TECHNICAL INSTRUCTION

T.5

BBC Frequency-checking Equipment

First issued March 1954

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CIRCUIT DRAWINGS

BBC FREQUENCY-CHECKING EQUIPMENT

SECTION A

INTRODUCTION

General

The term *frequency checking* as used in this Instruction implies the comparing of one frequency with another, adopted as a standard; it is not used in the sense of frequency measurement.

The items of apparatus described in this Instruction are:

The Type-FRC.2B Frequency Comparator.

The Type-FRC.2BM Frequency Comparator.

The Type-FCM Frequency Checking Monitor.

The Type-FRM.4 Frequency Monitor.

The first three items are alternative types which employ a cathode-ray tube as the monitor. They can be used (*a*) to enable the carrier frequency of a medium-wave transmitter to be adjusted to a standard value and (*b*) to enable synchronisation of medium-wave carrier frequencies to be obtained in common-wave broadcasting. The Type-FRM.4 equipment is used for frequency checking on short waves. Its principle of operation differs completely from that of the medium-wave apparatus and is separately described in Section C of this Instruction.

The term *synchronisation* strictly implies alignment of both frequency and phase but has long been used in connection with common-wave broadcasting to imply the approximate alignment of two or more carrier frequencies regardless of phase, and it is in this sense that the term is used in this Instruction.

To synchronise the carrier frequencies of transmitters situated at sites remote from one another it is necessary either to excite the transmitters from a common r.f. source or to provide some means of frequency comparison by which the frequency of independent high-stability drive equipments located at the individual transmitters may be adjusted to a common frequency. To drive all the transmitters from one r.f. source is ideal theoretically but is, in general, impracticable because of the difficulty in securing the perfect phase stability in the links which must be provided between r.f. source and the transmitters. Synchronisation by frequency comparison is the method used by the BBC.

Prior to 1944 the standard reference signal used for synchronisation was the carrier frequency of one of the transmitters in the common-wave group. This transmitter was termed the *master* and the others in the group the *slaves*. At the master station the carrier frequency was divided down to produce low-frequency tone. This tone was transmitted by line to the slave stations, where it was multiplied up to regenerate the original master carrier frequency. The difference between the slave carrier frequency and the regenerated master carrier frequency was found by beat-indication methods. This system has the disadvantage that a high order of phase stability is required in lines and associated apparatus if a clear indication of small frequency discrepancies is to be accurately observed. In some instances, particularly when large distances were involved or lines were noisy, clear beat indications were unobtainable.

This problem was investigated and new frequency-checking equipment was developed to overcome these disadvantages. This equipment, which first came into use in 1944, is now the standard BBC frequency-checking equipment. The operation of frequency checking in this system is dependent upon short-duration pulses which are derived from the reference tone. A cathode-ray tube forms the visual indicator and gives both the magnitude and sign of the frequency error.

The reference tone is 1 kc/s, either (*a*) generated by a master oscillator at Broadcasting House and transmitted by line to the transmitting station or (*b*) derived from the BBC 200-kc/s transmission, which is picked up by Type-RDT receiver equipments at the transmitting stations.

SECTION B

PRINCIPLES OF FREQUENCY CHECKING USING REFERENCE PULSES

Fundamental Principles

The improved system of frequency checking, introduced in 1944 and now representing the standard BBC practice, uses as the reference signal either 1,000 c/s tone generated by a master oscillator at Broadcasting House or 1,000 c/s tone derived from the Droitwich 200 kc/s transmission. From the reference tone, short-duration pulses are derived. Originally these pulses were produced at a repetition rate equal to the reference-tone frequency (i.e. one pulse per cycle of the 1,000 c/s tone), but for reasons given below, a pulse-repetition rate of 250 p.p.s. enables the comparator to have wider applications in frequency checking. The present practice is to divide the reference-tone frequency of 1,000 c/s by 4 in a divider included in the frequency-checking equipment, and to derive one pulse per cycle from the *divided* reference tone.

A cathode-ray tube is used as the indicating device, and the pulses are applied to its Y-plates. The time-base voltage, applied to the X-plates, is of saw-tooth waveform. This voltage is derived from the local r.f. voltage, and thus the time-base frequency is locked to the local r.f.

If an integral number of time-base cycles occur during the period of one cycle of the reference tone, i.e. if an integral number of time-base cycles elapse between the instant of one pulse and the next, then the trace of a pulse on the screen will be stationary. The process of frequency adjusting at the local station is that of adjusting the drive frequency to the setting which produces a stationary image. This will now be considered in closer detail.

Let F c/s = *correct* drive output frequency
N = division ratio of time base (i.e. F/N c/s is a time-base frequency giving a stationary image)
P = pulse-repetition frequency in p.p.s.

For pulses of very short duration, the interval of time between two successive pulses may be taken as $1/P$ second. When the local drive is adjusted to the correct frequency, the number of time-base cycles which occur in the period $1/P$ second is

$$\frac{F}{NP}$$

For a single stationary pulse this expression must be an integer.

All BBC medium frequencies are exact multiples of 1 kc/s. With a pulse-repetition frequency of 1,000, the expression F/NP will be an integer provided that N is a factor of $F/1{,}000$, (i.e. a factor of the r.f. expressed in kc/s).

For example, let $F = 908$ kc/s, $N = 4$ and $P = 1{,}000$. Then:

$$\frac{F}{NP} = \frac{908{,}000}{4 \times 1{,}000} = 227$$

Some BBC medium frequencies are prime numbers when expressed in kc/s, and with a pulse-repetition frequency of 1,000 the condition stated above, for a single stationary pulse image, cannot be satisfied. If, however, the values of N and P are so chosen that their *product* equals 1,000, then the expression F/NP will be an integer for all frequencies that are exact multiples of 1 kc/s.

For example, let $F = 1{,}151$ kc/s, $N = 4$ and $P = 250$. Then:

$$\frac{F}{NP} = \frac{1{,}151{,}000}{4 \times 250} = 1{,}151$$

In practice these particular values of N and P are generally used, but, depending on the frequency of the drive, it is sometimes possible to use other values of N. The r.f. to be checked is applied to a time base which is used to produce a saw-tooth waveform at one-quarter of the applied frequency. The time base is a free-running type which is locked by the r.f. input. The 1,000 c/s reference tone is applied to a divider dividing by 4 to give a frequency of 250 c/s, which is fed into a pulse generator designed to give an output of 1 pulse per cycle.

The production of a stationary pulse image does not, in theory necessarily indicate that the frequency being checked has a particular value, because a stationary image can be obtained for any value of F which is a multiple of 1 kc/s. This represents one of the virtues of the checking system, since it permits the use of one reference tone for general frequency checking in the medium-frequency band. In practice no ambiguity arises, because the system is only applied where the difference between the local r.f. and its correct value (an integral multiple of 1 kc/s) is likely to be extremely small.

The effects indicated on the screen of the cathode-ray tube when there is a small difference between the local carrier frequency and its standard value will now be considered. Let the frequency be n c/s high, where n is very much less than 1 kc/s, so that the frequency is $F + n$ c/s, and assume that the visible time-base deflection is from left to right across the screen.

The time-base frequency $= (F + n)/\mathcal{N}$ c/s.

The period between the instant of one pulse and the next is 1/250 second. In this period the time base will execute

$$\frac{F}{\mathcal{N} \times 250} + \frac{n}{\mathcal{N} \times 250} \text{ cycles}$$

The first term of the above expression represents an integral number of cycles; the second term, for a small value of n, represents a fraction of a cycle. Let the sweep distance across the screen of the tube $= S$. The additional fraction of a time-base cycle will move the tracing spot, in the direction left to right, a distance of

$$\frac{n}{\mathcal{N} \times 250} \cdot S$$

and each trace of the pulse will be displaced this distance to the right of the preceding trace.

The effect will be that the pulse trace will not be stationary but will travel across the screen, in the direction left to right, at a velocity equal to $n/\mathcal{N}$ of the sweep distance per second.

By similar reasoning it can be shown that if the local carrier frequency is n c/s low, the pulse trace will travel across the screen in the opposite direction (i.e. from right to left) at a velocity of $n/\mathcal{N}$ of the sweep distance per second.

A great advantage of this frequency-checking system over the earlier system will now be apparent: with this system the *sign* of the frequency discrepancy is indicated.

Stepped Time-base Deflection

In the above it has been assumed that the time-base deflection is linear, such that, in the absence of vertical deflection, the horizontal trace on the screen of the cathode-ray tube would appear as a uniform line. With this form of deflection there is the disadvantage that small erratic phase shifts in the reference tone would, if sufficiently rapid in occurrence, cause the pulse image to become confused. In this circumstance it would be difficult to observe accurately the arrival time of the pulse at any particular position.

This difficulty has been overcome by employing a stepped time-base deflection. The tracing spot moves during a half-period of the r.f. cycle, remains stationary for the next half-period, moves again during the succeeding half-period, and so on. The resulting horizontal trace appears as a straight line containing a number of bright spots. If the flyback of the time base were instantaneous, the number of bright spots would correspond to the division ratio of the time base, in this instance 4. In practice, the finite time taken for the flyback may be responsible for one of the spots being lost during this period.

In the condition of synchronism, and with the spot-calibrated time base, the pulse trace will be stationary. If the mean position, in time, of the pulse corresponds to one of the calibration spots, the pulse will appear as a vertical straight line standing on the calibration spot, as shown in Fig. B.1(*a*). If the mean position, in time, of the pulse is in the interval between two calibration spots, the pulse image will have the form shown in Fig. B.1(*b*).

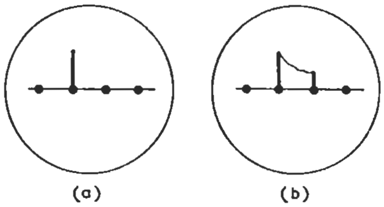

Fig. B.1. Pulse Traces on Cathode-ray Tube used with Calibrated Time Base having a Division Ratio of 4.
(a) *Pulse Instant Coincident with Calibration Spot,*
(b) *Pulse Instant in Interval between Spots*

With a small frequency discrepancy in the r.f. voltage the pulse image passes from spot to spot along the time-base trace, appearing as a vertical straight line on each spot in turn.

If there are any random phase shifts in the tone applied to the pulse generator (i.e. 250 c/s signal), with consequent shifts in the time of the pulses, then for a normal condition as represented in Fig. B.1(*a*) no apparent movement of the pulse image will be caused if the phase shift corresponds to a time displacement less than the time for which the cathode beam is stationary at the calibration spot. A greater degree of continuous random phase shifting, or modulation of receiver derived tone, will be responsible for the production of a confused image.

SECTION C

FREQUENCY-CHECKING APPARATUS

Frequency Comparator, Type FRC.2B (Figs. 1 and 2)

The frequency comparator Type-FRC.2B is a frequency-checking unit which operates on pulse-technique principles and incorporates a cathode-ray tube as the means of monitoring. The unit is built for rack mounting on a standard bay, has a panel depth of 11¼ in. and is normally used with Type-CP.17E crystal-drive equipment.

The comparator contains:

1. Time base,
2. Frequency divider,
3. Pulse generator,
4. Cathode-ray tube and its power-supply equipment.

The circuit of the complete unit is given on two diagrams, Fig. 1 showing details of items 1 and 4, whilst Fig. 2 covers items 2 and 3.

Operating supplies for the valves in the comparator are almost wholly drawn from external sources. The h.t. supplies for the time base, pulse generator and divider are obtained from the power-supply unit, Type HRL3 or Type HRL3A, used primarily with the Type-CP.17E drive equipment. The time base and pulse generator take their heater supplies from the l.t. transformer panel, Type LTT, fitted on Type-CP.17E bays specifically for use with frequency-checking apparatus. These external supplies amount to 7 amperes at 4 volts and approximately 65 milliamperes at 300 volts. A separate heater supply (0·6 ampere at 6·3 volts) is provided for the valves in the divider stages only, from the power transformer associated with the cathode-ray tube. The mains-input supply to the transformer is approximately 20 watts.

Plates I–III are photographs showing various views of the comparator.

1. *Time Base* (*Fig.* 1)

The time base is used for generating a voltage of stepped saw-tooth waveform, which is applied to the X-plates of the cathode-ray monitor tube. Before dealing with the practical time base shown in Fig. 1, the operation will be considered in general terms.

Principle of Operation

Fig. C.1 is a simplified diagram showing the basic arrangement of the time base; for clarity, screen-feed circuits for V1 and V3 have been omitted from the diagram.

The saw-tooth voltage is developed across C1, which is adjustable to enable ~~to~~ the time-base frequency to be locked to a sub-multiple of the frequency of the r.f. voltage applied to the input terminals. V2 is used for controlling the charging of C1 from the h.t. supply, and its anode is connected to the h.t. positive line through R1, of relatively small value. V3 is used as a triggering device for switching V2 rapidly from conduction to non-conduction, and vice versa. V1 is used for discharging C1 and conducts only during positive-going half-cycles of the r.f. input to its grid.

It will be assumed that the time base is in operation, the instantaneous circuit conditions for commencing the description being as follows:

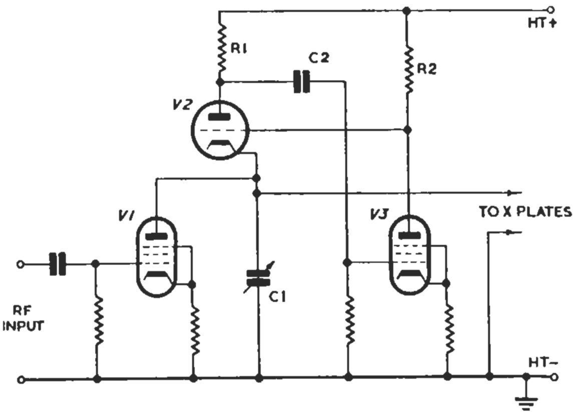

Fig. C.1. Simplified Diagram of Time Base

(*a*) V3 is conducting, the anode current being determined by the bias voltage developed across the cathode resistor.

(*b*) C1 is being discharged and the voltage across it is just sufficiently large to make V2 non-conductive, i.e. V2 cathode is slightly positive with respect to V2 grid.

(*c*) V1 is conducting and discharging C1.

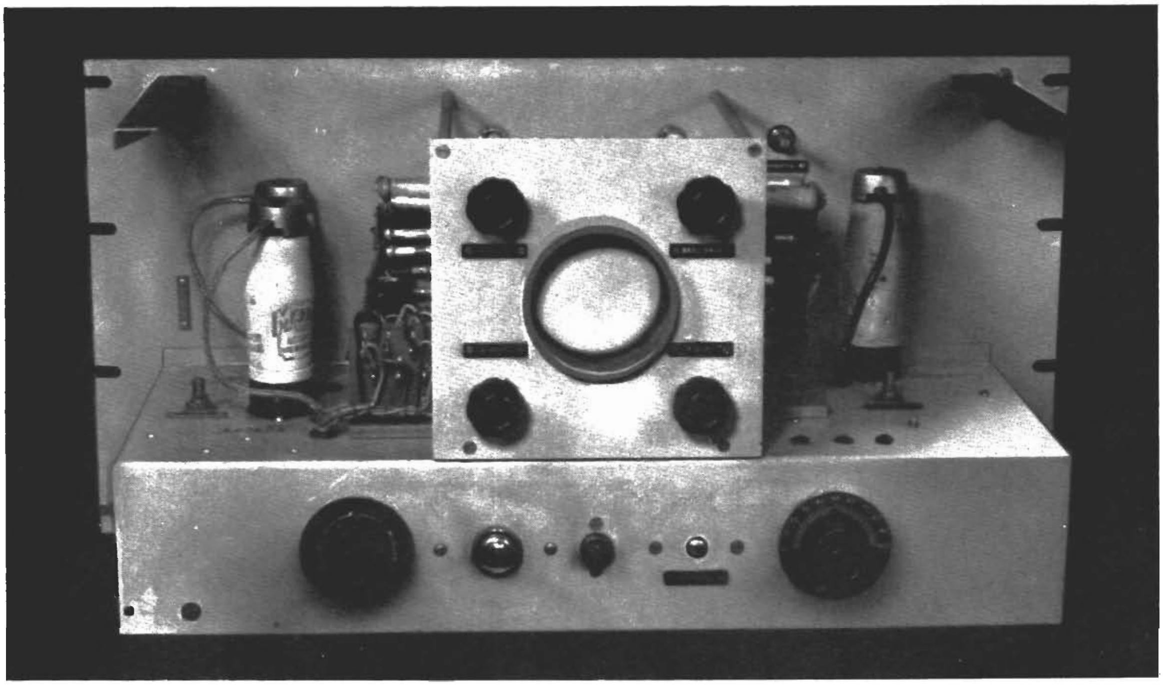

Plate I. *Frequency Comparator Type FRC.2B: Front View with Cover removed*

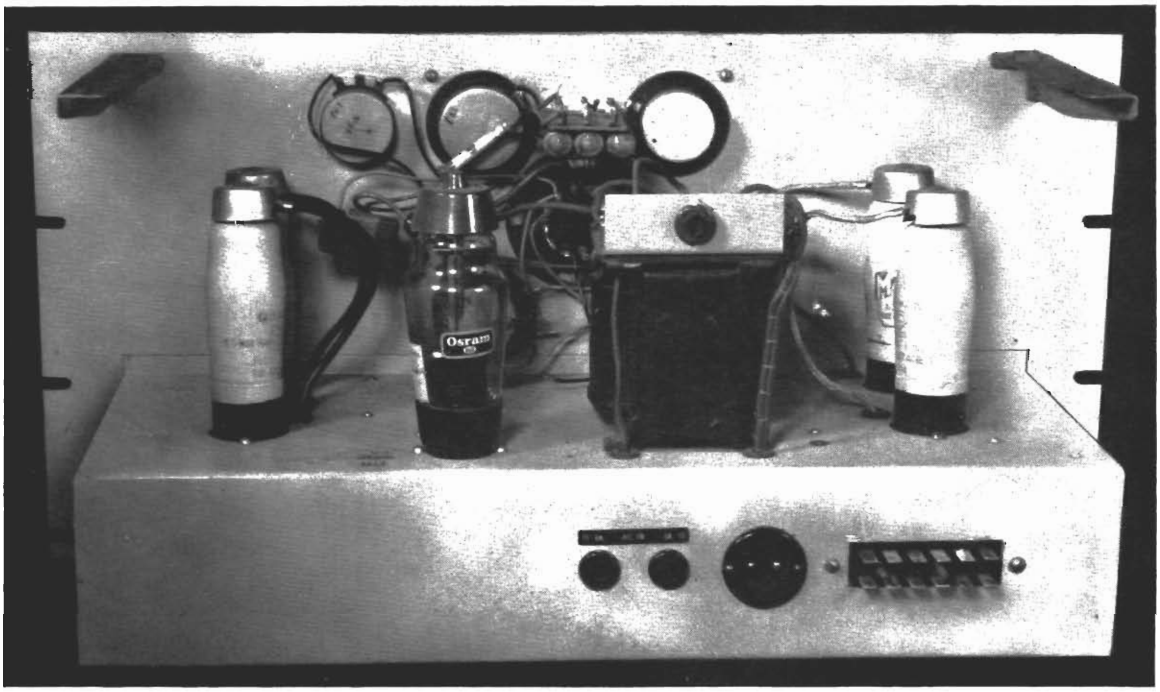

Plate II. *Frequency Comparator Type FRC.2B: Rear View with Cover removed*

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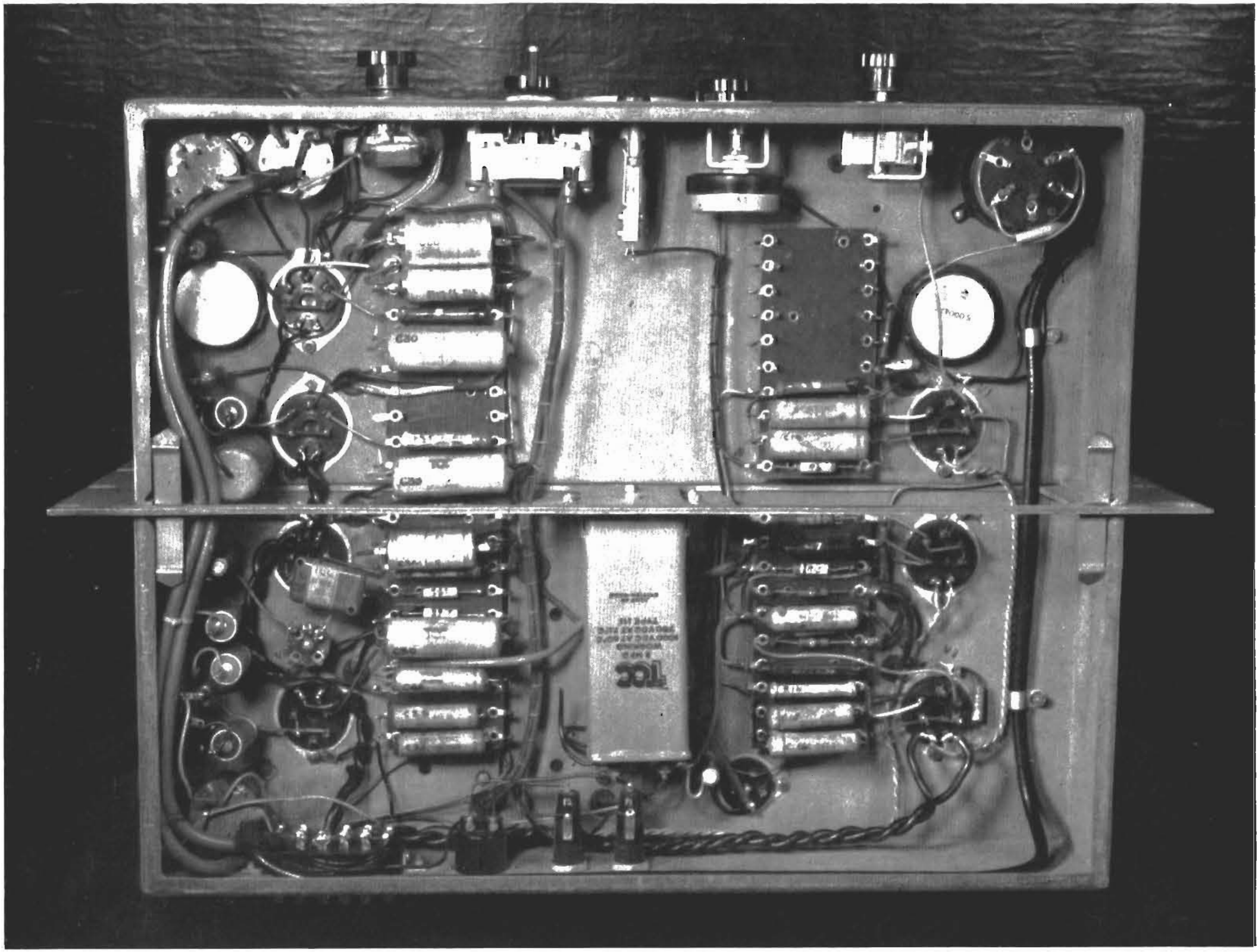

PLATE III. *Frequency Comparator Type FRC.2B: View of Underside of Chassis*

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*Charging of C*1

With the assumed initial conditions (*b*) and (*c*), the falling voltage on C1 soon reaches a value at which, due to the reduced V2 cathode potential, V2 starts to conduct.

If the grid potential of V2 were allowed to remain at the value fixed by the anode current of V3, very little charging current would flow into C1 because a slight increase of V2 cathode potential would be sufficient to cut off the V2 anode current. This tendency is counteracted, however, by the initially-small flow of current through R1, causing a negative-going voltage to be applied through C2 to the grid of V3. This causes the V3 anode voltage to rise, and thus the potential on the grid of V2 increases positively. In turn, the change of grid voltage increases V2 anode current, which leads to the negative-going signal increasing in amplitude, and a positive-feedback condition is established in which the V2 grid voltage moves rapidly towards h.t. positive as V3 anode current falls progressively towards zero. Thus C1 is subject to extremely rapid charging, the cathode voltage of V2 following the grid voltage in the positive direction.

The charging process ends abruptly. The voltage on the V2 grid rises to a limiting value closely approaching that of the h.t. positive line. Concurrently, the V2 cathode voltage is increasing until it attains a value at which the voltage across V2 starts to decrease. When this occurs, the anode current of V2 starts to fall, and therefore the amplitude of the negative-going triggering voltage also decreases. This reduction is equivalent, in effect, to applying a positive signal to the V3 grid; V3 starts conducting and the anode current of V2 is cut off abruptly.

This quick cessation is brought about by the positive-feedback action. In this instance it causes V3 anode current to rise very rapidly and, due to the voltage drop across R2, the V2 grid is driven considerably negative with respect to the V2 cathode. At the end of the feedback action the grid of V2 is held at a fixed potential which depends on the static anode current of V3.

C1 is now in a charged state, awaiting discharge by V1.

*Stepped Discharging of C*1

It will be assumed that the charging takes place during a period in which V1 has been rendered non-conductive due to the presence of a negative half-cycle of the r.f. input on its grid.

The arrival of the next positive half-cycle drives V1 into conduction and C1 begins to discharge. This process is interrupted by the arrival of a negative half-cycle, to be followed by another positive half-cycle in which discharging of C1 continues. The result of the alternation is that the voltage across C1, when measured against time, takes the stepped form shown in Fig. C.2; this diagram also includes the charging stroke.

By using a pentode for the purpose, the discharge current (pentode anode-current) is made virtually independent of the voltage across the capacitor, and thus there is constant-current discharging of V1. Thus a linear discharge of C1 is obtained and the voltage across the capacitor falls by an equal amount for each of a number of r.f. cycles fed into the time base.

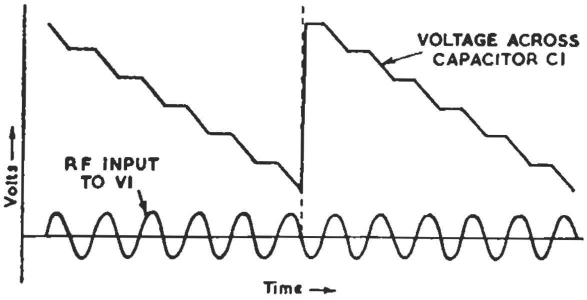

Fig. C.2. Stepped Saw-tooth Waveform of Time Base related to Applied R.F.

C1 continues to discharge intermittently until the voltage on the cathode of V2 has fallen to a value where the charge/discharge cycle commences again.

As the decrease of p.d. across C1 for each cycle of r.f. input approximates to a constant, it is a simple matter to choose the value of C1 so that charging commences after an integral number of cycles have elapsed. Thus the circuit functions as a divider in which the number of steps in the sawtooth waveform corresponds to the division ratio. Although capable of larger division ratios, the divider is normally adjusted to divide by 4 in the particular application with the frequency-checking apparatus.

Practical Circuit (*Fig.* 1)

Fig. 1 shows the circuit of the time base, which employs three Type-AC/SP3 valves. The valve reference numbers correspond to those of the diagram given in Fig. C.1, V2 having the anode, suppressor grid and screen grid strapped so that it functions as a triode.

In some of the Type-FRC.2B units the r.f. input is fed through a wide-band transformer, TR1, whilst in others it is taken directly to potentiometer R1, labelled 'Input.' This component is a presetting type (screwdriver adjustment) and is situated on the platform behind the front cover of the unit.

The other two controls are on the front panel. One is the variable capacitor C4, for adjusting the time-base frequency. The dial is marked *Velocity* and has a 180-degree scale divided into 100 parts. The other control is the variable resistor R5 in the cathode circuit of V1, labelled *Locking* and used for presetting the working mutual conductance of this valve.

2. *Frequency Divider* (*Fig.* 2)

The frequency divider has two stages, each dividing by a factor of 2, which are used to derive a 250 c/s output from the 1,000 c/s reference tone, for application to the pulse generator.

Each stage uses a Type-6F12 pentode in a circuit developed from the balanced-modulator divider. Apart from dealing with different frequencies, both stages operate similarly. The method of dividing is described below by references to the circuit associated with V10, in the first stage.

The reference tone is applied to the input transformer TR3 via an acceptor circuit, L2 and C24, tuned to 1,000 c/s. The transformer has an impedance ratio of 600 : 100,000 ohms. Its secondary is loaded by a fixed potentiometer, R48 and R50, the values of which are chosen to provide a suitable input voltage to the modulator in the grid circuit of V10.

In the anode circuit of V10 is the transformer TR4, with the primary tuned by C42 to resonate at a frequency of 500 c/s. The secondary is connected between diagonally-opposite corners of a bridge formation of instrument-type metal rectifiers. The other two corners of the bridge are connected to the grid of V10 and earth. This arrangement of half-wave rectifiers is, in applications of this sort, generally known as a Cowan modulator, although its arrangement is identical with that of the full-wave bridge rectifier employed for power-supply purposes; the connections from TR4 are taken to the *d.c.* terminals.

(The difference in the ring modulator, used in balanced modulator dividers, is that all four rectifiers face the same way when moving round the bridge.)

A disturbance of the circuit conditions, such as the application of h.t., causes a surge in the anode circuit and excites the tuned primary of TR4 into oscillation at 500 c/s, the voltage developed across the secondary being fed to the modulator. During one half-cycle of the 500 c/s signal all rectifiers of MR1 conduct, and thus the grid of V10 is connected to earth through a resistance of relatively low value. With this condition only a small part of the 1,000 c/s signal developed across R50 is applied to the valve, the fraction being dependent on the 'forward' resistance of the modulator in relation to R49.

During the next half-cycle of 500 c/s signal the rectifiers are non-conductive, and their high 'backward' resistance in this state results in a large fraction of the voltage across R50 being transferred to the valve. Fig. C.3 illustrates the effect produced by the modulator on the signal applied to the grid of V10. This diagram has been simplified by the assumptions (*a*) of an arbitrary phase relationship between the 1,000 c/s and 500 c/s signals and (*b*) that instantaneous changes occur between two values of grid/earth resistance representing the conducting and non-conducting states of the modulator. In practice, of course, the resistance curve will not be rectangular, as indicated by the dotted line in Fig. C.3, the shape of the curve being dependent on the voltage/resistance characteristics of the rectifiers.

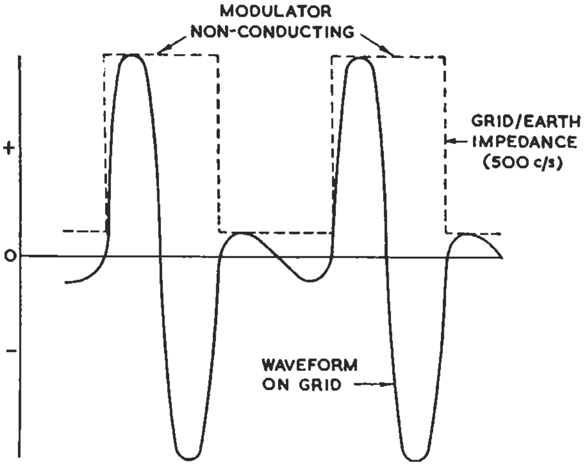

Fig. C.3. Showing the Effect of imposing 500 c/s Modulation on 1,000 c/s Carrier by means of Cowan Modulator

As a result of the rectification in the grid circuit, the signals appearing at the anode of V10 consist mainly of 1,000 c/s carrier together with the sum and difference sideband frequencies 1,500 c/s and 500 c/s. Of these frequencies only the 500 c/s component is subject to large amplification by V10, due to the selective nature of the anode load. Thus the signal passed through C43 for further division in the following stage has an almost pure 500 c/s waveform, as shown by inset (3) of Fig. 2.

The 500 c/s signal also maintains the modulator in action, but this is not accomplished by feedback as it is usually understood in connection with valve oscillators. On the contrary, the method of modulating through the intermediary MR1 obviates the possibility of the modulating voltage being applied across the grid circuit, provided that the rectifiers in the modulator form a balanced bridge. Thus the divider in a quiescent state is stable, and any 'ringing' of the tuned-anode circuit will die out rapidly unless the 1,000 c/s input is present to support the modulation process. Despite the stability, the use of a high-Q primary in TR4 ensures that the divider is self-starting, and applying the reference tone, either before or after the power supply, is sufficient to set it into operation.

The chief merits of the type of circuit described are (*a*) simplicity, compared with the balanced modulator divider, for which two accurately balanced transformers are required, (*b*) reliable division by factors up to 5 can be obtained by suitably adjusting the values in the tuned circuit, and (*c*) operation which is largely independent of changes in the h.t. voltage.

The two valves, V10 and V11, are situated near the cathode-ray tube towards the front of the unit. To their left is a terminal block through which the divider input, output and power-supply connections are taken. The block can be seen in the photograph (Plate I), and the circuit positions of the numbered tags are shown in Fig. 2.

3. *Pulse Generator* (*Fig.* 2)

The pulse generator produces short-duration pulses, at a rate of one per cycle of the approximately sinusoidal input, for application to the Y-plates of the cathode-ray monitor tube. It is a four-stage amplifier with an AC/SP3 valve in each stage, the first two valves being operated as pentodes whilst the last two work as triodes.

The 250 c/s input from the divider is passed to the grid of V6, the first stage, through a simple resistance-capacitance phase-shifting network, of which R26 is a variable element. This resistor is the *Phase Shift* control, used for positioning the pulses in the horizontal sense on the screen of the monitor tube.

The valve V6 is driven hard and acts as a limiter. The centre of the wave, about the zero datum, is given maximum amplification, whilst the remainder of the cycle is subject to the limiting process.

Under normal operating conditions the anode current of V6 is swept between the two extremes of cut-off and limitation. To ensure equal limits for the corresponding positive and negative excursions of anode voltage V6 is given a static operating condition in which the h.t. voltage is divided equally between the valve and the anode-load resistor R30. This condition is obtained by making R30 a high value and by choosing a suitable value of screen-grid voltage.

The high-value resistor R28 in series with the grid of V6 is for limiting the flow of grid current during the positive half-cycles of input signal. Its presence is responsible for causing clipping of the positive half-cycles, with the result that the voltage waveform on the grid itself is similar to that shown on inset 5 of Fig. 2.

V6 has a variable cathode resistor R29, used for adjusting the value of negative bias on the grid of the valve. This *Origin* control acts differentially on the input signal and is correctly adjusted when the static anode current of V6 is at the midpoint of the I_a–V_g characteristic. The effect of correct adjustment is to obtain a symmetrical operating condition.

The anode-voltage waveform, shown in inset 6 of Fig. 2, is that of a clipped sine wave whose peak amplitude, in the absence of limiting, would be equal to the peak amplitude of the input signal multiplied by the gain of the stage. The peak-to-peak amplitude of the anode voltage cannot exceed the h.t. supply voltage, and therefore the full voltage amplification is only realised at the centre of the wave before limiting occurs.

The output waveform of V6 has sides which are not truly vertical, and also rounded corners due to the comparatively gradual change of slope on the I_a–V_g characteristic near the limiting positions. Further amplification and limiting are provided in the next stage, V7, to obtain a substantially-rectangular waveform derived from the centre of the signal. The main function of this stage is to produce a steep slope on the negative-going part of the anode-voltage waveform, as this voltage is used for abruptly cutting off the cathode emission of the valve in the next stage.

To achieve this steepness V7 must be capable of passing a large anode current so that any stray capacitances in the circuit will be discharged quickly; the anode and screen resistors are therefore lower values than those in the first stage. The bias resistor R34 in the cathode circuit is a higher value than usual to prevent a large cathode current in the static condition, and, as in the first stage, there is a high-value resistor R33 in series with the grid to limit grid current. The output waveform of V7 is illustrated on inset 7 of Fig. 2.

The pulses are generated in the third stage, in which V8 is a triode-connected pentode with an inductor, L3, in the anode circuit. The application of the output waveform of V7 to the grid of this valve causes the anode current to be cut off and released very abruptly, on the negative-going and positive-going slopes respectively, at approximately the times when the amplitude of the input wave is zero. The pulses of anode current produce pulses of voltage across L3 which, due to being shunted by its self-capacitance and stray capacitances, is effectively connected in a parallel-tuned circuit.

The effect of suddenly stopping the flow of anode current is to cause a rapid rise of anode voltage, so that the capacitance across L3 is charged. Next, the shunt capacitance discharges through L3 and is subsequently recharged as the field about the inductor collapses. Thus the sudden change is responsible for shock-exciting the tuned circuit into oscillation at its frequency of resonance, an effect usually referred to as *ringing*. The oscillations are highly damped by the resistance of the inductor and die out after a few cycles have been completed. During the positive-going part of the input signal the abrupt commencement of anode current initiates a similar train of oscillations, but in this instance the first half-cycle starts in the negative direction. This method of producing pulses is particularly useful, as the pulse width is determined by the frequency of resonance of the tuned circuit and can be adjusted merely by altering the value of inductance or shunt capacitance.

The pulsed waveform is passed to V9 by conventional resistance-capacitance coupling, but the components used for the purpose, C35 and R42, are both made relatively low values in order that the RC combination shall have a short time-constant. By this means the waveform is subjected to *differentiation*, which has the effect of discriminating in favour of the first half-cycle in each group of pulses. The modified waveform at the grid of V9 is illustrated on inset 9 of Fig. 2, in which each leading half-cycle appears as a 'spike' of large amplitude in relation to the remainder of the wave.

The final stage functions as a current amplifier and also serves to reject all but the first half-cycle in each positive-going wave train. The pentode valve, V9, is connected as a triode, and the output pulses for the monitor tube are taken from its cathode circuit. A simplified basic circuit of the final stage is shown in Fig. C.4 to facilitate a description of the operation.

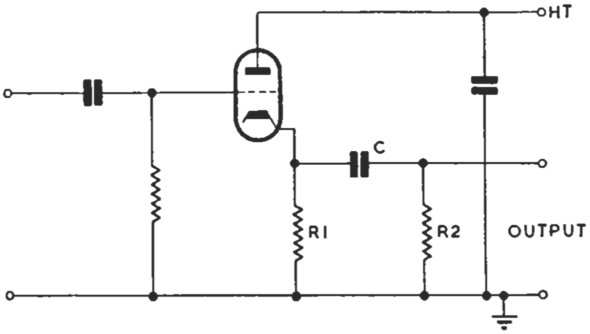

Fig. C.4. Final Stage of Pulse Generator: Basic Circuit

The valve draws very little anode current in the static condition, due to its grid being biased highly negative by the voltage developed across the cathode resistor R1. During the rapid positive-going excursion of grid potential, provided by the waveform of inset 9, the large-value capacitor C has little time in which to charge, even though R2 is very small compared with R1. Thus, although there is a heavy flow of anode current, most of which passes through R2 into C, the voltage across the capacitor rises only very slightly.

On the arrival of the negative half-cycle of the input wave the valve current is cut off and C starts discharging through R1 and R2 in series. This condition differs from that during charging, when R2 only is in series with the capacitor, and the great increase of resistance means that only a fractional discharge can take place in a similar interval. The result is that after one cycle there is a net gain in the charge on C and the cathode potential becomes slightly more positive. Successive cycles slowly increase the charge until equilibrium is reached, when the discharge through R1 and R2 offsets the reduced charge acquired during the positive half-cycle.

The progressive increase of cathode voltage is equivalent to gradually increasing the negative bias on the grid, and thus the valve conducts for less and less of each input cycle until the balanced charge/discharge condition is attained. By varying the value of R2, any desired portion of the peak of the positive-going half-cycle can be accepted and passed on to the cathode-ray tube. Inset 10 of Fig. 2 shows these positive-going pulses, which have a repetition rate of 250 per second.

It is interesting to note that with short-duration pulses at comparatively low repetition frequency it is possible to develop 30 volts across a 300-ohm resistor, representing a peak current flow of 100 mA from a valve with a maximum continuous rating of 20 mA. The exceedingly high instantaneous flow is due to the sudden release of the space charge which collects near the cathode when the grid potential is negative. The mean anode current of a valve operating under these conditions is usually only one or two milliamperes, as indicated by a meter.

The anode circuits of V8 and V9 incorporate decoupling elements with the object of preventing the steep-fronted waveforms passed by them from being superimposed on the h.t. supply. As a further precaution, the h.t. supply for the valves in the pulse generator is fed through an inductance-capacitance filter, L4 and C37, to ensure that no component of the pulse repetition frequency is fed back through the supply unit to other items of equipment.

4. *Cathode-ray Oscillograph and its Power Supply* (*Fig*12)

The circuits of the oscillograph and its power-supply equipment shown in Fig.12 are arranged conventionally apart from the inclusion of certain components used in a pulse-brightening circuit. The purpose of this circuit is to compensate for the lack of illumination of the tube screen which results from the relatively low repetition rate of the pulses. The method is to modulate the beam by applying the pulses to the grid of the tube in addition to their being applied to the deflecting plate Y1.

The e.h.t. supply for the tube is derived through a half-wave rectifier circuit loaded by a series chain of fixed and variable resistors to enable suitable intermediate voltages to be tapped off for various electrodes. Two of the three variable elements in this chain are the externally-operated potentiometers, R21 (*Brilliance*) providing for limited adjustment of the negative bias on the grid, and R19 (*Focus*) for adjusting the potential on the second anode. The third is a variable resistor, R47 (*Brighten*), situated on the main panel inside the comparator; it is a presetting type for determining the range of adjustment obtainable from R21. The negative voltage from these controls is applied both to the grid of the tube and to the anode of a diode in the pulse-brightening circuit.

The other two externally-operated controls are potentiometers R17 (*X-shift*) and R16 (*Y-shift*) for moving the position of the trace in the horizontal and vertical directions respectively by adjustment of the d.c. potentials on the X1 and Y1 deflector plates. The potentiometers are connected in series with fixed resistors across the 300-volt h.t. supply for the comparator. The method of linking this circuit with the e.h.t. circuit through R18 gives each control a working voltage range extending positively and negatively with respect to earth. With this arrangement the control can be used to apply either a positive or negative potential to the associated deflecting plate, thus enabling the trace to be moved to either side of a mean position.

The pulses used for brightening purposes are fed through blocking capacitor C18 to a potential divider consisting of L1 and R22 in series. The resistor is effectively connected between grid and cathode of the tube, as also is the diode V4 used for limiting. The negative bias on the grid of the tube is adjusted to reduce the intensity of the beam below normal in the absence of the pulse signals. The arrival of a pulse provides a positive voltage to the grid and increases the illumination for the duration of the pulse.

For the whole of the deflection pulse to be subject to a constant degree of brightening it would be necessary for the signal applied to the grid to rise instantaneously to the required voltage and remain at that value until the pulse ended. In practice, however, the pulse waveform is not rectangular but approximates to a half sine-wave. With a brightening signal of this shape there would be gradual brightening of the deflection pulse up to a maximum at the peak amplitude, and then a gradual decrease to minimum as the pulse voltage fell towards zero. The effect would be to produce a pulse image which when stationary on the screen appeared as a vertical line decreasing in brightness from top to bottom.

The method used to obtain substantially constant brightening, so far as the image is concerned, is to provide pulses of large amplitude to the brightening circuit and arrange for the voltage appearing on the grid to be restricted by means of the limiter. This is equivalent to increasing the brightening level whilst ensuring freedom from over-modulation, which would cause defocusing, on the peaks.

The diode V4 is connected with its anode negative to the cathode by the bias voltage applied to the tube and thus does not conduct until the pulse amplitude reaches a value approximately equal to the bias voltage, when the instantaneous grid voltage will be zero. Limiting is effected by means of the inductor L1, which is of much larger impedance than the diode in the conducting state.

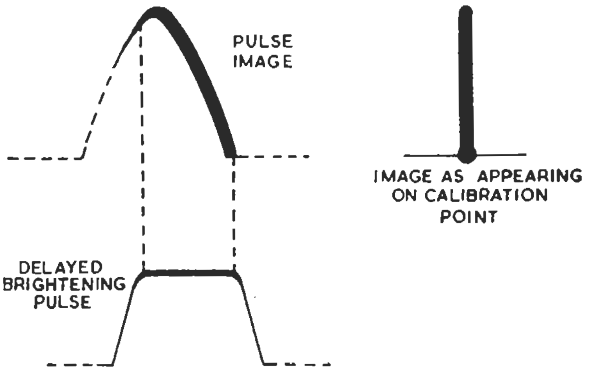

Fig. C.5. Showing the Effect of Limiting and Delay on Brightening of the Pulse Image

The inductor is responsible also for delaying the brightening pulses, with the result that brightening extends to the base of the pulse image, as shown in Fig. C.5.

Operating Instructions for Type-FRC.2B Comparator

(*a*) *R.F. Input to Comparator*

In most instances the comparator is used for checking the frequencies of several r.f. drive equipments, not necessarily working on the same frequency. In these circumstances the outputs of all the drive equipments are taken to a link panel, from which each can be connected through an individual attenuator to the comparator. The attenuator associated with each r.f. drive is set to provide a suitable input voltage to the comparator time base. The voltage required is dependent partially on the frequency being checked, and thus no particular value can be given. The operation of the time-base controls is given below.

Velocity Control

This control is adjusted to the position in which the time base is dividing by four, as indicated by the presence of four dots in the time-base trace. This is the normal condition, but in a few instances it may only be possible to obtain a setting in which three dots appear, due to one being lost in the flyback period. This effect is due to a combination of two factors, the frequency being checked and larger stray capacitance than usual in the particular comparator.

This control requires careful adjustment, as if set inaccurately there is a possibility of a dot-twinning effect similar to that due to inadequate locking.

Locking Control

The locking control is adjusted to produce sharply-defined single dots along the time-base trace. Incorrect adjustment is shown by the presence of pairs of dots spaced at intervals. When the comparator is used for checking different frequencies, the control is set to an optimum position which is a compromise between the settings required for the individual frequencies.

(*b*) *Reference-tone Input for Comparator*

The required level of reference tone for the comparator is + 4 db. The purposes of the controls in the reference-tone circuits are given below.

Phase-shift Control

The *Phase Shift* control is provided for use in circumstances where the pulse trace is moving slowly but appears at an inconvenient position for counting the beat period. An example of this is where the pulse trace is moving slowly to the right and appearing at the right-hand end of the time-base trace. As the trace moves onwards there would be a long period in which it could not be seen, due to the pulses occurring during the flyback period of the time base. The time taken would depend not only on the speed with which the trace was travelling but also on whether one of the time-base dots was missing, a possibility mentioned above. In other words, it would depend on whether the extreme left-hand dot was the next or the next but one from the dot on the right-hand end of the time-base trace.

Thus with a small frequency error much time would be spent in waiting for the pulse to reappear. By means of the *Phase Shift* control, however, the pulse can be moved instantaneously. It is only necessary to turn the control in either direction to an extent which places the pulse trace in the required position.

Origin Control

The correct setting for this control has to be ascertained whilst the pulse trace is stationary. As a preliminary, the reference tone is fed to the comparator via a switched attenuator with a loss of about 4 db. A rapid insertion and removal of the 4 db loss pad will cause the pulse trace to move to one side of its normal position. Whilst still operating the attenuator, the *Origin* control is rotated slowly until it reaches a position where the pulse trace is just starting to move to the opposite side of its normal position. The required setting is that in which the minimum movement occurs as the attenuator is being switched into and out of circuit.

(*c*) *Estimating the Frequency Error and its Sign*

To provide some idea of the way in which the frequency error is indicated it will be assumed that a frequency of 1,000 kc/s is being checked by the comparator. This frequency is chosen for convenience only, and the argument given below can be applied equally to frequencies actually used. It will also be assumed that the pulse trace is initially over one of the four dots showing on the time-base trace.

If the frequency being checked is correct, then during the interval (1/250 sec.) between successive pulses 4,000 cycles will be applied to the time base. With the division ratio of 4, these will be divided into 1,000 groups and superimposed so that four dots are continually shown on the screen of the tube. As there are an exact number of groups, the two successive pulses appear above the same dot and will continue to do so as long as the frequency remains correct.

Suppose that the frequency is 1 c/s high. Then, in the interval between two successive pulses, the output from the time base will be 1,000 groups of 4 cycles plus 1/250th of a cycle. Thus the second pulse will be displaced along the time-base datum a distance equivalent to 1/250th of a cycle in 1/250 sec., that is, a distance equivalent to one cycle in one second. One cycle is represented on the time-base trace by the distance between two adjacent dots, and therefore, with an error of 1 c/s, the pulse trace will move from one dot to the next in one second.

By the same reasoning, it can be shown that an error of + 0·5 c/s and + 0·1 c/s will move the pulse trace from one dot to the next in 2 seconds and 10 seconds respectively. This is another way of saying that the error, in c/s, is the reciprocal of the time taken, in seconds, for the pulse trace to move from one dot to the next.

The monitor tube is placed with the X1 plate to the left and the X2 plate to the right, as viewed from the front. With this positioning, the electron beam is moved towards the right by a decrease in the positive voltage applied to the X1 plate from the time base. Thus, considering the output voltage of the time base, the visible deflection takes place from left to right and the flyback of the spot from right to left.

For the stated direction of visible deflection, the pulse trace moves to the right for positive frequency errors and to the left for negative frequency errors, as described on page 3.

(*d*) *Cathode-ray Tube*

Monitor Tube Controls

These four controls, labelled *X Shift*, *Y Shift*, *Focus* and *Brilliance*, are grouped round the front of the tube. Their purpose is self-explanatory and their operation is conventional.

Brighten Control

This control is used for adjusting the brightness of the pulse trace. Normally it is left at the maximum position, and the tube hood should be so placed that maximum shadow is cast over the tube face.

Mumetal Screen

The screen must be in its usual position, surrounding the tube, when the comparator is to be used. This precaution is necessary to avoid distortion of the trace due to the beam being deflected by external magnetic fields, chiefly that produced by the mains transformer.

Frequency Comparator Type FRC.2BM (Fig. 3)

The Type-FRC.2BM comparator is similar, both electrically and operationally, to the Type FRC.2B but is considerably smaller and has completely self-contained power-supply equipment. The power consumption is approximately 75 watts. The circuit diagram of the comparator (Fig. 3) shows few changes from that of the Type FRC.2B (Figs. 1 and 2) in both circuit arrangement and component values. There are, however, an appreciable number of differences in component types, chiefly of capacitors. Photographs showing the layout of the comparator are given in Plates IV–VII inclusive.

The comparator is assembled on a standard 22-in. rack-mounting panel which is 5⅝ in. high, half the corresponding dimension of the Type-FRC.2B model; the front/back measurement of both units is approximately the same. To facilitate access to components on the front deck the front panel is hinged at the bottom corners so that it can be pulled outward and downward after removing the front cover and two screws, placed one on either side of the metal visor-plate of the monitor tube (see Plates IV and V).

The reduction in size can be attributed partly to the use of Type-EF50 valves in all stages, this type being an equivalent of the much taller Type-AC/SP3 valves (excepting the heater voltage and current), and also Type-6F12 valves employed in the larger unit.

The various sections of the comparator are briefly referred to below in relation to their counterparts in the Type-FRC.2B comparator and followed by details of the additional power-supply circuit.

1. *Time Base* (*V*1, *V*2 *and V*3)

Identical in component values and circuit, without the potentiometer for controlling the input to V1.

2. *Frequency Divider* (*V*10 *and V*11)

Identical in component values and circuit. An addition is the monitoring jack for the reference tone, mounted on the front panel and connected across terminals 11 and 12.

3. *Pulse Generator* (*V*6, *V*7, *V*8 *and V*9)

Apart from two changed component values, these circuits are identical with those of the Type FRC.2B. L3, in the anode circuit of V8, is 1 millihenry instead of 500 microhenries, and R46 in the output circuit is 1,000 ohms instead of 330 ohms. References to the effect of altering these values are made on pages 8 and 9 respectively.

4. *Cathode-ray Oscillograph and its Power Supply*

The cathode-ray tube is the same type, and its power supplies are derived by similar means to those employed in the Type-FRC.2B comparator. The e.h.t. circuit, however, is designed to provide a larger output voltage to enable the tube to be operated with much higher d.c. potentials on the various electrodes.

The power transformer has an e.h.t. winding giving a maximum output voltage of 2,000 volts, but is used with the connection for the rectifier circuit on a 1,500-volt tapping. The half-wave rectifier valve V5 is a Type U33 with a maximum input-voltage rating of 6,300 volts compared with 2,500 volts for the Type U17 which it replaces. Its maximum d.c. output rating is, however, only 3 milliamperes, one-tenth that of the Type U17; the total value of resistance in the load, comprising the smoothing resistor and the potential-divider circuit, is sufficiently high to ensure a normal load within this figure (see table on page 13).

The use of a higher e.h.t. voltage has necessitated a rearrangement of the potential-divider circuit in order to provide suitable ranges of adjustment for the three controls, *Brilliance* (R21), *Brilliance* (R47) and *Focus* (R19). In addition there are changes at the high-potential end of this circuit, permitting the value of negative bias applied to the grid of the tube to be made different from that on the anode of the limiter diode V4 in the pulse-brightening circuit. As can be seen in Fig. 3, the two bias voltages will not be completely independent, as the grid/cathode voltage for the tube is determined partly by the setting of R21, used primarily for adjusting the negative bias on the anode of the diode. This effect is not reciprocal, as the bias for the tube can be altered by means of R47 without affecting the diode bias.

In the pulse-brightening circuit the slight change in value of L1 is not specially significant; it is due to fitting a different make of inductor.

5. *Power Supplies for Valve Stages*

Supplies for valves in the time base, pulse generator and frequency divider are drawn from internal power-supply equipment whose circuit arrangement is given in Fig. 3.

The primary of transformer TR6 is tapped for mains voltages of 200 volts to 250 volts in 10-volt steps and connected in parallel with the primary of TR2 (oscillograph supply), so that energising of both is controlled by a rotary-type d.p. switch S2, below the *Phase Shift* control on the front panel. The common pair of mains fuses, F1 and F2, are at the rear with the mains-input socket.

The outputs from TR6 comprise (i) an h.t. supply to a full-wave rectifier valve Type UU6, followed by a π-section smoothing circuit, (ii) a 4-volt supply for the rectifier heater and (iii) two 6·3-volt heater supplies, one rated for 1 ampere and the other for 3 amperes. The 1-ampere winding is associated exclusively with V2 in the time base, whilst the 3-ampere winding feeds the heaters of the remaining valves. V2 operates with high d.c. potentials on the cathode, and to avoid subjecting

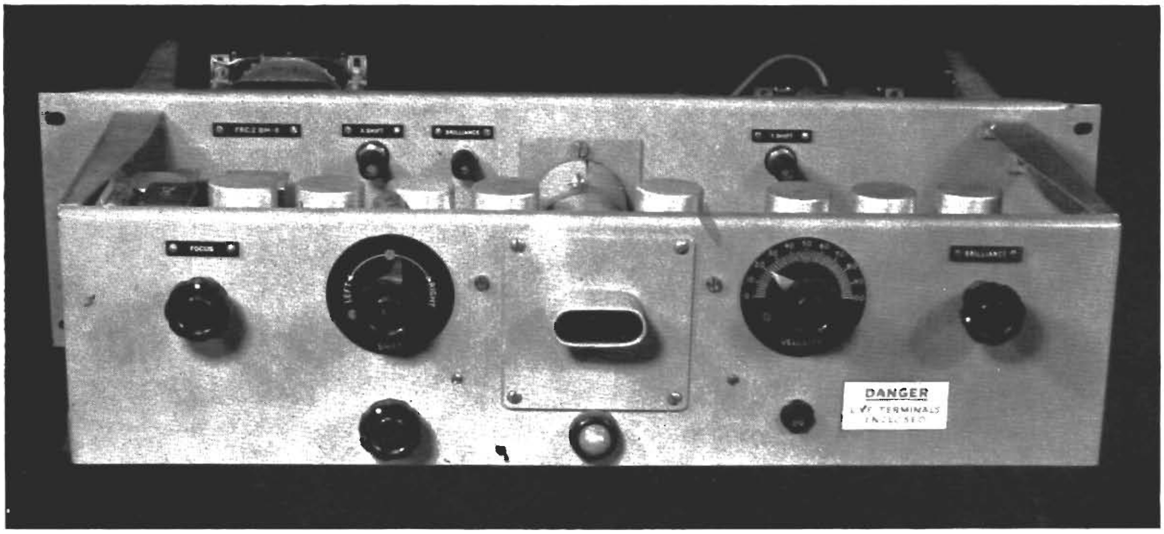

Plate IV. *Frequency Comparator Type FRC.2BM: Front View with Cover removed*

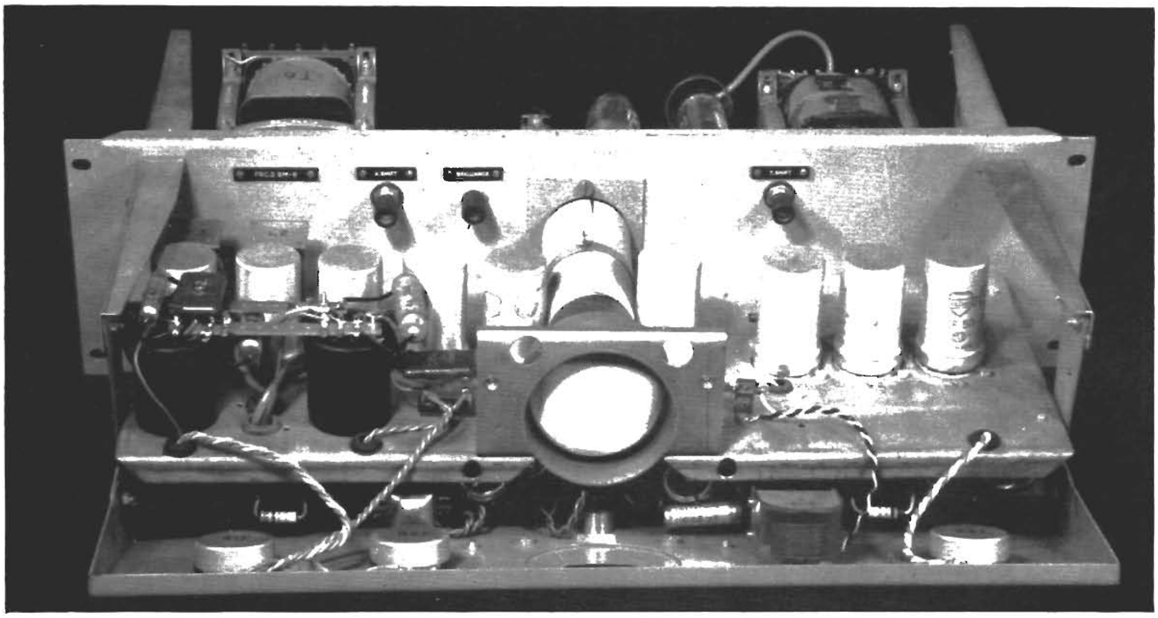

Plate V. *Frequency Comparator Type FRC.2BM: Front View with Cover removed and Hinged Front Panel lowered*

PLATE VI. *Frequency Comparator Type FRC.2BM: Plan View with Covers removed*

[Facing Plate VII

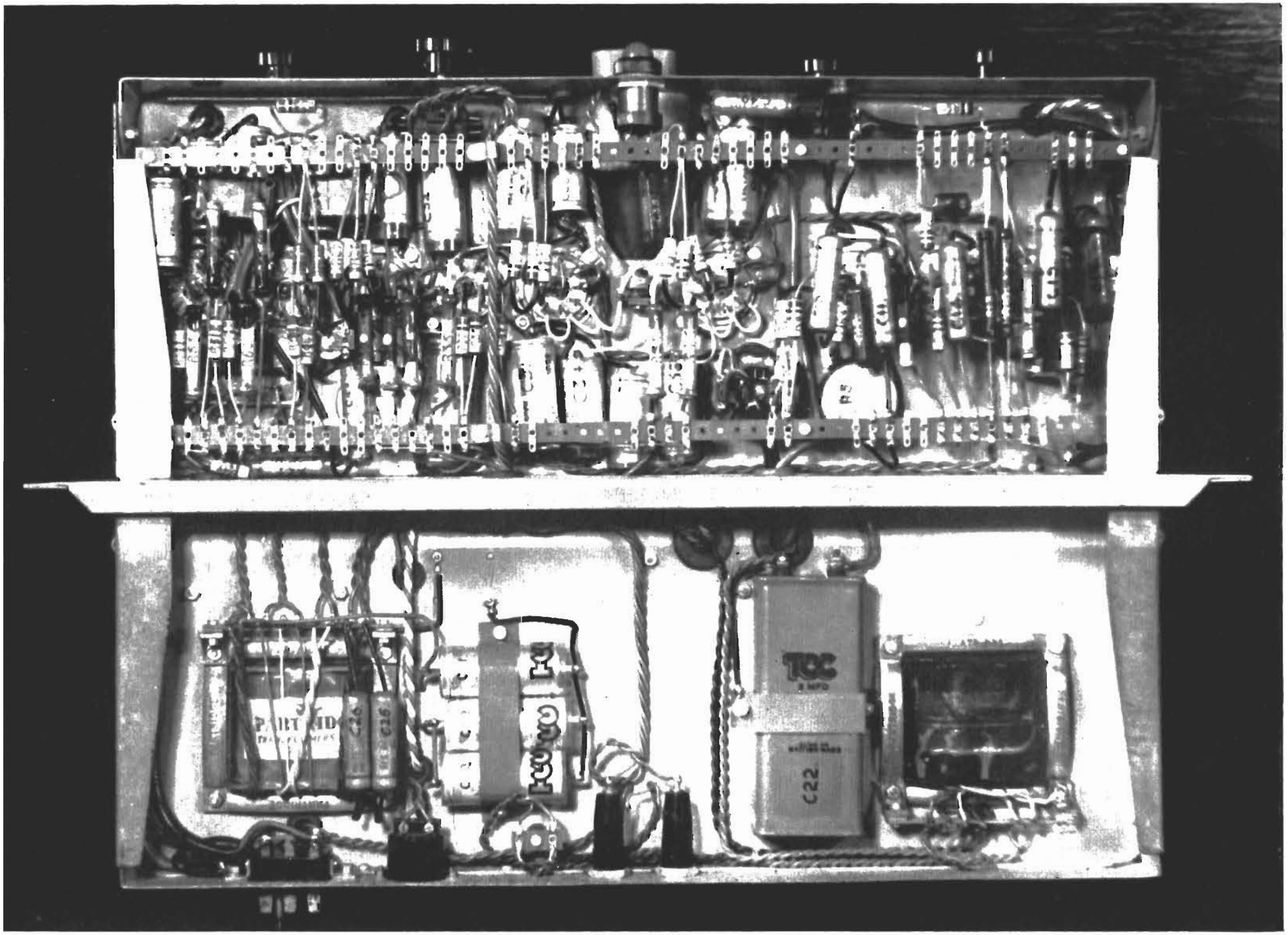

Plate VII. *Frequency Comparator Type FRC.2BM: View of Underside of Chassis* the heater/cathode insulation to these voltages the l.t. winding is not connected to earth. The 3-ampere winding also has no direct earth but is provided with an a.c. earth through the centre-tap connection from capacitors C25 and C26.

The purpose in employing an indication lamp of 12-volt rating across the 3-ampere l.t. supply is to ensure that its illumination is sufficiently low to avoid interference with observation of the trace on the monitor-tube screen.

Operating Instructions for Type-FRC.2BM Comparator

The operating details are as given for the Type-FRC.2B comparator on page 10. It is necessary, however, to make a slight amendment regarding the reference under item (*d*) to the stray field of the mains transformer. The use of two mains transformers in the Type-FRC.2BM comparator has made it possible to obtain a substantial degree of mutual cancellation of their stray fields at the position of the cathode-ray tube. This has been done by placing the transformers symmetrically with respect to the tube (see Plate VI) and phasing their connections so that the stray fields are in opposition. If, therefore, either transformer is removed temporarily, it is important to employ the original method of connection when restoring it to the circuit. Even with this arrangement *the Mumetal screen must be in position* when the equipment is being used for frequency checking. Tests have shown that, even when the transformers are a considerable distance from the comparator, the beam is still influenced by stray magnetic fields.

The following is a summary showing the position of the various controls, the items listed under (*b*) and (*c*) being presetting types arranged for screwdriver adjustment.

(*a*) *Front Panel.* *Focus* (R19), *Phase Shift* (R26), *Velocity* (C4), *Brilliance* (R21) and mains switch (S2).

(*b*) *Main Panel.* *X Shift* (R17), *Y Shift* (R16) and *Brilliance* (R47).

(*c*) *Front Deck.* *Origin* (R29) near the left-hand end, and *Locking* (R5) near the right-hand end.

Note. The *Brilliance* control (R21) is used for adjusting the negative bias on the grid of the tube and therefore controls the intensity of the beam. The *Brilliance* control (R47) has a similar function to the *Brighten* control referred to under item (*d*) in the operating instructions for the Type-FRC.2B comparator.

The list given below is a specimen set of readings taken at various points in the comparator. The e.h.t. voltages were measured with a meter having a resistance of 20,000 ohms per volt and the a.c. (a.f. and r.f.) measurements with a peak-reading valve voltmeter calibrated for r.m.s. voltages.

Mains Voltage 230 volts

E.H.T. Circuit (*with primary tappings of TR*6 *at* 0 *and* 220 *volts*)

E.H.T. voltage:	
Unsmoothed	−1,620 V
Smoothed	−1,100 V
Load current	2·35 mA
C.R.T. cathode	−1,050 V
C.R.T. grid	−1,075 V

H.T. Circuit (*with primary tappings of TR*2 *at* + 10 *and* 220 *volts*)

H.T. voltage:	
Unsmoothed	+ 385 V
Smoothed	+ 370 V
H.T. (junction R15–R16/17)	+ 270 V

Valve Stages (*D.C. voltages*)

		V_a	V_{g2}	V_k
Time base ..	V1	425	337	—
	V2	425	—	—
	V3	200	280	—
Diode limiter ..	V4	−1,075	—	−1,050
Pulse generator	V6	95	108	0·7
	V7	187	180	24·0
	V8	270	—	75·0
	V9	350	—	6·2
Frequency divider	V10	300	280	2·4
	V11	310	285	2·5

A.C. Signal Voltages

Tone in (1,000 c/s)		0·8 V r.m.s.
Secondary of TR3		3·5 V r.m.s.
V10	Grid	0·35 V
	Anode (500 c/s)	20·0 V
V11	Grid	0·65 V
	Anode (250 c/s)	6·5 V
V6	Grid	2·85 V
	Anode	65·0 V
V7	Grid	47·0 V
	Anode	120·0 V
V8	Grid	103·0 V
	Anode	20·0 V
V9	Grid	20·0 V
	Cathode	0·1 V

R.F. input:	
TR1 primary	1·55 V r.m.s.
TR1 secondary	7·2 V r.m.s.
Time-base output	40·0 V

Frequency-checking Monitor Type FCM (Fig. 4)

The frequency-checking monitor has the same basic form as the Type-FRC.2 comparators in the arrangement of time base, frequency divider, pulse generator and oscillograph. A complete circuit diagram of the unit, which incorporates its own power supplies, is given in Fig. 4. The power consumption is approximately 55 watts.

The monitor is constructed on a rack-mounting panel which is the same size as that for the Type-FRC.2BM comparator, the height being 5⅜ in. and the standard width, 22 in. Plates VIII–X are from photographs showing the internal construction and layout, designed to give easy access to all parts of the circuit. The cathode-ray tube and power-supply components are placed at the right-hand end of the monitor to allow hinged sub-panels to be fitted in the centre of the front and rear sections. Each sub-panel is secured by a single snap-action locking device which is released by turning the slotted head through 90 degrees, allowing the panel to be pulled outwards. The front sub-panel (Plate VIII) carries the time-base valves and components, while the rear panel (Plate IX) holds the valves and components of the frequency divider and pulse generator.

The only major circuit change is the use of a modified form of locked-oscillator circuit (cathode-coupled type) as a frequency divider for the 1,000 c/s reference tone instead of the modulator type employed in both comparators. Another difference is the transfer of the phase-shifting network (at the input to the pulse-generator section in the comparators) to the input circuit of the reference-tone system prior to the frequency divider.

The valves also are different types, one being the Type Z77, a pentode with similar characteristics to the pentodes used in the comparator equipments; the other is a double triode, Type 12AT7. One of the latter is used in the frequency-divider circuit, and the two halves of another are in the last two stages of the pulse generator, in place of triode-connected pentodes as used in the two circuits previously described.

A description of the frequency divider is given below together with brief details of the other sub-sections of the monitor. The latter are chiefly concerned with the practical differences from their counterparts in the original Type-FRC.2B circuit. When applying the foregoing descriptions to the operation of the monitor it must be remembered that the reference numbering of valves and components differs extensively from that of the comparator.

1. *Time Base*

The circuit and component values are identical except that (i) a different input transformer is used, (ii) an r.f. input control is not fitted and (iii) the *Locking* control has a higher value of resistance. A description of the operation of the time base is given on page 4.

2. *Frequency Divider*

A simplified diagram showing the essentials of the divider circuit used in the monitor is given in Fig. C.6. Although previously termed a modified locked oscillator the circuit could equally be described as a modified multivibrator, as it constitutes an arrangement intermediate to these two types of circuit.

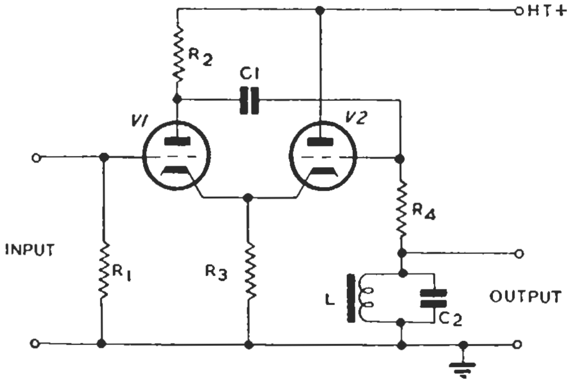

Fig. C.6. Locked-oscillator Divider Circuit

Without the resistor R4, the circuit shown is that of a cathode-coupled oscillator producing a sinusoidal output and having provision for the injection of a locking signal at the grid of V1; if locking is not required, the grid of this valve can be directly earthed. The common cathode resistor acts as a coupling element between the two valves in such a way that positive feedback is obtained to sustain oscillations. Suppose, for instance, that some circuit disturbance causes a negative-going voltage to

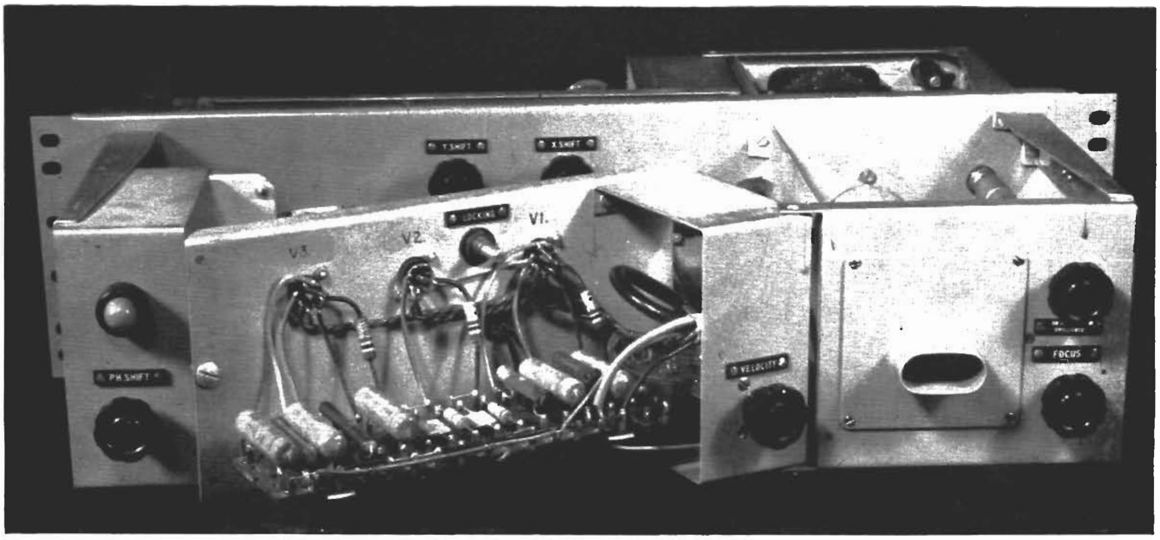

Plate VIII. *Frequency-checking Monitor Type FCM: Front View with Cover removed and Hinged Sub-panel swung forward*

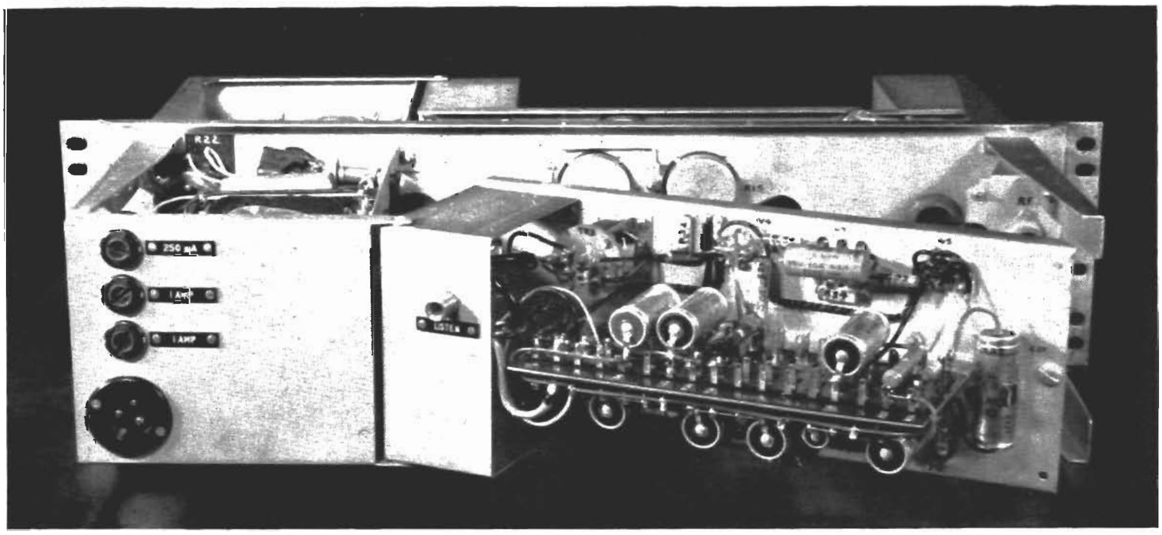

Plate IX. *Frequency-checking Monitor Type FCM: Rear View with Cover removed and Hinged Sub-panel swung forward*

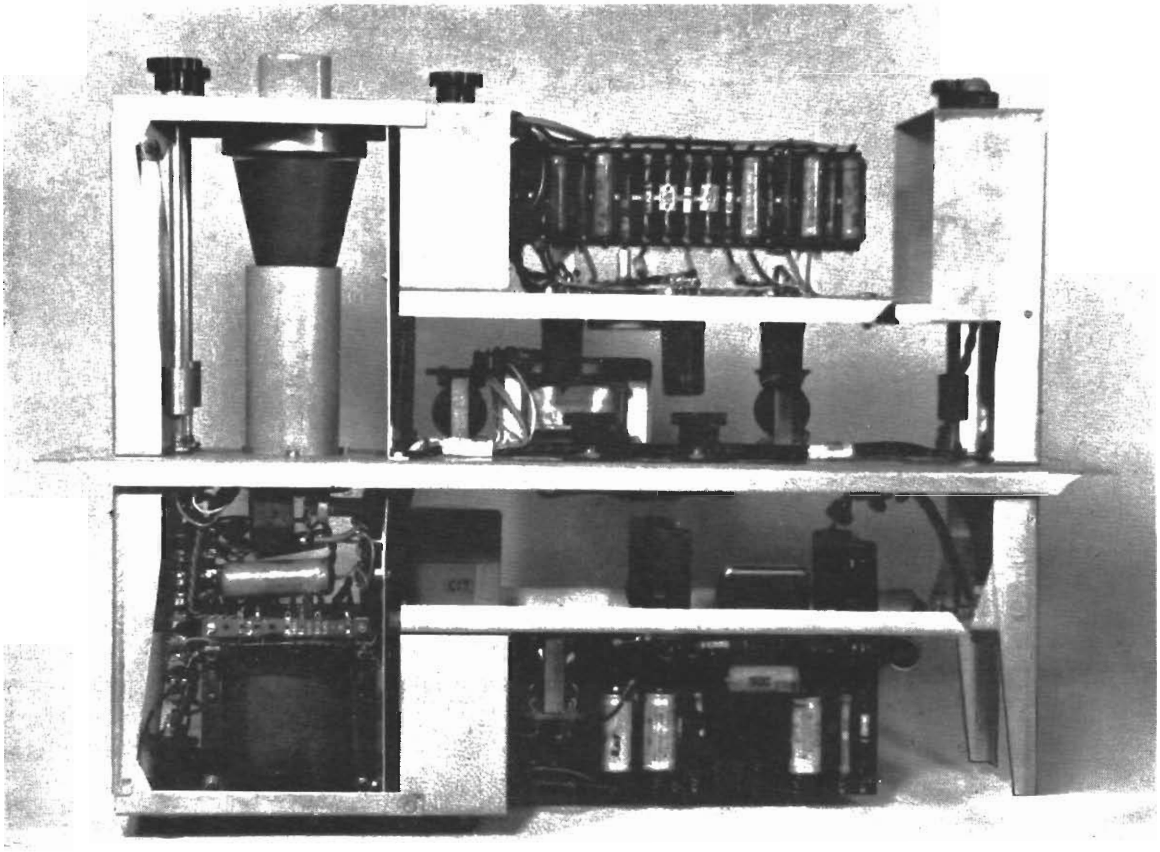

PLATE X. *Frequency-checking Monitor Type FCM: Plan View with Covers removed and Hinged Sub-panels bolted in Position* appear on the grid of V2, then the anode current of V2 falls and the voltage drop across R3 falls also.

The negative-going change of voltage on the cathode of V1 is equivalent to applying a positive-going voltage to the grid, with the result that the anode current of V1 increases, the voltage drop across R2 increases, and a negative-going voltage at the anode is applied through C1 to the grid of V2. Thus the feedback voltage is in phase with the initial voltage and oscillation is maintained at a frequency determined by the values of L and C2.

The sinusoidal oscillator has good frequency stability, but when used for dividing it is not susceptible to easy locking, due to the virtual absence of harmonic frequencies, synchronising occurring by the effect of cross-modulation between the locking frequency (*nf*) and harmonics of the oscillator frequency (*f*). A way of obtaining the harmonics is to give the oscillator circuit some properties of the multivibrator, this being done by inserting R4 in the grid circuit of V2.

To show how the multivibrator action introduces harmonics, there follows a brief explanation of the effect of including R4 in the circuit (see Fig. C.6).

Suppose there is no reference-tone input to V1 and that a circuit disturbance causes the application of a positive-going voltage to the grid of V1. The resulting voltage drop on R2 leads to a negative-going change of voltage at the anode of V1. The change is applied through C1 to the grid of V2 and the anode current of this valve starts to fall. As with the sinusoidal oscillator, there is a cathode-following action on R3, and a negative-going signal is fed back to the cathode of V1. This has the same effect as the initial positive-going signal on the grid, and a regenerative condition is produced in which V1 is driven rapidly into full conduction whilst V2 becomes non-conductive. The rapid change of voltage at V2 grid is only possible because of the presence of R4 in series with the tuned circuit. Once this switching action has started, the process continues even if the triggering signal is removed, and after it ceases the grid of V2 is highly negative with respect to the cathode, due to the large charge on C1.

The circuit then starts to revert to the original condition as C1 begins to discharge. This process, depending on the discharge time-constant, is slow at first, and usually takes a considerably longer time than the switching action. So far we have ignored the effect of the tuned circuit LC2, which has been impulsed by the sudden negative-going voltage change at the anode of V1 and continues oscillating at the natural frequency. Half a cycle later the voltage across LC2 reverses, and the grid of V2 is then driven positive. The regenerative process leads to V2 being switched rapidly to full conduction and V1 being cut off. A further regenerative action occurs at the next reversal of voltage across the tuned circuit, and thus the process continues.

The regenerative changes are responsible for an output voltage waveform having steep leading and trailing edges, which means that the output has a large harmonic content. The greater the steepness achieved, the wider is the frequency spectrum occupied by the harmonics.

The application of a locking signal to V1 grid causes variations in the anode current during the periods of conduction of V1, and this signal causes the frequency of LC2 to synchronise at a submultiple of the locking frequency. The introduction of R4 can be regarded as the means of increasing the loop gain of the sinusoidal oscillator circuit at the high-order harmonic frequencies, with the object of securing more efficient control by the locking signal. In a practical divider circuit the value of this resistor is usually found empirically and has to be a compromise between low values with which insufficient harmonic content is obtained, and high values which cause the tuned circuit to lose control so that the circuit tends to function as a relaxation oscillator.

The divider circuit shown in Fig. 4 is used for dividing the 1,000 c/s reference tone by 4, the division being effected in a single stage incorporating the twin triodes of a Type-12AT7 valve and a tuned circuit, L4, C24 and C25, adjusted to resonate at the required output frequency of 250 c/s. The reference tone is passed to the divider via an input circuit of generally similar arrangement to that in the comparator but including additionally the phase-shifting network for adjusting the position of the pulse image on the screen of the cathode-ray tube (see page 10). The other components in series with the primary of the input transformer TR3 are C20 and L3, which form an acceptor circuit tuned to 1,000 c/s. Provision is made for monitoring the reference tone by the connection of a P.O.-type jack across the transformer primary, the jack being mounted at the rear of the monitor and labelled *Listen* (see Plate IX).

As shown on inset 3 of Fig. 4, the output voltage applied to the pulse-generator section has a substantially sinusoidal waveform; it is interesting to compare this with the waveform shown on inset 2.

which shows that considerable distortion is present at the grid of the second triode V4B.

3. *Pulse Generator*

The circuit operates on similar principles to those of the pulse generator in the Type-FRC.2B comparator as given on page 7. Unlike the comparator, however, there are no controls associated with this part of the monitor, as, in addition to the phase-shifting components being transferred to a position in front of the divider, the variable resistor, known as the *Origin* control, is omitted from the cathode circuit of the first valve. The valve V5 has the cathode directly earthed, and the negative bias on the grid is produced solely by the flow of grid current whilst an input signal is applied. With this self-compensating arrangement the bias voltage depends on the amplitude of the input signal, the positive-going half-cycles of which are clipped severely by the grid-current action, as indicated by the waveform inset 4 in Fig. 4. The negative-going half-cycles are clipped in the anode circuit due to the anode current driven into cut-off; the output waveform of the stage is shown on inset 5 of Fig. 4.

Other practical differences in the circuit are (i) the use of a higher value for the inductor L5, in the third stage (V7A), and the use of a shunt resistor for damping purposes, and (ii) changes in the value of several resistors, including R52, across which the output pulse voltage is developed. Only the changes of value for L5 and R52 are of special significance (see the description of operation referred to above).

4. *Oscillograph and General Power Supplies*

The circuits for applying the deflection signals, d.c. shift potentials and operating voltages to the tube are like those in the comparator except for the omission of the diode limiter from the pulse-brightening circuit. As in the comparator, the brightening pulses are applied to the grid of the tube from the tapping point on a potential divider, L5 and R24 in Fig. 4, but the elimination of the diode means that only one control, R22 (*Brilliance*), is needed for adjusting the pulse-image brightness. The control determines the bias applied to the grid of the tube; R21 is connected in series with the potentiometer to ensure that the grid is still negative to the cathode at the minimum-voltage setting of the control.

All power supplies for the valves and cathode-ray tube are obtained through a single mains transformer, TR2, with the primary winding tapped to provide for mains voltages between 200 and 250 volts in 10-volt steps. The d.p. mains switch SW1 is incorporated in the *Brilliance* potentiometer R22 and closes when this control is moved off its minimum position. The mains-input socket, a pair of primary fuses and an h.t. fuse are grouped at the rear of the monitor (Plate IX) and appropriately labelled.

The four l.t. windings of the transformer provide heater supplies for (i) the cathode-ray tube, (ii) the h.t. rectifier valve, (iii) V2 in the time base and (iv) all other valves. The purpose in segregating V2 from the other valves is to enable it to be fed from an l.t. winding with no earth connection; in this way the heater/cathode insulation is not stressed by the high voltages appearing on the cathode during operation.

The h.t. supply is obtained from a full-wave rectifier circuit employing a Type-UU6 valve, the d.c. output from which is passed through a π-section smoothing filter. The h.t. feed to V5, V6 and V7 is decoupled by the components L2 and C34 to prevent pulse signals from being passed, via the common impedance of the h.t. supply circuit, to other sections of the monitor.

An e.h.t. supply for the cathode-ray tube is obtained by utilising the h.t. secondary of TR2 as the source of an input to a rectifier circuit employing three half-wave rectifiers. MR2, rated for 750 volts r.m.s. is connected across the whole secondary, providing 700 volts r.m.s., whilst MR1 and MR3, both rated for 500 volts r.m.s., are each connected across a half-secondary. The circuit constitutes an unusual arrangement of the voltage-doubler type, the doubling being relative to the full h.t. secondary voltage. Conduction through MR2 occurs on alternate half-cycles with those in which 'paired' conduction by MR1 and MR3 occurs. The transfer of stored charges in the circuit is such that C15 deals with higher voltages than C14 and therefore has a high voltage rating; in maintenance work care must be taken to see that these capacitors are not transposed.

Operating Instructions for Type-FCM Frequency-checking Monitor

Reference should be made to the itemised details given on page 10 regarding the operation of the Type-FRC.2B comparator. The information given there, on the subjects of (i) the r.f. and reference-tone inputs and (ii) the method of determining the frequency error, is applicable to the monitor. The individual descriptions on the uses and adjustment of the various controls are also relevant where there is an equivalent control in the monitor. This equipment has only seven controls, of which four are those generally associated with an oscillograph. Their positions are summarised below:

(*a*) *Front Panel. Focus* (R19), *Phase Shift* (R26), *Velocity* (C2) and *Brilliance* (R22) combined with a mains switch (SW1).

(*b*) *Front Hinged Panel. Locking* (R4).

(*c*) *Main Panel. X Shift* (R16) and *Y Shift* (R15).

Frequency Monitor, Type FRM.4 (Figs. 5–8)

Introduction

The frequency monitor Type FRM.4 is used for checking frequencies within the range 5·5 to 27 Mc/s and thus covers the entire group of frequency bands normally used for BBC short-wave transmissions. It is usually employed in association with the variable-frequency drive equipment installed at short-wave stations.

The design of the monitor makes use of the fact that all frequencies allotted for use on BBC short-wave transmissions are multiples of 5 kc/s. The method adopted is to generate harmonic frequencies spaced at 5-kc/s intervals over a gamut which includes the above-mentioned range and to use these signals as 'markers,' enabling the frequency of an r.f. source to be compared with that at a 5-kc/s point. Provision is made for detecting and monitoring the resultant beat frequency, and by this means the frequency being checked can be adjusted until it coincides with the reference frequency.

Fig. C.7 is a block schematic showing the basic arrangement of the frequency monitor.

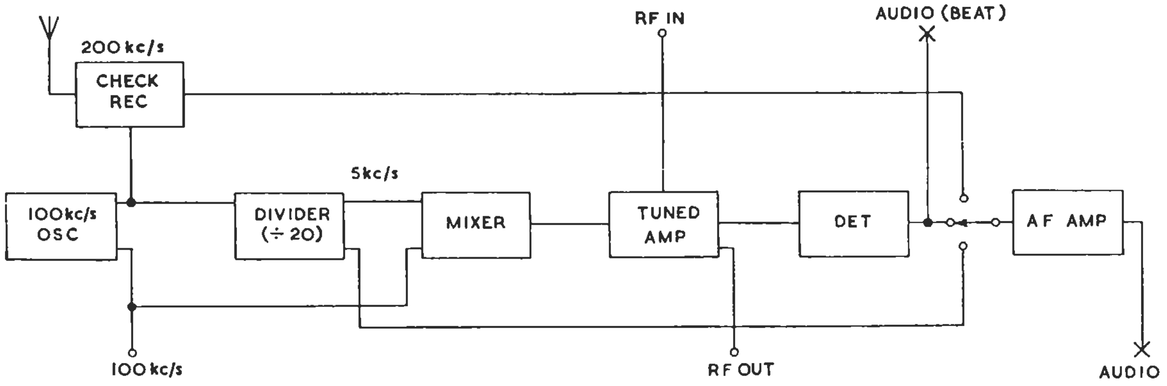

Fig. C.7. Block Schematic of Frequency Monitor Type FRM.4

The 100-kc/s oscillator has two outputs, one being connected directly to the mixer stage whilst the other provides an input to the divider used for deriving a 5-kc/s signal which is also applied to the mixer. The intermodulation in the mixer is responsible for producing harmonics spaced at 5-kc/s intervals; the high-order harmonics in the short-wave range act as the marker frequencies with which the r.f. drive frequencies are compared.

These harmonics are fed into the tuned amplifier, in which the required intermodulation product is selected and mixed with the signal under test (*R.F. In*). The following stage is used for detecting the beat signal and its output is connected to a jack marked *Audio* (*Beat*) in Fig. C.7 for feeding this signal to the beat monitor Type BM.1 forming part of the variable-frequency drive equipment. The beat signal can also be connected by the three-way switch to an a.f. amplifier with its output connected to a second jack for use as a headphone monitoring position.

The monitor incorporates a check receiver to enable the frequency of the 100-kc/s oscillator to be checked, the frequency standard being the 200-kc/s carrier provided by the BBC long-wave transmitter. The checking and adjustment of the oscillator frequency is carried out by monitoring the beat-frequency output of a detector stage. Normally this is done by switching a d.c. meter to the detector circuit, to be used as a visual indicator for very slow beat signals. If required, however, the output of the detector stage can be fed through the three-way switch to the headphone-monitoring position.

The 100-kc/s oscillator has good frequency stability, and, as the monitor is left continuously powered, the frequency should remain sensibly

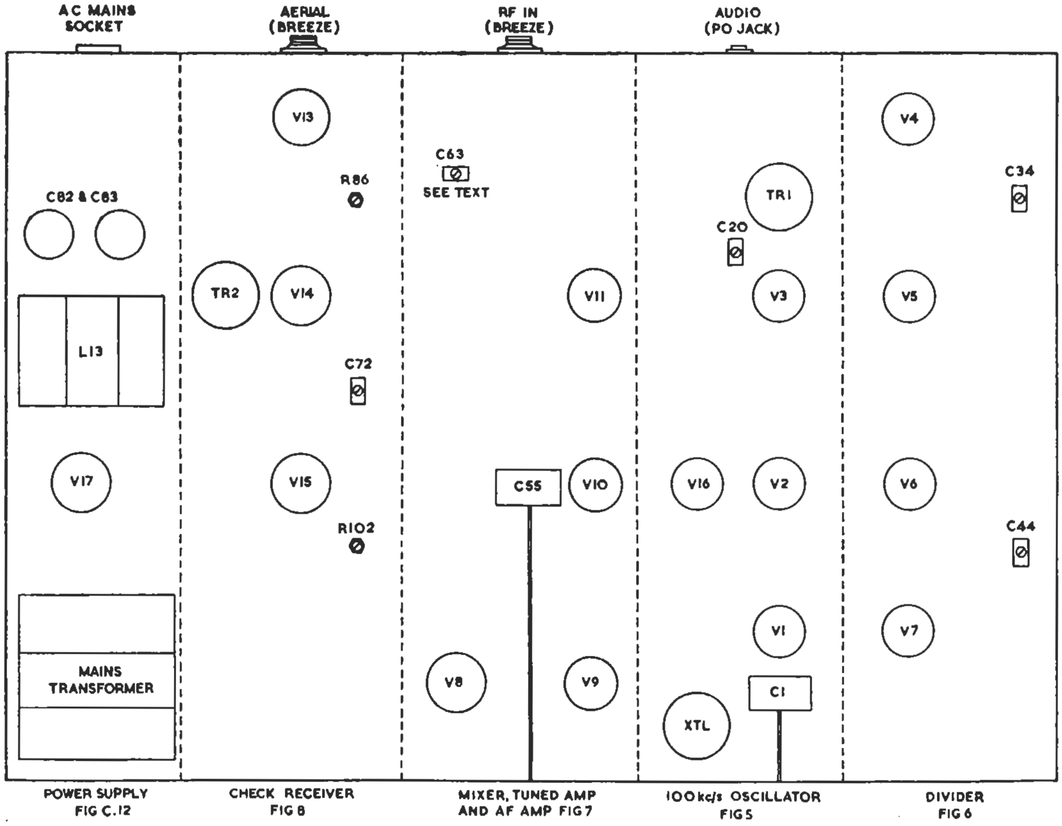

Fig. C.8. Plan View of Frequency-monitor Chassis

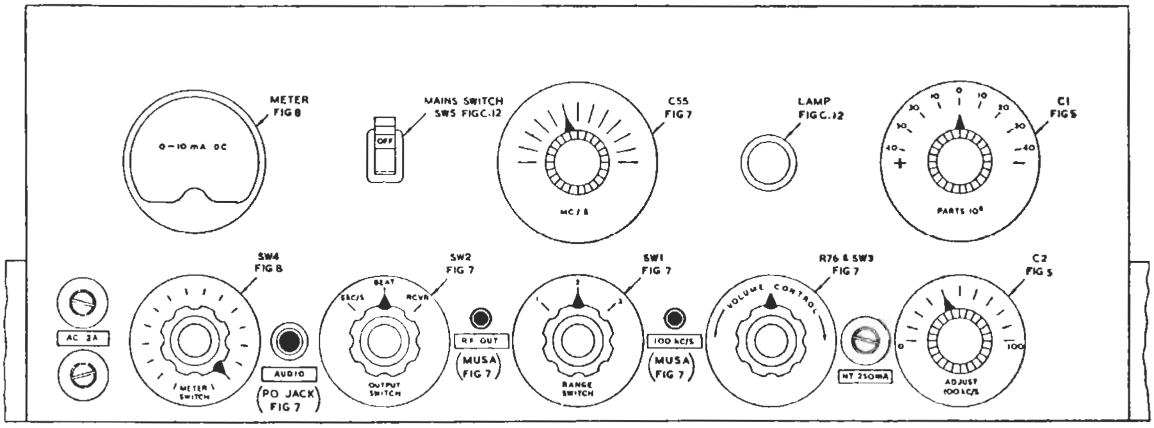

Fig. C.9. Front Panel of Type-FRM.4 Frequency Monitor constant for a considerable time after being checked and adjusted with reference to the 200-kc/s signal. Although this is the normal method of checking, it may sometimes be necessary to check the frequency when the long-wave transmitter is closed down. There are two methods of doing this, both of which involve using one of the short-wave standard frequencies (maintained with an accuracy of ± 0·5 parts in 10^6) as the reference signal. The procedure is included with information on the method of operating the monitor (page 24).

A spare harmonic generator (Type HGM.4) is employed as auxiliary equipment in permanent association with the frequency monitor. Its purpose is to provide the frequency multiplication required to enable a variable-frequency oscillator undergoing test to be checked and adjusted under the carrier-frequency condition. The output circuit of the harmonic generator is connected to the *Dummy Load* and also, through an attenuator, to the *R.F. In* position at the monitor (see Fig. C.7). The attenuator is preset to an optimum position, giving a suitable input voltage to the monitor over the range of frequencies which require to be checked.

The information which follows relates to a standard version of Type-FRM.4 monitor as used at most short-wave stations, excepting Daventry and O.S.E.3, which have prototype versions. At O.S.E.10 work has been carried out with a view to improving the performance of the monitor, mainly with regard to the mixing of the test and reference frequencies, and also to facilitating its operation. It is probable that some of the modifications made at O.S.E.10 will be applied to the standard monitor, and therefore, as an interim measure, the changes are described on page 26.

Construction and Layout of Monitor

The equipment shown in Fig. C.7, together with a self-contained power supply, is fitted on a steel chassis measuring 28⅜ in. by 19½ in. by 2¾ in. These dimensions were chosen to enable the monitor to be mounted in a position normally occupied by a Type-HGM.4 harmonic generator in the steel cabinets used for housing the variable-frequency equipments.

The underside of the chassis is divided into five compartments by screens between the front and back walls. The positions of these screens are indicated by dotted lines in Fig. C.8, a plan view of the chassis, intended as a key to the positions of the valves and certain controls.

A drawing showing the layout of the front panel, 19 in. by 7⅛ in., is given in Fig. C.9. This drawing is not to the same scale as Fig. C.8.

Monitor Circuits

The circuits contained in the five compartments of the monitor are given separately in the following diagrams:

Fig. 5. 100-kc/s Oscillator
Fig. 6. Divider
Fig. 7. Mixer, Tuned Amplifier and A.F. Amplifier
Fig. 8. Check Receiver
Fig. C.12. Power Supply
Fig. C.10 is a key diagram showing the interconnection of the circuits given in Figs. 5–8.

The monitor employs a total of sixteen valves, comprising fourteen Type EF50, one Type D.63 and one Type U50, the latter being the h.t. rectifier. Switched metering equipment is provided on the monitor for measuring the individual cathode currents of the Type-EF50 valves, the h.t. voltage and, as already mentioned, the beat signals from the check receiver.

In those stages in which a tuned-anode circuit is employed, the tuning capacitors are connected between the anode of the valve and earth. Thus they are effectively connected across the associated inductor via the larger value of capacitance used for decoupling purposes on the h.t. side of the anode circuit.

100-kc/s Oscillator (Fig. 5)

The 100-kc/s oscillator contains a quartz crystal and four valves in a circuit essentially similar to that of the crystal maintaining amplifier which forms part of Type-CP.17E drive equipment. A description of this type of circuit is given in Instruction T.2, together with the theoretical consideration concerning the design of the oscillator circuit (Appendix B.1).

The circuit of Fig. 5 can be described briefly as follows. The oscillator valve V1 is a tetrode-connected pentode with its output fed to V2, which functions as a limiter. The method of limiting is to use V2 in conjunction with the diode V16 to derive d.c. voltage from the 100-kc/s signal being amplified, this voltage being applied as a negative bias to the control grid of the oscillator valve. Thus any tendency to increased output from the oscillator stage is counteracted by the increased bias applied to the oscillator valve. The 100-kc/s signals are also fed from V2 into the grid circuit of V3, which serves as a separator (or buffer) stage.

The quartz crystal is a bar type, contained in an evacuated glass envelope which is mounted on an International-octal type valve base. It is plugged into a valve-holder situated near the front of the monitor (see Fig. C.9) and fitted with a close-fitting cover lined with felt. This type of crystal is liable to fracture if allowed to oscillate violently, and as a safeguard the oscillator-circuit parameters are so chosen that failure of the limiter circuit should not cause the voltage across the crystal to become dangerously high. There is, however, a possibility that an h.t. surge would increase this voltage above the safe value, and therefore the crystal should be removed immediately in the event of a fault condition occurring in the limiter circuit.

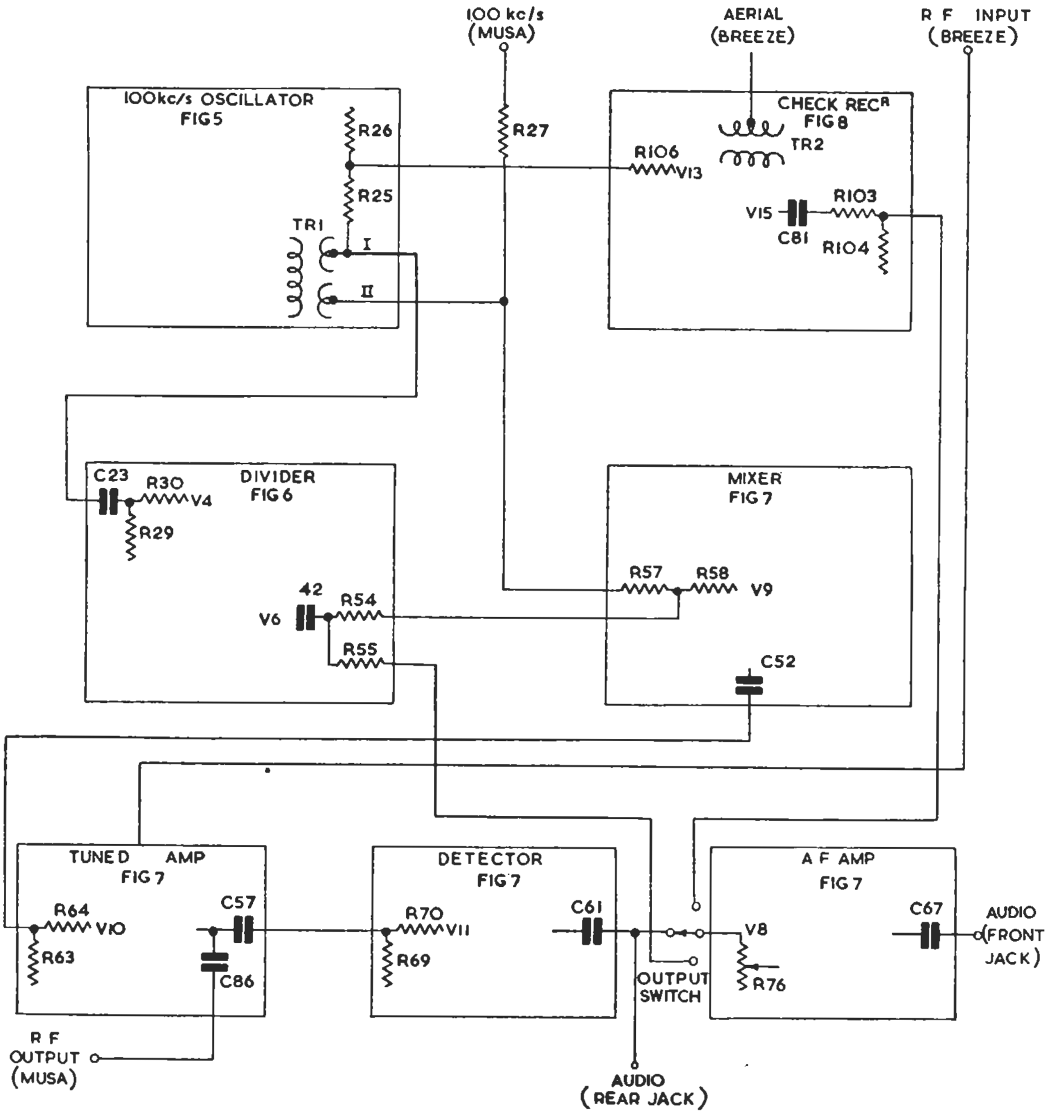

Fig. C.10. Key Diagram showing Interconnection of Operational Circuits of Type-FRM.4 Monitor

The provision for adjusting frequency consists of two identical variable capacitors, C1 and C2, connected in parallel with each other and in series with the crystal. The dial plate of C1 is titled

Parts 10^6 and is marked with a centre-zero position, at which the moving plates of the capacitor are half engaged with the fixed plates. The dial, shown in Fig. C.9, is marked with positive and negative signs on opposite sides of the centre zero and calibrated on each side in steps of 10 up to 40. The dial of C2, also shown in Fig. C.9, has a 180-degree scale divided into 100 parts and is titled *Adjust 100 kc/s*. The calibration of the *Parts 10^6* is relative to that setting of the *Adjust 100 kc/s* control at which the oscillator frequency is 100 kc/s. During the initial testing of the frequency monitor, the circuit conditions are arranged to ensure that the oscillator frequency will be 100 kc/s when the *Parts 10^6* capacitor is at the centre-zero setting and the *Adjust 100 kc/s* capacitor is at the mid-point of the scale (50 divisions). The latter setting may not be obtained in practice but should be close to the mid-point. The purposes of these controls are described in the operating instructions given later.

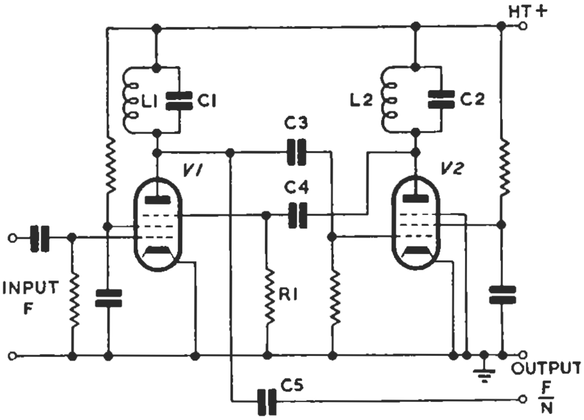

Fig. C.11. Basic Arrangement of Divider Circuit

The only other control is C20, a presetting type for tuning the primary of the output transformer TR1; the positions of these components are shown in Fig. C.8.

Divider (*Fig.* 6)

The divider is used for deriving a 5 kc/s output from the 100 kc/s signal provided by the oscillator. The division by 20 is effected by employing two divider stages in cascade, the first having a division ratio of 5 and the second dividing by 4. Each stage has two pentode valves, one being used as a mixer whilst the other functions as a harmonic generator. Apart from dealing with different frequencies, both stages operate on the same principle, which is described below.

Principle of Operation

Fig. C.11 is a diagram showing the basic arrangement of the two-valve divider circuit, in which V1 is the mixer valve and V2 is the harmonic generator.

Let F = frequency input signal to divider.
N = division ratio (an integer).
Then F/N = output frequency

The tuned-anode load for V1 comprises L1 and C1, whose values are chosen for resonance to occur at the required output frequency, F/N. The tuned-anode load for V2 comprises L2 and C2, the values of these components being selected to obtain a frequency of resonance:

$$\frac{F}{N}(N-1) = F - \frac{F}{N}$$

One method of approach to the operation of the circuit is to consider the effect of an electrical disturbance in the circuit, for example by the application of h.t. This provokes the tuned-anode circuit of V2 into momentary 'ringing' oscillations at the frequency $F - F/N$, the frequency of resonance of L2, C2. These oscillations, of relatively small amplitude, are applied through the coupling components C4 and R1 to the suppressor grid of V1. If the signal at frequency F is present on the V1 grid it is modulated by the signal from V2, and, due to the non-linear condition of operation of V1, sum and difference terms of the two frequencies appear at the anode of V1. These terms are represented by the expression

$$F \pm \left(F - \frac{F}{N}\right)$$
$$= \left(2F - \frac{F}{N}\right) \text{ and } \frac{F}{N}$$

The first of these terms is the sum frequency and the second is the difference frequency. As the anode circuit of V1 is tuned to the difference frequency (F/N) there is considerable amplification of this signal by V1, the amplified signal being fed through C3 to the grid of V2. The non-linear operating condition of V2 is responsible for the generation of harmonic frequencies, and one of these frequencies will be the same as that produced by the initial 'ringing' of the V2 anode circuit.

That this will be so can be seen from the expression for the frequency of resonance of this circuit:

$$\frac{F}{N}(N-1)$$

which shows that the required harmonic frequency is $(N-1)$ times the required output frequency. Therefore, as N is an integer, $(N-1)$ is an integer and the required harmonic frequency will be an integral multiple of the frequency applied to the grid circuit from V1.

The conditions in the circuit are such that the signal at the required harmonic frequency appears in the anode circuit of V2 with the phasing necessary to assist the original 'ringing' oscillations in the tuned circuit. Thus a state of positive feedback is established in which the voltages of the internally-generated oscillations, at the divider-output frequency and the harmonic-generator output frequency, increase until a state of equilibrium is attained. These oscillations can only be maintained in the presence of the input signal at the grid of V1; if this signal is removed, the circuit falls into a quiescent state in which there is no output from the divider. The output at the divided frequency is taken through C5 from the anode of V1.

Practical Circuit (*Fig.* 6)

Fig. 6 is a circuit diagram of the divider, which employs four Type-EF50 valves. V4 and V5 are the mixer and harmonic-generator valves of the first divider stage; V6 and V7 are the corresponding valves of the second divider stage. The various multiplying and dividing factors and also the operating frequencies in each of the anode circuits are indicated on the circuit diagram.

The only controls in the divider circuit are the capacitors C34 and C44, used for tuning the inductors in the anode circuits of V5 and V7. They are ceramic presetting types situated, as shown in Fig. C.8, on top of the chassis.

Mixer, Tuned Amplifier and A.F. Amplifier (*Fig.* 7)

The input to the first of the four stages shown in Fig. 7 consists of two signals, one being the 100-kc/s signal taken from the crystal oscillator, whilst the other is the 5-kc/s signal derived in the divider. V9 mixes and distorts these signals so that the output contains intermodulation products consisting of signals spaced every 5 kc/s; the high-order harmonics constitute the reference signals in the short-wave range.

The harmonic frequencies are fed into the next stage, containing the triode-connected pentode V10, in which a required intermodulation product can be selected by means of the tuned circuit and mixed with a signal undergoing test. The tuning capacitor C55 is effectively connected across two coils in series, one being either L8, L9 or L10, selected by means of the *Range Switch* (SW1), whilst the other is L7, which is used to couple the test signal into the tuned circuit. C55 has a dial plate titled *MC/S* and is calibrated for the three ranges obtainable with the switched inductors; the details are as follows:

Range 1.	L8	5·5– 9·5 Mc/s
Range 2.	L9	9·5–16·5 Mc/s
Range 3.	L10	16·5–27 Mc/s

The test signals are fed into the monitor through a Breeze-type connector fitted on the rear of the chassis and labelled *R.F. In* (see Fig. C.8).

The *R.F. Out* connection from the anode of V10 terminates at a Musa socket situated on the front panel (Fig. C.9). This outlet is for use when checking the frequency of the 100-kc/s oscillator by a method in which a short-wave standard frequency is utilised to provide a reference signal; details are given later, with the operating instructions.

V11 is operated as an anode-bend detector for the purpose of detecting the beat between the reference and test signals. When a frequency check is in progress, the output of V11 consists chiefly of 5-kc/s tone modulated by the beat signal. This output is taken to a P.O. jack at the rear of the monitor, provided for making connection to the *Line Input* of the Beat Monitor Type BM.1.

If required, the beat output can also be fed into the a.f. amplifier V8 by turning the *Output Switch* SW3 to the *Beat* position; headphones are connected to the output of this stage through a P.O. jack (*Audio*) on the front panel. A 5-kc/s filter comprising L11, C62 and C63 can be switched into circuit by turning the potentiometer R76 to the maximum position.

Note. In some monitors L11 is tuned for resonance by means of fixed capacitors. In others C63 is fitted to provide for adjustment of tuning; its position is shown in Fig. C.8.

Two other positions of the *Output Switch* provide for headphone monitoring of the output of the divider (5 *kc/s*) and also of signals from the check receiver (*RCVR*).

Check Receiver (*Fig.* 8)

This section of the monitor contains the means of checking the frequency of the 100-kc/s oscillator, using the 200-kc/s carrier received from the BBC long-wave transmitter as the reference frequency.

The circuit diagram given in Fig. 8 shows three stages. V13 is used for amplifying the signal fed from the oscillator, and the output of this stage is choke-capacitance coupled to a potentiometer, R86. This control is a presetting type for adjusting the amplitude of 100-kc/s signal fed into the suppressor grid of V14, which is in the first stage of the receiver. The position of the potentiometer is shown in Fig. C.8.

V14 serves as a mixer, as in addition to the signal on its suppressor grid the received 200 kc/s signal is applied to the control grid from the tuned r.f. transformer TR2. The receiving aerial is connected to the transformer primary through a Breeze-type socket, labelled *Aerial*, at the rear of the chassis (Fig. C.8). One of the capacitors, C72, connected across the secondary is a preset type providing for limited adjustment of tuning. The positions of the transformer and C73 are shown in Fig. C.8.

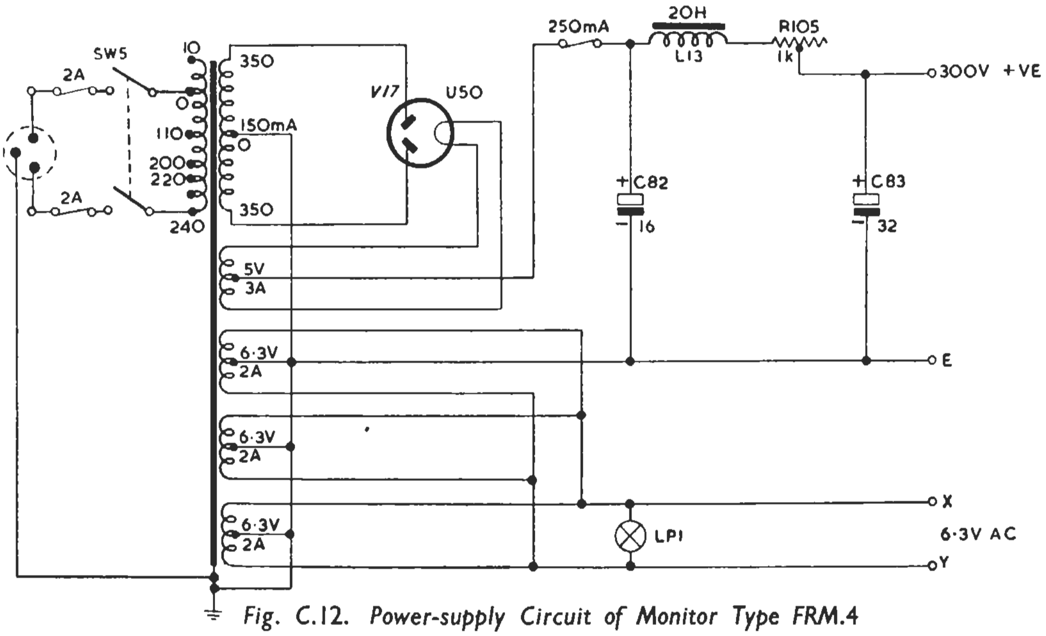

Fig. C.12. Power-supply Circuit of Monitor Type FRM.4

The mixed-frequency output of V14 is applied through resistance-capacitance coupling to V15, which serves as a detector and amplifier of beat signals. The output of this stage is resistance-capacitance coupled to the *RCVR* position on the *Output Switch* to enable beat frequencies in the audible range to be monitored at the headphones monitoring position (see Fig. 7). To provide for visual monitoring of very low beat frequencies, the anode of V15 is connected through R101 and R102 to the *Adj. 100 kc/s* position on the *Metering Switch.* R102 is a variable resistor used for presetting the mean current shown on the meter; its position is shown in Fig. C.8.

The following example is given to illustrate how a beat signal of relatively low frequency can be produced by mixing the 100-kc/s and 200-kc/s signals. Suppose the frequency of the crystal oscillator is 99·999 kc/s, i.e. 1 c/s low. This signal is applied to the suppressor grid of V14 and the 200-kc/s signal is applied to the control grid. As a result of the multiplicative mixing in V14 there are four frequencies in the anode circuit, the original frequencies, 99·999 kc/s and 200 kc/s, together with the sum and difference terms, 299·999 kc/s and 100·001 kc/s respectively. When these frequencies are applied to the detector valve V15 a beat is produced between the 99·999 kc/s signal (from the crystal oscillator) and 100·001 kc/s (the difference term). Thus the beat signal indicated on the meter is 2 c/s, twice the frequency error of the crystal oscillator.

Power Supply (*Fig. C.*12)

Heater and h.t. supplies for the valves in the monitor are obtained from power-supply equipment with the circuits arranged as shown in Fig. C.12.

Metering Equipment

The meter and the associated multi-position switch is shown in Fig. 8. The list given below is a set of typical readings taken with this equipment; all current readings are the cathode currents of the Type-EF50 valves.

Oscillator	*Limited*	*Non-limited*
V1	0·4 mA	1·2 mA
V2	6·8 mA	8·4 mA
V3	6·8 mA	

Divider	*Static*	*Driven*
V4	5·6 mA	6·8 mA
V5	5·2 mA	4·4 mA
V6	5·0 mA	4·4 mA
V7	5·4 mA	4·4 mA
H.T. voltage	300 V	

Mixer, etc.	*Static*	*Driven*
V8 (A.F. amp.)	7·2 mA	
V9 (mixer)	4·8 mA	7·2 mA
V10 (tuned amp.)	14·0 mA	10·0 mA
V11 (detector)	4·0 mA	5·2 mA

Check Receiver	
V13	8·4 mA
V14	7·6 mA
V15	4·4 mA

Operating Instructions for Type-FRM.4 Frequency Monitor

The frequency monitor is left continuously powered, with the following *permanent* external connections.

(i) The rear *Audio* jack of frequency monitor is connected to the *Line* input of the beat monitor Type BM.1. Information on the beat monitor is given in Instruction TT.4.

(ii) An aerial for receiving the 200-kc/s transmission is connected to the *Aerial* socket of the frequency monitor.

(iii) The spare harmonic generator multiplier Type HGM.4 has its output connected through an attenuator to the *R.F. In* socket of the frequency monitor.

The purpose of the harmonic-generator multiplier is to provide the necessary frequency multiplication, enabling variable-frequency oscillators undergoing a frequency check to be adjusted under carrier-frequency conditions.

Before giving details of various operations it must be emphasised that the successful use of the frequency monitor depends largely on the care taken in carrying out adjustments referred to below.

This warning applies firstly to setting the frequency of the crystal oscillator to 100 kc/s, as any error at this frequency will be greatly multiplied in the derivation of the harmonics which act as the reference signals in the short-wave bands.

Further, the relatively close spacing (5 kc/s) of these reference frequencies involves the need for obtaining an initial output frequency from the drive equipment (the variable-frequency oscillator and the harmonic-generator multiplier mentioned under item (iii)) as close as possible to the required frequency *before checking is carried out.* Otherwise it is easily possible to adjust the variable-frequency oscillator to obtain zero beat with other than the correct reference frequency. As an instance of ambiguity in this respect, suppose the frequency being checked is 2·5 kc/s from the correct frequency. Under this condition it would be difficult to decide in which direction to make an adjustment, due to the test frequency being intermediate to two adjacent reference frequencies.

Lastly, when frequency checking is in progress, it will be found that the a.f. output of the frequency monitor consists of a main beat frequency accompanied by several subsidiary beat frequencies. The latter are caused by small-amplitude components at interstage frequencies appearing in the output of the harmonic-generator multiplier and beating with reference frequencies produced in the monitor. Although these spurious beat signals are usually much weaker than the main beat they may be of lower frequency, and care must be taken to avoid making adjustments by reference to one of them.

1. *Checking and Adjustment of* 100-*kc/s Oscillator Frequency by Means of Long-wave Signal on* 200 *kc/s*

(*a*) Set pointer of *Parts* 10^6 to zero.

(*b*) Turn *Meter Switch* to *Adj. 100-kc/s* position. This operation connects the meter to the anode circuit of the detector valve in the check receiver, for monitoring the very low beat frequencies normally to be expected. If, however, it is desired to monitor the received signal, plus beat, on headphones:

(*c*) Place *Output Switch* to *RCVR* position. Plug headphones into *Audio* jack on the front panel and operate *Volume Control* as required.

(*d*) Using the visual and aural indication, turn the *Adjust 100 kc/s* control to obtain as low a beat frequency as possible.

2. *Checking the Frequency of a Variable-frequency Oscillator.*

Preliminary Conditions

(*a*) Set up the variable-frequency oscillator to predetermined settings for the required output frequency.
(*b*) Connect output of variable-frequency oscillator to the spare harmonic-generator multiplier used with the frequency monitor.
(*c*) Adjust the harmonic-generator to obtain the desired carrier frequency.

Operation of Frequency Monitor

(*d*) Adjust the tuned amplifier to the settings for the desired carrier frequency by (i) selecting the appropriate waverange (1, 2 or 3) by means of *Range Switch* and (ii) turning the *MC/S* control to the calibrated setting for the frequency which is to be checked.
(*e*) Place *Meter Switch* to read cathode current of V11; this is the detector following the tuned amplifier. Carry out final tuning adjustment of tuned amplifier by reference to the current shown on meter, i.e. tune for maximum current.

A 5-kc/s note modulated by the beat signal will now be available at the beat monitor Type BM.1 and can be heard on the loudspeaker when the switch on this unit is operated to *Line*. To listen to this signal at the Type-FRM.4 monitor:

(*f*) Place *Output Switch* to *Beat* position. Plug headphones into *Audio* jack on front panel and adjust *Volume Control* as required.

Note. The 5-kc/s filter can only be switched into circuit by turning this control to maximum.

The variable-frequency oscillator can then be adjusted to obtain zero beat signal. Finally, *check the setting of the variable-frequency oscillator against previously determined settings*. If the settings are abnormal it is advisable to repeat the above operations.

3. *Checking and Adjustment of* 100-*kc/s Oscillator Frequency by Means of Local Standard-frequency Equipment*

At some short-wave stations a highly-stabilised crystal-drive equipment is installed for use on one of the standard-frequency transmissions. For this purpose the crystal drive is used in place of a variable-frequency oscillator to provide the input to a harmonic-generator multiplier adjusted to obtain the required carrier frequency. This frequency is maintained with an accuracy of ± 0·5 parts in 10^6.

Where such equipment is available, it can be utilised for checking the frequency of the 100-kc/s oscillator as follows:

(*a*) Connect output of standard-frequency crystal oscillator to the harmonic-generator multiplier used with the frequency monitor.
(*b*) Set up the harmonic-generator multiplier to obtain the desired carrier frequency.

Operation of Frequency Monitor

(*c*) Carry out the operations described under items 2(*d*) to 2(*f*) inclusive.
(*d*) Treating the standard-frequency source as the reference signal, adjust the frequency of the 100-kc/s oscillator to zero beat by means of the *Adjust 100-kc/s* control.

4. *Checking and Adjustment of* 100-*kc/s Oscillator Frequency by Means of a Received Standard-frequency Transmission*

This method necessitates the use of a receiver tuned to one of the standard-frequency transmissions. No details will be given here of the frequencies used for these transmissions, as this information is available at short-wave stations.

(*a*) Tune receiver to the standard-frequency transmission.
(*b*) Connect *R.F. Out* (Musa connection) on front panel of frequency monitor to aerial terminal of receiver, making provision if necessary for adjusting the amplitude of the applied signal.
(*c*) Ensure that there is no input to the *R.F. In* position of the frequency monitor.
(*d*) Adjust the tuned amplifier by means of *Range Switch* and *MC/S* control to the required frequency.

Then, whilst monitoring by means of the loudspeaker on the receiver, adjust the 100-kc/s oscillator for zero beat by means of the *Adjust 100-kc/s* control.

5. *Checking the Frequency of a Received Carrier by means of Frequency Monitor*

The method for checking a received carrier frequency is only applicable if the frequency is known within relatively close limits. It is assumed that the frequency of the 100-kc/s oscillator has been previously checked and suitably adjusted.

(*a*) Proceed as in items 4(*a*) to 4(*d*).
(*b*) Leaving the *Adjust 100 kc/s* control at the normal setting, turn the *Parts* 10^6 control to obtain zero beat on the receiver loudspeaker.

Then, from the reading indicated on the *Parts 10^6* dial, the frequency difference can be calculated, this difference being relative to the nearest 5-kc/s point (reference frequency).

Modified Type-FRM.4 Frequency Monitor (O.S.E.10)

The chief aims in modifying the frequency monitor at O.S.E.10 were (i) to facilitate the operation, (ii) to reduce the possibility of ambiguities during frequency checking due to spurious beat signals appearing with the main beat signal (see reference on page 24) and (iii) to obtain harmonic (reference) frequencies of greater amplitude from the mixer stage.

The majority of the circuit alterations are confined to that section of the frequency monitor containing the mixer, tuned amplifier and A.F. amplifier (V8 to V11). These changes are included in a revised circuit diagram, which is shown in Fig. 9. In addition an auxiliary item of equipment has been produced, a self-contained tuning circuit connected between the harmonic-generator multiplier and the frequency monitor (*R.F. In*). The purpose of this device is to use the selective properties of the tuning circuit to discriminate against the small-amplitude components at inter-stage frequencies which are present in the output of the harmonic-generator multiplier. These inter-stage frequencies are largely responsible for the spurious beat signals which are heard at the a.f. output of the frequency monitor. Also, as a supplementary aid to reducing spurious beat signals, the output of the tuning circuit is fed into the suppressor grid of the detector stage (V11) which follows the tuned amplifier. The arrangement of the tuning circuit is described below and followed by brief descriptions of the circuit alterations in the monitor.

Auxiliary Tuning Circuit

A diagram of the tuning circuit is given in Fig. C.13. The input to this circuit is taken through a flying lead consisting of a length of screen-twin cable terminating at a link-coupling coil. This coil is placed in a position giving very weak coupling to the output circuit of the harmonic-generator multiplier. The input-coupling coil L1 is wound on a former, placed at one end of L2, and fitted with a shaft so that its position can be adjusted by turning a knob on the front panel. The dial plate for this control is marked *Max* and *Min* at the 180-degree limits of its travel. This coupling arrangement obviates the need for fitting an attenuator between the harmonic-generator multiplier and the *R.F. In* terminals of the frequency monitor, which is the practice with the standard units. The dial plate for C1 is not completely calibrated but only shows the positions to which the pointer should be set to tune to the short-wave bands on which transmissions are made. The ranges covered are:

L2 tuned by C1 plus C2 ..	6 and 7 Mc/s
L2 tuned by C1	9, 11, 15, 17 and 21 Mc/s

The only other control on the front panel is a toggle switch for connecting C2 in parallel with C1.

L3, a fixed output-coupling coil, is connected through a flying lead of concentric cable and a Breeze-type three-pin connector to the *R.F. In* socket of the frequency monitor.

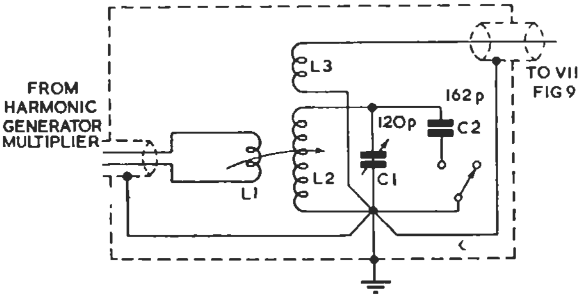

Fig. C.13. Circuit Diagram of Tuning Circuit used with Modified Type-FRM.4 Frequency Monitor

Circuit Changes in Frequency Monitor

1. *V9* (*Mixer*)

It was found desirable to be able to adjust the amplitudes of the reference and test signals in order to obtain large-amplitude beat signals. The test signal is capable of adjustment by varying the coupling in the tuning circuit described above. Accordingly the input circuit of the mixer stage has been altered to enable the amplitude of the harmonic (reference) frequencies to be preset to a suitable optimum value.

(*a*) The provision for adjusting the reference-signal amplitude was to fit parallel-connected 50-pF capacitors, instead of R57 (Fig. 7), in series with the 100-kc/s input to V9. This alteration necessitated the connection of a resistor between the grid of V9 and earth. The semi-variable 50-pF capacitor was adjusted to an optimum setting.

(*b*) Modification (*a*) caused a large increase in the voltage input to V9, the bias voltage across the grid resistor being 10–15 volts. The cathode bias resistor was increased to 5·6 kilohms.

(*c*) The anode-decoupling resistor of V9 was reduced from 50 kilohms to 470 ohms to increase the anode voltage, which previously was considerably lower than the screen voltage.

2. *V*10 (*Tuned Amplifier*)

(*a*) V10 has been converted from triode operation to pentode operation, which has improved selectivity of the tuned circuit.

(*b*) The *R.F. In* connection was transferred to the suppressor grid of V11.

(*c*) The *R.F. Out* connection was removed. The tuned-anode circuit was rewired.

The changes enabled the values of L8 and L9 to be increased, and the ranges now covered are:

Range 1. L8 .. .. 6 to 11 Mc/s
Range 2. L9 .. .. 15 to 21 Mc/s

L10 is not used.

3. *V*11 (*Detector*)

(*a*) The test signals are fed to the suppressor grid of V11 via the *R.F. In* socket.

(*b*) It was found that the detector-valve efficiency would be improved by reducing the screen volts. This was done by connecting a resistor between the screen grid and earth, to form a potential divider with the existing screen-feed resistor.

(*c*) The output-coupling capacitor has been reduced in value to obtain a shorter time constant in order to avoid momentary grid blocking of V8 during tuning adjustments in the anode circuit of V10.

(*d*) To obtain improved tuning indication a connection has been taken through a 3-kilohm resistor to a spare contact on the *Metering Switch.* The contact is that immediately after contact *p* (see Fig. 8), and this position is now used, when carrying out tuning adjustments in the anode circuit of V10, instead of switching to contact *k* as in standard frequency monitors. The value of series resistor was chosen to obtain a large reading, so that a larger current change would be seen than when measuring the correct cathode current via contact *k*.

4. *Output Switch and V*8 (*A.F. Amplifier*)

(*a*) The volume control was disconnected, so that now it is only used, when turned to maximum, for switching the 5-kc/s filter into circuit.

(*b*) A π-section filter, comprising two 100-pF capacitors and a 4·7-kilohm resistor, was fitted to filter r.f. which otherwise appeared with beat signals at the grid of V8.

(*c*) The rear *Audio* jack was paralleled with the front *Audio* jack.

5. *Check Receiver*

Refer to Fig. 8. A 470-pF capacitor was connected between V15 anode and earth to bypass r.f. which previously passed to V8 when the output switch was turned to RCVR.

6. *Divider*

Refer to Figs. 6 and C.10. A 0·01-μFd capacitor was connected between R55 and the *Output Switch.* Its purpose is to prevent the bias on the grid of V9 from being applied to V8 when the *Output Switch* is turned to the *5 kc/s* position.

JR 1253

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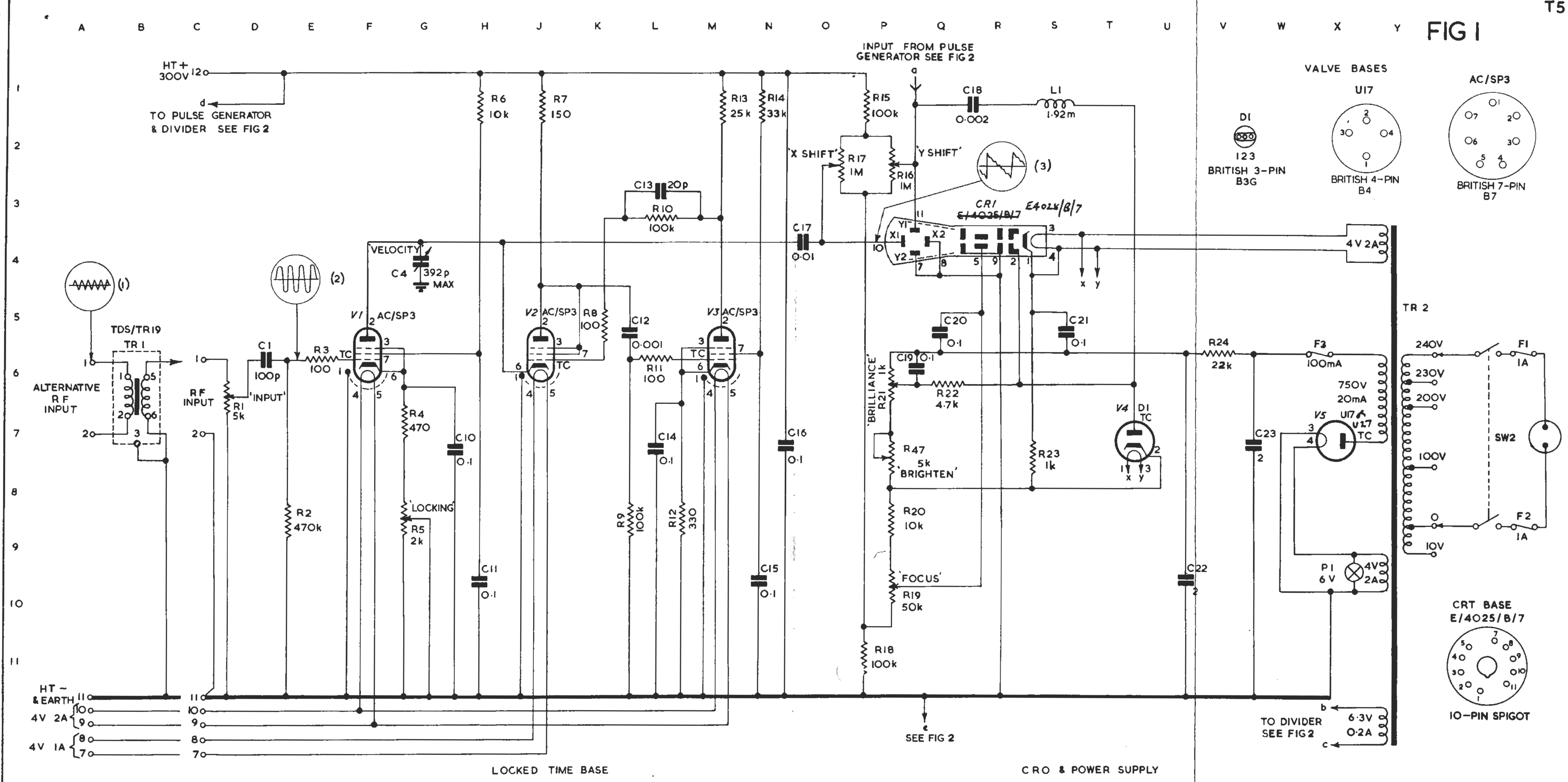
FIG I



COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER
C1	D6	M2	TCC	C22	U10	111	TCC	R7	J1	0·5W RMA8	ERIE	R21	P6	MNAR/10250/32000	MORGAN CRUCIBLE
C4	G4	C73.01/1	WINGROVE & ROGERS	C23	W7	111	,,	R8	K5	0·25W RMA9	,,	R22	Q6	1.0W RMA2	ERIE
C10	H7	341	TCC					R9	L9	0·5W RMA8	,,	R23	S7	0·5W RMA8	,,
C11	H10	341	,,					R10	L3	0·5W RMA8	,,	R24	V6	1·0W RMA2	,,
C12	L6	M2	,,					R11	L6	0·25W RMA9	,,	R47	P7	MNAR / 50250	MORGAN CRUCIBLE
C13	L3	401 SMP	UIC	L1	S1	26320X	EMI	R12	M9	0·5W RMA8	,,				
C14	L7	341	TCC					R13	M1	7·5W P302	PAINTON				
C15	N10	341	,,					R14	N1	1·0W RMA2	ERIE				
C16	N7	341	,,	R1	D7	MNAR/50250/20000	MORGAN CRUCIBLE	R15	P1	0·5W RMA8	,,	TR1	C6	TDS/TR19	BBC
C17	O4	M3	,,	R2	E9	0.5W RMA8	ERIE	R16	P3	MNAR/10550/32000	MORGAN CRUCIBLE	TR2	Y7		
C18	R1	M3GO	,,	R3	E6	0·25W RMA9	,,	R17	O3	MNAR/10550/32000	,,				
C19	Q6	341	,,	R4	G7	0·5W RMA8	,,	R18	P11	7·5W P302	PAINTON				
C20	Q5	341	,,	R5	G9	MNAR/20250/32000	MORGAN CRUCIBLE	R19	P10	MNAR/50350/32000	MORGAN CRUCIBLE				
C21	T5	341	,,	R6	H1	1W RMA2	ERIE	R20	P9	0·5W RMA8	ERIE	V1- V3		AC/SP3 Grade B	

FREQUENCY COMPARATOR FRC 2B: TIME BASE AND CRO

53/JR/101/DJE

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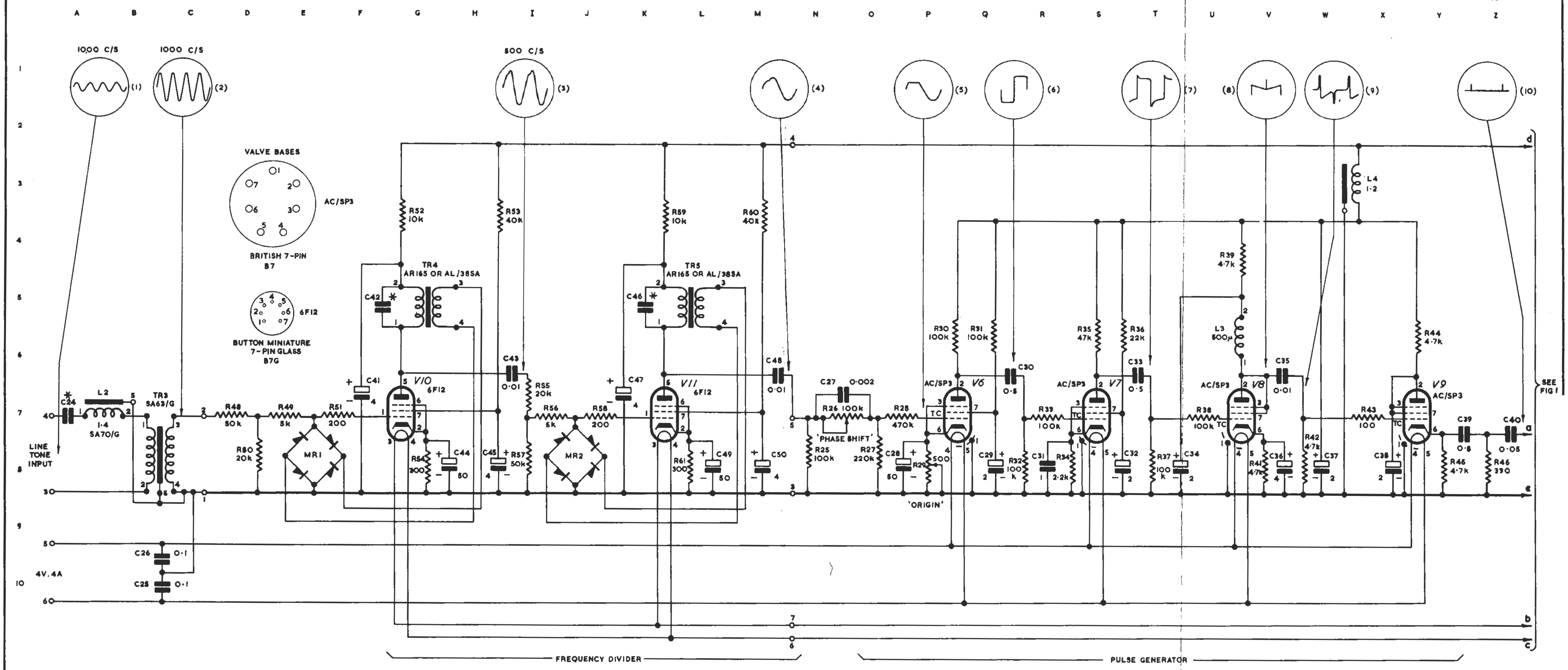
FIG 2 T5



COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER
C24 ✱	A7	TO BE FITTED ON TEST		C44	H8	CE61D	TCC	R27	O8	0·5W RMA8	ERIE	R49	E7	0·5W RMA8	ERIE
C25	C10	341	TCC	C45	I8	CE18L	"	R28	P7	0·25W RMA9	"	R50	D8	" "	"
C26	C10	"	"	C46 ✱	K5	TO BE FITTED ON TEST		R29	P8	MNAR/50150/20000	MORGAN CRUCIBLE	R51	F7	" "	"
C27	N7	M2	"	C47	K7	CE18L	"	R30	P6	1·0W RMA2	ERIE	R52	G4	1·0W RMA2	"
C28	P8	CE61D	"	C48	M6	M2	"	R31	Q6	" "	"	R53	I4	" "	"
C29	Q8	CE17L	"	C49	L8	CE61D	"	R32	R8	0·5W RMA8	"	R54	G8	0·5W RMA8	"
C30	R6	345	"	C50	M8	CE18L	"	R33	R7	0·25W RMA9	"	R55	I7	" "	"
C31	R8	"	"					R34	S8	0·5W RMA8	"	R56	I7	" "	"
C32	T8	CE17L	"					R35	S6	1·0W RMA2	"	R57	I8	" "	"
C33	T6	345	"	L2	B7	26320X	EMI	R36	T6	" "	"	R58	J7	" "	"
C34	U8	CE17L	"	L3	V6	26320G	BBC	R37	T8	0·5W RMA8	"	R59	L4	1·0W RMA2	"
C35	V6	M2	"	L4	X3	RXA1148/6	"	R38	U7	0·25W RMA9	"	R60	M4	" "	"
C36	V8	CE18L	"					R39	V4	1·0W RMA2	"	R61	L8	0·5W RMA8	"
C37	W8	CE17L	"					R41	V8	" "	"				
C38	X8	"	"	MR1	E8			R42	W8	0·5W RMA8	"				
C39	Z7	345	"	MR2	J8			R43	X7	0·25W RMA9	"	TR3	C7	SA63/G	
C40	Z7	M3	"					R44	Y6	0·5W RMA8	"	TR4	G5	AR165 OR AL/38SA	
C41	F6	CE18L	"					R45	Y8	" "	"	TR5	L5	" " "	
C42 ✱	F5	TO BE FITTED ON TEST		R25	N8	0.25W RMA9	ERIE	R46	Z8	" "	"				
C43	I6	M2	TCC	R26	O7	MNAR/10450/32000	MORGAN CRUCIBLE	R48	D7	0·5W "	"	V6-V9		AC/SP3 Grade B	

✱ VALUE TO BE ADJUSTED ON TEST

FREQUENCY COMPARATOR FRC2B : DIVIDER AND PULSE GENERATOR

COMPONENT TABLE FOR FIG 3

COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER
C1	D4	101 SMP	TCC	R8	J4	0·5W RMA8	ERIE
C4	I6	C73.01/1	WINGROVE & ROGERS	R9	J6	" "	"
C10	G6	345	TCC	R10	K2	" "	"
C11	H6	"	"	R11	K4	" "	"
C12	K4	M2N	"	R12	L6	" "	"
C13	K1	101 SMP	"	R13	L1	7W P302	PAINTON
C14	K6	345	"	R14	M1	1W RMA2	ERIE
C15	M6	"	"	R15	O1	1W "	"
C16	M4	"	"	R16	O1	MNAR/10550	MORGAN CRUCIBLE
C17	N2	M3N	"	R17	O1	"	" "
C18	Q1	M3GO	"	R18	O7	1W RMA2	ERIE
C19	Q3	345	"	R19	P6	MNAR/50350	MORGAN CRUCIBLE
C20	Q3	"	"	R20	P4	1W RMA2	ERIE
C21	R3	"	"	R21	P3	MNAR/50250	MORGAN CRUCIBLE
C22	T4	111 (2·0) 121B (0·25)	"	R22	Q4	1W RMA2	ERIE
C23	U4	121B	"	R23	R4	" "	"
C24	A14	TO BE FITTED ON TEST		R24	U3	2W A3635	WELWYN
C25	B17	345	TCC	R25	N14	0·5W RMA8	ERIE
C26	B16	"	"	R26	N15	MNAR/10450	MORGAN CRUCIBLE
C27	N13	M3N	"	R27	O14	0·5W RMA8	ERIE
C28	O15	CE32B	"	R28	O14	" "	"
C29	Q15	CE18P	"	R29	P15	MNAR/50150	MORGAN CRUCIBLE
C30	Q13	CP91S	"	R30	P12	1W RMA2	ERIE
C31	R15	CP91N	"	R31	Q12	" "	"
C32	T15	CE18P	"	R32	R15	0·5W RMA8	"
C33	T13	CP91S	"	R33	R14	" "	"
C34	U15	CE18P	"	R34	R15	" "	"
C35	V13	M3N	"	R35	S12	1W RMA2	"
C36	W15	CE18L	"	R36	T12	" "	"
C37	W15	CE18P	"	R37	T15	0·5W RMA8	"
C38	X15	"	"	R38	U14	" "	"
C39	Z14	CP91S	"	R39	V12	1W RMA2	"
C40	Z14	CP37S	"	R41	V15	0·5W RMA8	"
C41	F13	CE18L	"	R42	W15	" "	"
C42	F12	TO BE FITTED ON TEST		R43	X14	" "	"
C43	H13	M3N	TCC	R44	Y13	1W RMA2	"
C44	G15	CE32B	"	R45	Y15	0·5W RMA8	"
C45	H15	CE18L	"	R46	Z15	" "	"
C46	K12	TO BE FITTED ON TEST		R47	P5	CV2/K	PAINTON
C47	J13	CE18L	TCC	R48	C14	0·5W RMA8	ERIE
C48	M13	M3N	"	R49	D14	" "	"
C49	L15	CE32B	"	R50	D15	" "	"
C50	M15	CE18L	"	R51	E14	" "	"
C51	U8	CE19P	"	R52	F11	1W RMA2	"
C52	S8	2 × CE19P	"	R53	H11	" "	"
				R54	G15	0·5W RMA8	"
				R55	I13	" "	"
L1	R1	RXA 1148/10	BBC	R56	I14	" "	"
L2	A14	SA70/G	"	R57	I15	" "	"
L3	V13	RXA 1148/8	"	R58	J14	" "	"
L4	X11	SA71/G	"	R59	K11	1W RMA2	"
L5	T7	EEC/3	PARTRIDGE	R60	M11	" "	"
				R61	K15	0·5W RMA8	"
				R62	P6	2W A3635	WELWYN
MR1	D15			R63	P5	1W RMA2	ERIE
MR2	I15						
				TR1	C5	TDS/TR19	BBC
R2	E5	0·5W RMA8	ERIE	TR2	W5	CRT.1	PARTRIDGE
R3	E4	" "	"	TR3	B14	SA/63G	BBC
R4	G5	" "	"	TR4	G12	AR165 OR AL/38SA	"
R5	G6	MNAR/20250	MORGAN CRUCIBLE	TR5	L12	"	"
R6	H1	1W RMA2	ERIE	TR6	W7		PARTRIDGE
R7	I1	0·5W RMA8	"				

53/JR/102/DJE
EJ8251

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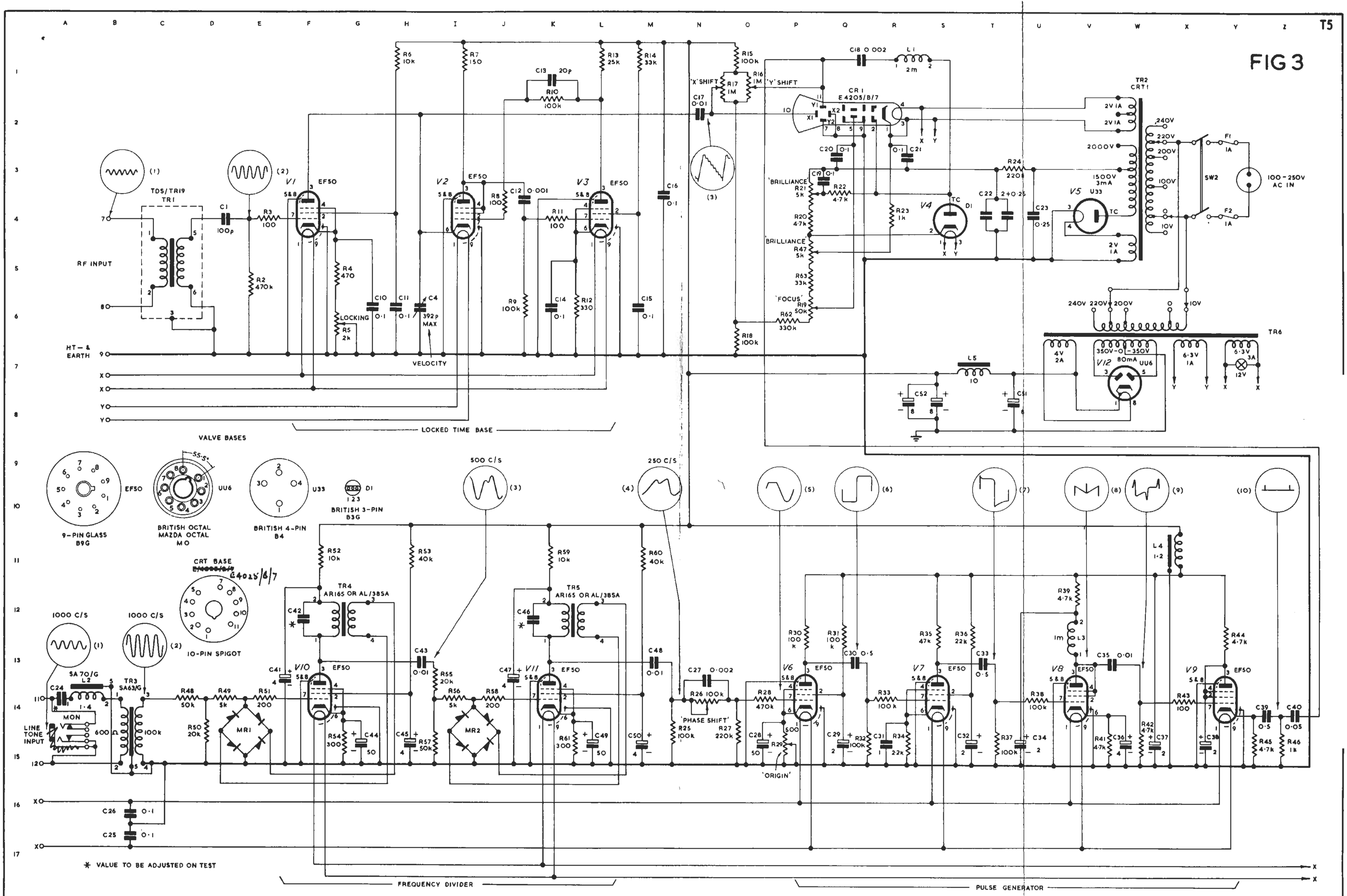
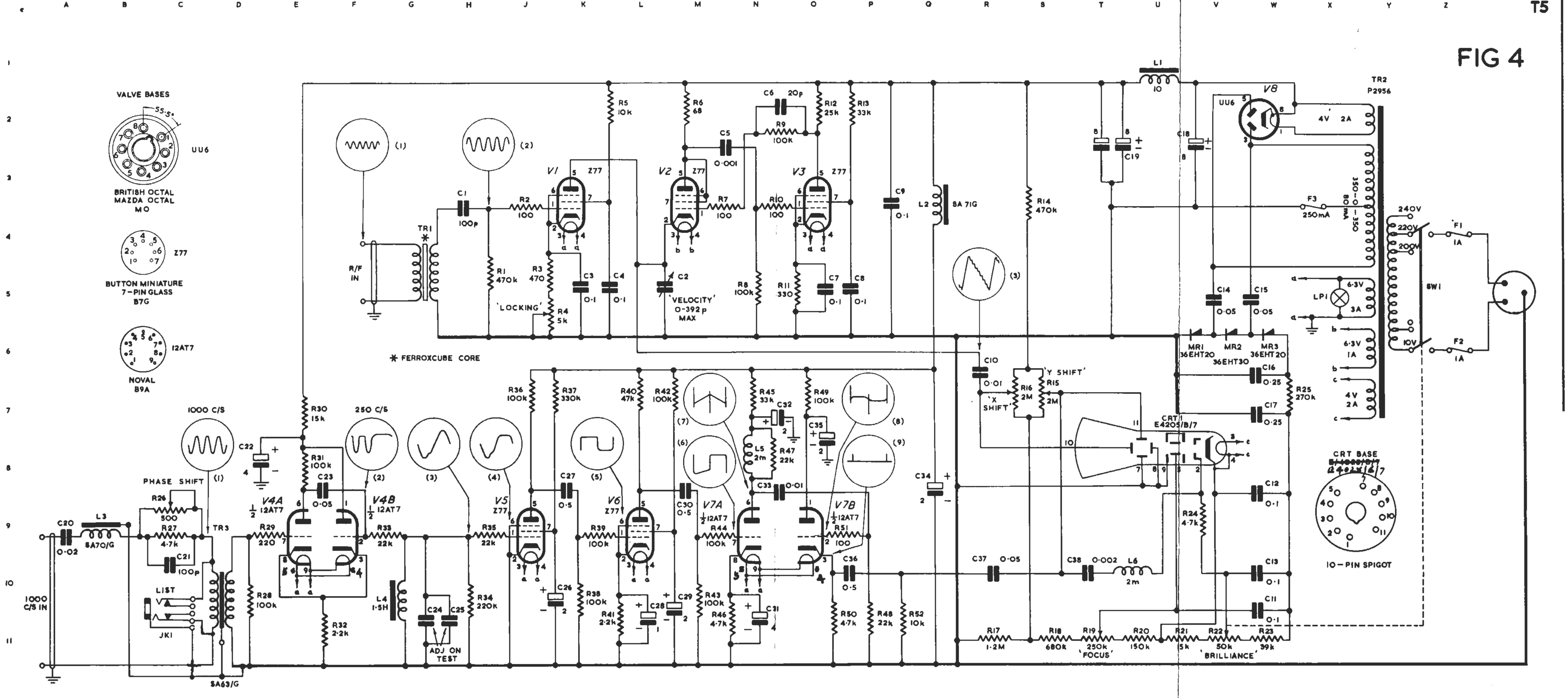
FIG 3



* VALUE TO BE ADJUSTED ON TEST

FREQUENCY COMPARATOR FRC2BM

FIG 4



COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER
C1	H4	101 SMP	TCC	C27	K8	CP47N	TCC	R5	L2	1W RMA 2	ERIE	R31	E8	1W RMA2	ERIE
C2	M5	C73.01/1	WINGROVE & ROGERS	C28	L11	CE32P	"	R6	M2	0·5W RMA 8	"	R32	F11	0·5W RMA8	"
C3	K5	CP45N	TCC	C29	M10	CE18P	"	R7	N4	0·5W "	"	R33	G9	0·5W "	"
C4	L5	"	"	C30	M9	CP47N	"	R8	N5	0·5W "	"	R34	H10	0·5W "	"
C5	N2	101 SMP	"	C31	N11	CE18L	"	R9	O2	0·5W "	"	R35	H9	0·5W "	"
C6	N2	"	"	C32	O7	CE18P	"	R10	O4	0·5W "	"	R36	J7	0·5W "	"
C7	O5	CP45N	"	C33	N8	CP33S	"	R11	O5	0·5W "	"	R37	K7	1W RMA2	"
C8	P5	"	"	C34	Q8	CE18P	"	R12	O2	7W P302	PAINTON	R38	K10	0·5W RMA8	"
C9	P4	"	"	C35	O8	"	"	R13	P2	1W RMA 2	ERIE	R39	K9	0·5W "	"
C10	R6	M3N	"	C36	P10	CP47N	"	R14	S4	0·5W RMA8	"	R40	L7	1W RMA2	"
C11	W11	CP45N	"	C37	R10	CP35N	"	R15	S7	MNAR 20350	MORGANITE	R41	L11	0·25W RMA9	"
C12	W9	"	"	C38	T10	M3GO	"	R16	S7	MNAR 20550	"	R42	M7	1W RMA 2	"
C13	W10	"	"					R17	R11	0·5W RMA 8	ERIE	R43	M10	0·5W RMA8	"
C14	V5	CP35N	"					R18	S11	0·5W "	"	R44	M9	0·5W "	"
C15	W5	154S	"	L1	U2	EEC/3	PARTRIDGE	R19	T11	MNAR 25450	MORGANITE	R45	N7	7W P302	PAINTON
C16	W7	121B	"	L2	Q4	SA71/G	BBC	R20	U11	0·5W RMA 8	ERIE	R46	N11	0·5W RMA8	ERIE
C17	W7	"	"	L3	B9	SA70/G	"	R21	U11	0·5W "	"	R47	O8	0·25W RMA9	"
C18	V2	CE19P	"	L4	G10			R22	V11	MSAR 50350 D.P.S.T	MORGANITE	R48	P11	0·5W RMA8	"
C19	T2	TWO SINGLE CE19P	"	L5	N8	TO RXA 1148/10		R23	W11	0·5W RMA8	ERIE	R49	O7	0·5W "	"
C20	A9	CP34S	"	L6	U10	"		R24	V9	0·5W "	"	R50	O11	0·5W "	"
C21	C10	101 SMP	"					R25	W7	1W RMA2	"	R51	O9	0·25W RMA9	"
C22	D8	CE18L	"					R26	C9	MNAR 50150	MORGANITE	R52	Q11	0·5W RMA8	"
C23	F8	CP35N	"	R1	H5	1W RMA 2	ERIE	R27	C9	0·25W RMA9	ERIE				
C24	G11	ADJ ON TEST	"	R2	J4	0·5W RMA8	"	R28	D10	0·25W "	"	TR1	G4		BBC
C25	H11	"		R3	J5	0·5W "	"	R29	E9	0·25W "	"	TR2	Y2	P 2956	PARTRIDGE
C26	K10	CE 18P	TCC	R4	J6	MNAR 50250	MORGANITE	R30	E7	0.5 W RMA 8	"	TR3	D10	SA63/G	BBC

FREQUENCY CHECKING MONITOR FCM

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52/LF0/1/AJP
RF162

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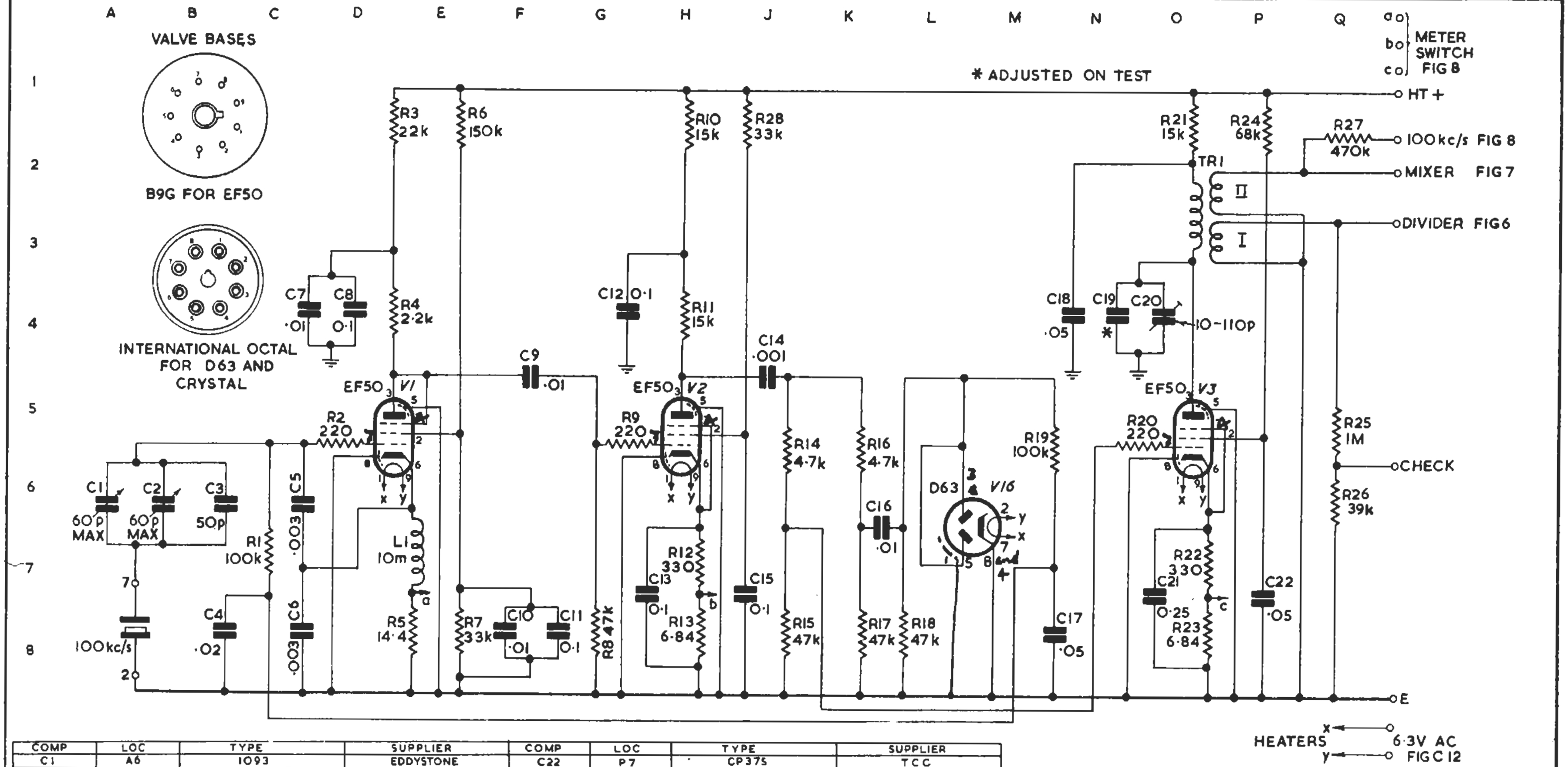

COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER
C1	A6	1093	EDDYSTONE	C22	P7	CP37S	TCC
C2	B6	"	"				
C3	B6	101SMP	TCC				
C4	B8	CP34S	"	L1	E7		BBC
C5	C6	601SMP	"				
C6	C8	"	"				
C7	C4	M3N	"	R1	C7	0·5W RMA8	ERIE
C8	D4	CP46S	"	R2	D5	0·25W RMA9	"
C9	F5	M3N	"	R3	D1	1W RMA2	"
C10	F8	"	"	R4	D4	" "	"
C11	G8	CP46S	"	R5	E8	METER SHUNT	BBC
C12	G4	"	"	R6	E1	1W RMA2	ERIE
C13	H7	"	"	R7	E8	" "	"
C14	J4	601SMP	"	R8	G8	0·5W RMA8	"
C15	J7	CP46S	"	R9	G5	0·25W RMA9	"
C16	L6	M3N	"	R10	H1	1W RMA2	"
C17	N8	CP37S	"	R11	H4	" "	"
C18	N4	"	"	R12	H7	" "	"
C19	N4	TO BE FITTED ON TEST		R13	H8	METER SHUNT	BBC
C20	O4	TCK1010	TCC	R14	J5	0·5W RMA8	ERIE
C21	O7	CP47S	"	R15	J8	" "	"

COMP	LOC	TYPE	SUPPLIER
R16	K5	0·5W RMA8	ERIE
R17	K8	"	"
R18	L8	"	"
R19	N5	"	"
R20	O5	0·25W RMA9	"
R21	O1	1W RMA2	"
R22	O7	"	"
R23	O8	METER SHUNT	BBC
R24	P1	1W RMA2	ERIE
R25	Q5	0·5W RMA8	"
R26	Q6	"	"
R27	Q1	"	"
R28	J1	1W RMA2	"
TR1	O2		BBC

FREQUENCY MONITOR FRM 4: 100kc/s OSCILLATOR

FIG 5 T5

52/LF0/2/N1B
RF161

FIG 6

T5

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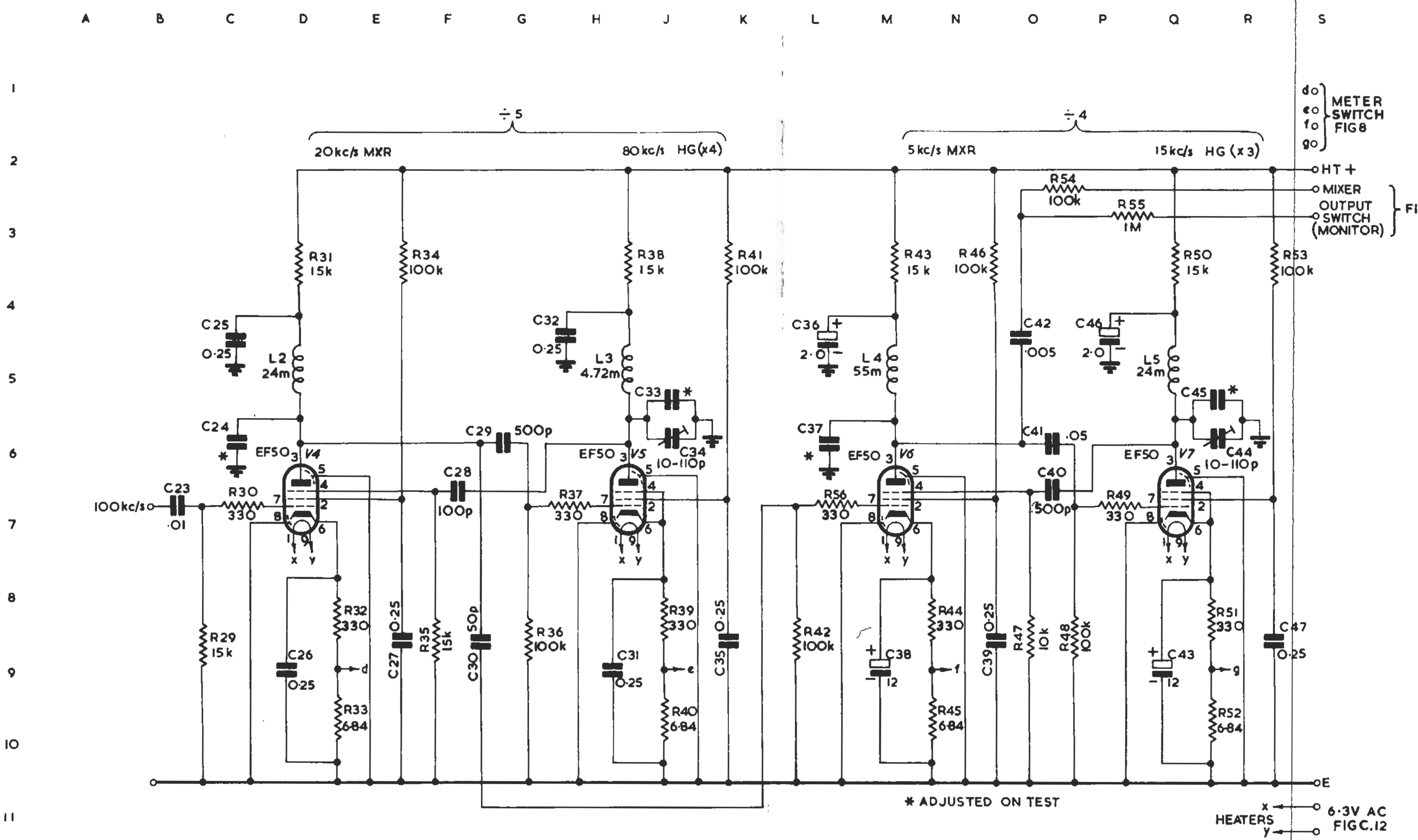
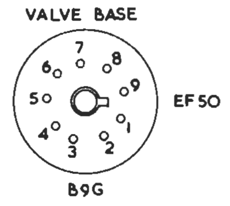


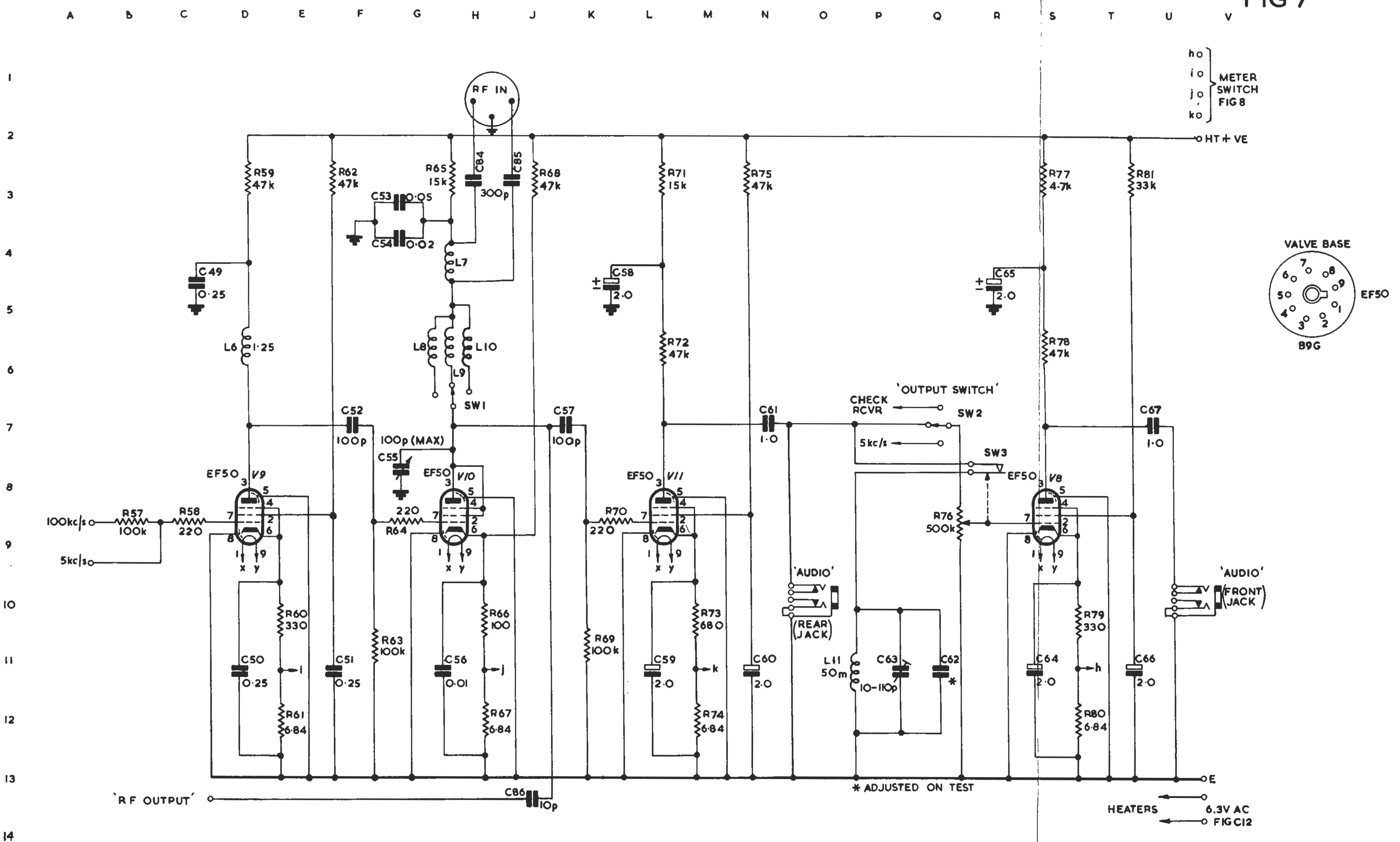
✱ ADJUSTED ON TEST



COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER
C23	B7	M3N	TCC	C39	N9	CP47S	TCC	R29	C9	0·5W RMA8	ERIE	R45	N10	METER SHUNT	BBC
C24	C6	TO BE FITTED ON TEST		C40	O7	501 SMP	"	R30	C7	0·25W RMA9	"	R46	N4	1W RMA2	ERIE
C25	C5	CP47S	TCC	C41	O6	CP37S	"	R31	D4	1W RMA2	"	R47	O9	0·5W RMA8	"
C26	D9	"	"	C42	O5	601 SMP	"	R32	D8	" "	"	R48	P9	" "	"
C27	E9	"	"	C43	Q9	CE31C	"	R33	D10	METER SHUNT	BBC	R49	P7	0·25W RMA9	"
C28	F7	101SMP	"	C44	R6	TCK1010	"	R34	E4	1W RMA2	ERIE	R50	Q4	1W RMA2	"
C29	G6	501SMP	"	C45	R5	TO BE FITTED ON TEST	"	R35	F9	0·5W RMA8	"	R51	R8	" "	"
C30	F9	101SMP	"	C46	P5	CE18P	"	R36	G9	" "	"	R52	Q10	METER SHUNT	BBC
C31	H9	CP47S	"	C47	R9	CP47S	"	R37	H7	0·25W RMA9	"	R53	R4	1W RMA2	ERIE
C32	H5	"	"					R38	H4	1W RMA2	"	R54	P3	0·5W RMA8	"
C33	J5	TO BE FITTED ON TEST						R39	J8	" "	"	R55	O3	" "	"
C34	J6	TCK1010	TCC	L2	D5		BBC	R40	J10	METER SHUNT	BBC	R56	L7	0·25W RMA9	"
C35	K9	CP47S	"	L3	H5		"	R41	K4	1W RMA2	ERIE				
C36	L5	CE18P	"	L4	L5		"	R42	L9	0·5W RMA8	"				
C37	L6	TO BE FITTED ON TEST		L5	Q5		"	R43	M4	1W RMA2	"				
C38	M9	CE31C	TCC					R44	N8	" "	"				

FREQUENCY MONITOR FRM4: DIVIDER

FIG 7



COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER	COMP	LOC	TYPE	SUPPLIER
C49	C5	CP47S	TCC	C64	S11	CE18P	TCC					R70	K9	0·25W RMA9	ERIE
C50	D11	"	"	C65	R5	"	"					R71	L3	1W RMA2	"
C51	F11	"	"	C66	T11	"	"	R57	B9	0·5W RMA8	ERIE	R72	L6	" "	"
C52	F7	101SMP	"	C67	U7	345	"	R58	C9	0·25W RMA9	"	R73	M10	" "	"
C53	G3	CP37S	"	C84	H3	425SMP	TCC	R59	D3	1W RMA2	"	R74	M12	METER SHUNT	BBC
C54	G4	CP34S	"	C85	J3	"	"	R60	D10	" "	"	R75	N3	1W RMA2	ERIE
C55	G8	1130	EDDYSTONE	C86	J13	101SMP	"	R61	D12	METER SHUNT	BBC	R76	Q9	MSAR/50450	MORGAN CRUCIBLE
C56	H11	M3N	TCC					R62	F3	1W RMA2	ERIE	R77	S3	1W RMA2	ERIE
C57	K7	101SMP	"					R63	F11	0·5W RMA8	"	R78	S6	" "	"
C58	K5	CE18P	"	L6	D6	1010	EDDYSTONE	R64	G9	0·25W RMA9	"	R79	S10	" "	"
C59	L11	"	"	L7	H4		BBC	R65	H3	1W RMA2	"	R80	S12	METER SHUNT	BBC
C60	N11	"	"	L8	H6		"	R66	H10	" "	"	R81	T3	1W RMA2	ERIE
C61	N7	345	"	L9	H6		"	R67	H12	METER SHUNT	BBC				
C62	Q11	TO BE FITTED ON TEST	"	L10	H6		"	R68	J3	1W RMA2	ERIE				
C63	P11	TCK1010	TCC	L11	O11	S62722	TMC	R69	K11	0·5W RMA8	"				

FREQUENCY MONITOR FRM4 : MIXER, TUNED AMPR & AF AMPR

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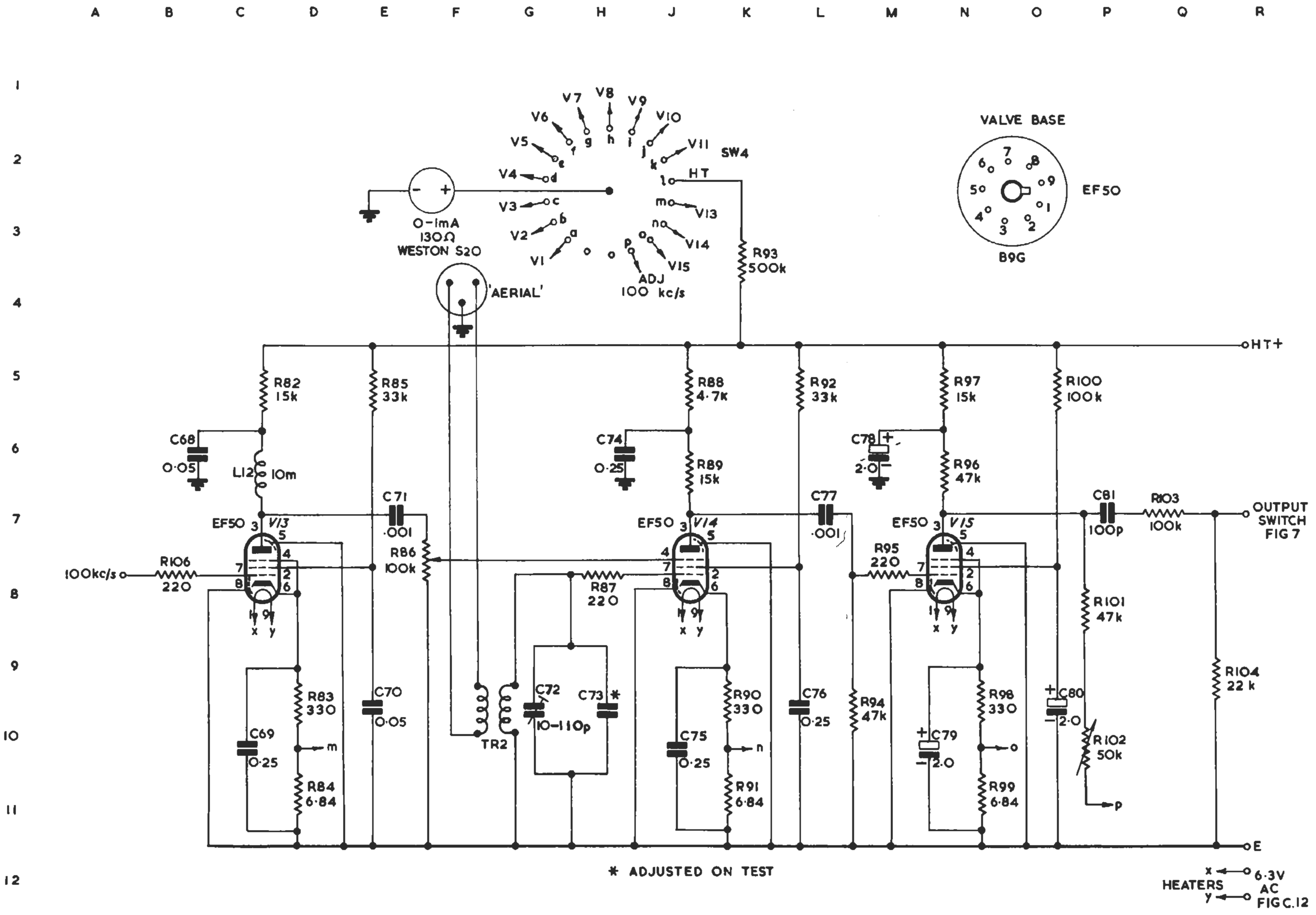
FIG 8 T5



COMP	LOC	TYPE	SUPPLIER
C68	B6	CP37S	TCC
C69	C10	CP47S	"
C70	E10	CP37S	"
C71	E7	601 SMP	"
C72	G10	TCK 1010	"
C73	H10	TO BE FITTED ON TEST	
C74	H6	CP47S	TCC
C75	J10	"	"
C76	L10	"	"
C77	L7	601 SMP	"
C78	M6	CE18P	"
C79	M10	"	"
C80	O10	"	"
C81	P7	101 SMP	"
L12	C6		BBC
R82	C5	1W RMA2	ERIE
R83	D10	" "	"
R84	D11	METER SHUNT	BBC
R85	E5	1W RMA2	ERIE
R86	E8	MNAP/10450	MORGAN CRUCIBLE
R87	H8	0·25W RMA9	ERIE
R88	J5	1W RMA2	"
R89	J6	" "	"
R90	K10	" "	"
R91	K11	METER SHUNT	BBC
R92	L5	1W RMA2	ERIE
R93	K4	1W A3634	WELWYN
R94	L10	0·5W RMA8	ERIE
R95	M8	0·25W RMA9	"
R96	N6	1W RMA2	"
R97	N5	" "	"
R98	N10	" "	"
R99	N11	METER SHUNT	BBC
R100	P5	1W RMA2	ERIE
R101	P8	" "	"
R102	P10	5W TW	RELIANCE
R103	Q7	0·5W RMA8	ERIE
R104	R9	" "	"
R106	B8	0·25W RMA9	"
TR2	G10		BBC

FREQUENCY MONITOR FRM4 : 100kc/s CHECK RECEIVER

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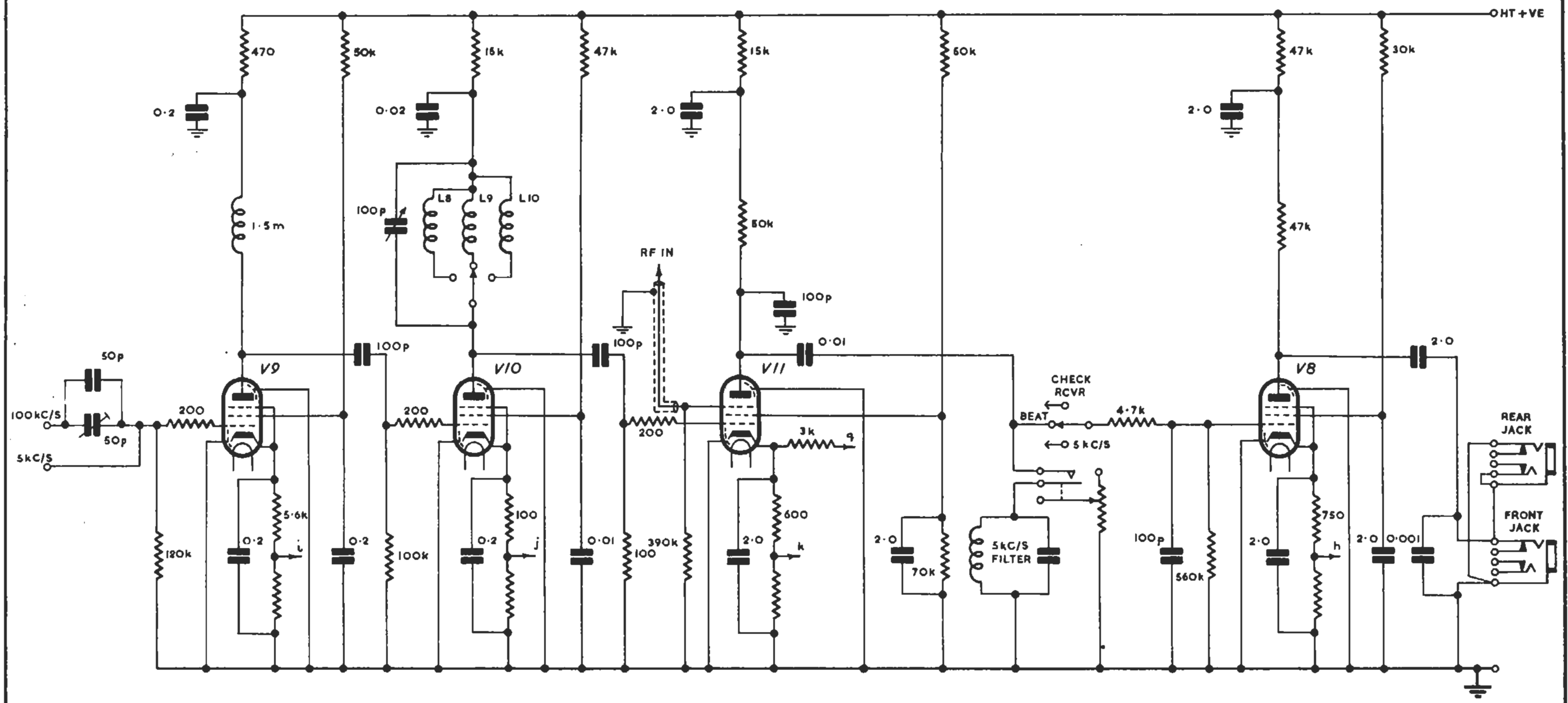
53/JR/103/DJE
RF 164A



FREQUENCY MONITOR FRM4: MIXER, TUNED AMPR AND AF AMPR (MODIFIED)

FIG 9