TECHNICAL INSTRUCTION
TT.2

B.B.C. Crystal Drive Equipment
Type CP.17E

BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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B.B.C. CRYSTAL DRIVE EQUIPMENT.

TYPE CP.17E.

SECTION A. GENERAL DESCRIPTION.

Introduction.

The type CP.17E Crystal Drive Equipment is of a design employing modern technique and incorporating improvements upon earlier B.B.C. crystal drives. It has been necessary to exercise economy in components and material, but the performance and reliability of the equipment has not been allowed to suffer on this account. The diagrams in this Instruction are based upon equipments with serial numbers 1 to 35. Certain minor modifications are being introduced on equipments with serial numbers 36 and higher. References to the latter are made in the text, in so far as circuit details or component values are concerned.

The equipment is mains operated and is entirely self-contained. It normally incorporates one quartz crystal of Post Office type 6B and, in this case, the equipment is characterised by a very high inherent frequency stability comparable with that of modern primary frequency standards. The long-time frequency stability is of the order of $\pm 2.5/10^8$ (i.e. ± 2.5 parts in one hundred million), over a period of one month. The short-time frequency stability is of the order of $\pm 1/10^8$ (i.e. ± 1 part in one hundred million) over a period of several hours. To appreciate what a high order of stability this is, it should be noted that a clock having a long period stability of rate equivalent to that of the CP.17E oscillator would lose or gain at the rate of one second in some 460 days.

The complete equipment has been designed to operate with a minimum of alteration on any output frequency between 150 kc/s and 1,600 kc/s, a frequency range which covers the long and medium wave broadcasting bands. For frequencies lying in the range below 600 kc/s, crystals for direct control of the output frequencies would in general possess dimensions such that certain of their characteristics (temperature-frequency coefficient, activity, and freedom from coupling), would be below the standards laid down for the equipment and, for this reason, frequency division is employed to obtain these frequencies, using crystals operating at higher frequencies. As an example, an output frequency of 200 kc/s (1,500 metres), would be obtained by using a rystal cut for 1,000 kc/s, in conjunction with a Frequency Divider dividing by 5. For frequencies between 600 kc/s and 1,200 kc/s crystals cut for the output frequencies direct are used and on these frequencies the Crystal Maintaining Amplifier is connected to the Crystal Output Amplifier direct. For frequencies higher than 1,200 kc/s crystals operating at the output frequencies are so reduced in thickness that difficulties are met in clamping them in the holder. For this reason crystals cut for lower frequencies are used and the desired output frequencies obtained by frequency multiplication. As an example, an output frequency 1,474 kc/s (203.5 metres), would be obtained by using a crystal cut for 737 kc/s, in conjunction with a Frequency Multiplier multiplying by 2.

Thus, the layout of the equipment will, as shown in Fig. 1, be dependent upon whether: *(a)* a Frequency Divider is used; *(b)* the crystal is cut for the output frequency; or *(c)* a Frequency Multiplier is used.

The equipment is rack-mounted. Fig. 3 shows the bay layout, with its nine panels. The units comprising the equipment are, reading upwards from the base of the rack :—

Termination Panel.
H.T. Rectifier and L.T. Supply Unit.
L.T. Transformer Panel.
Crystal Oven and Oven Temperature Relay.
Crystal Maintaining Amplifier.
Frequency Multiplier, or Frequency Divider, or,
  if neither of these is required, a link panel.
Crystal Output Amplifier.
Meter and Switch Panel.
Oven Alarm Relay Panel.

The L.T. Transformer Panel is provided in all CP.17E equipments, but is only used for L.T. supply purposes when frequency checking equipment is mounted in the space at the top of the bay.

The CP.17E drive equipment is designed to operate from a 50 cycle A.C. source at any of the following input voltages :—100, 110, 200, 210, 220, 230, 240 and 250. The mains input power varies between approximately 200 and 250 watts, without frequency checking equipment.

The Crystal Output Amplifier is designed to work into a balanced non-reactive load of 100 ohms and will deliver 6 watts of H.F. power to such a load on all frequencies between 150 kc/sec. and 1,600 kc/s with a low harmonic content.

Schematics showing the inter-panel connections are included for reference (Fig. 4), and the abbreviations used in this and other diagrams are as follows :—

TMN : Termination Panel.
HRL : H.T. Rectifier and L.T. Supply.
CO : Crystal Oven.
OTR : Oven Temperature Relay.
CMA : Crystal Maintaining Amplifier.
FDV : Frequency Divider.
FM : Frequency Multiplier.
COA : Crystal Output Amplifier.
MRS : Meter and Switch Panel.
OAR : Oven Alarm Relay Panel.
OHT : Oven Heating Transformer.

A number followed by one of the above abbreviations signifies a particular tag connection on the unit concerned. Thus, 15.MRS refers to tag No. 15 on the Meter and Switch Panel tag block.

VALVE TYPES.

All valves used are of B.B.C. preferred types. The valve allocation in the equipment is given in the following table :—

	AC/SP3	AL60	D42	UU5
H.T. Rectifier and L.T. Supply ...				2
Crystal Maintaining Amplifier ...	3		1	
Frequency Divider	4			
Frequency Multiplier	1			
Crystal Output Amplifier		2	1	
Oven Temperature Relay	1			

SECTION B. THE CRYSTAL.

The high degree of frequency stability of the CP.17E equipment is in the main due to the type of crystal used and the following points should be noted :—

(1) The Post Office Engineering Department has done very considerable research and development work upon quartz oscillator crystals and the crystal normally used in the CP.17E equipment is the type 6B supplied by that Department. The quartz plate is cut from specially selected material and the angle of cut is chosen to give a low temperature-frequency coefficient.

(2) The angle of cut is one of the so-called inclined cuts, generally AT or BT, and the crystal plate is characterised by a very low temperature-frequency coefficient (i.e. the change of frequency for unit change of temperature is very small), and by negligible interaction between alternative modes of oscillation.

(3) The crystal plate has a shear mode of fundamental vibration and this enables the crystal to be clamped in its holder with a minimum of damping of its vibrations. The nature of the shear vibrations is as indicated in Fig. 2, from which it will be seen that a nodal plane exists bounded by the bisection of the edges of the plate.

(4) In addition to using a crystal of very low temperature-frequency coefficient the temperature of the crystal and its holder is held within close limits. This is the function of the crystal oven and oven temperature relay.

(5) The crystal vibrates in a partial vacuum, the pressure being reduced to about 10 cms. of mercury (reference 76 cms. atmospheric pressure), thus preventing air resonances, reducing damping and improving the Q of the equivalent electrical circuit of the crystal.

NOTE.—Information regarding quartz crystals, types of cut, equivalent electrical circuit, etc., is given in Technical Instruction TT.3 which supersedes Technical Instruction 16.1 of Volume 2.

The Crystal Holder (Fig. 5).

A photograph of the assembled P.O. crystal holder, type 6B, is given in Fig. 5. The crystal plate and the method used for clamping can be seen clearly in this photograph.

The top electrode takes the form of a sputtered gold film on the underside of a glass disc, the bearing surfaces of which are made optically flat for fitting to the main stainless steel block. It is connected by a metal screw to the top terminal which is sealed in the disc. The bottom electrode is a circular threaded metal boss which is screwed into the crystal holding carriage and is electrically in contact with the main body of the assembly.

The holder is of the double air-gap type. The gaps are adjusted during production by rotating the bottom electrode relative to the crystal holding carriage for adjustment of the lower gap, and rotating the crystal holding carriage and the bottom electrode together relative to the base, for adjustment of the upper gap.

The crystal is clamped on its nodal plane and is held in its carriage by means of four clamped pins engaging in holes in the plate.

The final processes of manufacture are the reduction of the internal air pressure of the holder and the sealing of the glass disc to the main body.

SECTION C. THE CRYSTAL OVEN (Figs. 6, 7, 8, 9 and 10).

The purpose of the crystal oven is to maintain the temperature of the mounted quartz crystal within close limits in spite of variations in ambient temperature, i.e. temperature of the air surrounding the oven.

Construction of Oven.

The oven consists of three main parts : (*a*) the outer box ; (*b*) an assembly carrying the heater mats ; and (*c*) an inner chamber in which the crystal holder is mounted.

The Outer Box is made up of two tinned iron boxes with a layer of "Tentest" heat insulation material between them and reference in this Instruction to the Outer Box refers to the above combination. The assembly carrying the heater mats will be referred to as the First Inner Oven, while the inner chamber containing the crystal holder will be referred to as the Second Inner Oven.

The back of the Outer Box is removable and the photograph (Fig. 6), shows the Crystal Oven unit as it appears when the back of the Outer Box is removed.

The outer surfaces of the Outer Box are finished matt, while the inner surfaces are given a bright finish in order to minimise heat radiation from the inner oven assemblies. This applies also to the First and Second Inner Ovens.

The First Inner Oven is shown in the photograph (Fig. 7), as it would appear if removed from the Outer Box, the screened connection tube and the indicating thermometer being reinserted after removal. The First Inner Oven consists of a cylindrical brass box with lid, heater mats being fitted to all the outer surfaces. A tube fixed to the side of the assembly carries the contact thermometer, which thus operates with changes of temperature of the First Inner Oven. Another view of the First Inner Oven is shown in Fig. 8 (right-hand side of photograph). In this case the unit is shown in a partly dismantled condition. There are three heater mats, top, bottom and side. The heater mat connections, the contact thermometer connections and an earth connection are all brought up to a hinged tag block on the Outer Box. This tag block can be swung back to permit removal or fitting of the inner oven assemblies. The tag block can be seen in the photograph, Fig. 6.

The Second Inner Oven is shown in a dismantled condition but with the screened connection tube inserted, on the left-hand side of Fig. 8. The Second Inner Oven consists of a cast brass pot with removable lid. It is heat insulated from the First Inner Oven (into which it fits), by a thick layer of felt which can be seen inside the First Inner Oven in the view of the latter given in Fig. 8. The lid carries a brass bracket, in which the crystal holder is fixed, and a spring-loaded socket for the screened connection tube used to connect the crystal to the external oscillating circuit. These arrangements are clearly shown in Fig. 8, the crystal holder and the screened connection tube being shown fitted in position. The screened connection tube is of similar design to that which has been in use for some time in B.B.C. Crystal Drive equipments and a detailed description of it will be found in Technical Instruction, Vol. 2, Item 16.2, page 5. An earth connection is taken to the lid of the Second Inner Oven by means of a length of studding which is long enough to pass through the lid of the First Inner Oven. A bakelite plug is fitted to the Second Inner Oven to locate it inside the First Inner Oven and a pin in the flange seating of the Second Inner Oven locates its lid.

An indicating thermometer, the upper part of which can be seen in Fig. 7, is inserted so that it passes through the lids of both the First and Second Inner Ovens. It gives an indication of the temperature inside the Second Inner Oven, i.e. of the space immediately surrounding the crystal holder itself.

Oven Heating Circuit (Figs. 9, 10).

The temperature-frequency coefficient of the crystal is of the order of plus or minus $0.2/10^6/°$ C. (i.e. plus or minus two parts in ten million per degree Centigrade). While this coefficient is small, to obtain the order of frequency stability required it is necessary nevertheless to control the temperature of the crystal within close limits.

The direct switching of the heating current is carried out by the Oven Temperature Relay, this being controlled in turn by the contact thermometer in conjunction with the oven relay valve.

During the operation of the thermal cycle the maximum variations of temperature inside the Second Inner Oven are of the order of ±0.01° C. for ambient temperature changes of ±5° C. The change of frequency for a temperature change of ±0.01° C. would thus be $\pm 2/10^9$, taking the temperature-frequency coefficient given above.

The CP.17E Drive Equipment will normally be installed in a screened drive room the ambient temperature of which is controlled within ±5° F. of 70° F. and thus the frequency variation due to ambient temperature variations can usually be neglected.

The normal operating temperature of the crystal is 50° C. The indicating thermometer is calibrated from 40° C. to 60° C.—one degree occupying 1/20″ of scale—and it will be appreciated that in view of the very small variations of temperature inside the Second Inner Oven under normal conditions the mercury column of the indicating thermometer will appear stationary. This thermometer is of use, however, during the initial warming-up period and during fault conditions.

Fig. 9 shows the oven heating circuit. The Y1 relay contacts are the main switching contacts, relay Y1 being mounted on the Oven Temperature Relay Panel. The Y3 relay contacts are inserted into the circuit for protective purposes. These relays are considered in detail later in this section of the Instruction.

The Oven Heating Transformer, which is mounted on the front of the Crystal Oven and Oven Temperature Relay Panel, has a primary winding tapped at 100, 110, 200, 210, 220, 230, 240 and 250 volts. In equipments with serial numbers 1 to 35 the secondary taps are at 100, 110, 120, 130, 140, 150 and 160 volts. For equipments with serial numbers 36 and higher the secondary taps are at 60, 70, 80, 90, 100, 110, 120, 130 and 140 volts. Another modification is the introduction of fuses in the primary circuit in the latter equipments. The secondary voltage tap is adjusted during installation to give a balanced thermal cycle at the average ambient temperature near the equipment.

The oven heating current is indicated on the right-hand meter on the Meter and Switch Panel, with the meter switch in position 6. This meter reading will follow the *on/off* periods of the thermal cycle, providing thereby a visual indication of its operation. The oven heating circuit voltage is indicated on the right-hand meter of the Meter and Switch Panel, with the switch in position 2. The meter reading is independent of the thermal cycle.

The Contact Thermometer (Fig. 10).

The contact thermometer is a straight stem mercury glass thermometer fitted with four contacts. Contact T1 is connected to −30 V. D.C., contact T2 to the "Oven Low" alarm relay, contact T3 to the grid of the oven temperature relay valve, and contact T4 to the "Oven High" alarm relay. The mercury column will be at contact T2 when the temperature of the First Inner Oven is at 45° C., approximately. It will reach contact T3 at 50° C. and contact T4 at 55° C., approximately.

Oven Temperature Relay (Fig. 11).

The switching of the oven heating circuit is controlled by the relay Y1 (Fig. 11), in conjunction with the oven temperature relay valve which, in turn, is controlled by the contact thermometer. In equipments with serial numbers 1 to 35 relay Y1 is of a type employing mercury contacts. In equipments with serial numbers 36 and higher the relay is of a type employing silver-nickel contacts.

The oven relay valve is an AC/SP3 used with its anode, suppressor grid and screened grid joined together, thus acting as a triode. According to the position of the mercury column in the contact thermometer there are two alternative operating conditions for the valve. When there is no contact between the mercury column and contact T3 of the thermometer (Fig. 10), the control grid has approximately zero bias and the anode current is of the order of 10 milliamps. When there is contact between the mercury column and contact T3, a negative bias of 30 volts is applied to the control grid. Under this condition the valve is biased beyond cut-off and the anode current is reduced to zero.

The winding of the relay is in series with the anode circuit of the oven relay valve and is thus energized by its anode current. Under the zero bias condition (mercury column below contact T3 in the thermometer), the relay coil is energized, the relay contacts are closed and the oven heating transformer is connected to the oven heating mats. When the control grid is negatively biased (mercury column at, or above, contact T3 in the thermometer), there is no current in the relay coil, the relay contacts are open and the oven heating circuit is broken.

Owing to the inductance of the oven heating transformer winding and of the oven heating mats (Fig. 9), it is necessary to include an arc suppressing shunt across the relay contacts and this is provided by the components R4, C2 (Fig. 11).

The anode circuit of the oven relay valve contains the voltage dropping resistance R2 and the meter shunt resistance R3. The condenser C1 provides decoupling, in conjunction with the resistance R2.

The anode current of the oven relay valve is indicated on the left-hand meter of the Meter and Switch Panel with the switch in position 1, in which condition the meter is connected across the shunt R3 (Fig. 11). It should be noted that the anode current of this valve will rise and fall with the thermal cycle.

The heater of the oven relay valve is supplied with A.C. at 4 volts from one winding of the filament supply transformer of the H.T. Rectifier and L.T. Supply Unit (Fig. 14). The H.T. supply is derived from the H.T. rectifier while the −30 V. bias is derived from a simple half-wave rectifier contained in the H.T. Rectifier and L.T. Supply Unit.

Oven Alarm Relay Panel (Figs. 12 and 13).

The Oven Alarm Relay Panel carries three relays Y1, Y2 and Y3 (Fig. 12). Each of these relays, when in the energized condition, is supplied with D.C. derived from the 30 volt bias rectifier of the H.T. Rectifier and L.T. Supply Unit.

Y1 is the " Oven Low " alarm relay. Normally it is energized and contacts BC and EF of Y1 (Fig. 12), are held open As the energizing supply is connected through the contacts T1 and T2 of the contact thermometer (Fig. 10), it follows that Y1 will remain energized as long as the temperature of the First Inner Oven is maintained at 45° C. or higher. Should the temperature fall below 45° C., the energizing circuit will be broken at T2 and the Y1 relay contacts BC and EF will close. An alarm bell and battery are connected across tags 8 and 9 of the Oven Alarm Relay Panel, via tags 4 and 5 of the Termination Panel, and the closing of the " Oven Low " alarm relay contacts BC will complete the bell circuit, thus giving an audible alarm. At the same time the closing of the relay contacts EF will complete a circuit from the battery through the " Oven Low " pilot lamp, P1 (Figs. 12 and 13), giving visual indication that low oven temperature is responsible for the alarm bell ringing.

Y2 is the " Oven High " alarm relay. Normally it is not energized. The 30 volt energizing circuit becomes completed, however, if the mercury column of the contact thermometer reaches contact T4. Thus the " Oven High " alarm relay operates only when the temperature of the oven is 55° C., or higher. The energizing of this relay causes the Y2 relay contacts BA to close, contacts ED to close and contacts JK to open. When contacts ED close they complete the alarm-bell circuit ; contacts AB closing will complete the circuit through the " Oven High " pilot lamp, P2, and contacts JK opening will break the energizing circuit of the Y3 relay.

Y3 is a protective relay, the function of which is to switch off the oven heating current if the oven temperature rises sufficiently to operate the " Oven High " alarm relay. Contacts JK of relay Y2 are in series with the winding of relay Y3 so that the energizing circuit of Y3 is broken when Y2 is energized. The contacts BA of the Y3 relay are in series with the oven heating circuit (Fig. 9).

Since, in the normal course of events, the alarm circuits are not operative, it is important that means of testing their operation be provided. This is the purpose of the test keys S1 and S2 (Fig. 12). S1 is normally closed and is in series with the winding of the " Oven Low " alarm relay. Pressing S1 will break the energizing circuit of this relay, thus simulating the effect of breaking the connection between the mercury column and T2 of the contact thermometer. S2 is normally open and is connected on one side to T4 of the contact thermometer, via tag 7 of the Oven Alarm Relay Panel and tag 5 of the Crystal Oven, and on the other side to −30 V., via tag 4 of the Oven Alarm Relay Panel and tag 1 of the H.T. Rectifier and L.T. Supply Unit. Pressing S2 completes the energising circuit through the " Oven High " alarm relay winding, thus simulating the effect of contact between the mercury column and T4 of the contact thermometer.

Resistances R1 and R2 are current limiting resistances in series with the windings of the Y1 and Y2 relays, respectively. In equipments with serial numbers 36 and higher, a 1,000 ohms resistance is also included in series with the winding of the Y3 relay.

SECTION D. H.T. RECTIFIER AND L.T. SUPPLY UNIT (Fig. 14).

This unit provides high tension for the entire equipment, including frequency checking apparatus, if fitted, and low tension A.C. for the crystal drive equipment only (see Section L). A 30 volt D.C. supply for energizing the alarm relays and for the negative biasing of the oven relay valve is also provided.

The H.T. rectifier circuit employs two rectifier valves in a full-wave circuit. The bias supply rectifier circuit employs two half-wave Westinghouse rectifiers connected in parallel. The low tension A.C. supplies are provided by a transformer having a number of L.T. secondary windings, each individual winding supplying a particular unit.

H.T. Rectifier.

The H.T. rectifier circuit utilizes two secondary windings of transformer T1 (Fig. 14). The primary of this transformer is tapped 100, 110, 200, 210, 220, 230, 240 and 250 volts and the voltage tap is adjusted at the time of installation in accordance with the particular mains voltage. The centre tapped H.T. secondary is a 400-0-400 volts winding, while the rectifier filament secondary is a 4 volts winding.

As the D.C. output required exceeds the rating of a single, full-wave rectifier valve, type UU5, two such valves are used, in a conventional circuit, each valve having its two anodes joined together. These valves are of the indirectly heated cathode type and are operated with their heaters connected in parallel.

30 Volt Bias Rectifier.

This circuit is of simple half-wave type employing two Westinghouse H.10 rectifiers connected in parallel and operating from a 30 volt winding on the transformer T1 (Fig. 14). A reservoir condenser, C3, is used and provides adequate smoothing for this circuit. R1 is a loading resistance which serves to improve the regulation. The maximum current drawn from this rectifier is 10 milliamps at 30 volts D.C.

L.T. Supplies.

Low tension A.C. for the valve heaters is provided by the four secondary windings of transformer T2 (Fig. 14). The primary of this transformer is tapped similarly to that of transformer T1. The four secondary windings supply, respectively, the Crystal Output Amplifier valves, the Oven Temperature Relay valve, the Crystal Maintaining Amplifier valves and the Frequency Multiplier (or Divider), valves, if one of these units is fitted. All valve heaters in the above units are of four volt rating. Between the transformer windings and the valve heaters there are potential drops due to contact resistance in the fuse holders and resistance in the cable form and panel wiring. With one exception the transformer L.T. secondaries are wound to give more than four volts, in order to compensate for these potential drops. The exception is that of the winding supplying the oven relay valve. In this case, as only one valve is supplied, the potential drop is negligible. In equipments with serial numbers 1 to 35 the transformer windings, with the exception mentioned above, provide 5 volts at their terminals. For equipments with serial numbers 36 and higher, there is a slightly modified voltage specification owing to the fact that no L.T. fuses are provided.

For the purpose of giving visual indication that the H.T. Rectifier and L.T. Supply Unit is operating, a pilot lamp (with red cap) is energised by the L.T. winding supplying the Crystal Output Amplifier.

Fuses.

The fusing of the H.T. Rectifier and L.T. Supply Unit in equipments with serial numbers 1 to 35 is as shown in Fig. 14. Fuses are fitted in the following circuits: A.C. input, 30 volt D.C. output, H.T. output, and in each leg of the low tension A.C. outputs.

In equipments with serial numbers 36 and higher, fuses are omitted from the low tension A.C. circuits, the other fuses being retained and rearranged in the mounting.

SECTION E. METER AND SWITCH PANEL (Fig. 15).

Two meters are used, in conjunction with suitable shunts, multipliers and a current transformer. By appropriate switching all the routine current and voltage measurements in the equipment can be made.

The left-hand meter is a 0/1 milliammeter, with a scale reading of 0-200 divisions and having an internal resistance of 60 ohms $\pm 1\%$. According to the position of its rotary switch this meter will indicate, reading in a clockwise direction from position 1 :—

(1) Oven temperature relay valve anode current (milliamps). Divide scale reading by 10.

(2) Total of anode and screen currents (milliamps), of the oscillator valve of the Crystal Maintaining Amplifier. Divide scale reading by 10.

(3) Total of anode and screen currents (milliamps), of the limiter valve of the Crystal Maintaining Amplifier. Divide scale reading by 10.

(4) Total of anode and screen currents (milliamps), of the separator valve of the Crystal Maintaining Amplifier. Divide scale reading by 10.

(5) If a Frequency Multiplier is fitted, the total of the anode and screen currents (milliamps), of the multiplier valve. Divide scale reading by 10. Alternatively, if a Frequency Divider is fitted, the total of all the anode and screen currents (milliamps), of the valves in the Divider unit. Divide scale reading by 5.

(6) Total of anode and screen currents (milliamps), of the two valves in the Crystal Output Amplifier. Direct reading.

The right-hand meter measures voltages except with its rotary switch in position 6, when the oven heating current is indicated. The meter is a 0/1 milliameter, with a scale reading of 0-500 divisions, and having an internal resistance of 60 ohms ±1%.

On the A.C. ranges, 5 mA Westinghouse instrument type rectifiers are used. The output of this type of rectifier must not be connected to an open circuit nor must the voltage drop across it exceed 150 millivolts, otherwise it will be damaged. These limitations have been dealt with in the CP.17E equipment by shunting each rectifier with a resistance equal to the meter resistance, so that with the meter disconnected the maximum voltage drop across the rectifier is of the order of 60 millivolts.

A current transformer is used in the circuit for measuring the oven heating current, in order to avoid the use of an additional meter.

According to the position of the associated rotary switch the right-hand meter will indicate, reading in a clockwise direction from position 1 :—

(1) A.C. supply volts. Divide scale reading by 2.
(2) Oven heating volts. Divide scale reading by 2.
(3) D.C. bias volts. Divide scale reading by 10.
(4) H.T. rectifier output volts. Direct reading.
(5) H.F. output volts of the Crystal Output Amplifier. Divide scale reading by 10. (N.B.—A diode rectifier associated with this measuring circuit is contained in the Crystal Output Amplifier).
(6) Oven heating current (milliamps). Multiply scale reading by 2. This reading will vary with the thermal cycle. It should be noted that if the " Oven High " alarm test key is operated while the oven heating circuit is closed a null reading will be obtained until the key is released.

SECTION F. CRYSTAL MAINTAINING AMPLIFIER (Figs. 16 and 17).

The Crystal Maintaining Amplifier (Fig. 16), contains three stages: oscillator, limiter and separator. Type AC/SP3 valves are used in the three stages, with the addition of a D.42 diode which forms part of the limiting circuit. In the case of the oscillator stage the anode and suppressor grid of the AC/SP3 are connected together so that this valve operates as a tetrode and not as a pentode.

Oscillator Stage.

The design of the oscillator circuit differs radically from that of the CP.2 type oscillator circuit described in Technical Instructions, Vol. 2, Item 16.2, page 9, and has been evolved in order to overcome certain disadvantages of the latter. Thus an understanding of the new circuit necessitates consideration of the earlier design.

Any oscillator circuit making use of the principles of resonance for frequency control may be represented schematically as in Fig. 17A. Essentially there must be provided: (1) a frequency determining network; (2) an energy supplying circuit; and (3) an amplitude limiter.

In crystal oscillator circuits the crystal may be represented as an LCR network of very high Q (i.e. wL/R), value. The amplitude limiter need not be a separate stage as it is possible for the limiting action to take place in the amplifier itself, e.g. by means of grid current limiting.

In order that a state of oscillation may exist in the circuit of Fig. 17A, the following conditions must be fulfilled: (*a*) There must be zero voltage gain round the loop. That is to say, the gain through the amplifier must equal exactly the loss through the frequency determining network. (*b*) There must be zero phase shift (or an integral multiple of 360° phase shift) round the loop. In other words, the phase shift through the amplifier must be equal and opposite to that through the frequency determining network.

Under the steady oscillation condition the amplifier supplies energy to the frequency determining network at exactly the same rate as energy is expended in the latter. In order that oscillations may build up in the first place, however, the gain of the amplifier must be in excess of the gain required for the maintenance of oscillations in the steady state. The purpose of the limiter is then to reduce the gain of the amplifier to that required for the steady state.

By maintaining a small amplitude at the input, the waveform in the oscillatory circuit is maintained as free from harmonic content as possible. Reduction of harmonic components reduces the amplitude of intermodulation products of consecutive harmonics which, in turn, give rise to additional components at the fundamental frequency the phase and amplitude of which vary with the valve parameters.

The frequency stability of an oscillator is largely dependent upon the phase angle/frequency characteristic of the frequency determining network. Typical characteristics are shown in Fig. 17D. Curve 1 is applicable to a high Q network while curve 2 is applicable to a low Q network. (The dotted lines represent the limits for infinite Q). It will be seen from the figure that the higher the Q of the network the smaller will be the change of frequency for a given change of phase angle. Similarly, with a given Q value, the further the network is operated from the resonant frequency the greater will be the change of frequency for a given change of phase angle.

The equivalent Q of a crystal is very high and it is desirable that the maintaining circuit shall be arranged to give as small a phase shift as possible in order that the equivalent network of the crystal may be operated on the steepest part of its phase angle/frequency characteristic. The Q values of P.O type 6B crystals vary between 20,000 and 90,000, resulting in a very steep phase angle/frequency characteristic. (It should be noted that a high-grade LC circuit would have a Q value no greater than 500).

Figs. 17B and 17C show the essential differences between the type of oscillator which represented B.B.C. standard practice, prior to the introduction of the type CP.17E equipment, and the type which is in use in the latter equipment. (For the sake of simplicity the automatic biasing arrangements are omitted from both figures).

Considering first Fig. 17B, the crystal is connected to the grid resistance R, the frequency adjusting condenser C and the effective input impedance, Z_{in}, of the valve. In this oscillator circuit the equivalent network of the crystal can be represented by a resistance in series with a high value of reactance.

A disadvantage of this circuit is that owing to the direct shunting of the crystal by the effective input impedance of the valve this impedance becomes a factor of great importance in determining the frequency stability and the conditions of oscillation.

The effective input impedance of the valve must have a negative resistance component if the valve is to supply energy to the crystal. Thus, as explained in Technical Instructions, Vol. 2, Item 16.2, page 9, it is necessary with the earlier circuit to tune the parallel resonant circuit in the anode to a frequency higher than the operating frequency in order that the valve input impedance shall include this negative resistance component. The adjustment of this circuit necessary to obtain the correct value of negative resistance is such that the input impedance has negative resistance, and capacitive reactance, with a phase angle of about −87°. It follows that for the maintenance of steady oscillation there must be a phase shift of +87° in the equivalent network of the crystal, that is, the crystal must operate at a frequency corresponding to a phase angle of +87° in its equivalent network.

Both the negative resistance and capacitive reactance components of the valve input impedance are dependent partly upon the inter-electrode capacities of the valve. This means that the impedance components and the phase angle are almost certain to change when the oscillator valve is replaced and with the circuit of Fig. 17B any such change will cause a considerable change of oscillator frequency. As an example, a Pen.DD 1360 valve replacement can, in the earlier type of oscillator, cause a change of frequency of the order of 1 to 3 parts in 10^6, even after a period of pre-service valve ageing. Variations are also possible with the ageing of the valve in service, due to small changes in the inter-electrode capacities. For example, a $1\mu\mu$F change in the grid/cathode capacity of the oscillator valve will cause a change of frequency of from 7 to 10 parts in 10^7.

Now, considering the CP.17E circuit (Fig. 17C), it will be seen that the circuit embodies low impedance coupling between the crystal and the valve circuit. Fig. 17E is a schematic of the oscillator circuit. In this figure C_s L_s R_s represent the equivalent series network of the crystal and C is the frequency adjusting condenser. The H.F. choke which is connected across C3 is omitted from Fig. 17E as its reactance is sufficiently high in comparison with that of C3 for it to be neglected in this explanation.

It will be seen from an inspection of the diagrams that the input impedance of the valve is shunted by the condenser C4. This condenser is of relatively large capacity compared with the input capacity of, say, $18\mu\mu$F for an AC/SP3 valve, so that changes in the valve input capacity will have only a minor effect on the value of the total reactance.

It is, of course, just as necessary with this circuit as it is with that of earlier design that the valve input impedance shall have a negative resistance component. An analysis of the circuit of Fig. 17E will show that the impedance between the points A and B is, for all practical purposes, equivalent to a negative reactance :

$$-j\,\frac{C_3+C_4}{wC_3C_4}$$

in series with a negative resistance :

$$-\frac{G_m}{w^2C_3C_4}$$

where G_m is the mutual conductance of the valve and $w=2\pi F$.

(The derivation of the above expressions will be found in Appendix A.)

The reactance expression will be recognised as that of two capacities (C_3 and C_4) connected in series.

If the negative resistance component of the valve input impedance is greater than the equivalent series resistance of the crystal network, R_s, the effective loss in the circuit will be negative, which implies a gain. In this condition, if initially excited, the circuit will continue to oscillate with increasing amplitude until the mutual conductance of the valve is reduced by limiting and the negative resistance component of the valve input impedance becomes just equal to the equivalent series resistance of the crystal.

In the case of the CP.17E circuit the phase angle at which the crystal operates is approximately +66°. (See Appendix A.)

Adjustable control of fequency is effected by the condenser C (Figs. 17C and 17E), in the following manner: The frequency of oscillation is the resonant frequency of the series combination L_s, C_s, C, C_3 and C_4. That is to say, the frequency of oscillation is such that

$$wL_s = \frac{1}{wC'}$$

where C' is the total capacity of C_s, C, C3 and C4 in series.

The frequency adjusting condenser C controls the frequency in so far as the value of C' is partly dependent upon the value of C.

Owing to the fact that the CP.17E oscillator circuit operates on a steeper part of the phase angle/frequency characteristic than in the case of the circuit of Fig. 17B, the change of frequency for a given phase angle change is much less than with the latter circuit. Calculation shows that with a circuit operating at +66° on its phase angle/frequency characteristic the change of frequency for a given change of phase angle is 65 times less than if the circuit was operating at +87°.

It has been pointed out already in this Instruction that the waveform of the oscillations should be as sinusoidal as possible. In both the earlier and the CP.17E oscillator circuits the amplitude is restricted, by limitation, to such an extent that the operative portion of the oscillator valve characteristic is sensibly straight, thus minimising the production of harmonics. In the CP.17E circuit, however, there is the added advantage that the series equivalent network of the crystal together with C_3 and C_4, form a low pass filter with high attenuation at harmonic frequencies.

The complete diagram of the oscillator circuit is given in Fig. 16. The oscillator valve is capacity coupled to the limiter stage. Since the oscillator valve is only required to operate with low gain the anode resistance, R3, is reduced to 1,000 ohms.

R4 acts as a voltage dropping resistance and also, in conjunction with C5 and C6, as decoupling resistance. R5 and R6 form a voltage divider providing the D.C. voltage for the screen grid of the valve. It is important that the screen grid should be effectively decoupled in order to obtain the maximum mutual conductance of the oscillator valve and the two condensers C8 and C9 connected in parallel across R5 are provided for this purpose.

The HF choke, L1, provides the necessary D.C. path between negative HT and cathode. A grid stopper resistance R2 prevents any tendency towards parasitic oscillation at very high frequencies due to oscillatory circuits being formed by the inductance of wiring and stray capacities.

R7, in the H.T. supply lead is a meter shunt which carries both the anode and screen currents. The left-hand meter of the Meter and Switch Panel is connected across R7 when the meter switch is in position 2.

The biasing of the oscillator valve will be dealt with under the heading Limiter Stage.

As noted on Fig. 16, the values of C3 and C4 are determined during tests made at the time of installation. The correct values are dependent upon the Q value of the crystal and the mutual conductance of the valve. For example, in the range 600 kc/s to 1,200 kc/s capacity values ranging between .0015uF. and .0005uF. may be used.

Limiter Stage (Crystal Maintaining Amplifier)

In the oscillator circuit described in Technical Instructions, Vol. 2, Item 16.2, page 8, the amplitude limiting is due to the presence of grid current in the oscillator valve. In later circuits of this general type the diodes of the type Pen. DD 1360 oscillator valve are used to rectify an H.F. voltage obtained from the partially undecoupled screen grid of the separator valve and the rectified D.C. voltage obtained is used to control the gain of the oscillator valve.

In the CP.17E design, the amplitude limiting process is effected by two additional valves, V2 and V4 (Fig. 16).

The output of V2, the limiter valve, is connected to the diode valve, V4, and also to the separator valve, V3, the magnitude of the voltage in each case being adjusted during installation tests. The limiter valve V2 is cathode biased, R10 being the bias resistance, and C10 the decoupling condenser.

The gain of the limiter stage is greater than that of the oscillator stage, and choke-capacity coupling is used to the Separator Stage, the anode choke being L2 and the coupling condenser C14.

The anode circuit is decoupled by R11 in conjunction with C11 and C12. R11 also acts as a voltage dropping resistance. R12 is a voltage dropping resistance in the screen grid supply circuit which is also decoupled by this resistance in conjunction with C13. R9 is a grid stopper resistance.

The output circuit consists of two H.F. potential dividers connected in parallel. One consists of R13 and R14 and the other of R16 and R17.

The H.F. output from V2 to the diode, V4, is taken from the junction of R13 and R14 via the condenser C15. The action of V4 is as follows: The H.F. voltage developed across R13 is applied (via C15) between anode and cathode of the diode. The anode of the diode thus becomes alternately positive and negative with respect to cathode. When the anode is positive the diode becomes conductive and provides a low resistance path across R24. The lower terminal of C15 is thus virtually connected to earth in this condition. When the anode is negative with respect to cathode the diode becomes non-conductive and under this condition a pulse of current flows through R24. The effect is thus one of half-wave rectification. A suitable filter is provided to smooth the unidirectional pulses of voltage developed across R24. This consists of R23, C21 and R1 and the filtered output of the rectifier is applied as a bias voltage to the grid of V1. In view of the fact that the diode is non-conductive only when its anode is negative with respect to its cathode, the polarity of the rectified voltage will be such as to make the grid of V1 negative with respect to its cathode.

The grid bias so applied to V1 will be dependent upon the amplitude of the H.F. voltage applied to the diode. This is a fixed fraction of the limiter output which, in turn, is dependent upon the ouput of the oscillator. Thus, the greater the output of the oscillator valve, the greater will be its negative bias and the greater its negative bias the smaller the gain of this stage. The case is thus one of automatic gain control with its consequent amplitude limiting effect.

The potential divider R13, R14, is not variable and the value of R13 is determined upon installation of the equipment. A resistance value is chosen which will give the correct anode feed to the oscillator valve, this value being always considerably smaller than that of R24, the diode D.C. load resistance. C15 is a blocking condenser and prevents R13 forming a D.C. shunt across R24.

The common anode and screen grid supply lead contains the meter shunt resistance, R15. The left-hand meter of the Meter and Switch Panel is connected across this shunt when the associated switch is in position 3.

Separator Stage (Crystal Maintaining Amplifier).

In order that the load on the oscillator valve shall be independent of any variations in the loading conditions imposed by apparatus that follows the Crystal Maintaining Amplifier and in order to provide sufficient excitation for the Crystal Output Amplifier (or Frequency Multiplier or Frequency Divider, if used) the separator stage (V3, Fig. 16) is introduced.

This functions as the output amplifying stage of the Crystal Maintaining Amplifier, working under Class A conditions. The output coupling is provided by the tuned primary H.F. transformer L3. The Crystal Output Amplifier, Frequency Multiplier and Frequency Divider are designed to match to 100 ohms input and output impedances, and in the case of L3 of the Crystal Maintaining Amplifier a suitable winding specification is employed (according to the frequency), to ensure this impedance matching.

The separator valve is cathode biased, the bias resistance being R22 and the decoupling condenser C18. The anode circuit is decoupled by R20 in conjunction with C19 and C20. R20 is also a voltage dropping resistance. The screen grid is supplied through the voltage dropping resistance R19 which also acts as decoupling resistance in conjunction with C16.

The input of the separator stage is taken from the potential divider R16, R17, through the grid stopper R18. The potential divider is of fixed type but the value of R17 is chosen at the time of installation, to ensure the separator stage operating without grid current and yet having sufficient output to excite the next unit.

The common anode and screen supply lead contains the meter shunt R21 across which the left hand meter on the Meter and Switch Panel is connected when the associated switch is in position 4.

SECTION G. FREQUENCY MULTIPLIER (Fig. 18).

For any output frequency in the range 1,200kc/s to 1,600 kc/s a crystal cut for half this frequency is normally used and a Frequency Multiplier, multiplying by 2, is connected between the Crystal Maintaining Amplifier and the Crystal Output Amplifier.

The Frequency Multiplier (Fig. 18) contains one valve only. This valve is operated at high voltage

H.F. input level such that the grid operates over a sufficiently large portion of the valve characteristic that the curvature of the latter causes distortion of the anode current waveform which contains a strong second harmonic component. The anode circuit includes the tuned primary winding of an H.F. transformer, L1, and this inductance is tuned to the second harmonic frequency. It is designed to have a sufficiently high L/C ratio to be very selective at this frequency and as a result, there is a high impedance set up in the anode circuit at twice the crystal frequency and comparatively low impedance at the fundamental and at the harmonic frequencies other than the second.

The secondary of the transformer is designed to match into a 100 ohms output impedance.

The input transformer is designed to give a 10 to 1 voltage step-up between primary and secondary. The grid input is taken from a potentiometer, R1, shunted across the secondary of the input transformer. With the potentiometer at maximum setting the input to the grid is of the order of 20 volts R.M.S.

The valve is driven into grid current and in order that grid current rectification shall build up a D.C. bias voltage across R2 (additional to that developed across the cathode bias resistance, R4) the condenser C5 is provided. R3 is a grid stopper resistance.

The cathode bias resistance is R4 and the decoupling condenser C4. Anode decoupling is provided by C2 in conjunction with R6, which also acts as a voltage dropping resistance. The screen grid is supplied through the voltage dropping resistance R5. C3 is the screen decoupling condenser.

In the common supply lead to anode and screen grid is the meter shunt resistance R7. The left-hand meter on the Meter and Switch panel is connected across R7 when the associated switch is placed in position 5.

SECTION H. BALANCED MODULATOR FREQUENCY DIVIDER (Figs. 19 and 20).

The action of the Balanced Modulator Frequency Divider is such that a frequency f_1 applied to the input by the Crystal Maintaining Amplifier is converted to a lower frequency f_2 which appears at the output terminals of the divider, $f_2 = \frac{f_1}{n}$ where n is the division ratio of the divider which, in the case of the CP.17E equipment may be 3 or 5 according to the value of f_2 required.

Further, f_2 is exactly equal to the difference between the applied frequency f_1 and a frequency f_3 which appears in the divider itself.

That is, $f_2 = f_1 - f_3$.

In practice, f_1 is the frequency provided by the Crystal Maintaining Amplifier, f_2 is the Drive output frequency and f_3 is $(n-1)$ times the Drive output frequency.

Double Balanced Modulator.

If two sine wave voltages of two different frequencies, say, f_1 and f_3 (f_3 being lower than f_1), are together impressed on a circuit containing a rectifying device, the output of the latter will have a complex waveform.

It can be shown by mathematical analysis, and proved in practice, that the output (in the case of a single rectifier), is the combination of a D.C. component and a number of sine wave components of various frequencies. The most pronounced of the latter in amplitude are f_1, (f_1+f_3) and (f_1-f_3).

The existence of "sum" and "difference" frequencies will be noted and as regards the resultant of f_1, (f_1+f_3) and (f_1-f_3) it will be seen that this is equivalent to a carrier of frequency f_1, modulated by a frequency f_3. For further details reference should be made to standard text-books on modulation theory.

In the present case the object is the production and utilization of the frequency (f_1-f_3) and from the above it will be appreciated that one method of obtaining this frequency would be to apply frequencies of f_1 and f_3 to a rectifying device and to balance, or filter out, from the complex modulated output all components other than the desired (f_1-f_3) component.

Before considering the detailed arrangements of the Balanced Modulator Frequency Divider the following particular requirements should be noted :—

(*a*) The frequency f_3 must not be a frequency generated independently of f_1 but must bear an integral relation to it.

(*b*) If the output from the Crystal Maintaining Amplifier fails (i.e. if f_1 disappears), it is desirable that the output of the divider should also disappear. The same requirement applies in the case of the failure of f_3. In short, there must be no risk of any unwanted frequency being produced by the Drive equipment in the event of a breakdown in the normal dividing process, or failure of the divider input voltage.

A schematic of the arrangement of the various sections of the Balanced Modulator Frequency Divider is shown in Fig. 19. The production of the "difference" frequency (f_1-f_3) takes place in the double balanced modulator which will now be considered in detail.

The Double Balanced Modulator (Fig. 20), consists of two transformers, T1 and T2, and four Westinghouse rectifiers, W1, W2, W3 and W4. The secondary of T1 and the primary of T2 are accurately centre-tapped. The primary of T1 is connected to the output of the Crystal Maintaining Amplifier from which is derived the frequency f_1. A frequency f_3 equal to the desired drive output frequency multiplied by $(n-1)$, where n is the required division ratio of the divider, is applied between the centre taps of T1 and T2. This frequency f_3 is derived from the harmonic generator stage.

In the absence of the frequency f_3 there will be no current at the frequency f_1 in the primary of T2 and consequently no output from the secondary of T2. The reason is that, in the absence of f_3, the arrangement of transformers and rectifiers forms a balanced bridge.

In the absence of the frequency f_1 there will be no output from the secondary of T2. Currents at the frequency f_3 will flow in the two halves of the secondary of T1, but the two halves will be carrying currents equal in magnitude and opposite in direction. The same condition will apply to the two halves of the primary of T2. Owing to the accurate centre tapping of the transformers there will be no voltage induced in the secondary of T2.

When both the frequencies f_1 and f_3 are applied, the following conditions occur: At an instant when the polarity of f_3 is such that terminal 4 of T1 is positive to terminal 4 of T2 the rectifiers W2 and W4 will be conductive. In one half of the secondary of T1 the f_1 and f_3 voltages will be assisting; in the other half they will be opposing. Thus the resultant voltages across the two halves of T1 will be unequal. The balance of the modulator will be disturbed and the currents in the two halves of T2 will not be equal. This will lead to voltages being induced in the output winding of T2. At an instant when the polarity of f_3 is such that terminal 4 of T2 is positive to terminal 4 of T1 the rectifiers W1 and W3 will be conductive. Again there will be assisting and opposing f_1 and f_3 voltages in the two halves of T1, the circuit will become unbalanced as before, output voltages appearing in the secondary of T2.

Under these circumstances the currents between T1 and T2 will undergo rectification and, as has been described earlier, this will lead to the production of modulation components. The frequency f_3 modulates the frequency f_1 and produces sum and difference frequency components in the output of the modulator, the D.C. and the f_1 components being balanced out. The non-existence of the f_1 component in the output of a double balanced modulator is the particular feature in which it differs from a single modulator system.

The output of the double balanced modulator therefore consists of the frequencies (f_1+f_3) and (f_1-f_3). (There are other components but they are of negligible magnitude). Both these sideband frequencies are passed on to the limiter stage and to the selective amplifier stage but the (f_1+f_3) component is filtered out by the latter so that the separator stage is driven by a voltage whose frequency is (f_1-f_3).

Taking a numerical example, in the case of a 200 kc/s drive output a 1,000 kc/s crystal would be employed so that $f_1=1{,}000$ kc/s. The division ratio would be 5 and f_3 would be $(5-1)\times 200=800$ kc/s, while f_2 would be $1{,}000-800=200$ kc/s.

In this case the outputs of the double balanced modulator would be $1{,}000+800=1{,}800$ kc/s and $1{,}000-800=200$ kc/s. The output of the semi-aperiodic limiter stage would also be 1,800 kc/s and 200 kc/s. The output of the selective amplifier stage and of the separator stage would be 200 kc/s. The input of the harmonic generator would be 200 kc/s and the output 800 kc/s (i.e. the 4th harmonic of its input voltage).

Since f_3 must be $(n-1)$ times the drive output frequency it follows that in the special case of a divider with a division ratio of 2, no harmonic generator is required.

Transformers T1 and T2 are H.F. transformers using toroidal cores constructed of mu metal tape. The 1,000 ohms resistance R1 shunted across the secondary of T2 is provided for the purpose of referring the correct impedance to the input circuit.

Limiter Stage (Frequency Divider).

This is a pentode stage resistance-capacity coupled to the next stage, which is the selective amplifier. The anode load resistance R6 is of low value compared to the anode A.C. resistance of the valve and as a result the gain of the stage is low and limitation occurs due to anode circuit saturation.

The purpose of the limiter stage is to limit the amplitude to a value which gives sinusoidal output from the selective amplifier.

Referring to the circuit of the limiter in Fig. 20, the valve is cathode biased by the resistance R4 with C2 acting as decoupling condenser. The screen is supplied through the voltage dropping resistance R3. C1 is the screen decoupling condenser. R5 and C4 provide anode decoupling.

Selective Amplifier.

The input to the grid of the selective amplifier consists of the sum and difference frequencies referred to in the section dealing with the double balanced modulator. It is the function of the selective amplifier to amplify the difference frequency (f_1-f_3) to the exclusion of the sum frequency (f_1+f_3). In series with the anode there is a fixed tuned circuit L1, C6, C16, which is tuned to (f_1-f_3). This circuit is highly selective at its resonant frequency and presents a high impedance to the difference frequency but a low impedance to the sum frequency. The H.F. voltages set up across the tuned circuit are passed to a potential divider, R12, R13, via the coupling condenser C7. Both the harmonic generator and the separator derive their inputs from this potential divider.

The valve is cathode biased, R10 being the bias resistance. This resistance is not decoupled, which results in negative feedback being applied. The reason for giving the selective amplifier this degree of negative feedback is that the action of the limiter leads to some distortion in its output. As a consequence the selective amplifier input has some harmonic content and the presence of negative feedback removes this distortion to a large extent.

Harmonic Generator.

The function of the Harmonic Generator is to provide the frequency f_3, referred to in the description of the Double Balanced Modulator. This frequency is the ($n-1$)th harmonic of the frequency applied to the harmonic generator by the selective amplifier, n being the division ratio of the Divider.

The harmonic generator valve operates on the same principle as the valve of the Frequency Multiplier described in Section G. The valve receives a large input voltage from the selective amplifier and the anode current waveform has pronounced harmonic content. In series with the anode is the tuned circuit L2, C11 (Fig. 20), which is adjusted to resonate at the ($n-1$)th harmonic of the frequency applied to the control grid. This tuned circuit is highly selective at its resonant frequency and presents a high impedance to the ($n-1$)th harmonic and a low impedance to the fundamental and to other harmonic frequencies.

The anode is coupled by the condenser C13 to a potential divider consisting of R18 and R19 and the voltage developed across R19 at the ($n-1$)th harmonic frequency (i.e. at the frequency referred to as f_3 in the description of the Double Balanced Modulator), is fed back to the Double Balanced Modulator.

The anode circuit is decoupled by R17 and C12. The screen grid is supplied through the voltage dropping resistance R15. C10 is the screen decoupling condenser, R16 and C9 are the cathode bias resistance and decoupling condenser, respectively. R14 is a grid stopper resistance and it will be noted that its value of 3,000 ohms is much higher than other grid stopper resistances in the equipment. The reason for this is that the harmonic generator valve control grid voltage is of such a large amplitude that it is necessary to provide for limitation of grid current for the protection of the valve.

Separator Stage (Frequency Divider).

This is the output amplifying stage of the Frequency Divider. Working under Class A conditions it provides the excitation for the Crystal Output Amplifier and also prevents the selective amplifier from being affected by any variations of external loading.

The input is derived from the potential divider R12, R13. The separator valve requires a much smaller input voltage than the harmonic generator so that its grid is tapped down on this potential divider. The valve is cathode biased, the bias resistance being R23 and the decoupling condenser C17. The early issues of the CP.17E Frequency Divider contained a wideband output transformer, T3, in the anode circuit, but in subsequent issues this is replaced by a tuned primary transformer. T3, when a wideband transformer, employs a toroidal RHOMETAL ~~mumetal~~ tape core and, with R24 shunted across the primary, matches the divider into 100 ohms at its output. The screen grid of the separator valve is supplied through the voltage dropping resistance R22. C14 is the screen decoupling condenser. Anode decoupling is provided by R25 and C15.

NOTE.—In the Frequency Divider there is a voltage dropping resistance, R27, which is in the common +H.T. supply lead to all the anodes and screen grids.

Also in the common H.T. supply lead is the meter shunt resistance, R26. The left-hand meter of the Meter and Switch Panel is connected across R26 when the associated rotary switch is placed in position 5.

SECTION J. CRYSTAL OUTPUT AMPLIFIER (Figs. 21 and 22).

The Crystal Output Amplifier operates from an input derived either from the Crystal Maintaining Amplifier direct, or from the Frequency Multiplier, or the Frequency Divider (according to the particular output frequency), and provides an output of 6 watts to a balanced 100 ohms non-reactive load.

No tuning adjustments are necessary or provided in this amplifier, for it has been designed to have a flat frequency response characteristic between 140 kc/s and 2 mc/s. The amplifier characteristic is shown in Fig. 22.

The amplifier contains two pentode valves connected in parallel. A diode is also fitted, but this is associated with the metering circuit only.

The input and output transformers T1 and T2 are wideband transformers of special design and construction. The amplifier must, however, be considered as a whole in connection with the characteristic of Fig. 22 and it should be noted that the over-all characteristic is partly dependent upon the use of negative feedback.

A feature of the core material employed in the transformers is its high permeability producing a relatively high inductance with a high coefficient of coupling, and a characteristic whereby the open circuit inductance can be made large for a small number of turns. Another important property of this material is that the rate of decrease of permeability with increasing frequency is the same as the rate of increase of inductive reactance. The lower frequency limit of working is determined by the open circuit inductance required to provide the load impedance into which the transformer is required to work and the upper frequency limit is dependent on shunt capacity reactance. Since this is largely the determining factor of the load into which the secondary will work it also fixes the value of the open circuit inductance at the lowest frequency.

The frequency range over which any transformer will operate is limited. Between those frequencies at which amplification is required, the open circuit reactance of the primary must be large compared to the resistance with which the primary is associated. The primary shunt resistance equivalent to iron losses must be kept high if it is to be neglected at the lower frequencies ; in practice, this is usually between five and ten times the load impedance at the lowest frequency, and since it is independent of frequency can be neglected also at the upper limit.

Both primary and secondary shunt capacities are also of account and the capacity between windings is a determining factor. The equivalent secondary capacity is proportional to the impedance ratio and in the case of the output transformer is quite large, namely .001 μF.

The output transformer, T2, is provided with a tertiary winding which is connected in series with the common cathode circuit of the two valves. This winding provides negative feedback. (Details regarding negative feedback theory will be found in standard textbooks). It is important that the proper phase shift between input and feedback voltage should hold throughout the wide frequency band. Should the phase shift at any particular frequency be such that the voltage fed back is *in* phase with the input voltage, the amplifier would self-oscillate at that frequency. The output transformer is designed to maintain the proper feedback phase relationship over the whole range of operating frequencies. By using negative feedback in this amplifier frequency distortion is reduced considerably, any noise generated in the amplifier is almost entirely eliminated and the amplification is rendered independent of small anode voltage changes.

Referring to the circuit details of Fig. 21 : The valves are cathode biased by the resistance R10 which is common to the two cathode circuits. C1 and C2 in parallel form the decoupling capacity. With the operation of two valves of this type in parallel, particular precautions against parasitic oscillations must be taken due to the high effective mutual conductance and, in this case, anode stopper resistances R11 and R12 are employed in addition to the grid stopper resistances R2 and R4.

The common anode circuit is decoupled by the components R6 and C5. The screen grid of V1 is supplied through the voltage dropping resistance R3, and C3 is the decoupling condenser in this case. The screen grid of V2 is supplied through the voltage dropping resistance R5 with C4 as the associated decoupling condenser.

R1 and R7 are loading resistances inserted to give the correct impedance ratios in the transformers T1 and T2 respectively.

Connected in series with the common +HT supply lead to both the anodes and both the screen grids is the meter shunt resistance R8. The left-hand meter of the Meter and Switch Panel is connected across this resistance when the associated rotary switch is in position 6.

The diode valve, V3 (Fig. 21), is used for the measurement of the H.F. output volts. The H.F. voltage developed across the secondary of T2 is applied between anode and cathode of the diode, through the condenser C7. When the rotary switch of the right-hand meter on the Meter and Switch Panel is placed in position 5 the meter is connected between R9 and cathode (Fig. 21). R9 then becomes the load resistance of the rectifying circuit. The mean D.C. in R9 will be proportional to the H.F. peak volts but by means of this adjustable resistance the reading of the scale is calibrated to indicate the R.M.S. value of the H.F. output voltage.

SECTION K. TERMINATION PANEL.

On this panel is mounted a junction box to which the external A.C. supply is connected. In parallel with this junction box is a 5 amp. 3-pin switch plug to which test apparatus, such as a valve voltmeter, etc., may be connected.

The output plug board is mounted on the front of the panel. It should be noted that the drive output should be taken to the transmitter on balanced feeders only. Any attempt to use an unbalanced cable would have undesirable results on the performance of the Crystal Output Amplifier. The characteristic impedance of the cable used should not exceed 100 ohms nor be less than 80 ohms.

SECTION L. L.T. TRANSFORMER PANEL.

This is an auxiliary panel and may not be used on some equipments. It is provided to supply the L.T. voltages for frequency checking equipment if this is installed. (Frequency checking equipments will be dealt with in Technical Instruction TT.6). The transformer is rated as follows :—

(i) 4 volts 10 amps. centre-tapped.
(ii) 4 ,, 6 ,, ,, ,,
(iii) 4 ,, 6 ,, ,, ,,
(iv) 4 ,, 4 ,, ,, ,,

SECTION M. MAINTENANCE.

Meter Readings.

Although for reasons of economy in components only two meters are provided in this equipment, the meter switching arrangements are so comprehensive that the meters can prove to be very useful aids in the event of a fault developing.

Any abnormal change in a meter reading should be investigated at once. An example of a case where a change in meter reading might indicate a fault before the latter becomes obvious in other ways is that of an increase above normal of the anode current of the oscillator valve in the Crystal Maintaining Amplifier. Such an effect would occur if the diode valve failed in this amplifier (thus removing the D.C. bias from the oscillator valve).

Under normal conditions, and except when the routine logging of readings is being carried out, the left-hand meter switch should be left in position 1 and the right-hand switch in position 5. The left-hand meter will then indicate the anode current of the oven relay valve, the reading rising and falling with the breaking and making of the contact between the mercury column and T3 of the contact thermometer. This will provide a visual check on the thermal cycle. The right-hand meter will provide a continuous check upon the drive output volts. It is important that the routine checking of readings should include the indicating thermometer.

Replacement of Oscillator Valve.

As described in Section F, the CP.17E crystal maintaining circuit is less dependent upon the oscillator valve inter-electrode capacities, from the standpoint of frequency changes, than is the earlier design of circuit. Nevertheless, a frequency check should be made at an early opportunity if it becomes necessary to replace the oscillator valve.

Crystal Oven.

If, due to a fault condition, it becomes necessary to remove the inner oven assemblies, the correct procedure is as follows :—

Disconnect the mains input to the bay. Remove the rear cover of the frequency adjusting condenser box. Remove the screened connection tube and the indicating thermometer. Take the back off the Outer Box and unsolder the seven beaded connections from the hinged tag block. The inner assemblies can now be removed by swinging back this tag block. Next, remove the earth stud fixing nut and distance-piece and lift off the lid of the First Inner Oven. The lid of the Second Inner Oven is next removed by unscrewing the four holding-down screws, placing two of them in the two threaded holes provided in the lid and with their aid lifting out the inner assembly. Since the inner assembly carries the crystal holder the greatest care should be exercised in handling it.

Note.—When reassembling the oven, which is carried out in the reverse order to the above, it is very important to remember to reconnect the earth connection to the top of the earth stud.

Oven Alarms.

In the event of an " Oven Low " alarm occurring, the first step should be to inspect the indicating thermometer. There are certain conditions under which an " Oven Low " alarm can occur even though the oven temperature is normal. Risk of confusion on this point will be avoided if the oven temperature is checked.

Assuming that the oven temperature proves to be low, possible faults to be investigated are : (1) Failure of oven relay valve. Inspect L.T. heater fuse F7 or F8 (Fig. 14). (This applies only to equipments with serial numbers 1 to 35). (2) Disconnected fuse in the primary circuit of the oven heating transformer. (This applies only to equipments with serial numbers 36 and onwards).

(3) Open circuited heater mat or other disconnection in the oven heating circuit.

The meters should be used to test for :—

(*a*) Oven relay valve anode current.
(*b*) Oven heating current.
(*c*) Oven heating volts.

If the oven relay valve has failed or if there is a break in the L.T. heater circuit, then (*a*) and (*b*) will give zero indications but (*c*) will show a reading.

If there is a break in the primary circuit of the oven heating transformer then (*a*) will show a reading but (*b*) and (*c*) will give zero indications. These indications will also apply in the case of an internal break in the oven transformer secondary winding.

If there is an open circuited heater mat then (*a*) will show a reading, (*b*) will give zero indication and (*c*) will show a reading.

There are several conditions under which an " Oven Low " alarm indication can be given although the oven temperature is normal. One condition involves a failure of both the 30 volt D.C. supply and the main H.T. supply. In this case there will be a failure of drive output and the matter will be considered in the notes dealing with drive failure. In the case of a failure of the 30 volt D.C. only, such as would occur if the 30 volt supply fuse, F3, (Fig. 14), became disconnected, the energizing current of the " Oven Low " relay would fail and an " Oven Low " alarm indication would be given. Also, the energizing current of the protective relay, Y3 (Fig. 12), would fail and the contacts of this relay would open, breaking the oven heating circuit. The oven temperature relay valve would have no bias and therefore would be passing its normal maximum anode current. As far as meter readings are concerned there would be (*a*) an oven relay valve anode current indication ; (*b*) no oven heating current ; (*c*) an oven heating volts indication.

A disconnection at the T2 contact of the contact thermometer or between the latter and the " Oven Low " alarm relay would cut the energizing supply from the " Oven Low " alarm relay, thus giving an " Oven Low " alarm indication. In this case, the oven temperature would be normal and the meter indications would be normal, the anode current of the oven relay valve and the oven heating current varying with the thermal cycle in the usual manner.

In the event of an " Oven High " alarm occurring and the oven temperature proving to be high, possible faults to be investigated are :—

(1) Disconnection at contact T3 of the contact thermometer, or between the latter and the control grid of the oven relay valve. (2) Oven temperature relay contacts sticking in the " make " position.

The first type of fault will break the bias circuit to the oven relay valve and this valve will carry anode current continuously, keeping the oven temperature relay contacts closed with the consequent result of the oven temperature becoming too high. In the case of the oven temperature relay contacts sticking, the circumstances will be that the oven heating circuit will carry current until the mercury column in the contact thermometer reaches T4, but the relay valve anode current will be zero. This latter fact will provide the distinction between the two cases mentioned above.

There have been one or two cases where the mercury column of the contact thermometer has split, the break occurring at the T2 contact. In this case the first effect is that the bias is cut off from the control grid of the oven relay valve. As the oven temperature rises the mercury rises in the capillary tube until the small gap in the column reaches contact T3. The surface of contact T3 will bridge the gap, restoring the bias to the oven relay valve. If, as is very possible, the top of the mercury column touches contact T4, the result will be that the oven temperature relay will open when the oven high alarm relay closes. As the oven cools, the mercury column will recede, breaking contact at both T3 and T4. Simultaneously, the oven high alarm relay will open and the oven temperature relay will close. These effects will be repeated intermittently.

Drive Failure.

If the H.F. output of the Crystal Output Amplifier fails, the procedure to be adopted must be determined by the nature of the indications provided by the Meter and Switch Panel.

A failure of main H.T. supply such as will be caused by the H.T. supply fuse, F4 (Fig. 14), becoming disconnected is easy to detect. Position 4 of the right-hand meter switch will give a zero reading (H.T. volts). In addition, the various anode and screen current indications of the left-hand meter will all be zero.

If there is a disconnected fuse in the primary circuit of transformer T1 (Fig. 14), there will be a failure of all supplies, with the exception of the 6-volt external alarm battery supply. Thus there will be a failure of drive output and, in addition, the " Oven Low " alarm will operate.

If there is a failure of drive output, but not of main H.T. supply volts, there are many possible causes, but the first action should be to look for the failure of a valve or of the L.T. supply to one of the valves. A test of anode and screen current readings will provide the necessary clues.

If the fault proves to be obscure it may be necessary to use a valve voltmeter to locate the particular unit containing the fault. The voltmeter should be used to test the H.F. output volts of each unit in turn.

It is impossible, in the space available, to present an exhaustive list of possible faults, but the foregoing is intended to serve as a guide to the first steps that should be taken in the event of some of the more likely faults being experienced.

Typical Test Specification

The following Table is a test specification of a particular CP.17E equipment used on a frequency between 600 kc/sec. and 1,200 kc/sec. Certain small differences exist between one equipment and another, but the Table can be regarded as a representative example :—

H.T. Rectifier and L.T. Supply.

H.T. volts, no load	470
,, ,, normal	305
Bias volts	30

Crystal Oven.

Oven heater current...	460 mA.

Crystal Output Amplifier.

L.T. volts	4.0
Anode and screen current, total ...	120 mA.
Input volts (H.F.)	2.5 R.M.S.
Grid volts (H.F.)	5.5 R.M.S.
Output volts (across 100 ohms resistive load)	25 R.M.S.

Oven Temperature Relay.

L.T. volts	4.0
Anode current, normal	9.6 mA.
,, ,, with −30 V. ...	zero

Crystal Maintaining Amplifier.

L.T. volts	4.0
Oscillator anode and screen current, total	7.4 mA.
Limiter anode and screen current, total	11.4 mA.
Separator anode and screen current, total	12. mA.
Crystal volts (H.F.)	2.2 R.M.S.
Oscillator grid volts (H.F.) ...	0.9 R.M.S.
Limiter ,, ,, ,, ...	0.6 R.M.S.
Separator ,, ,, ,, ...	0.5 R.M.S.
Diode input volts (H.F.)	3.5 R.M.S.
Output volts (across 100 ohms resistive load)	2.5 R.M.S.

APPENDIX A

EQUIVALENT OSCILLATOR CIRCUIT (Fig. 17E).

The following shows the derivation of the expression for the impedance, looking towards the valve, between the points A and B of Fig. 17E :—

Imagine the crystal to be replaced by a generator providing an H.F. voltage, E.

Then the general expression for the impedance, Z_g, between the points A and B of Fig. 17E is,

$$Z_g = \frac{E}{I_1}$$

where I_1 is the current supplied by the generator. Now,

$$E = -jI_1X_{c4} - jI_1X_{c3} - jI_2X_{c3}$$

where X_{c4} is the reactance of C_4, X_{c3} is the reactance of C_3 and I_2 is the H.F. component of anode current.

But I_2 is the result of I_1 flowing through C_4 and in consequence giving rise to I_2 by virtue of the valve action. Thus,

$$I_2 = -jI_1X_{c4}G_m$$

because $e_g = -jI_1X_{c4}$ and $I_2 = e_gG_m$; where e_g=grid/cathode volts and G_m=mutual conductance of valve.

Therefore,

$$E = -jI_1X_{c4} - jI_1X_{c3} + j^2I_1X_{c4}X_{c3}G_m$$

and since $Z_g = \frac{E}{I_1}$,

$$\begin{aligned} Z_g &= -jX_{c4} - jX_{c3} - X_{c4}X_{c3}G_m \text{ (since } j^2 = -1) \\ &= -j(X_{c4} + X_{c3}) - X_{c4}X_{c3}G_m. \end{aligned}$$

Thus the impedance consists of a capacitative reactance $(X_{c4} + X_{c3})$, in series with a negative resistance $-X_{c4}X_{c3}G_m$.

Substituting $\frac{1}{wC_4}$ for X_{c4} and $\frac{1}{wC_3}$ for X_{c3}

$$Z_g = -j\frac{C_3 + C_4}{wC_3C_4} - \frac{G_m}{w^2C_3C_4}$$

where $w = 2\pi F$.

Phase Angle.

Under a steady state of oscillation the negative resistance component of the impedance (looking towards the valve), between points A and B of Fig. 17E is equal in magnitude to the equivalent series crystal resistance, R_s. Thus,

$$R_s = \frac{G_m}{w^2C_3C_4}$$

From the above expression the maximum permissible value of the two capacities, C_3 and C_4, may be determined providing that the equivalent series crystal resistance is known. Tests have shown that in the case of Post Office type 6B crystals the value of this resistance may vary from 75 to 200 ohms but an average figure is in the region of 100 ohms. It will, of course, be advantageous for the crystal to be shunted by the largest capacity that the mutual conductance of the maintaining valve will permit, for this will not only reduce the effective valve input impedance but also the phase shift, on which will depend the frequency deviation from the resonant frequency of the crystal.

From the above expression,

$$C_3C_4 = \frac{G_m}{w^2R_s}$$

and as the total capacity is at a maximum when $C_3 = C_4$, we may write,

$$C_3 = C_4 = \frac{1}{w}\sqrt{\frac{G_m}{R_s}}$$

from which it will be seen that for any given mutual conductance and equivalent series crystal resistance, the minimum permissible reactance of the total capacity of C_3 and C_4 in series is a constant, independent of frequency, with a value :

$$2\sqrt{\frac{R_s}{G_m}}$$

As an example, taking a mutual conductance value for the oscillator valve of 8 mA/v and an equivalent series crystal resistance value of 100 ohms, this reactance becomes,

$$2\sqrt{\frac{100}{8 \times 10^{-3}}} = 224 \text{ ohms, approximately.}$$

Thus the frequency of the oscillator will be such as to produce a phase angle of the crystal impedance of

$$\phi = \tan^{-1}\frac{224}{100} = +66^\circ \text{, approximately.}$$

The importance of this phase angle is stressed in Section F of this Instruction.

APPENDIX B

H.T. RECTIFIER. DESIGN CONSIDERATIONS.

The maximum D.C. output required from the H.T. rectifier circuit is 250 mA. at 300 volts. This is in excess of the requirements of the normal CP.17E Drive equipment but allowance has been made to meet the possibility of supplying H.T. current to frequency checking apparatus.

The total series resistance of the two smoothing chokes, L1 and L2 (Fig. 14), is 115 ohms, approximately, so that the chokes will be responsible for a voltage drop of about 30 volts. The internal voltage drop in the rectifier valves is about 30 volts so that the total voltage drop from transformer winding to the output of the smoothing will be approximately 60 volts. The average voltage required of each half of the H.T. transformer secondary is, therefore, approximately 360 volts. As the ratio, $\frac{\text{Average value}}{\text{R.M.S. value}}$, of the voltage wave of each half of the secondary is 0.9, the R.M.S. voltage required of each half of the secondary is 400 volts.

It is particularly important that the ripple voltage in the H.T. rectifier output should be of very small magnitude, otherwise there would be a likelihood of frequency and amplitude modulation of the drive output at the ripple frequency of 100 c/s.

The smoothing is effected by the filter consisting of L1, C1, L2, C2 (Fig. 14). This is a choke-input filter which, if suitably designed, reduces the ratio

$$\frac{\text{Ripple voltage at output of filter}}{\text{Ripple voltage at input of filter}}$$

to a negligible value. It can be shown that this ratio is inversely proportional to the product $(L_1L_2C_1C_2)$. Practical considerations, however, impose upper limits on the inductance and capacity values that can be used.

The voltage applied to the filter by the rectifiers (full-wave connection), can be regarded as consisting of a D.C. component upon which is superimposed an alternating voltage component at the ripple frequency of 100 c/s. There are other alternating components at higher frequencies and considerably lower amplitudes but these can be disregarded. The peak value of the alternating voltage component at 100 c/s is 0.667 of the D.C. voltage component.

The current in the input filter choke, L1, can thus be considered as consisting of a D.C. component upon which is superimposed an alternating component at 100 c/s. The ratio of the peak value of the alternating current component in L1 to the D.C. component will depend not only upon the ratio of the corresponding voltage values but also upon the ratio of the reactance of L1 at 100 c/s to the total resistance consisting of the resistance of L1, plus the resistance of L2, plus the external load resistance.

The reactance of L1 at 100 c/s must be such that the current passing through the inductance from the rectifiers never falls to zero. This implies that the reactance must be large enough to prevent the peak value of the alternating current component in L1 becoming equal to the D.C. component. This condition is fulfilled if the reactance of L1 is greater than 0.667 of the total resistance.

Applying this argument to the filter under discussion, L1 (Fig. 14), has an inductance of 15 henrys. The reactance of this at 100 c/s=9,400 ohms, approximately. Taking the D.C. output at 250 mA, 300 volts gives a load resistance value of

$$\frac{300}{0.25} = 1{,}200 \text{ ohms.}$$

The total resistance of L1, L2, and the load is thus 1,315 ohms. The reactance of L1 at 100 c/s is therefore over 7 times the total resistance, a condition which very generously meets the requirements stated above.

The condenser C1 has a capacity of 16μF. Its reactance at 100 c/s=100 ohms, approximately.

The ripple voltage applied to the input of the filter can, for all practical purposes, be considered as distributed between L1 and C1 in the ratio of their reactance. Thus the ripple voltage across C1 will be

$$= \frac{100\,E_r}{9{,}400}$$

where E_r is the ripple voltage applied to the input of the filter.

L2 has an inductance of 18 henrys. At 100 c/s its reactance is 11,300 ohms, approximately.

C_2 has a capacity of 16μF and a reactance of 100 ohms, approximately, at 100 c/s.

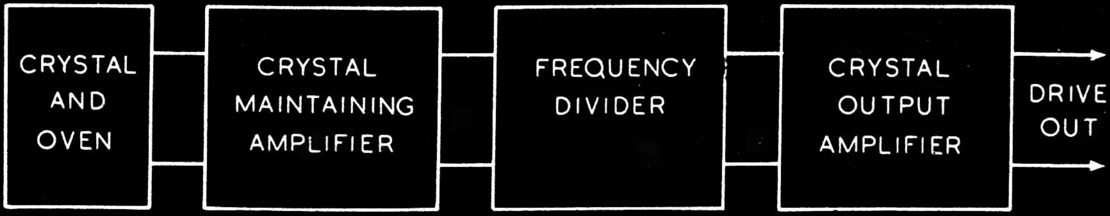
The ripple voltage across C1 can be considered, for all practical purposes, to be distributed between L2 and C2 in the ratio of their reactances. Thus the ripple voltage across C2 will be

$$= \frac{100\,E_r'}{11{,}300} = \frac{100 \times 100 \times E_r}{11{,}300 \times 9{,}400} = \frac{E_r}{10{,}600}$$

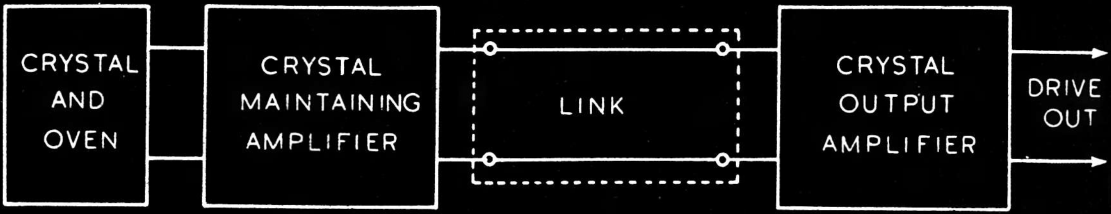
where E_r' is the ripple voltage across C1.

Thus the ripple voltage at the output of the filter is less than 1/10,000th of the ripple voltage applied to the filter, i.e. a reduction of ripple voltage of over 80 db.

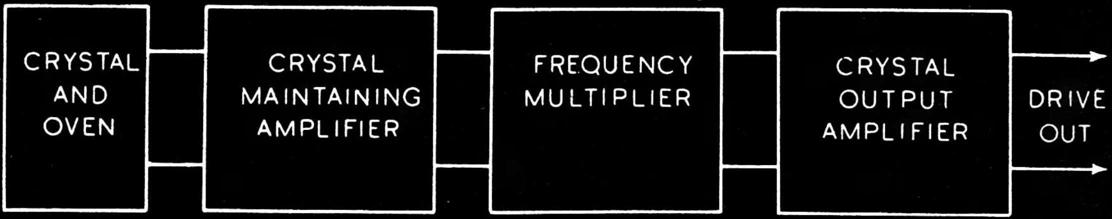
FIG. 1.



150 KC/S–600 KC/S



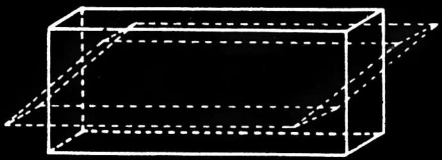
600 KC/S–1200 KC/S



1200 KC/S–1600 KC/S

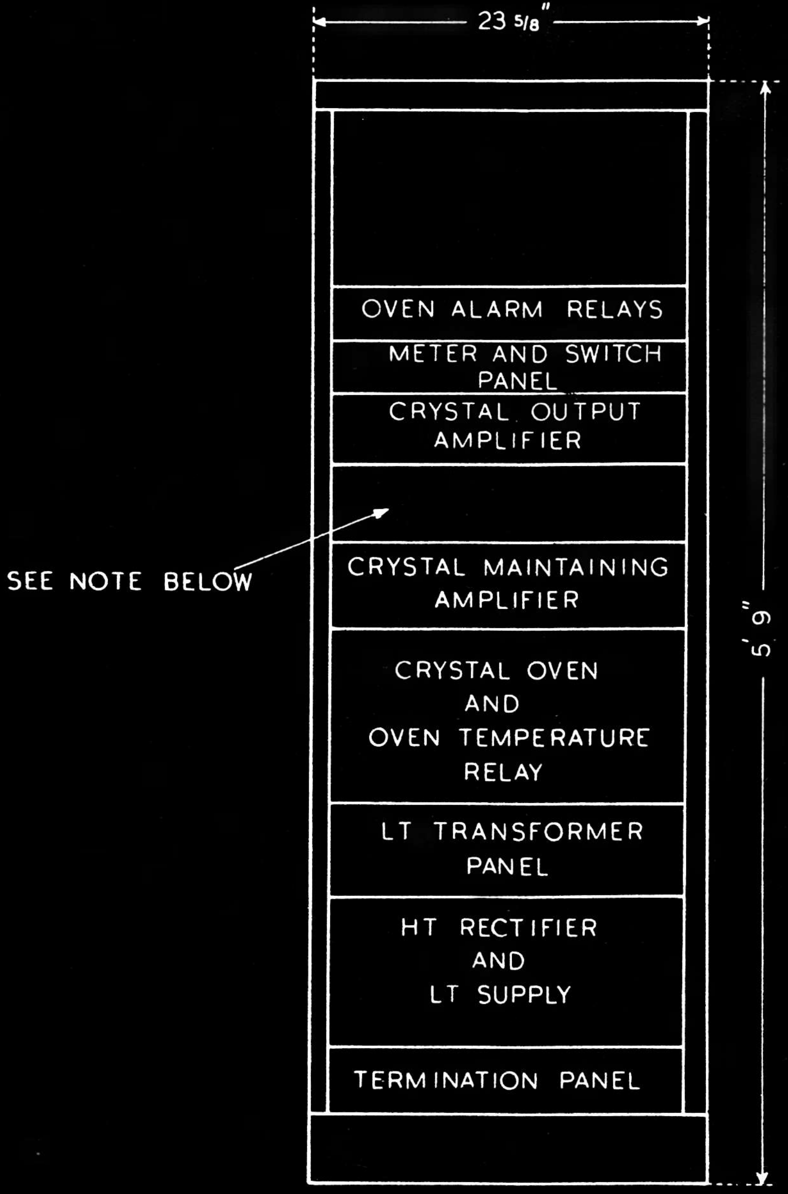
ALTERNATIVE ASSEMBLIES

FIG. 2.



SHEAR MODE OF VIBRATION

FIG. 3.



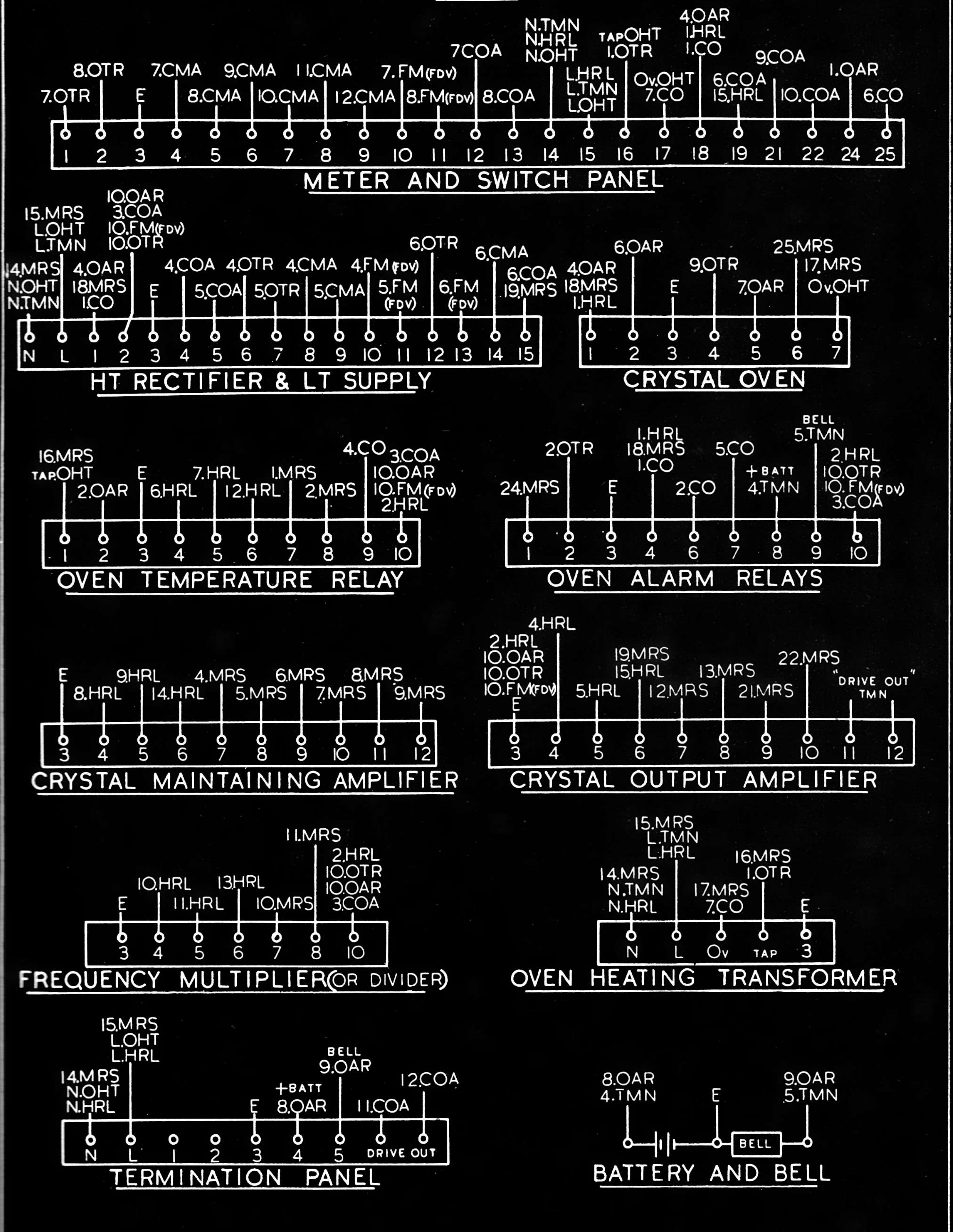
NOTE: 150 KC/S—600 KC/S: A BALANCED MODULATOR FREQUENCY DIVIDER IS FITTED.

600 KC/S—1200 KC/S: A DUMMY LINK PANEL IS FITTED.

1200 KC/S—1600 KC/S: A FREQUENCY MULTIPLIER IS FITTED.

BAY LAYOUT

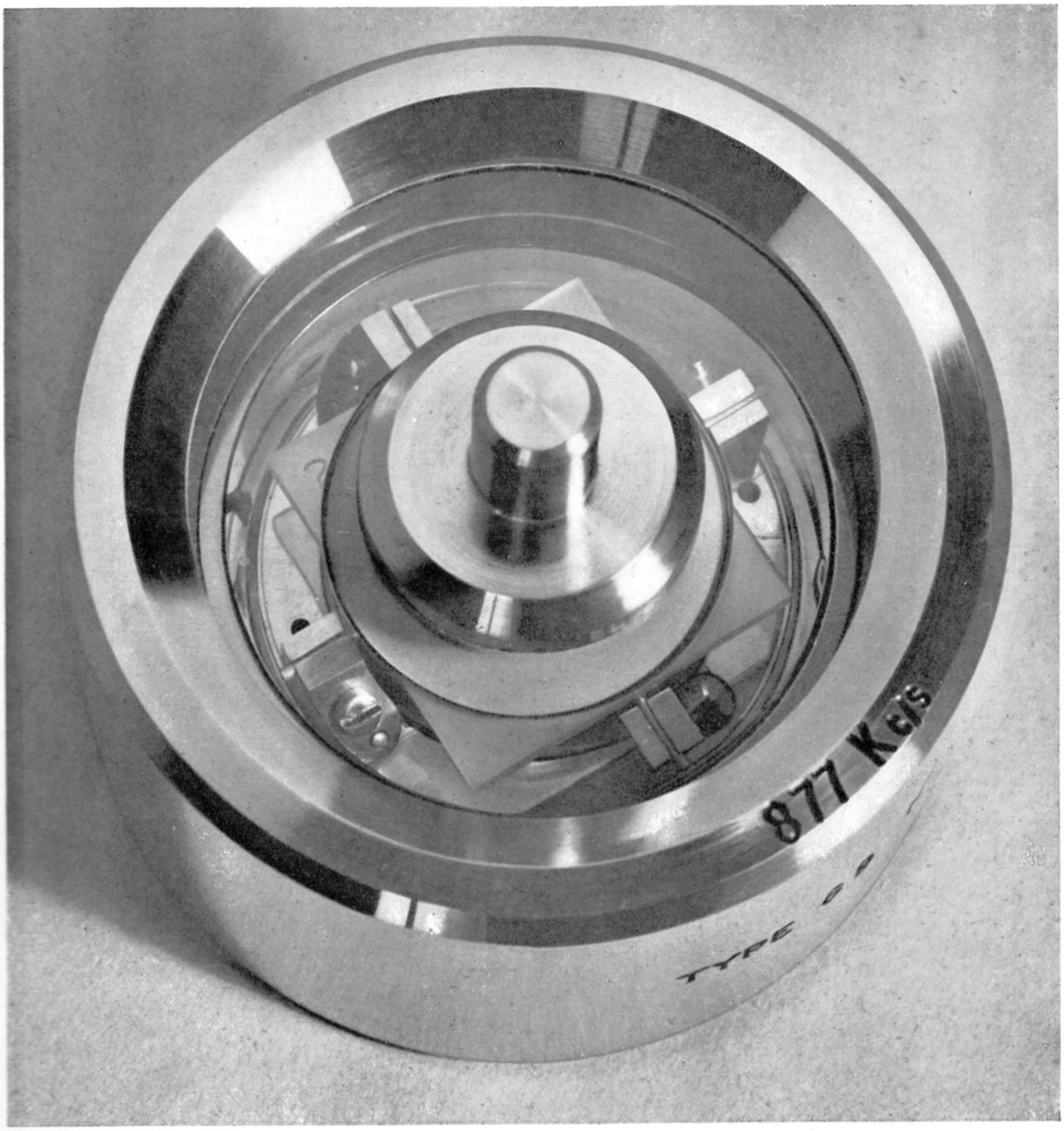
FIG.4.



TERMINAL CONNECTIONS

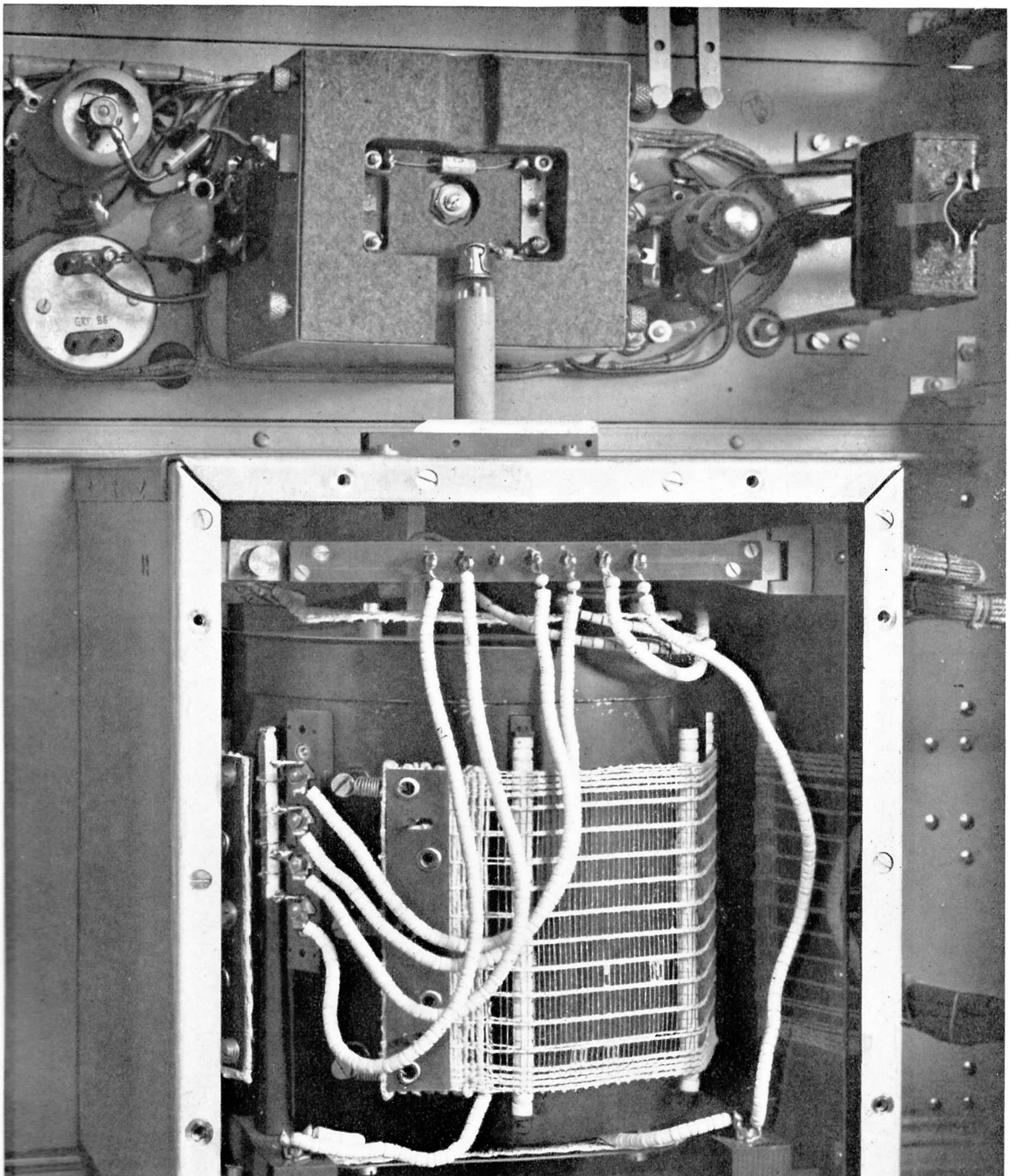
42018/TT2/LFO

Fig. 5



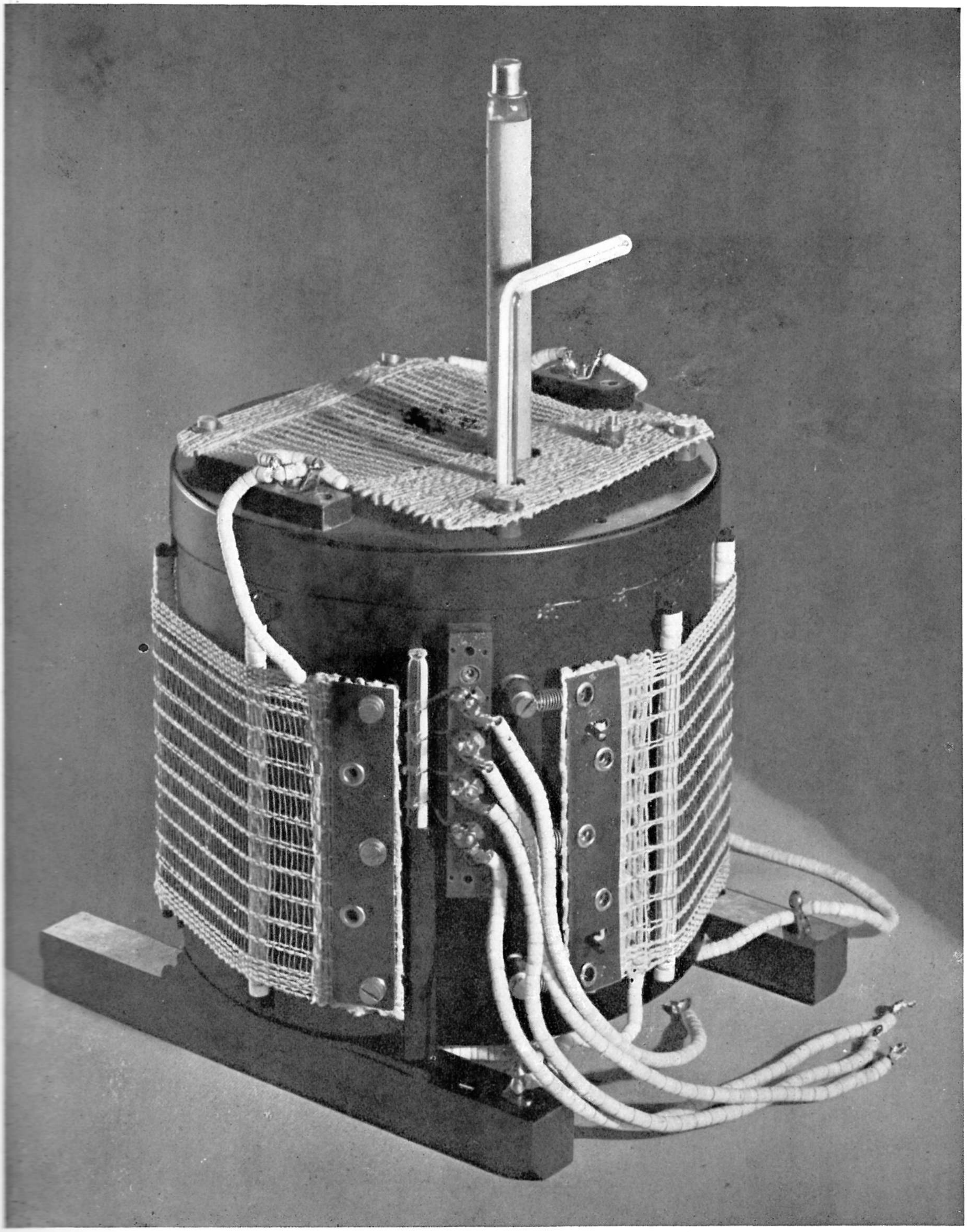
Crystal Plate and Holder Details. Post Office Type 6B

Fig. 6



Complete Crystal Oven Assembly and Frequency Adjusting Condenser. Rear Covers Removed

Fig. 7



Crystal Oven. First Inner Oven Assembly showing Contact Thermometer, Indicating Thermometer and Connection Tube

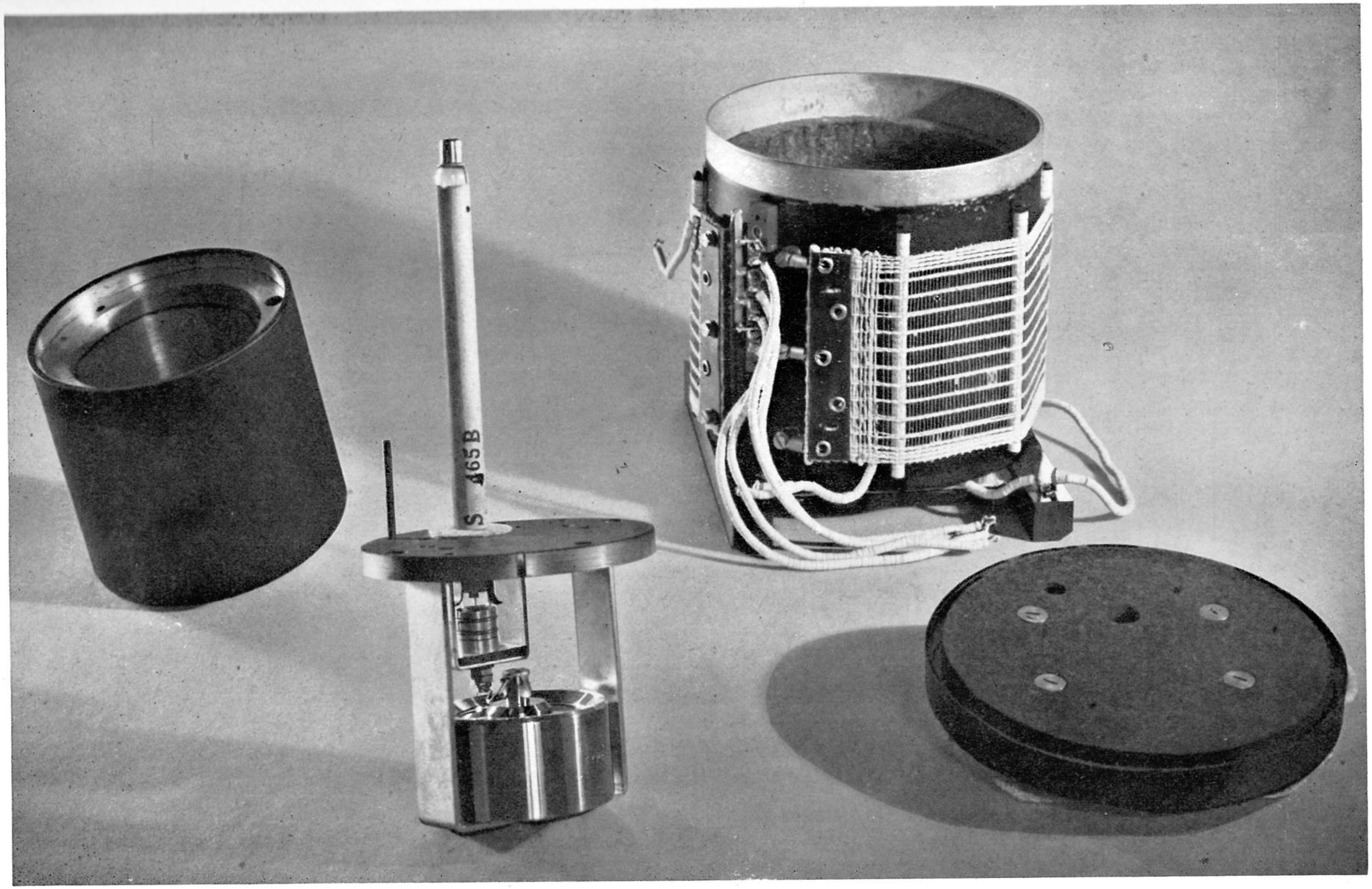
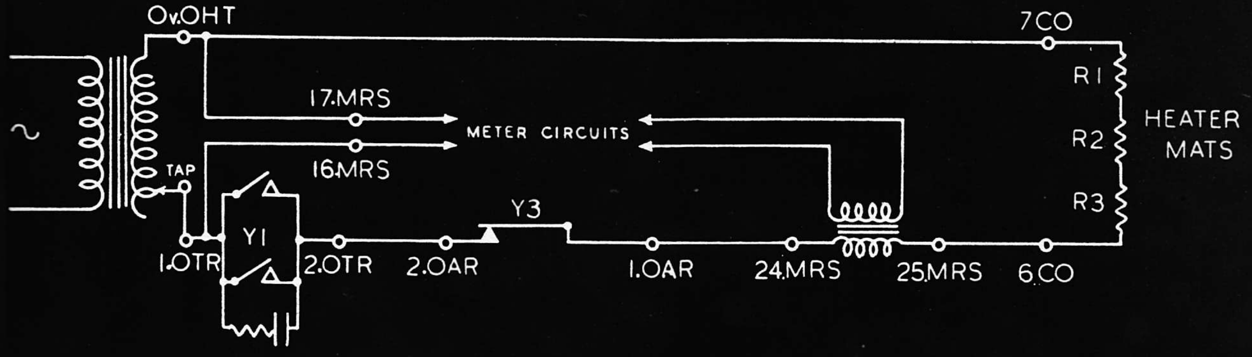


Fig. 8

Crystal Oven. Inner Oven Details

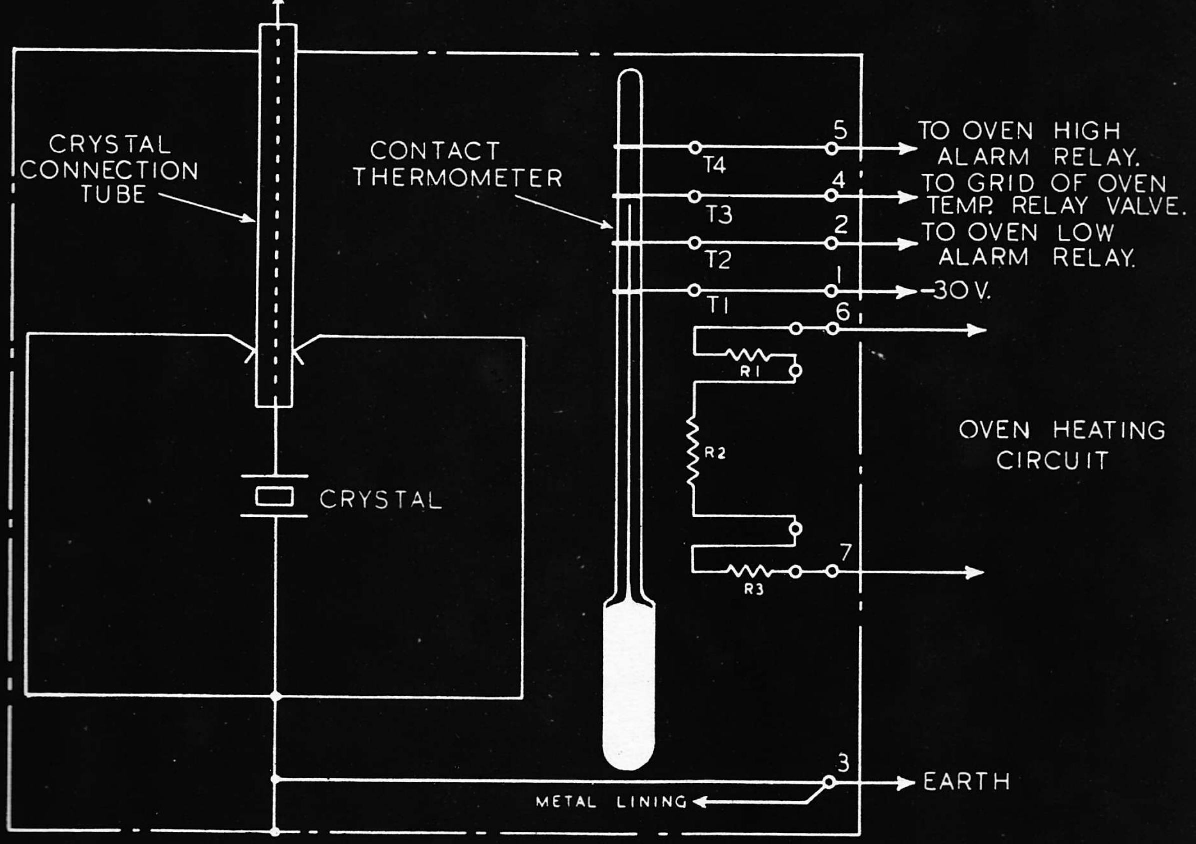
Left to right: (i) Second Inner Oven without Lid and Crystal Assembly. (ii) Second Inner Oven Lid and Crystal Assembly showing Connection Tube, Socket, Earthing Pin and Crystal Holder. (iii) First Inner Oven Assembly showing Contact Thermometer, Heater Mat Suspension and Thermal Lagging. (iv) Lid of First Inner Oven Assembly showing Thermal Lagging.

FIG. 9.



OVEN HEATING CIRCUIT

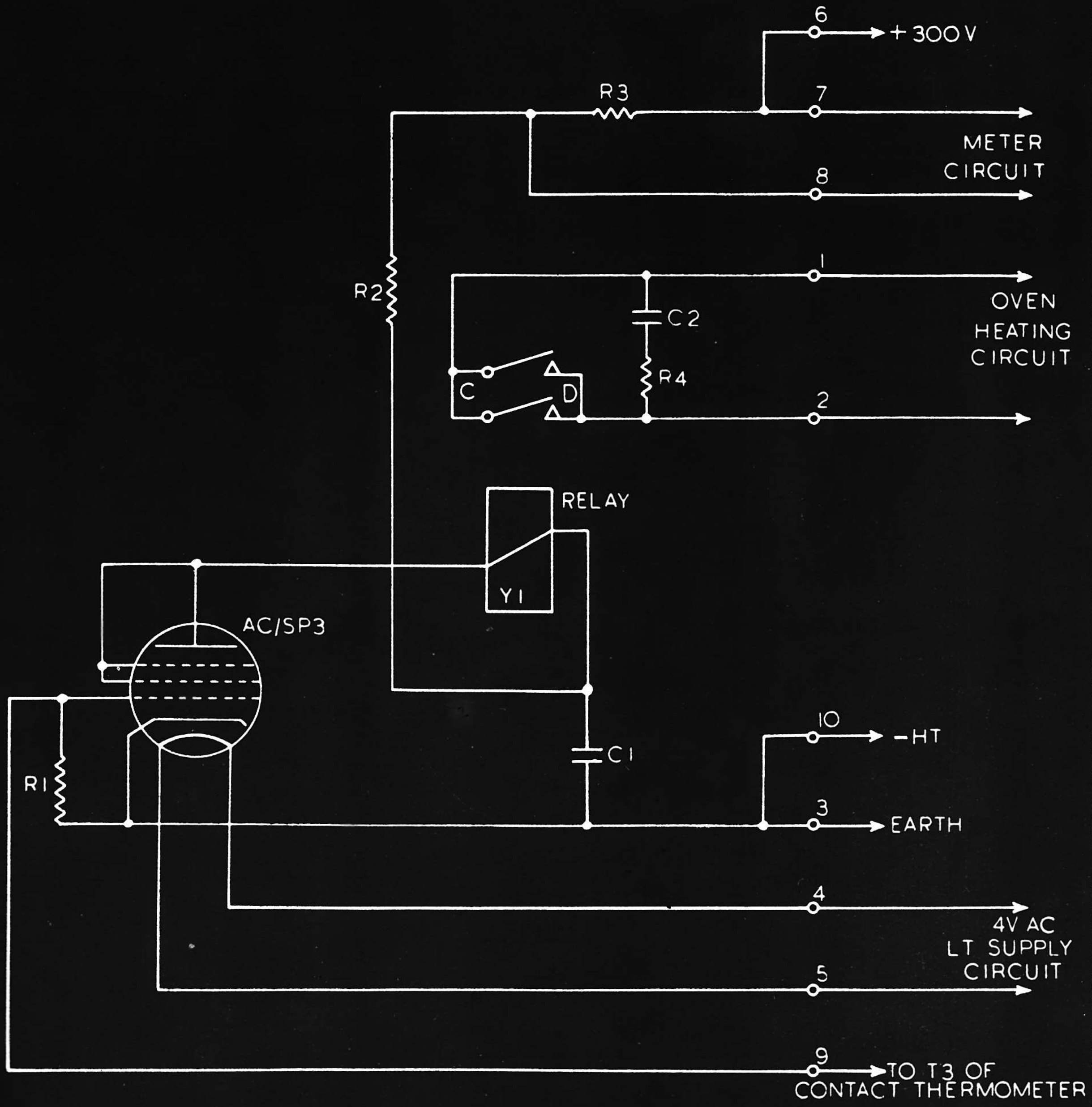
FIG. 10.



RESISTANCES	VALUES	RATINGS
R1	60 OHMS	0·5 AMP
R2	120 "	0·5 "
R3	60 "	0·5 "

CRYSTAL OVEN

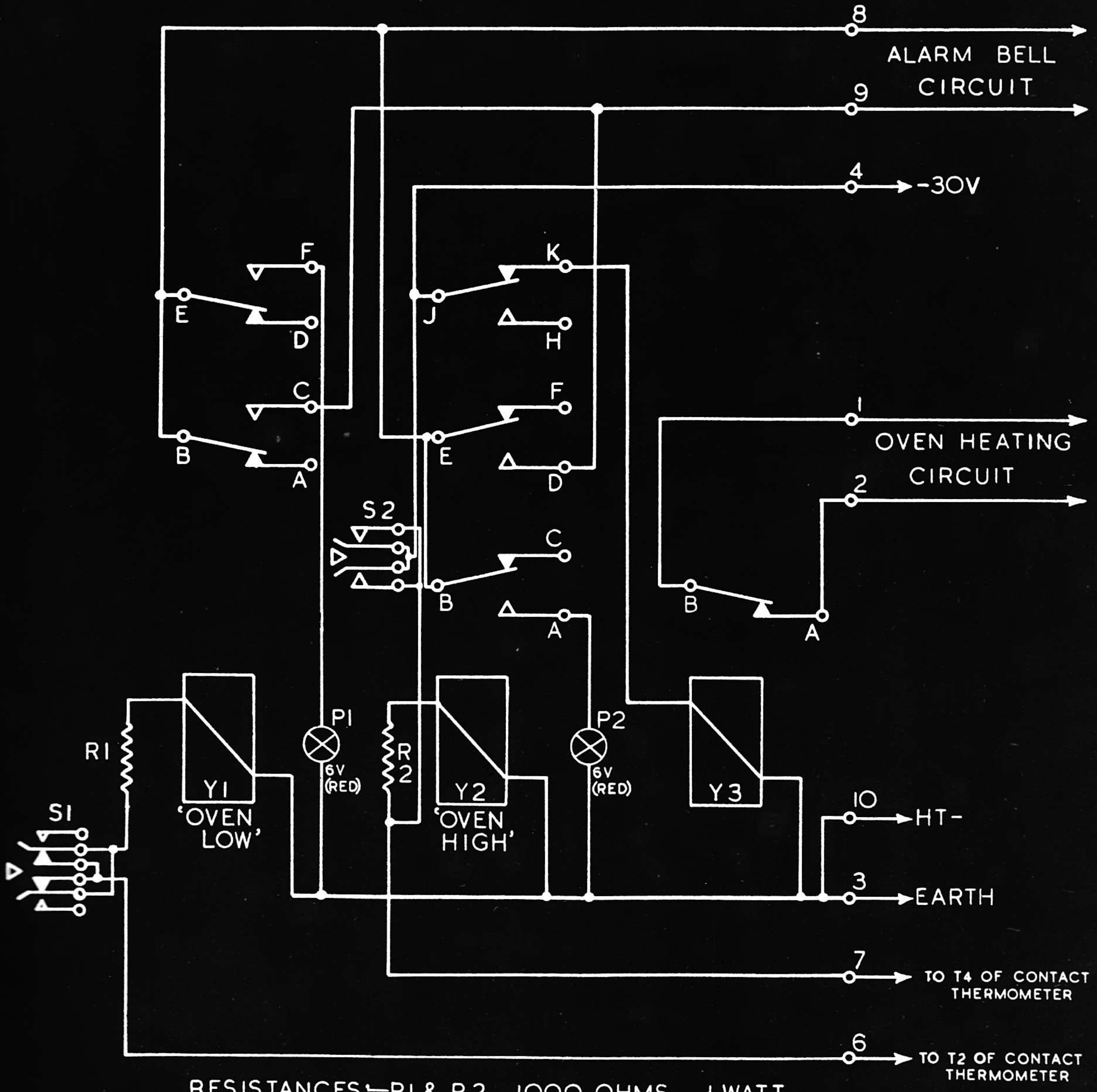
FIG. 11.



COMPONENTS	VALUES	RATINGS
C1	1 μF	
C2	·01 "	
R1	1 MEG	1 WATT
R2	15000 OHMS	2 WATTS
R3	3·157 "	
R4	100 "	1/2 WATT

OVEN TEMPERATURE RELAY

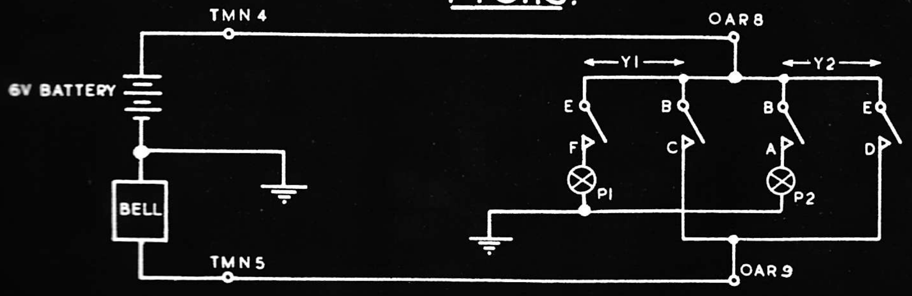
FIG.12.



RESISTANCES:—R1 & R2. 1000 OHMS. 1 WATT.

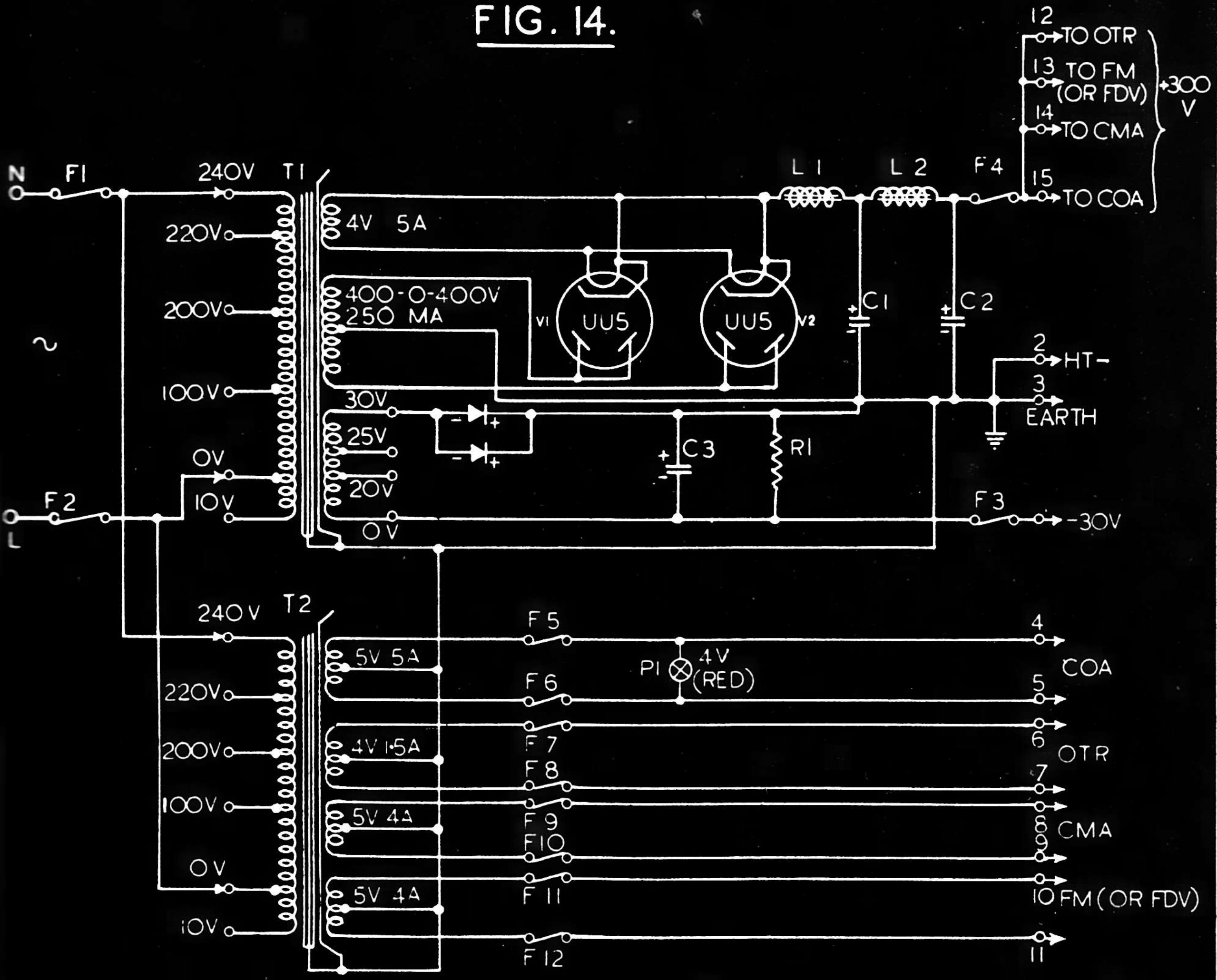
OVEN ALARM RELAYS

FIG.13.



ALARM BELL & LAMP CIRCUITS

FIG. 14.

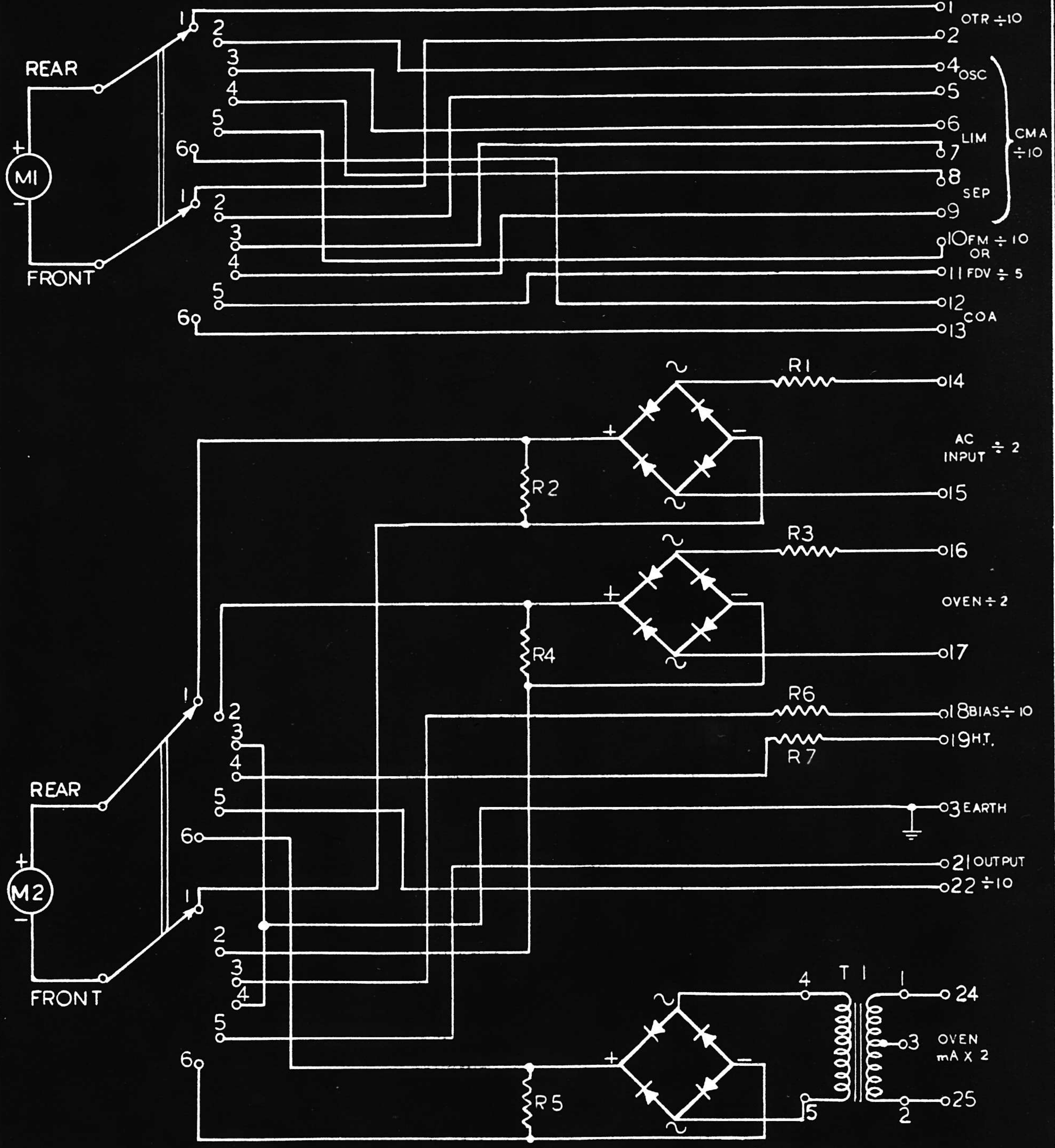


COMPONENTS	VALUES	RATINGS
C 1	16 μ F	500V WKG
C 2	16 "	500V "
C 3	50 "	50V "
L 1	15 H	
L 2	18 "	
R 1	5000 OHMS	3 WATTS

FUSES	RATINGS	FUSES	RATINGS
F 1	1 A	F 7	5 A
F 2	1 A	F 8	5 A
F 3	0·1 A	F 9	10 A
F 4	0·5A	F 10	10 A
F 5	10 A	F 11	5 A
F 6	10 A	F 12	5 A

H.T. RECTIFIER AND L.T. SUPPLY.

FIG. 15.

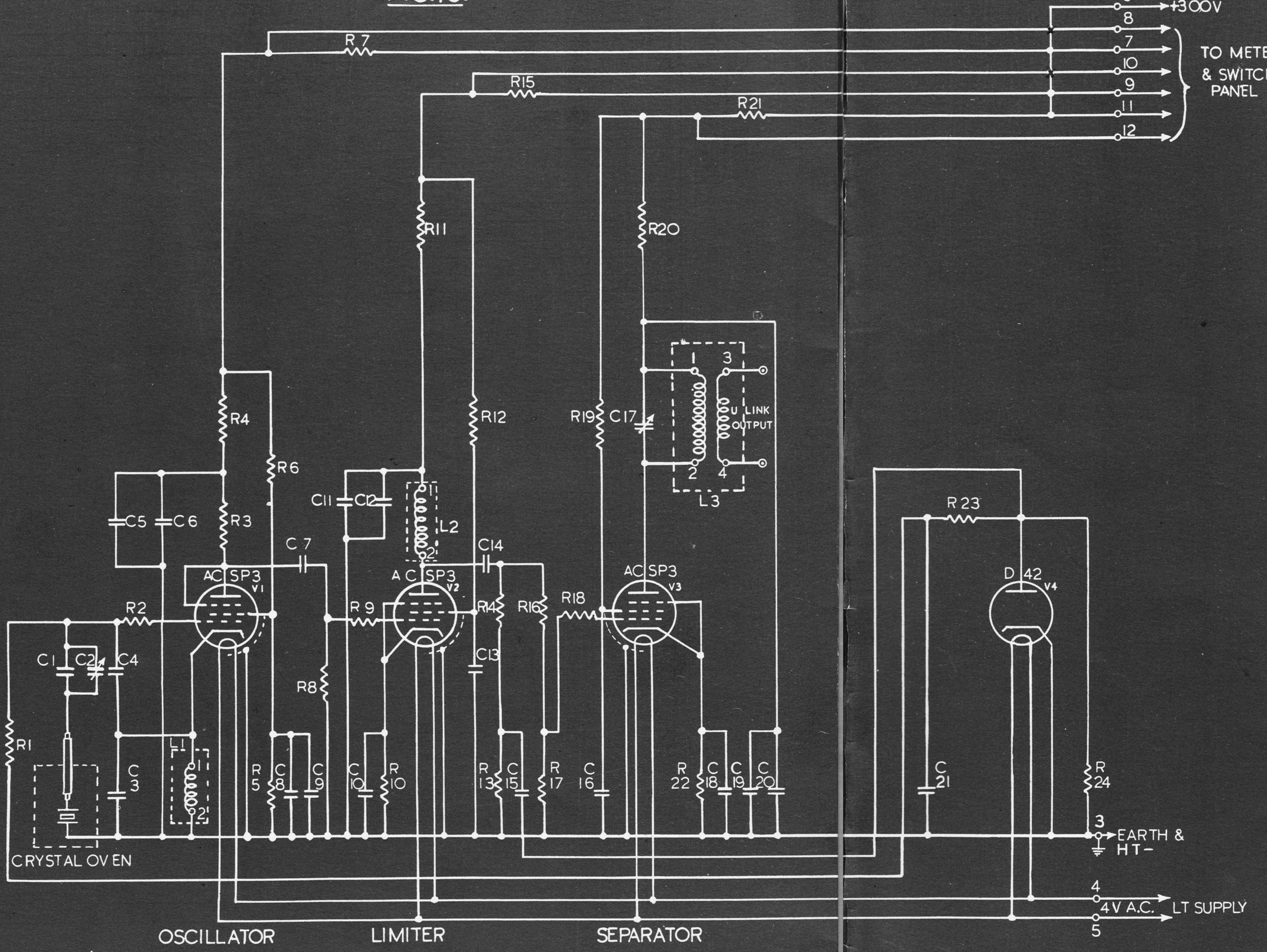


RESISTANCES	VALUES	RATINGS
R 1	112700 OHMS	1 WATT
R2	60 "	"
R3	112700 "	1 "
R4	60 "	"
R5	60 "	"
R6	50000 "	1 "
R7	500000 "	0·5 "

METER AND SWITCH PANEL.

42023/TT2/EJC

FIG.16.

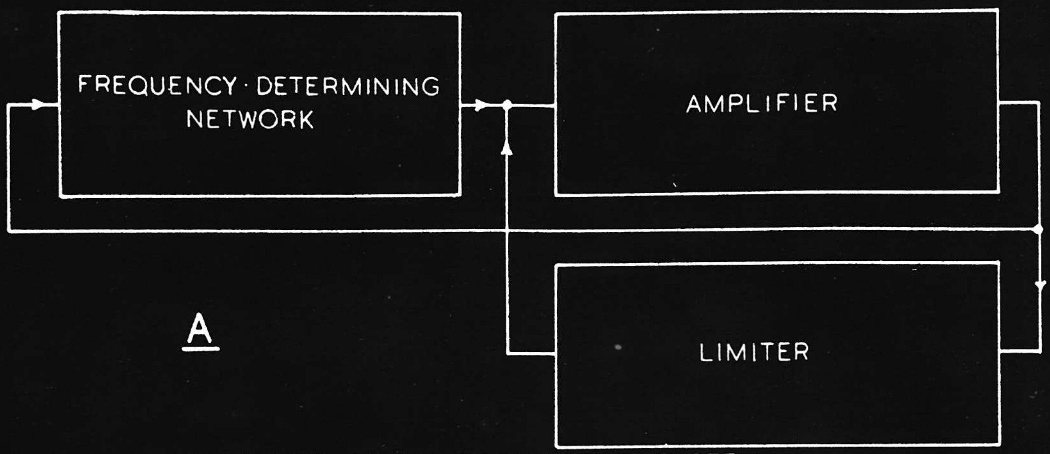


CRYSTAL MAINTAINING AMPLIFIER.

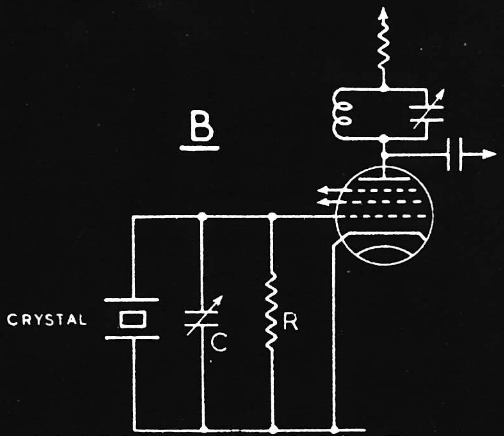
COMPONENTS	VALUES	RATINGS
C 1	50 μμF	
C 2	100 " "	
C 3	※SEE NOTE BELOW	
C 4	※ " " "	
C 5	·01 μF	
C 6	1 "	
C 7	·0001 "	
C 8	·01 "	
C 9	0·1 "	
C 10	0·1 "	
C 11	·01 "	
C 12	1 "	
C 13	1 "	
C 14	·005 "	
C 15	·0001 "	
C 16	1 "	
C 17	0001 "	
C 18	0·1 "	
C 19	1 "	
C 20	·01 "	
C 21	·005 "	
L 1	2·5 mH	
L 2	1 "	
L 3	ACCORDING TO FREQUENCY	
R 1	10 000 OHMS	0·5 WATT
R 2	200 "	0·5 "
R 3	1 000 "	1 "
R 4	15 000 "	2 WATTS
R 5	30 000 "	2 "
R 6	30 000 "	2 "
R 7	3·157 "	
R 8	50 000 "	0·5 "
R 9	200 "	0·5 "
R 10	300 "	1 "
R 11	15 000 "	2 "
R 12	30 000 "	2 "
R 13	※ SEE NOTE BELOW	
R 14	1 000 OHMS	0·5 "
R 15	3·157 "	
R 16	5 000 "	0·5 "
R 17	※ SEE NOTE BELOW	
R 18	200 OHMS	0·5 "
R 19	30 000 "	2 "
R 20	15 000 "	2 "
R 21	3·157 "	
R 22	300 "	1 "
R 23	50 000 "	0·5 "
R 24	50 000 "	0·5 "

※ NOTE: ADJUSTED UPON TEST AT TIME OF INSTALLATION.

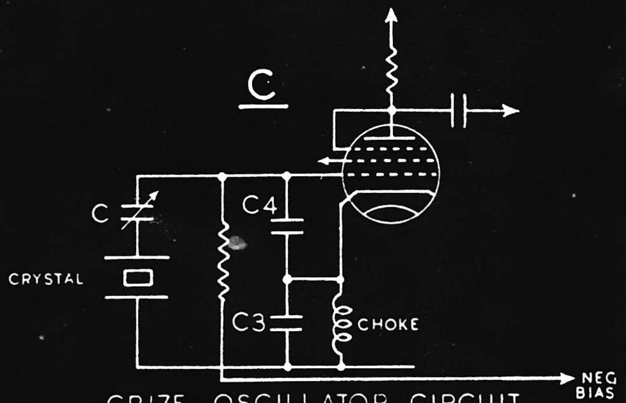
FIG. 17.



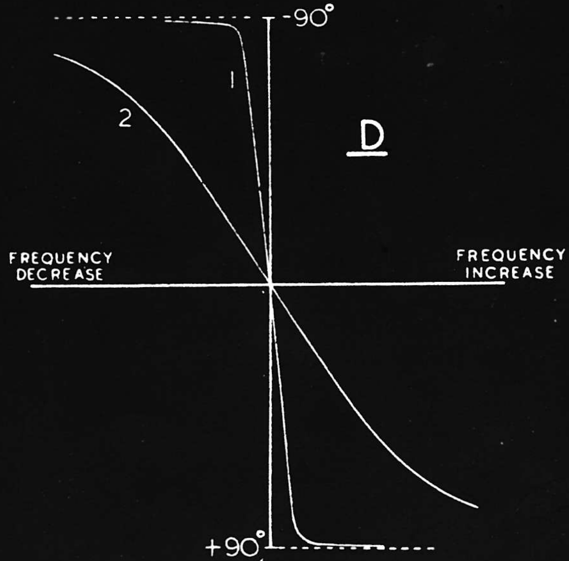
SCHEMATIC OF AN OSCILLATOR SYSTEM



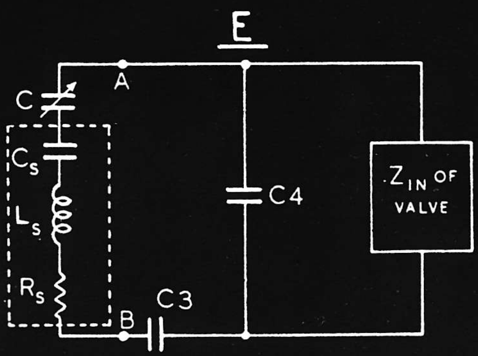
C.P. 2. OSCILLATOR CIRCUIT



C.P.17E. OSCILLATOR CIRCUIT



PHASE-ANGLE/FREQUENCY CHARACTERISTICS



CP 17E EQUIVALENT OSCILLATOR CIRCUIT

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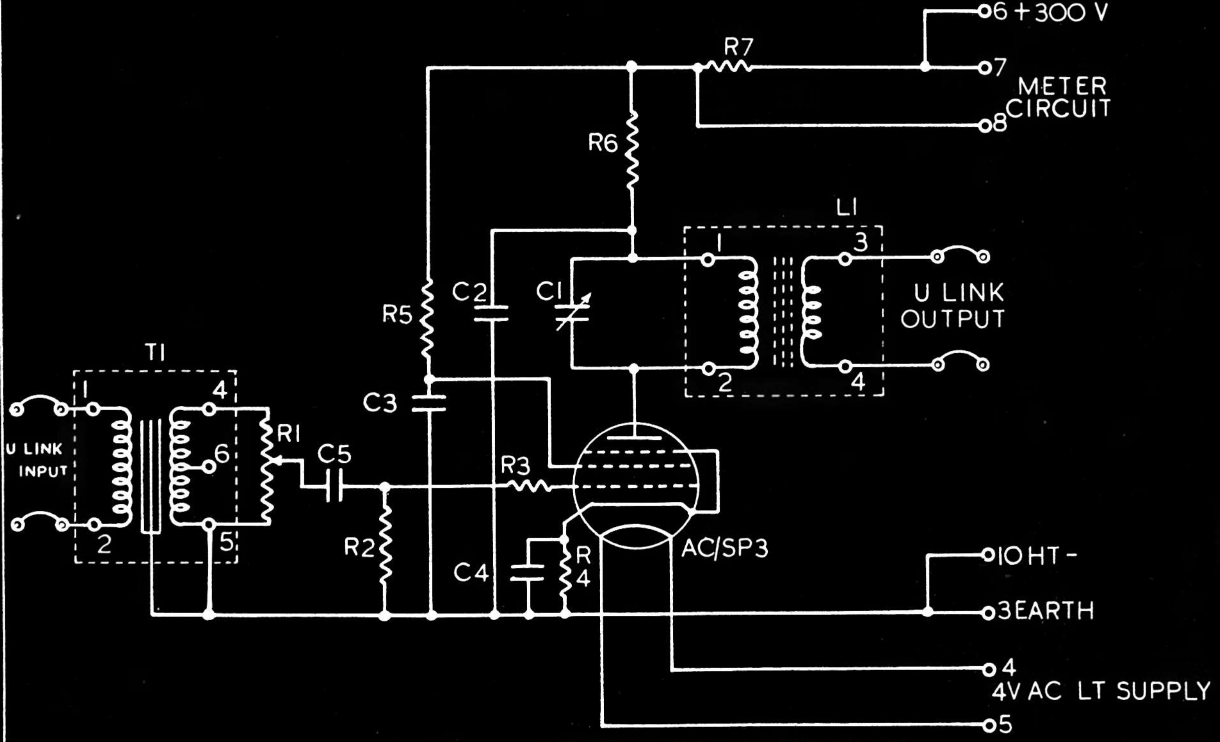
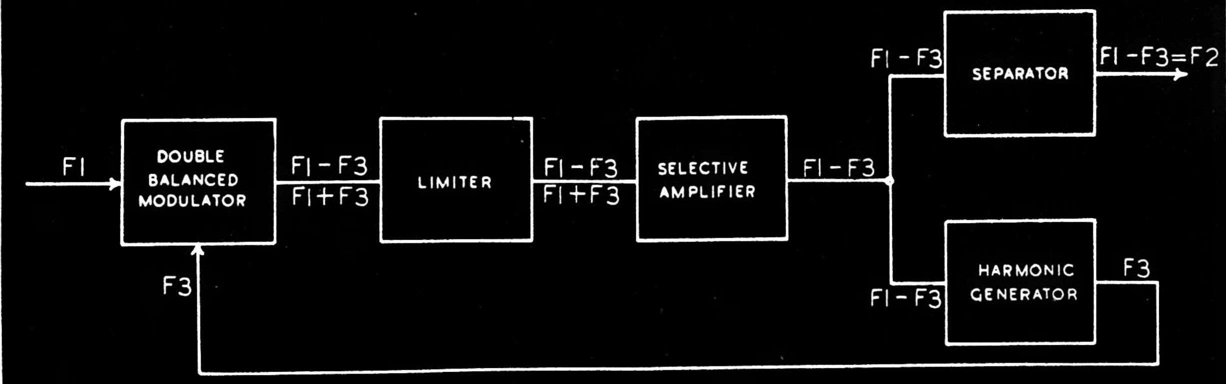
FIG. 18.



COMPONENTS	VALUES	RATINGS
C1	100 µµF	
C2	0·1 µF	
C3	0·1 "	
C4	0·1 "	
C5	·001 "	
L1	ACCORDING TO FREQ.	
R1	10000 OHMS	
R2	50000 "	0·5 WATT
R3	200 "	0·5 "
R4	300 "	1 "
R5	30000 "	1 "
R6	15000 "	2 WATTS
R7	3·157 "	

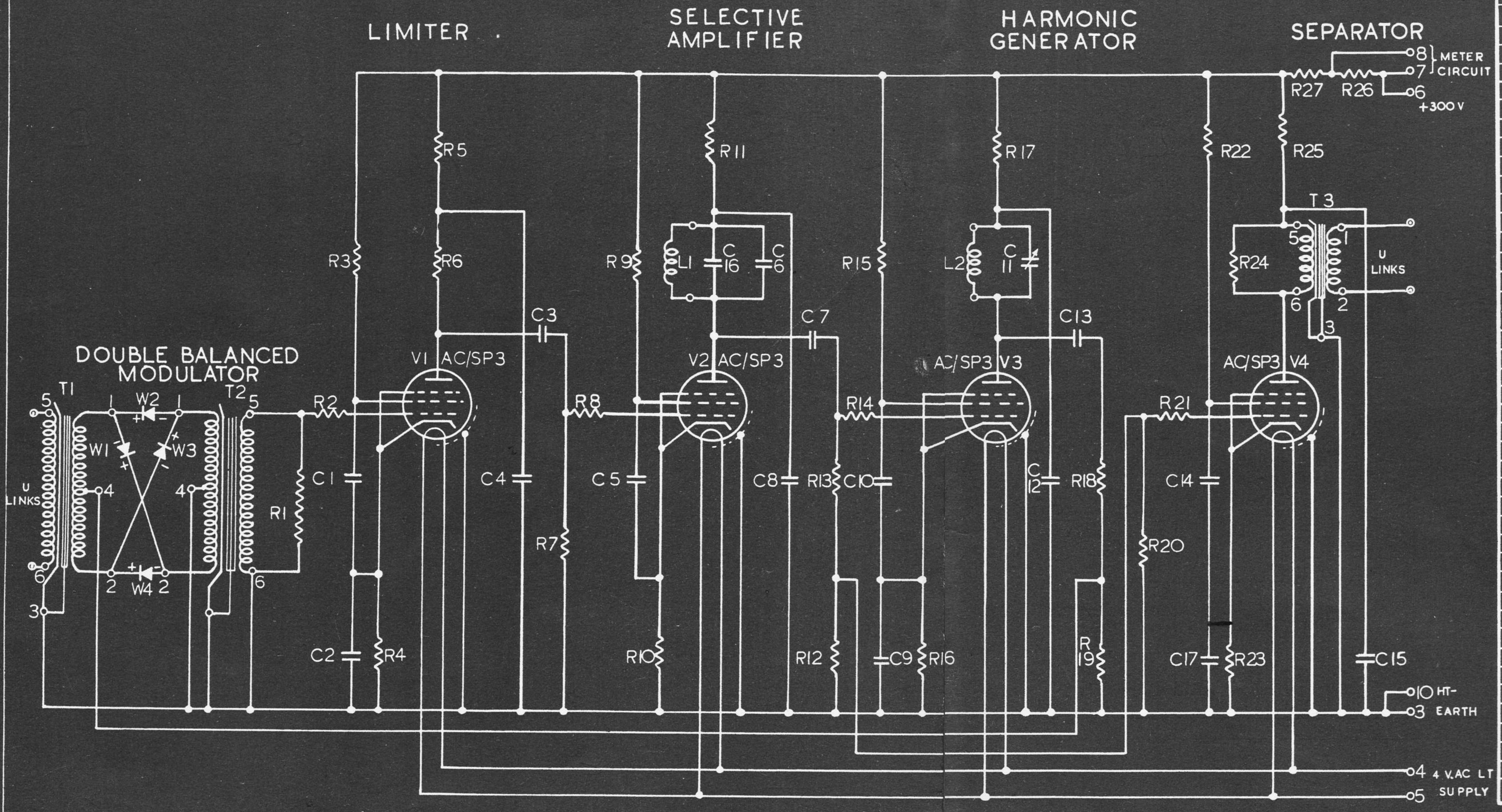
FREQUENCY MULTIPLIER

FIG 19



SCHEMATIC OF FREQUENCY DIVIDER

FIG.20.



COMPONENTS	VALUES	RATINGS
C1	0·1 μF	
C2	0·1 "	
C3	·01 "	
C4	0·1 "	
C5	0·1 "	
C6	·0004 "	
C7	·0005 "	
C8	0·1 "	
C9	0·1 "	
C10	0·1 "	
C11	100 μμF	
C12	0·1 μF	
C13	·0005 μF	
C14	0·1 "	
C15	0·1 "	
C16	VALUE DETERMINED DURING TEST	
C17	0·5 μF	
L1	1200 μH	
L2	DEPENDENT UPON DIVISION RATIO	
R1	1000 OHMS	0·5 WATT
R2	100 "	0·5 "
R3	20000 "	1 "
R4	300 "	1 "
R5	5000 "	1 "
R6	5000 "	1 "
R7	5000 "	0·5 "
R8	100 "	0·5 "
R9	20000 "	1 "
R10	300 "	1 "
R11	5000 "	1 "
R12	2500 "	0·5 "
R13	10 000 "	0·5 "
R14	3000 "	0·5 "
R15	20000 "	1 "
R16	500 "	1 "
R17	5000 "	1 "
R18	10 000 "	0·5 "
R19	2500 "	0·5 "
R20	20000 "	0·5 "
R21	100 "	0·5 "
R22	20 000 "	1 "
R23	300 "	1 "
R24	10 000 "	1 "
R25	5000 "	1 "
R26	1·54 "	
R27	3000 "	7·5 "

BALANCED MODULATOR R.F. DIVIDER.

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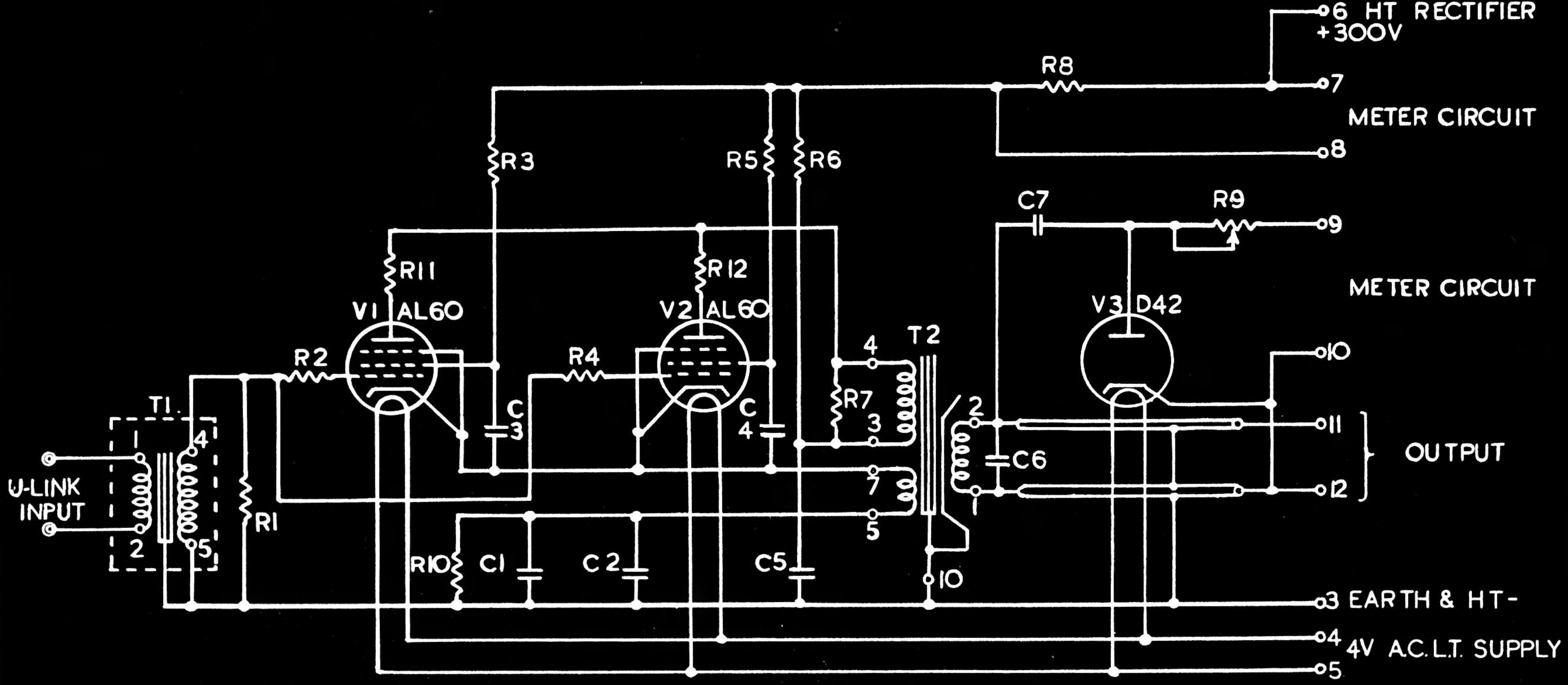

FIG. 21.

COMPONENTS	VALUES	RATINGS	COMPONENTS	VALUES	RATINGS
C1	1 μF		R4	100 OHMS	0·5 WATT
C2	·01 "		R5	30000 "	2 WATTS
C3	0·1 "		R6	100 "	2 "
C4	0·1 "		R7	5000 "	7·5 "
C5	4 "	350V DC	R8	0·352 "	
C6	·001 "		R9	100000 "	
C7	·01 "		R10	50 "	1 "
R1	1000 OHMS	0·5 WATT	R11	10 "	0·5 "
R2	100 "	0·5 "	R12	10 "	0·5 "
R3	30000 "	2 WATTS			

CRYSTAL OUTPUT AMPLIFIER.

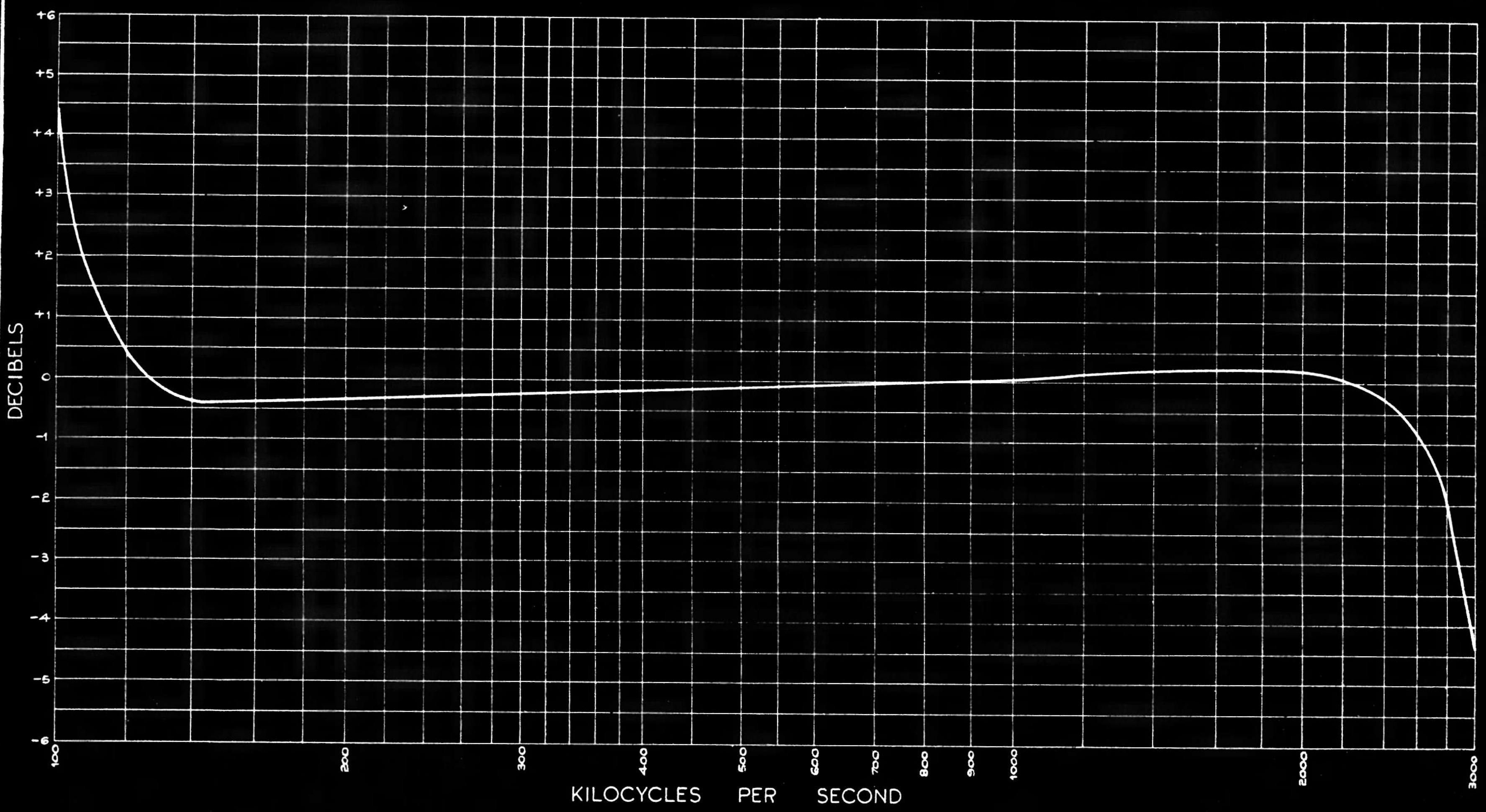

FIG. 22.

CRYSTAL OUTPUT AMPLIFIER. FREQUENCY CHARACTERISTIC.