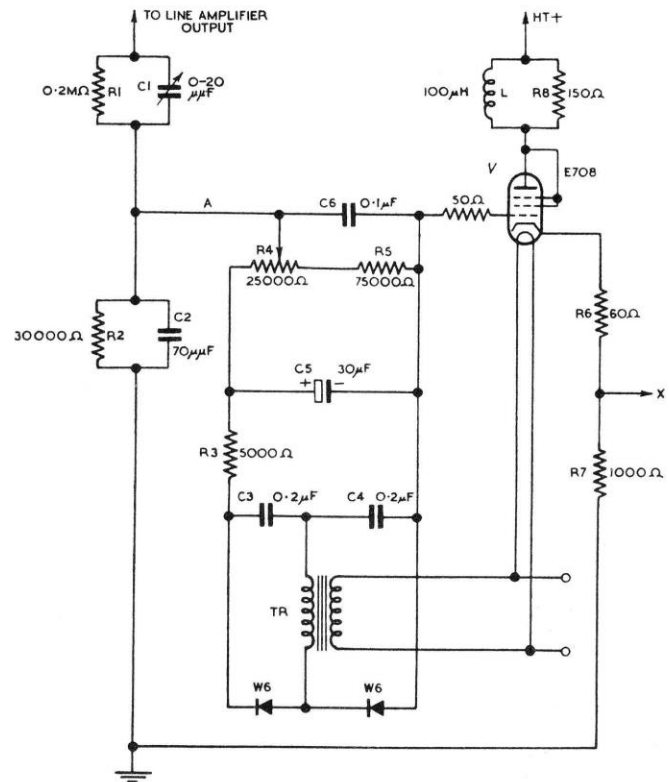

Figure 2. Waveform Monitoring Point at the Output of the Line Amplifier

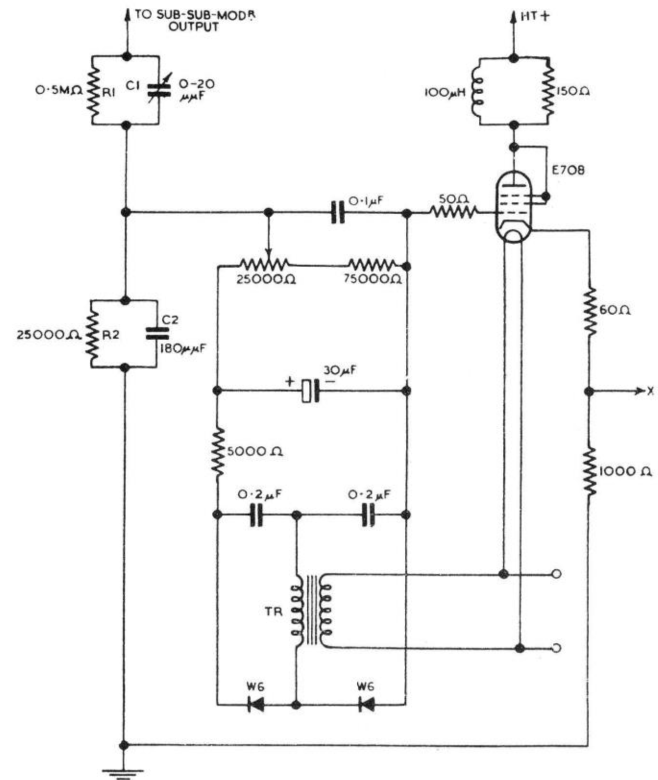

Figure 3. Waveform Monitoring Point at the Output of the Sub-Sub-Modulator

of a potentiometer by means of which the bias may be adjusted. The grid condenser C_6 by-passes the vision signals, which, as usual, should not be allowed to flow in the rectifier circuit. The resistances $R_6 R_7$ are normal cathode resistances in the cathode follower V.

As will be seen later, the smoothing circuit of the H.T. unit which supplies H.T. to the cathode follower V is built out to a constant impedance of 150 ohms, but this impedance is somewhat reduced at the upper vision frequencies by the capacity to earth of the H.T. lead. The impedance is once more restored to a constant value at all frequencies by the addition of the inductance L and the resistance R_8.

The Sub-Sub-Modulator Monitor Box

The circuit of this apparatus is illustrated in Fig. 3, and is identical with that of the Line Amplifier monitor box with the exception of the values of the capacity-resistance potentiometer C_1R_1, C_2R_2. These have new values suitable for reducing the further amplified vision signals at the output of the Sub-Sub-Modulator to the value required by the monitor amplifier.

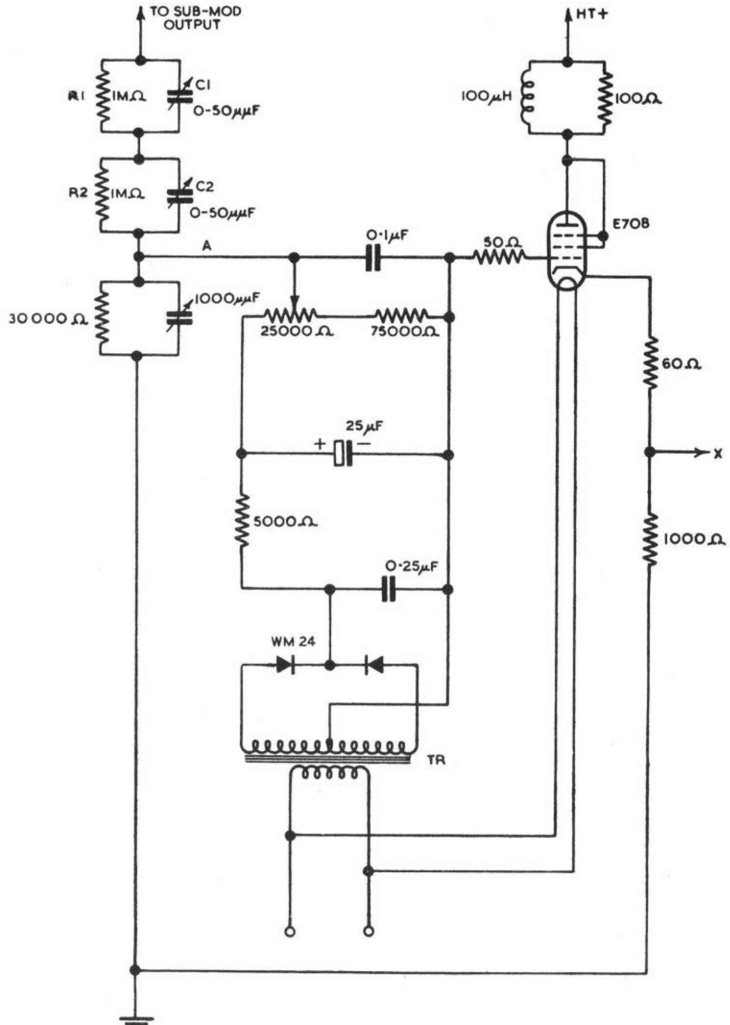

Figure 4. Waveform Monitoring Point at the Output of the Sub-Modulator

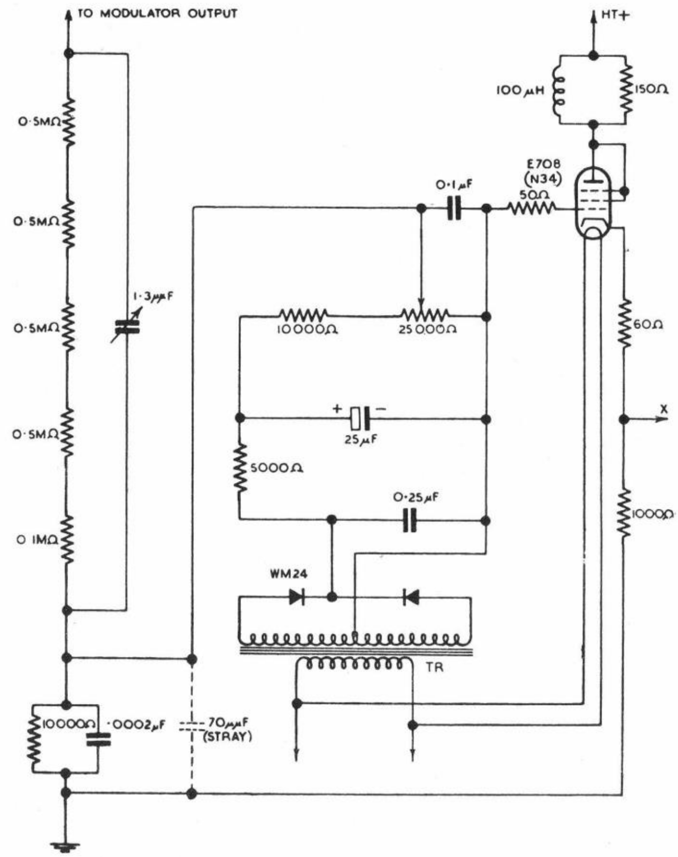

Figure 5. Waveform Monitoring Point at the Output of the Modulator

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The Sub-Modulator Monitor Box

This is illustrated in Fig. 4, and is substantially similar to the previous boxes. The resistance-capacity potentiometer has, of course, values appropriate to the amplitude of the vision signal at the output of the Sub-Modulator. It will be noticed that the upper part of this potentiometer above the point A is divided into two sections, C_1R_1 and C_2R_2. This is rendered necessary by the fact that although in theory R_1 and R_2 can be combined as one resistance and C_1 and C_2 as one capacity, the arrangement would not be satisfactory in practice. It is well known that when resistances of certain types are subjected to a fairly high voltage, the value of resistance may not remain stable owing to the development of slight negative resistance characteristics. Accordingly, if the whole of the voltage of the vision output at the end of the Sub-Sub-Modulator is developed across a single resistance at R_1R_2, the value of this resistance is liable to change with the value of the applied voltage, whereas for the purposes of the circuit it must remain constant. The resistance at this point therefore has been sub-divided into two parts so that only half of the voltage is developed across each part.

The only other difference between this monitor box and those previously described is that a somewhat lower value of hold-off voltage is required, and in order to retain the same type of hold-off rectifier transformer TR in all the monitor boxes, the rectifier circuit on Fig. 4 is arranged to be of the double wave type instead of the voltage doubler type used in the previously described boxes.

The Modulator Monitor Box

This unit is illustrated in Fig. 5, and is substantially identical with the Sub-Modulator box of Fig. 4.

The Radio Monitor Box

This is located in the Modulated Amplifier at a point adjacent to the aerial feeder, and the circuit is illustrated in Fig. 6. The condenser C_1 permits a small amount of H.F. energy to be withdrawn from the aerial feeder and applied to the tuned circuit $L_1 C_2$. This circuit is damped by the resistances $R_1 R_2$ in order that its response may be uniform over the frequency range occupied by both sets of sidebands. The H.F. voltage across the tuned circuit is applied to the push-pull rectifier $V_1 V_2$, and at the point A appear vision signals of the normal kind, which will, of course, have a radio P/S ratio of 70/30 instead of the ratio 1/1, which will be shown in the output from all the other monitoring points. The cathode follower V_3 is provided as before but, since the output from $V_1 V_2$ is negative, its control grid must receive a positive hold-off bias instead of the negative bias employed in the other monitor boxes. This bias is generated in the usual way by means of
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the transformer TR and the rectifiers WM_{24}, the load resistance and control potentiometer being the resistance R_3. The bias is then smoothed by the resistances $R_4 R_5$ and the condenser C_3. The resistances $R_6 R_7$ are provided to hold off the capacity of the rectifier and smoothing circuit from the grid of the cathode follower.

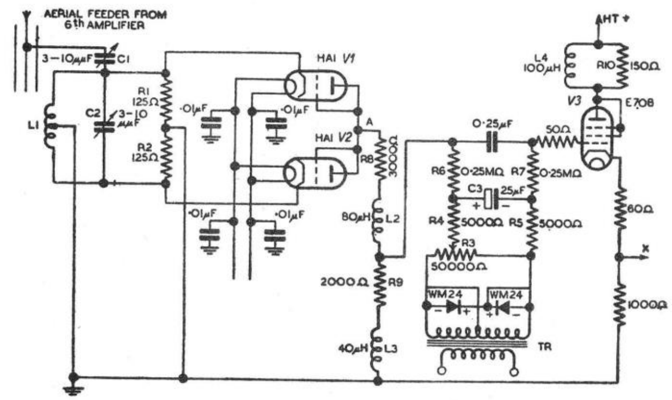

Figure 6. Waveform Monitoring Point on the H.F. Feeder from the Radio Transmitter

The push-pull rectifier $V_1 V_2$ requires an output impedance of 5,000 ohms, which will remain constant over the vision frequency range, but the output capacity of V_1 and V_2 and the input capacity of the circuit associated with V_3 will be in shunt to any load resistance connected between the point A and earth, and the impedance and consequently the output will become reduced at the upper vision frequencies. This is corrected by the circuit, involving the elements R_8, L_2, R_9 and L_3. The elements R_9 and L_3 form with the input capacity of the valve V_3, a very broadly tuned network whose impedance will remain at 2,000 ohms from zero frequency up to the cut-off frequency which is located at a suitably high value. The equivalent resistance of this arrangement may now be considered as added to the resistance R_8, giving a figure of 5,000 ohms, which, in combination with the inductance L_2 and the output capacity of V_1 and V_2, form a further broadly tuned network, whose impedance will remain at 5,000 ohms from zero frequency up to an appropriately located cut-off frequency. In this way it is arranged that the rectifier $V_1 V_2$ sees an impedance of 5,000 ohms over the working range of frequencies. The elements $L_4 R_{10}$, as before, maintain the impedance of the H.T. supply at a constant impedance of 150 ohms, and the output of the unit is taken from the point x.

The Power Supply Unit for the Monitor Boxes

The H.T. supply for the monitor boxes is generated by the rectifier illustrated in Fig. 7a. The H.T. is generated by the transformer TR_1, and the parallel connected rectifiers V_1, V_2, V_3 and V_4, which are followed by a constant impedance smoothing circuit. The rectifier impedance is approximately 150 ohms, and L_1 constitutes the first smoothing inductance. Accordingly the addition of the elements R_1 and C_1 will restore the circuit looking into the rectifier from the points AB to a constant impedance of 150 ohms. The output is now further smoothed by the condenser C_2, so that looking into the rectifier from the points CD, the circuit appears to consist of the resistance previously appearing at AB in parallel with the condenser C_2. The circuit is once more restored to constant impedance when measured into the rectifier from the points EF, by the addition of the elements L_2 R_2. A further smoothing condenser C_3 follows, the circuit being once more restored to constant impedance by the elements L_3 R_3. This is in turn followed by a final stage of smoothing involving C_4, L_4 and R_4.

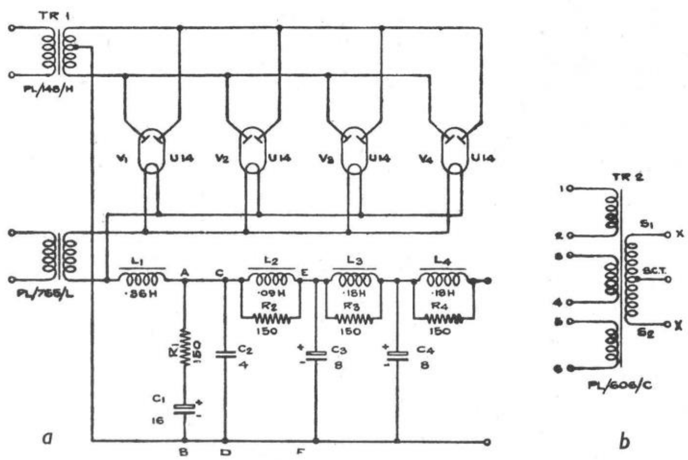

Figure 7. Power Supply Unit for the Monitor Boxes

The L.T. supply is derived from the transformer TR_2, illustrated in Fig. 7b.

The Monitoring D.C. Amplifier

The function of the monitoring D.C. amplifier is to receive the six outputs from the monitoring points, amplify them under D.C. conditions, and eventually apply them to the vertical deflection plates of the oscilloscope. It is of the greatest importance that the frequency characteristic of this amplifier should be good so that the waveform shown on the oscilloscope will faithfully represent that at the monitoring point under examination. The circuit of this amplifier is illustrated in Fig. 17.†

The outputs from the various monitoring points are applied to the input terminals as shown, and any one of these waveforms may be selected for examination by means of the selector switch S, the wiper of which applies the waveform to the grid of V_1. In the case of inputs 2 to 6 inclusive, the input amplitudes are somewhat reduced by the potentiometers R_1 R_2, R_3 R_4, R_5 R_6, R_7 R_8, and R_9 R_{10}, but the Line Amplifier input waveform arrives at the correct amplitude. The vision signals on the wiper of the selector switch S are applied to the control grid of the valve V_1, which, together with the valve V_2, forms a stage of push-pull amplification. The valves V_3 V_4 and V_5 V_6 form two pairs of parallel connected valves operating in push-pull to form a second stage of amplification, the output to the vertical deflection plates of the cathode ray tube being taken from the anodes of these valves.

The input is not of push-pull form, but the circuit associated with V_1 and V_2 is designed to give the push-pull operation from a normal or asymmetrical input. To achieve this, V_1 and V_2 have a common cathode resistance R_{14}. Let us now suppose that the input which is applied between the control grid of V_1 and earth tends at a certain moment to make the grid positive. Due to R_{14} the cathode of this valve becomes more positive but the increase of potential is less than that on the control grid so there is a net increase of potential between the control grid and cathode of V_1. The cathode of V_2, being directly connected to the cathode of V_1 also rises in potential, but the grid of this valve is earthed with respect to vision frequency potentials by the condenser C_1. There is therefore a net decrease in the grid-cathode potential of V_2. A change of potential in one direction therefore between the grid and cathode of V_1 is accompanied by an almost equal change of potential in the opposite direction between the grid and cathode of V_2, and these two valves are therefore in a state of push-pull operation

The value of the resistance R_{14} is determined from the consideration of obtaining push-pull operation, and this entails that the value should be comparatively high. Although the amplitude of the input vision signals is at all times positive with respect to earth, and consequently it will be necessary to provide an automatic grid bias for V_1 and V_2 so that these grids will not run into grid current on any part of the signal amplitude, the negative bias provided by R_{14} will be much greater than is required, and it becomes necessary to offset a part of this by adding in series with each grid a certain value of positive bias. In the case of V_1 this is effected by returning the lower end

† Figure 17 attached to page 9

The Monitoring D.C. Amplifier (*Contd.*)
of the grid leak R_{15} and the lower end of the input circuit to the junction of the resistances R_{12} and R_{13} instead of to the negative of the H.T. supply. Thus, between the grid and cathode of V_1 there are three potentials in series, namely,

(1) the negative potential across R_{14} (together with feed-back potentials across this resistance);
(2) a standing positive voltage across R_{13}, and
(3) the input vision signals.

The sum of all these three potentials is such that the range of grid-cathode potentials at vision frequency is that which the valve requires for normal linear amplification.

The control grid of V_2 is given a corresponding series positive bias by returning it to the slider of the potentiometer R_{12}. The object of making this potential variable is to provide a vertical shift control for the waveform on the vertical deflection plates of the cathode ray tube, so that the waveform can at all times be centralised and exact readings taken always over the same portion of the tube screen. We must therefore be able to vary the standing voltage (which will also be in push-pull) on the deflection plates. This in turn means that the standing anode potentials in push-pull of the valves V_3 V_4 and V_5 V_6 must be capable of variation, but since the amplifier is a D.C. amplifier it is quite possible to do this by applying an appropriately smaller adjustment to the standing potentials of the grids of V_1 and V_2. The potentiometer R_{12} will vary the standing potential at the grid of V_2, but by virtue of the push-pull action just described, this will result in a corresponding variation in the opposite direction of the standing potential of the control grid of V_1. Adjustment of the potentiometer R_{12} therefore will vary the position of the waveform on the tube screen, and this potentiometer is therefore brought out to a manual control designated **Position.**

The anode circuits of V_1 and V_2 are normal, and contain the decoupling resistances R_{16} and R_{17}, the decoupling condensers C_2 and C_3, the anode resistances R_{18} and R_{19}, and the anti-parasitic resistances R_{20} and R_{21}. The anode output of V_1 is applied to the control grids of the valves V_5 and V_6, and that from V_2 to the control grids of V_3 and V_4. The standing positive potential on these outputs is higher than can be accommodated at the grids of V_3 to V_6 and would require to offset it more automatic grid bias from the cathode circuit of these valves than can be provided from other circuit considerations. The standing potential is therefore reduced by the potentiometer R_{22} R_{23} in the case of the output from V_1, and similarly by the potentiometer R_{24} R_{25} in the case of V_2, the control grids of V_5 V_6 and of V_3 V_4 being connected to the junctions of these potentiometers. The full vision frequency potentials, however, are by-passed by the condensers C_4 and C_5. Since the impedance of these condensers rises at low frequencies, and is, of course, infinite under D.C. conditions, this arrangement will result
211 in a loss of gain at D.C. with respect to A.C., but this is corrected by the decoupling circuits R_{16} C_2 and R_{17} C_3, for it will be realised that the condensers C_2 and C_3 similarly rise in impedance at low frequencies and in the limit, that is to say under D.C. conditions, the decoupling resistances R_{16} and R_{17} are in effect added to the anode resistances R_{18} and R_{19} with a consequent increase of gain.

In view of the fact that the design of the circuit requires that the values of the anode resistances R_{18} and R_{19} shall be no greater than approximately 200 ohms, the effects of shunt capacity, even at the highest vision frequencies, are negligible, and the usual inductances either in series with the anodes or between these anodes and the control grids of V to V_6 are absent.

It will be noticed that there are certain small discrepancies between the values of the elements in the circuits associated with V_1 and those of V_2. This arises from the fact that the method already described of obtaining push-pull operation is not quite perfect in that the grid of V_2 does not receive exactly the same, but a slightly less, input amplitude than does that of V_1. Owing to the cathode following action of V_1 V_2, the input received by V_2 will be $\dfrac{R_{14}}{R_{14} + \dfrac{1}{S_m}}$ of the input applied to V_1, where S_m is the mutual conductance of the identical valves V_1 and V_2. It is further desired to present an exactly balanced input to the second stage V_3 to V_6. Assuming that the circuits of V_1 and V_2 have been designed to be identical, the required balanced output will be obtained by the following series of modifications. Firstly R_{19} is made greater than R_{18} in order to increase the effective gain of V_2 and so make up for its comparatively smaller input. It would now be possible to obtain equal and opposite inputs into the second stage by making R_{24}, C_5 and R_{25} equal respectively to R_{22}, C_4 and R_{23}, but the net result would be that there would be an unbalance as regards vision currents in the common H.T. supply, and it is desired if at all possible to avoid this, as otherwise the impedance of the H.T. supply will influence the performance of the amplifier. To avoid this therefore, the decoupling resistances are modified, R_{17} being made greater than R_{16}. The alteration of decoupling, however, upsets the equivalence of the output under D.C. conditions, but this may be corrected by making a corresponding modification to the values of the potentiometers R_{22}, R_{23} and R_{24} R_{25}. R_{22} and R_{24} are retained equal, but R_{23} is made greater than the paralleled R_{25} and R_{25A}. The input to the second stage under D.C. conditions will now be correct, but there will be a lack of equivalence under A.C. conditions, which is finally corrected by the modification of C_5 and C_4, C_5 being made somewhat greater than C_4.

The grids of V_3 V_4 and of V_5 V_6 therefore receive vision input in push-pull, that is to say, the currents in the cathode circuits of these two pairs of valves will be in mutual opposition, and there will be no resultant vision

The Monitoring D.C. Amplifier *(Contd)*

frequency current. All four cathodes may therefore be joined together, and automatic bias to all four valves provided by a common resistance, R_{26} to R_{30}. The portion R_{26} is made variable in order that the automatic bias, and consequently the anode feed, may be set to the correct value.

The anode circuits feed the vertical deflection plates of the cathode ray tube in push-pull. The deflection plates constitute a capacity, and arrangements must as usual be provided to incorporate this capacity in some form of low-pass filter in order that no loss at the upper vision frequencies will be experienced. The arrangements adopted in these particular anode circuits, however, are more complicated than usual and constitute an extension of the simpler low-pass filter technique employed in apparatus of earlier design.

In the first place, the usual type of prototype low-pass filter employed requires that the two end capacities should be more or less equal, but in this case they are unequal. Referring to Fig. 8, C_1 represents the capacity of the vertical deflection plates of the cathode ray tube, across which we must develop the vision frequency waveform without attenuation of the upper frequency components. C_2 represents the anode-earth capacity of one side of the output stage, for example V_3 V_4, and in the normal way we would arrange for these capacities to form part of a prototype low-pass filter section by inserting the inductance L_1 of Fig. 8. This is in fact done, this inductance being represented by L_1 in Fig. 17. Unfortunately the capacity C_2 is greater than C_1, and the section is asymmetrical. It would be possible to render the section symmetrical by increasing artificially the capacity of the deflection plates, but in that case, either the iterative impedance of the section would necessarily be lower for the same cut-off frequency, or, for the same iterative impedance we should have to be content with a lower cut-off frequency. Neither of these courses is desirable since the first would result in a lower voltage gain being obtained from the output stage, and the second would result in the reproduction of the waveform on the monitor tube screen being deficient in upper frequencies and consequently not a faithful representation of the original waveform. It is therefore desirable to find some means of reducing C_2, and it is found that this can be done with sufficient accuracy by the introduction of a negative inductance in series with it, as shown in Fig. 9, and designated $-L$. The negative inductance $-L$, together with the condenser C_2, will collectively simulate a condenser of lower capacity than C_2 up to a certain limiting frequency, but to a rough approximation only, since the impedance characteristic of the combination will be not precisely that of a pure condenser. The performance of the circuit is, however, effectively improved by the insertion of the negative inductance. It is, of course, not possible to make such an inductance physically, but it can be

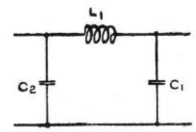

Figure 8

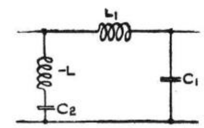

Figure 9

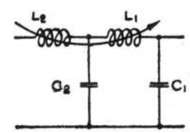

Figure 10

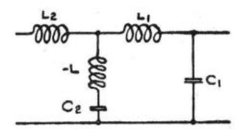

Figure 11

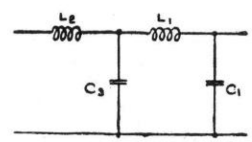

Figure 12

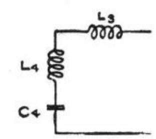

Figure 13

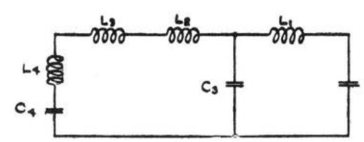

Figure 14

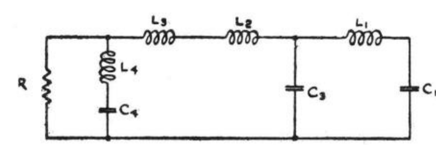

Figure 15

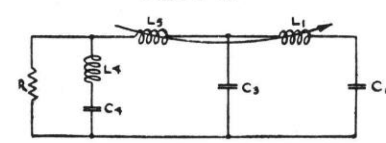

Figure 16

The Monitoring D.C. Amplifier *(Contd)*
simulated by adding to the circuit of Fig. 8 the further inductance L_2, as shown in Fig. 10, and arranging for a certain amount of coupling between L_1 and L_2. If this coupling is in the right direction, the circuit of Fig. 10 is equivalent to that of Fig. 11.

Before considering the circuit further, it will be a simplification if we can regard $-L$ and C_2 of Fig. 11 as behaving, as in practice they do, as one condenser. Fig. 12, therefore, shows Fig. 11 redrawn with this substitution made, the equivalent condenser in Fig. 12 being C_3. The modification to the original circuit of Fig. 8 in order to reduce the capacity C_2 has, it will be seen, resulted in the introduction of the extra inductance L_2. The circuit of Fig. 12 is still a low-pass filter, but it is no longer purely a π-section, rather it has the form of a ladder section which has been interrupted on the right-hand side, or receiving end, in mid-shunt, but on the left-hand side, or sending end, in mid-series. This filter must as usual be terminated, preferably at the sending end.

Since this amplifier forms part of a set of measuring equipment, it is obviously desirable that its frequency and phase response should be, if possible, superior to that of the apparatus whose performance it would be used to measure. The somewhat high capacities of the deflection plates and of the anodes of the two parallel valves V_3 and V_4, together with the voltage gain required from the stage, set a limit to the cut-off frequency of the filter, but it is clearly desirable that the filter should transmit to the cathode ray tube a frequency range which extends at the upper end as near as can possibly be managed to the cut-off frequency. The relationship between the effective pass band, that is to say, the pass band over which the frequency and phase characteristics are linear, is determined by the precise nature of the termination. Where the circumstances are less dificult, such filters may be terminated in a pure resistance, which is usually the anode resistance of the valve, or by a resistance in series with an inductance. In the former case the pass band of the filter will only extend up to half the cut-off frequency, and in the second case to an arbitrary figure somewhat greater than half the cut-off frequency. It is evident that neither of these types of termination are quite suitable for the present case, and it is necessary to resort to an m-derived termination.

Returning to Fig. 12, it has already been observed that the original π-section (L_1, C_1 and C_2 of Fig. 8) has been converted as far as the sending end is concerned into a T-section by the addition of L_2. This is of importance as the m-derived termination which we must apply to the new circuit (Fig. 12) will not be the same for a T-section as for a π-section. The appropriate m-derived section is illustrated in Fig. 13, and the two coupled together are shown in Fig. 14. The complete filter of Fig. 14 will, of course, require to be finally terminated by a pure resistance, which may as usual be the anode resistance, and the complete filter including the terminating resistance is shown in Fig. 15. Clearly we may add L_2 and L_3 of Fig. 15 together to form one inductance. We may accordingly redraw Fig. 15 as in Fig. 16, where L_5 of Fig 16 equals $L_2 + L_3$ of Fig. 15. L_5, because it incorporates L_2 of Fig. 15, will be coupled to L_1 in order to obtain the negative inductance effect described above, and this coupling is shown for convenience in Fig. 16. The circuit of Fig. 16 is therefore complete, and is that actually employed in the amplifier. It is applied individually to the anode circuits of each pair of output valves.

Comparing Figs. 17 and 16, all the elements illustrated in the latter figure will be found in the circuit, the equivalence between the two figures being shown in the following table :—

Elements in Fig. 16	*Elements in Anode Circuit of* V_3 V_4	*Elements in Anode Circuit of* V_5 V_6
C_1	Capacity of P_1	Capacity of P_2
L_1	L_1	L_2
C_3	Modified capacity of V_3 V_4 anodes	Modified capacity of V_5 V_6 anodes
L_5	L_3	L_4
L_4	L_5	L_6
C_4	C_6 C_7	C_8
R	Constant resistance circuit comprising R_{31}, R_{32}, C_9, L_7	Constant resistance circuit comprising R_{33}, R_{34}, C_{10}, L_8

As a further refinement towards the attainment of a good frequency characteristic the final push-pull stages V_3 V_4 and V_5 V_6 are cross-neutralised by the small condensers C_{11} and C_{12}. There is, of course, at no time any theoretical objection to the use of neutralising to remove effective shunt capacity in low-frequency circuits, but there are usually certain practical difficulties which prevent neutralised low-frequency circuits from functioning normally, and neutralisation is more commonly seen in high-frequency circuits. The difficulty ordinarily is that neutralisation requires that the voltages at opposite ends of the neutralising condenser shall be 180 degrees out of phase, but the usual impedances found in low- or vision-frequency circuits are not such as to present such exact phase opposition in push-pull circuits at the upper end of the frequency range. In the monitoring amplifier, however, the presence of the elaborate m-derived filter system in the anode circuits of the push-pull output stage modifies the anode impedances so that voltages at the anodes of V_3 V_4 will approach much more closely an exact out of phase relationship with the voltages on the grids of the other stage, V_5 V_6. A similar relationship, of course, applies between the anode voltages of V_5 and V_6 and the grid voltages of V_3 V_4. It becomes possible, therefore, to effect a degree of neutralisation by connecting the condensers C_{11} C_{12},

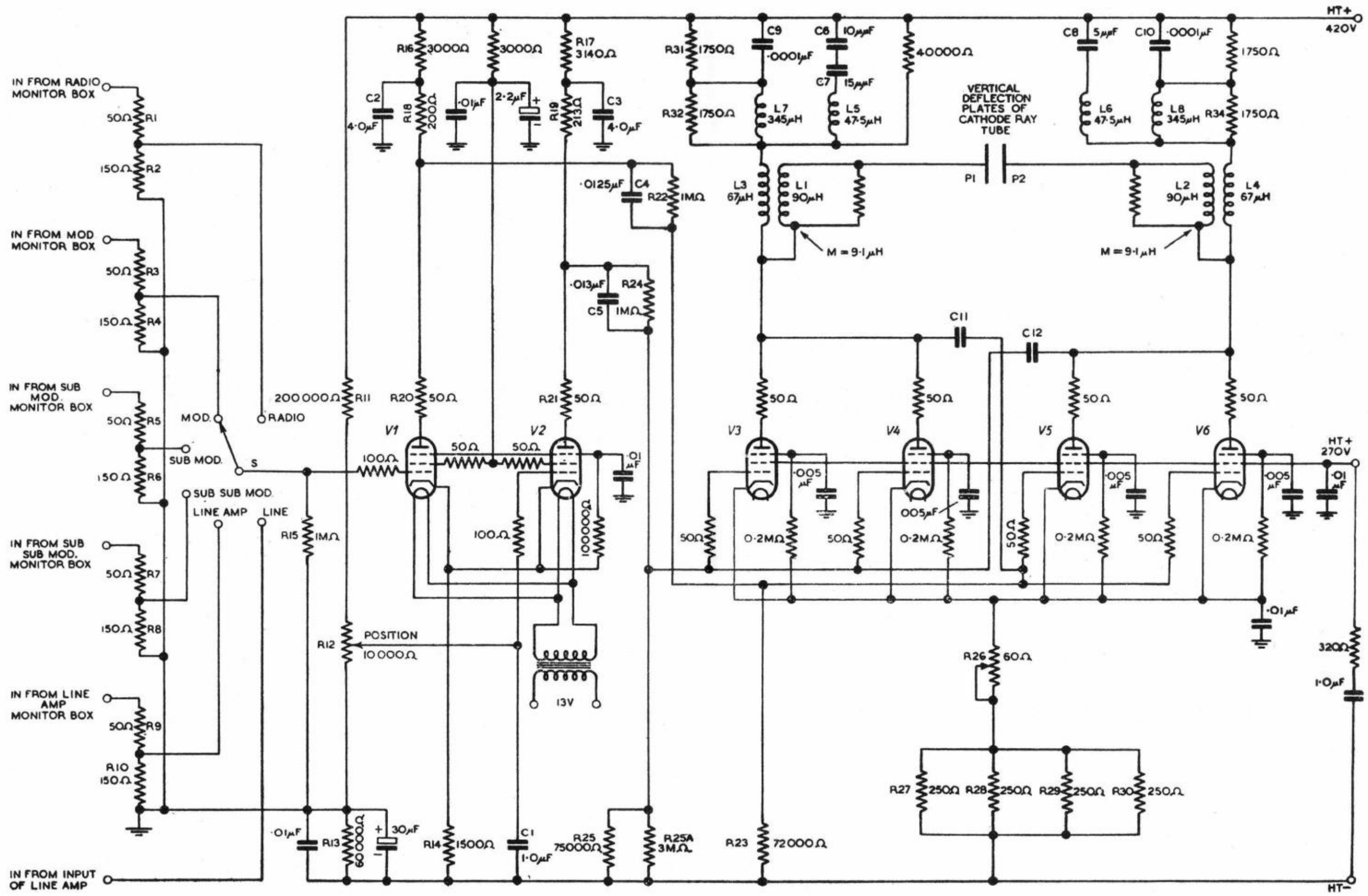

Fig. 17. Monitoring D.C. Amplifier

The Monitoring D.C. Amplifier *(Contd)*

and their effect is to reduce the effective anode capacity for which the m-derived filter is to be designed. The effective anode-earth capacity of this stage is therefore artificially reduced by two methods. Firstly the negative inductance effect already described, and secondly by the neutralising condensers C_{11} C_{12}.

The anode resistances of the two stages are properly R_{31} and R_{33}, but these resistances have to carry considerable dissipation and are of comparatively large physical size. Their shunt capacity therefore is sufficiently high to prevent them behaving as pure resistances at the upper frequencies, and they are built out to a constant resistance in the usual manner by the addition of the elements R_{32}, L_7 and C_9 in the case of R_{31}, and R_{34}, L_8 and C_{10} in the case of R_{33}.

The functions of the remaining components in the amplifier will be easily recognised. The screen grids are fed normally. The suppressor grids are operated at the same D.C. potentials as their associated cathodes. This is effected by connecting each suppressor grid to its appropriate cathode through a high resistance. The cathodes are rendered earthy by the addition of a small condenser connected directly to earth.

The Time Base

In order that the waveform of the vision signals which are being applied to the vertical plates of the oscilloscope may be observed, it is necessary that the spot should be deflected horizontally in a linear manner by means of a saw-toothed voltage applied to the horizontal deflection plates. In the generation of this scanning voltage the following conditions must be observed :

(1) The scanning voltage must be delivered as usual in push-pull to the two horizontal deflection plates.
(2) The frequency of the scanning voltage must be capable of being adjusted to line or frame frequency so that the line or frame waveforms can be examined at will.
(3) The scanning voltage must be synchronised with the vision waveform either at line or frame frequency.

The scanning voltage is generated by a separate unit known as the Time Base, the circuit of which is illustrated in Fig. 18.

It will be seen that the circuit comprises five valves. The scanning voltage is generated by V_2 and is applied to V_3, which is a phase reversing stage. The anode output from V_3 is applied to V_4 and a cathode output from V_3 is applied to V_5, so that the inputs to V_4 and V_5 will be mutually in phase opposition. The anode outputs of V_4 and V_5 are delivered to the two horizontal deflection plates of the oscilloscope. An input of vision waveform is applied to V_1, which delivers it to V_2 to effect synchronisation.

The scanning waveform is generated primarily as a voltage by the relaxation oscillator formed by the condensers C_1 (with C_2 in parallel when the switch S_1 is closed) and the resistances R_1, R_2 and R_3. At the commencement of the scanning stroke, the upper plate of the condenser C_1 is at a large negative potential with respect to earth, and since the control grid of V_2 is connected to this point, this grid is heavily biased back, and no anode current is flowing. The condenser C_1 now commences to charge slowly, the rate of charging being governed by the time constant C_1 (R_1 + R_2 + R_3). The potential of the upper plate of C_1, and consequently that of the control grid of V_2, rises until after a time the control grid of V_2 will have become sufficiently less negative with respect to its cathode as to permit the commencement of a flow of anode current. This anode current passing through the primary P of the transformer TR generates a voltage in the secondary winding S. This voltage is applied to the control grid in series with the voltage from the top plate of C_1. The windings of the transformer TR are so coupled that the sense of the secondary voltage is such as to make the grid more positive. It follows that increased anode current will flow, which in turn will increase the positive voltage delivered to the grid by the secondary S, and in a very short time this cumulative effect builds up until the secondary voltage is very large and is endeavouring to drive the control grid strongly positive. By this time considerable grid current is flowing, and in view of the high value of the resistances R_1, R_2, and R_3, this can only be derived from the discharge of the condenser C_1. The voltage therefore on the upper plate of C_1, having slowly risen, rapidly falls with the advent of the cumulative effect following upon the commencement of anode current in V_2. The slow rise of the voltage on C_1 in the positive direction constitutes the forward, or scanning, stroke of the time base saw-tooth, and the rapid fall constitutes the fly-back. During the fly-back an important operation is taking place at the control grid, which will result in its being left strongly negative at the conclusion of the fly-back. The growth of anode current in the primary P is very rapid, and the voltage generated in the primary and proportionately in the secondary, being as usual proportional to $\frac{Ldi}{dt}$, will be of considerable magnitude. The secondary voltage is sufficiently great 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 with respect to the cathode. Therefore at the moment during the return stroke when the maximum anode current is being drawn and the maximum positive potential is being applied to the grid, there coexists on the latter, due to D.C. restoration, a negative charge equal in value to the amplitude of the induced positive pulse. When the pulse has driven the grid as far positive as the restoration of D.C. will permit, the anode current can increase no further and is for the moment stationary. There is now no change of flux in the transformer, and the positive pulse is withdrawn leaving 214

The Oscilloscope

The oscilloscope is illustrated in Fig. 19. It is, as has been mentioned, an electrostatically deflected cathode ray tube, and contains the following electrodes.

1. A heater, rated to take 1.3 amperes at 4 V A.C.
2. A cathode.
3. A cathode screen, normally connected to the cathode.
4. An accelerator, requiring a positive potential of 250 V.
5. A grid.
6. A first anode, requiring a standing positive potential of 400 V.
7. A second anode, requiring a standing positive potential of 2,000 V.
8. A pair of horizontal deflection plates.
9. A pair of vertical deflection plates.

All these electrodes, with the exception of the vertical deflection plates, are connected to a number of sockets arranged round the base of the cap. The vertical deflection plates, which should have a minimum of capacity to earth, are brought out to a pair of studs located on the glass envelope itself. The cap sockets are colour coded in the following manner.

Heater connections	Brown
Cathode	White
Cathode screen	Yellow
Accelerator	Blue
Grid	Green
First anode	Red
Second anode	Pink
Horizontal deflection plates	Black

Power Supply Units to the Tube, Amplifier and Time Base

H.T. and L.T. supplies for the D.C. Amplifier and the Time Base, and the L.T. supply for the tube heater, are all obtained from a power unit illustrated in Fig. 20. The H.T. is generated by the transformer TR_1, the primary of which is connected to the 500 c/s supply, in conjunction with the four parallel connected double wave rectifier valves V_1, V_2, V_3 and V_4. This unsmoothed supply is then smoothed by a constant resistance smoothing system. The first stage of smoothing consists of the inductance L_1, so that looking into the rectifier from the point A, there will be an impedance consisting of L_1 in series with the internal resistance of a rectifier, which is 130 ohms. This impedance is transformed into a pure resistance by the addition of the elements R_1 and C_1. The output is further smoothed by the condenser C_2, so that the impedance looking into the rectifier from the point A and taking into account the addition of C_2 now appears to be a resistance of 130 ohms in parallel with the condenser C_2. This impedance is restored

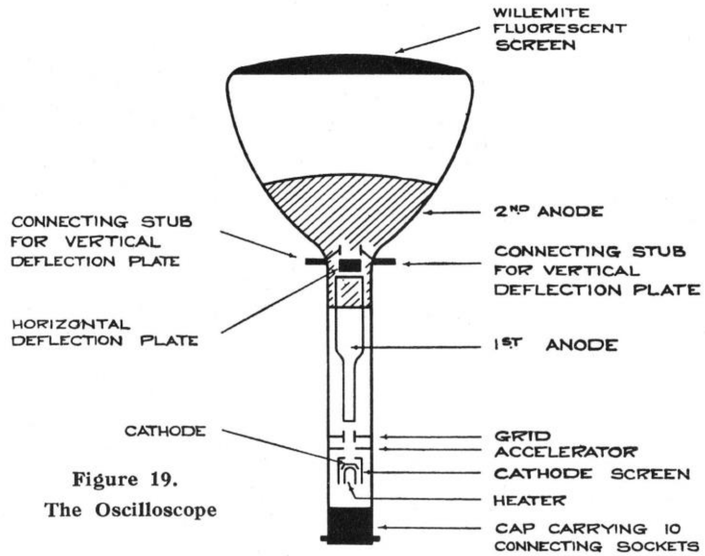

Figure 19.
The Oscilloscope

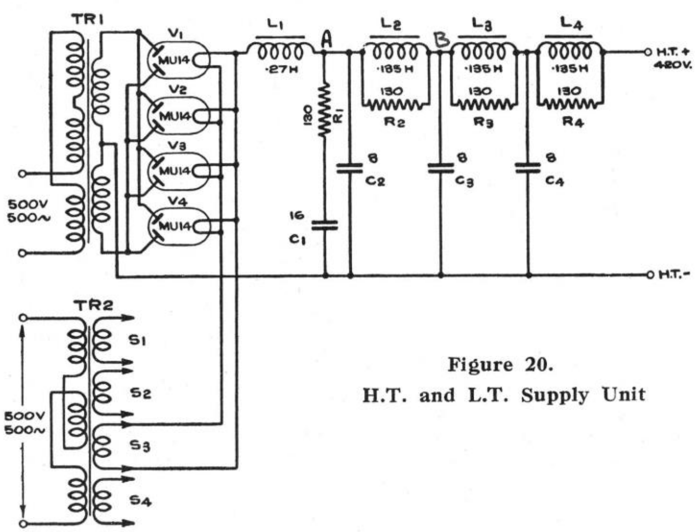

Figure 20.
H.T. and L.T. Supply Unit

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a negative charge due to D.C. restoration on the grid, which accordingly cuts off the anode current. The anode current in falling will induce a flux in the opposite direction in the transformer TR, which will momentarily drive the grid more negative than the potential due only to D.C. restoration; but when the anode current finally ceases, the flux in the transformer TR will again be zero and the negative pulse will cease, the negative potential of the grid being now that due to D.C. restoration alone. This last effect, however, involving the negative pulse on the grid, 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. The cycle of operations has now reached the point from which we started, the grid potential and that of the upper plate of the condenser C_1 being once more strongly negative, and the next forward stroke now commences.

A saw-toothed waveform will therefore exist across the condenser C_1. The time constant of the combination C_1 $(R_1 + R_2 + R_3)$ is approximately that required to generate the saw tooth at line frequency, but when frame frequency is required, the switch S_1 is closed, thus adding C_2 in parallel with C_1 and greatly increasing the time constant. In both cases a fine control of the frequency is obtained by the resistance R_2. The switch S_1 and the resistance R_2 are jointly brought out to a single manual control designated **Time Base: Line-Frame.**

The amplitude of the scan is controlled by varying the anode voltage of V_2. This voltage is taken from the potentiometer R_4, R_5, R_6, the section R_5 being made variable and being fitted as a preset control behind the panel. The elements R_7 and C_3 provide decoupling.

The saw-toothed output from the upper plate of C_1 is applied to the grid of V_3 via the condenser C_4 and the grid leak R_8. V_3 is not required to provide much gain, but should be as linear as possible, and accordingly its cathode circuit is provided with the unshunted resistance R_9, across which a considerable degree of feed-back is developed, which reduces the gain and improves the linearity. The cathode resistance R_{10} provides automatic grid bias, the grid leak R_8 being returned to the junction of R_9 and R_{10}.

The anode circuit of V_3 is normal and the anode output is applied via the usual coupling condenser C_5 and the grid resistance R_{11} to the control grid of the valve V_4. The cathode output from V_3 is taken from the upper side of R_9 via the coupling condenser C_6, and the grid resistance R_{12} to the control grid of V_5. The valves V_4 and V_5 are straightforward push-pull amplifiers having a small amount of feed-back provided by the unshunted cathode resistances R_{13} and R_{14}, which has the usual effect of rendering the valve characteristics more linear. The anode circuits contain the anode resistances R_{15} and R_{16} so that a voltage output in push-pull is generated at the anodes. These are directly connected to the two horizontal or x plates of the oscilloscope.

In order to hold the frequency of the saw-toothed oscillations generated by V_2 in synchronism with the vision input being examined, an input of vision signals is applied to the control grid of V_1 via the blocking condenser C_8 and the potentiometer R_{17} R_{18}. The section R_{18} is made adjustable in order that the firmness of the synchronism may be controlled, and this variable resistance is brought out as a manual control designated **Hold.** The valve V_1 is a straightforward amplifying stage having an anode resistance R_{19}, the anode output being coupled via the blocking condenser C_9 to the cathode of the oscillator V_2. Normal automatic grid bias is provided for V_1 via the elements R_{20} and C_{10}.

It will be noticed that a departure from normal practice is made in that the complete vision frequency waveform is applied to V_2 for the purpose of synchronising rather than synchronising signals only, which would be a preferable course. It will, however, be appreciated that the latter arrangement is not possible, since the vision waveform may be in either sense and it would be difficult to design a circuit for separating out the synchronising signals which would operate equally well for a vision input in either sense. Consequently no attempt is made to separate the synchronising signals from the complete waveform, the latter being applied unchanged except for amplification by V_1 to the control grid of V_2. Due to the presence of the picture components, the firmness of hold is not as good as would obtain had the picture components been eliminated, but the circuit is satisfactory in practice provided the frequency control R_2 is finely adjusted.

In order to ensure that the frequency generated by V_2 and the hold exercised by V_1 both remain constant, it is desirable to guard against any possible variations in the H.T. supply to these two valves. Accordingly the stabilising neon N_1 is connected across the potentiometer R_5 R_6, from which these two H.T. supplies are derived.

It will be remembered that an H.T. supply at 270 V for the screens of the output stage of the monitoring D.C. amplifier is required. This should also be stabilised, and it was found convenient to mount a simple neon stabiliser for this purpose in the Time Base unit. This stabiliser comprises the parallel resistances R_{21}, R_{22} and R_{23} and the two neons N_2 and N_3, the 270 V output being delivered from the upper side of the neon N_2, as shown in Fig. 18. In order to ensure that the two neons will strike they are shunted by the high resistances R_{24} and R_{25}.

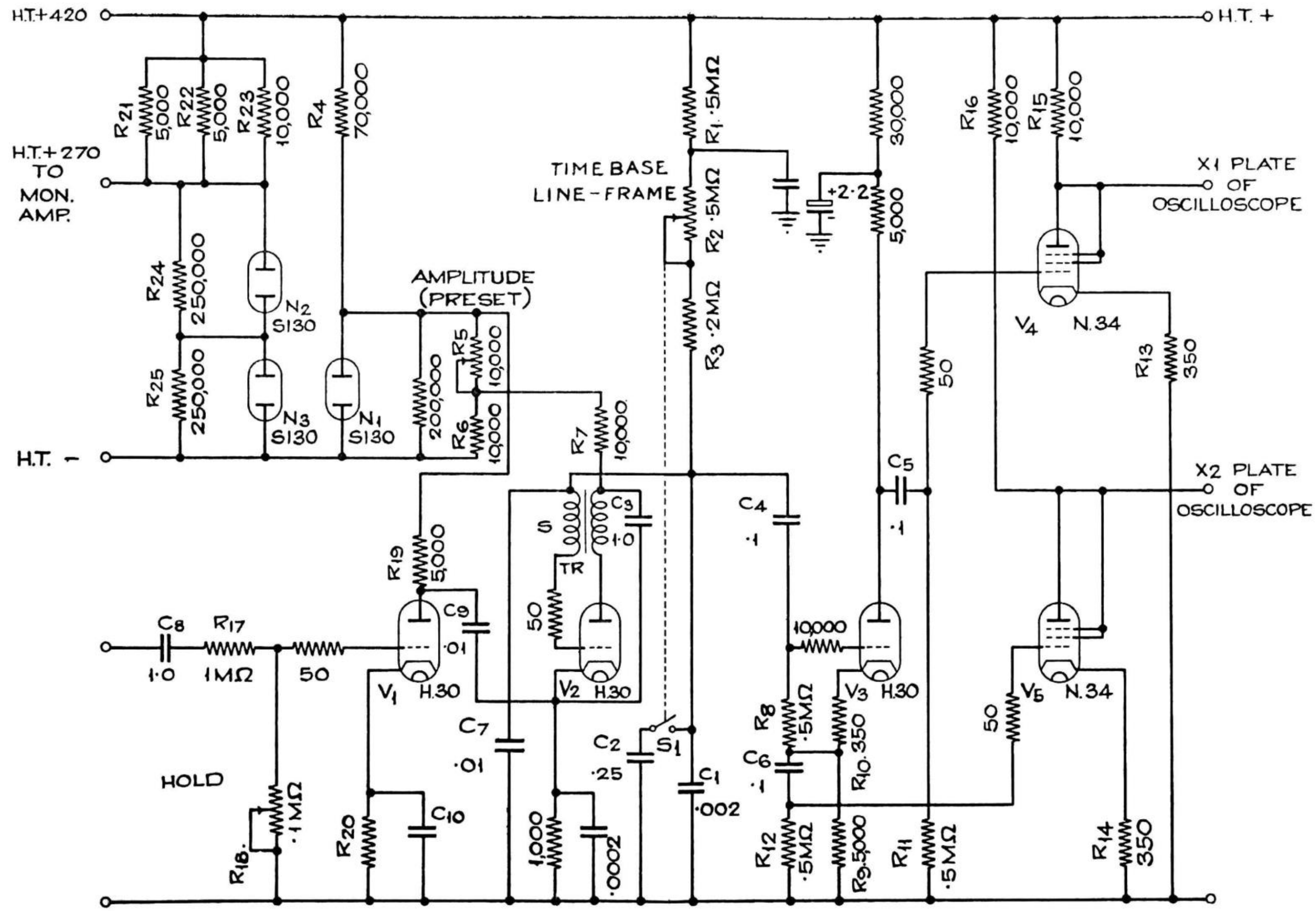

Figure 18. Oscillograph Time Base

to a pure resistance by the addition of the elements L_2 and R_2, so that looking back into the rectifier from the point B, the impedance is once more a pure resistance of 130 ohms. A further smoothing condenser C_3 is now added, the impedance being corrected as before by the addition of the elements L_3 and R_3. A similar final stage of smoothing follows comprising the elements C_4, L_4 and R_4.

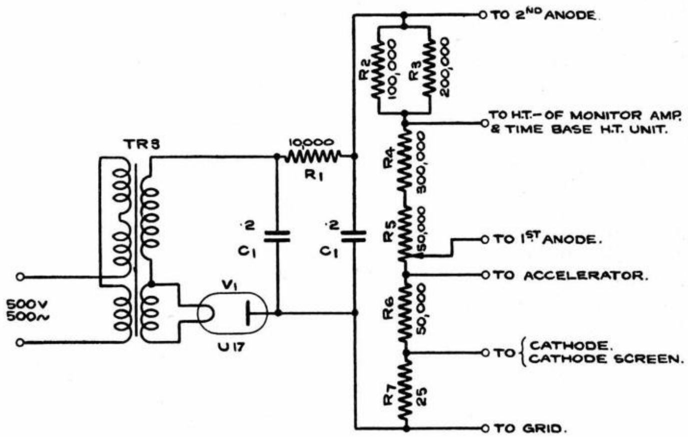

Fig. 21. 2000V H.T. Supply Unit

The L.T. supplies are provided by the transformer TR_2, the primary being connected to the 500 c/s supply. The secondary S_1 provides 3 A at 13 V for the D.C. Amplifier filaments. The secondary S_2 provides 2.1 A at 13 V for the time base filaments. The secondary S_3 provides 10 A at 4 V for the filaments of the rectifiers V_1, V_2, V_3 and V_4. The secondary S_4 provides 1.3 A at 4 V for the oscilloscope heater.

A further unit illustrated in Fig. 21 provides the 2,000 V H.T. supply for the oscilloscope gun electrodes. The H.T. is generated by the transformer TR_3 and the single $\frac{1}{2}$-wave rectifier V_1, and is smoothed by the simple network comprising the condensers C_1 and C_2, and the resistance R_1. This H.T. supply is then fed to the potentiometer, comprising the resistances R_2 to R_7, from the appropriate junctions of which the various gun electrodes derive their correct potentials. The focussing of the spot is dependent upon the ratio of the first and second anode potentials. Since this should be manually variable, the first anode potential is controlled by the variable potentiometer R_5, which is brought out to a manual control designated
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Focus.

Adjustments

There are no adjustments of the type which require to be specially set up before a transmission, but there are a small number of permanently preset controls. These comprise the negative grid bias potentiometers of the five monitor boxes illustrated in Figures 2 to 6, and the automatic grid bias resistance in the cathode circuit of the valves V_3 to V_6 in the monitor amplifier illustrated in Fig. 17.

Considering firstly the monitor boxes, the object in all cases is to arrange that at black level the cathode follower of a monitor box will pass 45 mA. In the case of the Line Amplifier and Sub-Sub-Modulator, black level can be obtained by simply turning the input potentiometer to zero, but in the Sub-Modulator, Modulator and Modulated Amplifier, true black level cannot be obtained unless the clamp is working, which entails the presence of synchronising signals. Before attempting, therefore, to set the grid bias potentiometers of the monitor boxes, the transmitter should be completely run up and black level and syncs radiated at normal level. True black level will now obtain in all circuits, but owing to the presence of synchronising signals the reading of a milliammeter in any given circuit for a given black level will depend upon the amplitude, duration and sense of the synchronising signals. The amplitude and duration will be standard, but the sense of the synchronising signals will vary with the particular monitor box being examined. In the boxes associated with the output of the Line Amplifier, the output of the Sub-Modulator and the aerial feeder, the synchronising signals are in the positive sense, whereas in the monitor boxes associated with the output of the Sub-Sub-Modulator and of the Modulator, the synchronising signals are in the negative sense. The integrated duration of the synchronising signals may be assumed to be 10 per cent., so that if a black level of 45 mA is required in all monitor box cathode followers, those in which the synchronising signal is positive must be set to give a reading of 50 mA under black level and sync conditions, while those in which the synchronising signal is negative should be set to show a reading of 40 mA.

The transmitter having been normally run up under black level and sync conditions, therefore, a milliammeter should be inserted in the anode circuit of each monitor box cathode follower in turn, and the grid bias potentiometers adjusted for the following readings :

Line Amplifier monitor box	50 mA
Sub-sub-modulator monitor box	40 mA
Sub-modulator monitor box	50 mA
Modulator monitor box	40 mA
Aerial Feeder monitor box	50 mA

With the transmitter still operating under black level and sync conditions, the automatic grid bias resistance (R_{26} in Fig. 17) may be set so that the combined anode current of the four valves V_3 to V_6 is 200 mA. Since this is a push-pull stage, there will be no synchronising signals in the common anode current and no correction is required. Each valve should then be taking 50 mA and will be operating over the middle of the linear portion of its characteristic.

Operation

All the power supplies to the monitor are switched on automatically by means of the Sub-Sub-Modulator H.T. push button contactor. The waveform should be brought into synchronism by means of the controls designated **Time Base** and **Hold.** The position of the controls should be adjusted until black level appears in the centre of the screen.

The **Focus** control should be adjusted until the waveform is as sharply defined as possible.

A calibrated scale enables the amplitude in volts of any part of the waveform to be measured, but owing to the potentiometer action of the monitor boxes the relation between scale divisions and actual volts at the point being examined will be different in each case. For normal working it is only necessary to have exact calibrations as regards line input and modulator output, and these are as follows:

Line input	0.55 V per division
Modulator output	110 V per division