MEDIUM FREQUENCY TRANSMITTERS

Lesson Text V35-8

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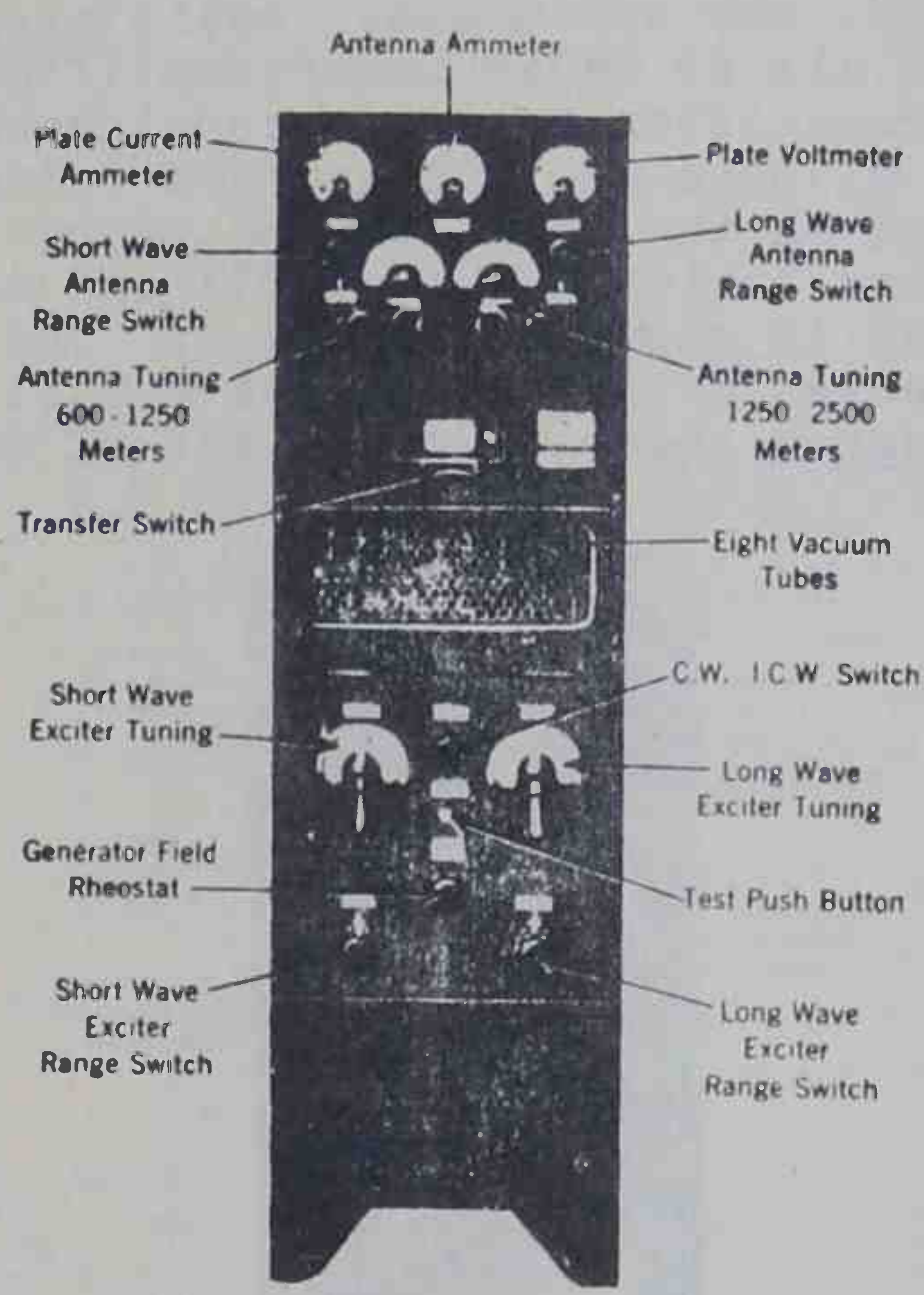

Figure 1--E.T.3626B 750-Watt Transmitter for CW and ICW Telegraph Service

Medium Frequency Transmitters

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E.T. 3626-B 750-Watt Transmitter for CW and ICW Telegraph Service. This transmitter utilizes eight vacuum tubes of the UV-211, fifty-watt type, one functioning as the master oscillator, one as an audio oscillator to provide for ICW transmission, and the other six as radio power-amplifiers. When used on the average ship antenna the transmitter covers a continuous range from 600 to 2500 meters, or 500 to 120 kilocycles. CW and ICW telegraphy are obtained by turning the signal switch on the panel to the proper position. The front panel view is shown in Figure 1 with all controls and meters identified. A side view of the transmitter is shown in Figure 2. The schematic circuit diagram showing the fundamental arrangement in the E.T. 3626-B transmitter is shown in Figure 3. The diagram shows only one set of Master oscillator (exciter)

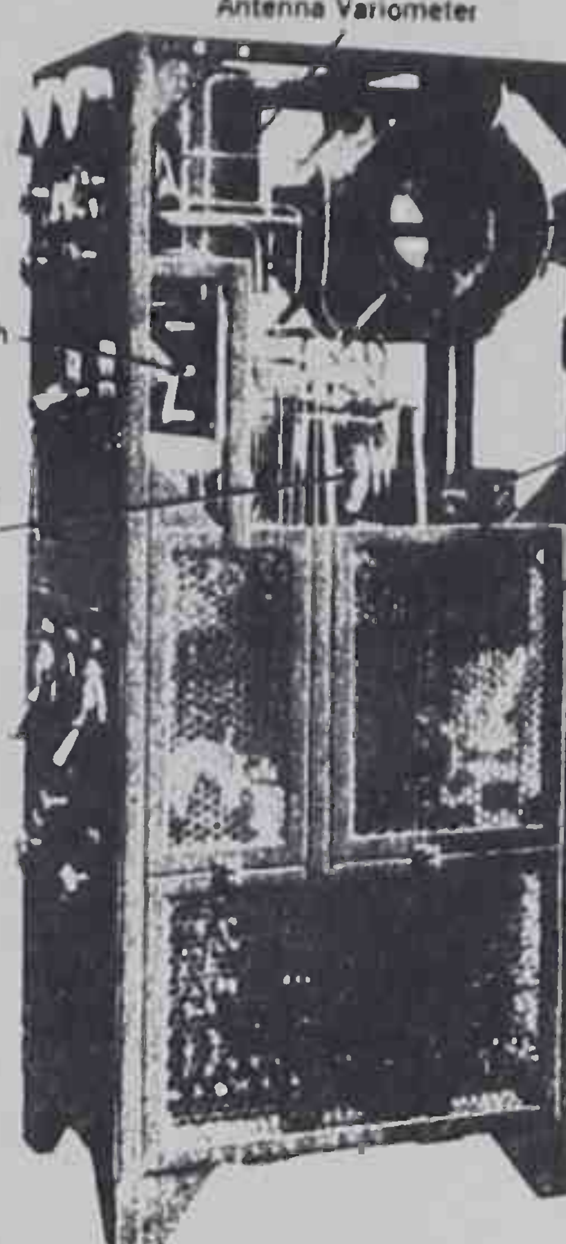

Figure 2

circuit elements and antenna tuning elements, whereas two sets are actually provided, one for the 600 - 1250 meter range and the other for the 1250 - 2500 meter range. Either the long or short-wave range may be selected by the seven-pole double-throw switch marked "transfer switch" on the photographs. The tubes are connected to the long-wave circuits when this switch is thrown up, and to the short-wave circuits when it is thrown to the down position.

The two pointers with long handles, shown just below the hinged screen door about mid-way of the panel in Figure 1, control the master oscillator (exciter) circuits by means of which the desired transmitting frequency is obtained. Loading of the antenna circuit is accomplished with a tapped inductor equipped with a rotor coil to permit fine tuning adjustment by the variometer method. The knobs controlling the antenna tuning are located on the upper part of the front panel. The short-wave exciter circuit is placed on the left and the long-wave on the right. By again making reference to the schematic diagram it is seen that the exciter oscillatory circuit or frequency-determining circuit consists of the inductor labelled 3 and the condensers 4. The inductor is also provided with a rotor coil which permits the variometer principle to be employed for changing the frequency. The plate and grid of the oscillator tube are connected to the tuned circuit by leads P and G through by-pass condensers 2 and 7 respectively. The filament is attached to the oscillator circuit through lead F. As previously stated, in the actual transmitter two of these inductors are supplied with the transfer switch to place either in the circuit, depending on the frequency desired.

Two control knobs on the panel, each marked "range switch", permit both the short-wave and long-wave ranges to be divided into two parts, namely: 600 to 900 meters and 900 to 1250 meters for the short-wave and 1250 to 1800 and 1800 to 2500 meters for the long-wave.

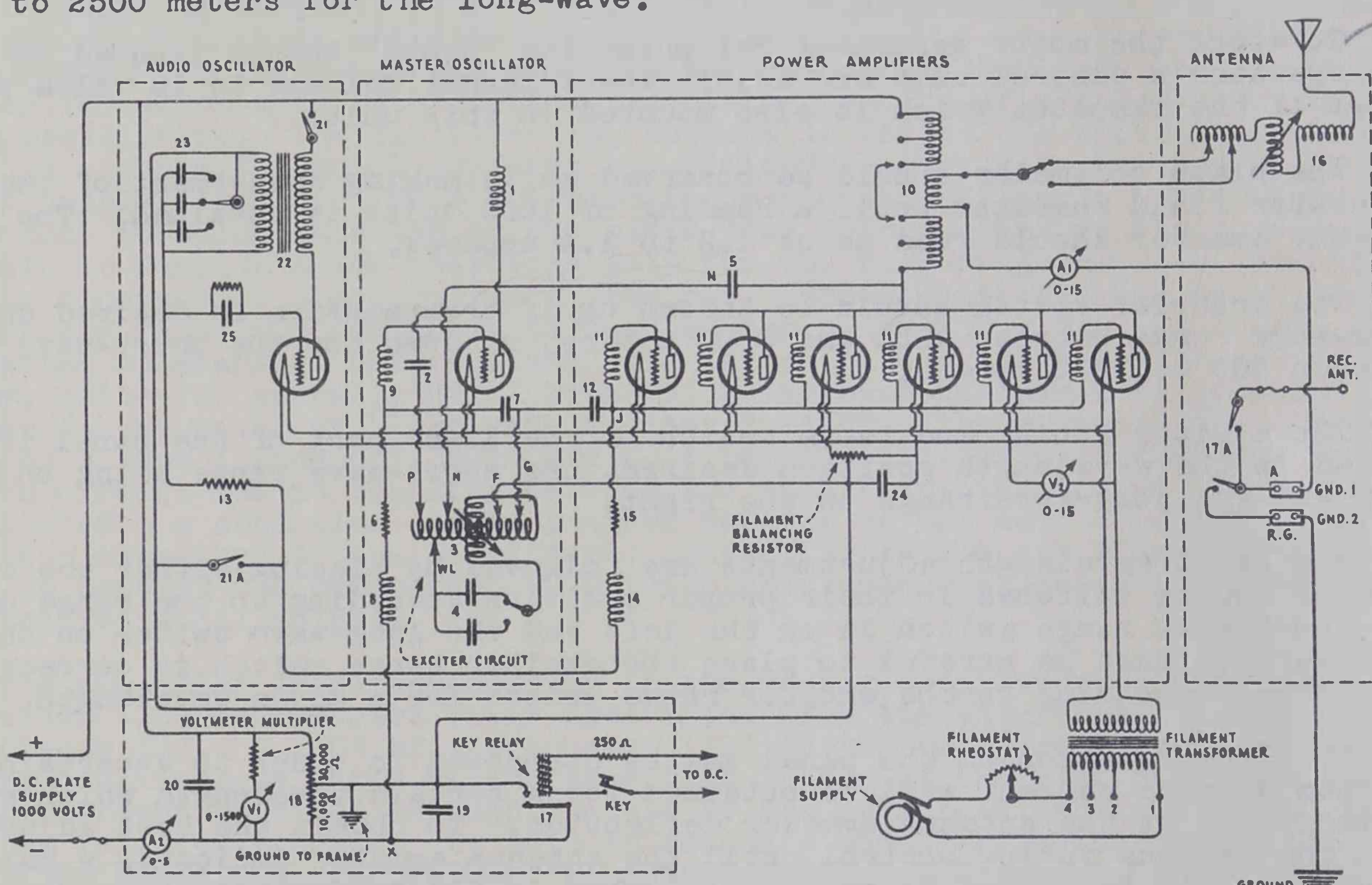

Figure 3

The following gives the approximate relation between antenna current and wavelength for the E.T. 3626-B when used with the average ship's antenna.

Wavelength	Antenna Current	Transfer Switch	Exciter Range	Antenna Inductance
600-900	10.1	Down	600-900 SW	600-900 SW
900-1250	10.0	Down	900-1250 SW	900-1250 SW
1250-1800	9.8	Up	1250-1800 LW	1250-1800 LW
1800-2500	9.4	Up	1800-2500 LW	1800-2500 LW

A key relay operated by power from a 110 V. d-c. supply, through a resistance and hand key, controls the grid circuits of both the master oscillator and amplifier tubes. While the key is up a negative bias of 250 volts is applied to all grids, thus stopping oscillation and insuring continued blocking of the

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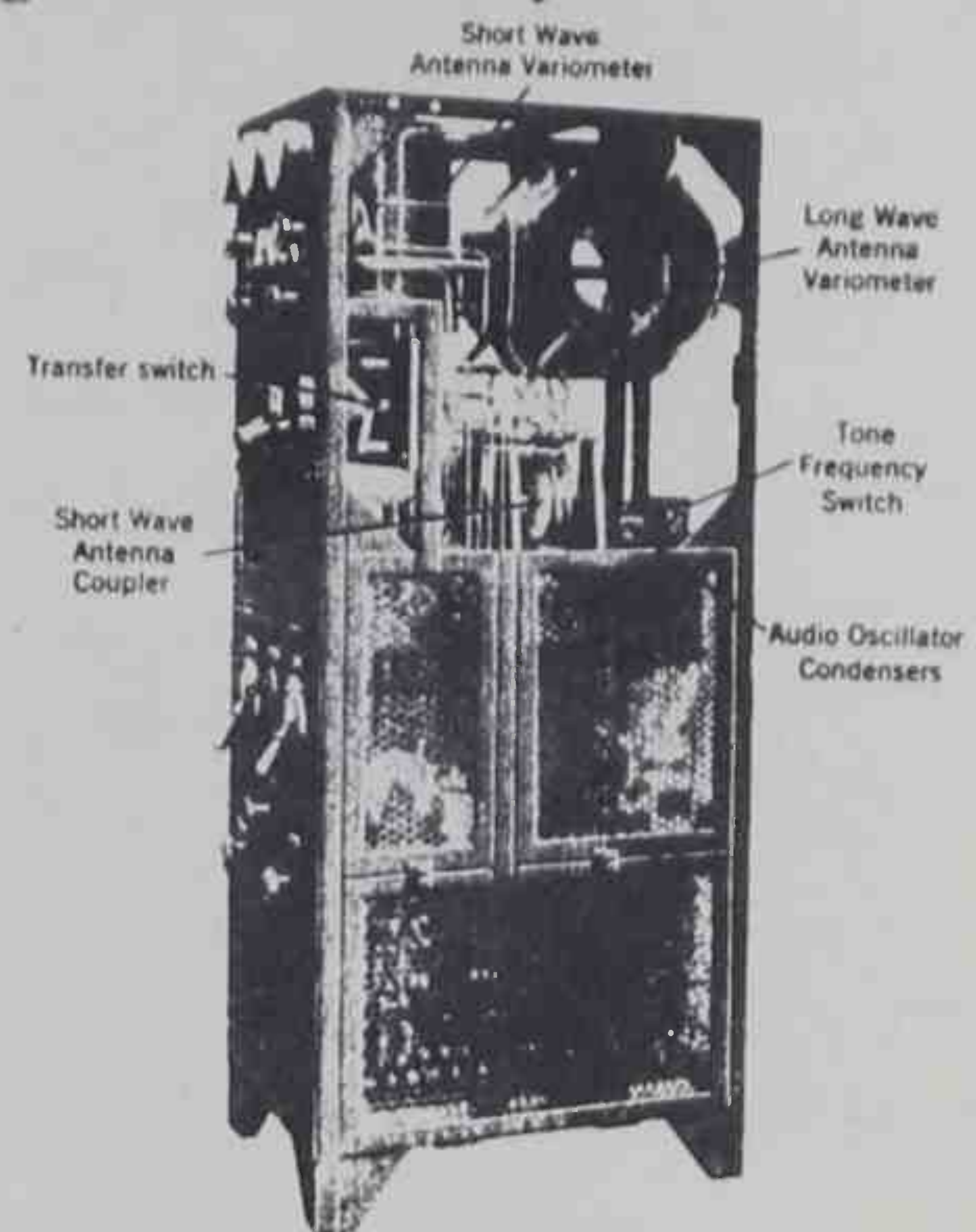

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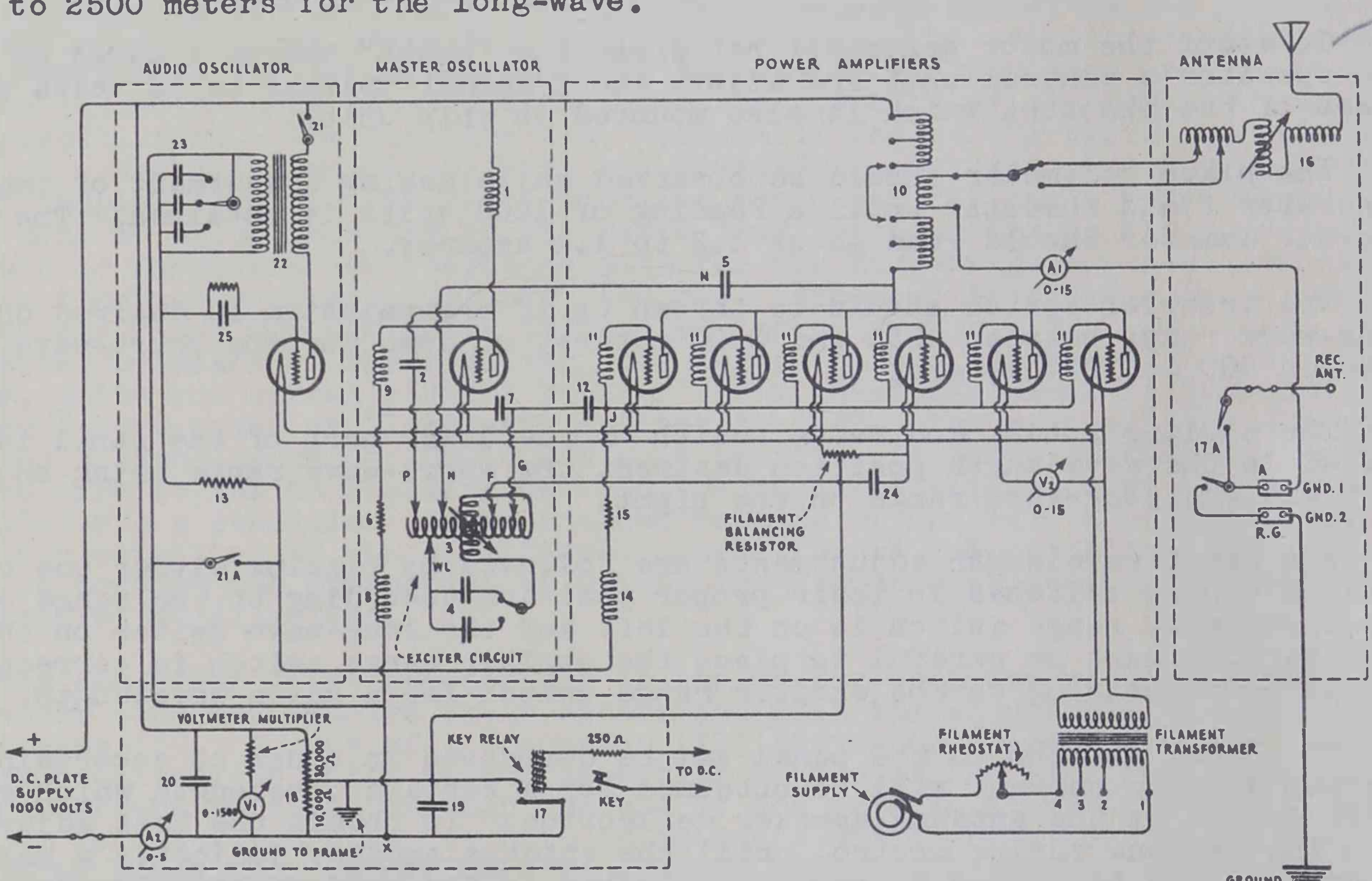

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A key relay operated by power from a 110 V. d-c. supply, through a resistance and hand key, controls the grid circuits of both the master oscillator and amplifier tubes. While the key is up a negative bias of 250 volts is applied to all grids, thus stopping oscillation and insuring continued blocking of the plate current. The keying relay is also provided with additional contacts giving break-in operation. While the key is up the receiving set is connected to the antenna and the relay is adjusted to have the break-in contacts closed before the keying contacts close, and also to have the break-in contacts open after the keying contacts open.

The motor armature of the motor-generator set is provided with slip rings from which 77 volts, 60-cycle power is obtained for filament heating. A step-down transformer gives the required filament input voltage with regulation through a rheostat. The d-c. generator for plate excitation is a two-pole, shunt-wound, separately excited machine delivering a potential of 1000 to 1200 volts d-c.

Placing the E.T. 3626-B into Operation: 1. Before starting the motor-generator set turn the filament and generator field rheostats to minimum voltage positions and close the main line switch if it has been opened.

2. To start the motor generator set press the "start" button located on the the operator's control unit and adjust the filament voltage to 10 volts by means of the rheostat which is also mounted in this unit.

3. The plate voltmeter should be observed while making adjustment of the generator field rheostat until a reading of 1000 volts is obtained. The plate current ammeter should read about 1.2 to 1.4 amperes.

4. The transfer switch should be thrown up if transmission is desired on the long-wave range between 1250 and 2500 meters, or down for the short-wave range between 600 to 1250 meters.

5. The exciter tuning and range switch on the lower part of the panel is next placed in the wavele th position desired, the short-wave r being on the left and the lo -wave r e the right.

6. T above wavele th adjustments are followed by placi either one of the te a t ing switches in their proper position according to the range desired, the short-wave ra e switch is on the left a the lo -wave switch on the right. T operator st care l to place the exciter ra e switch in correct position correspo i to the exciter r switch for a given wavelength.

7. The "test" tt the l y depressed order to ascertain if maximum antenna c nt will obtained for a certain wavele th which will indicated by the tenna ammeter deflecti . To obtain the best adjustment, t n t ante a tuni control til t te a ter i icates a maximum c rent. is t i adjust nt is attac d to t vari ter rotor coil and c seq ntly it be mani ated for any rti lar wavele th; it resonates t radiati circuit with t closed circuit.

8. n satisfactory radiation i ication is secured after t the set as outlined above, t se key y rated for the transmission of messages.

9. fore se i a ssage sure t "CW - ICW" switch is in proper position which, of c se, is gover d by the t of receiver employed at the station with which co icati is to establis d. n the sendi key is closed, a t " - ICW" switch is t own to the ICW position, the a io oscillator will generate o of t ee tone eq ies operati in conj ction with the ster oscillator radio amplifiers. The "to f q ncy switch" located in t right side of the trans tter frame should not be t hed while the motor-generator set is runni as the d-c. volt e is on the circuits.

10. n c ication is c pleted t set is s t d by pressing the "stop" tton on t operator's control nel.

Theory of Operation. Referring to the schematic diagram in Figure 3, only one coil system called the "exciter" circuit, involving the generation of oscillations, is shown since the circuit is fundamentally alike for the two wavelength bands. Only one antenna variometer (16) is shown for the same reason although two such coils are in the actual set.

Looking at the set from the front, the left hand tube is used as the master oscillator, coupled to a split inductance or "Hartley" type circuit to produce oscillations. In the diagram this tube is the second one from the right with its oscillating circuit (exciter circuit) consisting of variable inductance (3) and two fixed condensers (4). The capacitance of these condensers is .004 mfd. and .002 mfd. respectively and function in conjunction with the long and short-wave exciter. The feed-back voltage built up across inductance (3) between the taps marked G and F is used to excite the oscillator grid through the coupling condenser (7). This condenser blocks the d-c. grid current from the oscillating circuit. The loss of high-frequency energy in the grid leak and keying circuit is prevented by the choke (8). The correct negative grid bias for the oscillator is obtained by the use of the 5000-ohm grid leak resistor (6) which acts to hold back a certain quantity of electrons on the grid when oscillating. The positive d-c. voltage is fed to the oscillator plate through a choke (1) which prevents the radio-frequency from backing up in the power supply circuit. The plate blocking condenser (2) has a capacitance of .004 mfd. it being inserted in the plate lead P connecting to the oscillatory circuit to furnish a low reactance path for the high-frequency a-c. component of the fluctuating plate current. The d-c. component is blocked by this condenser and flows through choke (1) and to the generator. The inductance (3) is varied by means of the rotating coil marked on the diagram with a long arrow, while the actual control knob on the transmitter panel is labelled either "short-wave" or "long-wave exciter tuning". The neutralizing condenser (5) has a capacitance of .00014 mfd., it being designed to prevent any reaction effects due to coupling between the amplifier circuit and the master oscillator - a condition always present because of the self-capacity (grid to plate capacity) of the amplifiers. Choke (9) in the oscillator grid is used to prevent the production of ultra-high-frequencies generally known as "parasitic" oscillations.

The six amplifier grids are coupled to the master oscillator circuit through condenser (12) and receive their excitation from the adjustable lead G on the inductance (3). A .004 mfd. condenser (12) serves to by-pass the high-frequency oscillations while at the same time it blocks the d-c. bias voltage of the amplifiers obtained through the use of the grid leak resistor (15). This 100-ohm resistor operates to hold an adequate number of electrons on the amplifier grids thus furnishing the correct negative bias when the oscillations produced in the master oscillator circuit are being increased in power by the amplifiers. This condition obtains when the transmitting key is down.

The amplifier plates receive their excitation from the 1000-volt generator through the plate coil of the antenna coupling transformer (10). The choke (14) builds up a high reactance to radio-frequencies and blocks the flow of this energy through the grid leak and keying circuits thus preventing high-frequency losses.

Inductive coupling between the closed and open circuits is provided by antenna transformer (10). Two such transformers are included in the transmitter, the long-wave on the left side and the short-wave on the right side. The radio-frequency component of the plate current of the six amplifier tubes passes thro h the primary of (10) causi a rapid change in magnetism which acts on the secondary t ns and, as a consequence, an alternating e.m.f. is i uced in the latter coil which sets the tenna system into excitation. The large tput power of the plifier tubes is delivered to the antenna in this er. The 6.0 d. condenser (20) f nishes a low reactance path aro d the generator for the radio-frequency component. For a given plate voltage the ount of power transferred to the antenna is controlled by the ratio of turns in transformer (10). For example, a larger number of turns used in the secondary, or antenna coil, than in the primary will increase power. The proper relation of turns is made at the time the set is calibrated and does not require adjustments by the operator. Loading the antenna is accomplished with a tapped inductance (16) provided with a rotor coil for fine-tuning the antenna by the variometer method. It has been previously stated that two such devices are included in the transmitter and controlled by knobs on the front of the panel.

Small choke coils (11) are connected in the grids of the power amplifier tubes and are placed as close to the tube sockets as practicable. The function of these chokes is similar to choke (9) in the master oscillator grid circuit.

The transmission of telegraph signals is by the keying relay (17) controlled by the hand key, the latter being energized from the 110-volt d-c. supply. The auxiliary contacts on relay (17) are shown in the antenna circuit at (17A). Break-in operation is provided by the closing of the auxiliary contacts preceding the closing of the grid circuit contacts. The diagram shows the connection of the grid return from all tubes to the negative 1000 volts at point marked "X" and the filament circuit to the tapped point on resistor (18). This resistor is attached to positive and negative of the d-c. generator and serves as a potentiometer. The amplifier grid return is through switch contact (21A) when CW transmission is employed. It should be particularly observed that the negative 1000 volts is not grounded, but as previously mentioned the ground is formed at the tapped point on potentiometer (18). According to the principles explained by Ohm's Law we know that a drop in voltage of a definite amount will result in the windings of this resistance when current flows through. The amount of the voltage, in this instance called "bias voltage", depends upon the strength of the current and the resistance of the unit (18) measured in ohms. Hence, when the sending key is up radio energy cannot be radiated because the large negative bias obtained from (18) is applied to the grids and oscillation stops. Subsequently a current of low value passing through potentiometer (18) from the d-c. generator places a holding bias on the grids. The total resistance of the potentiometer is 20,000 ohms. It consists, however, of two separate resistors joined in series. When the key is depressed, as for sending, a short circuit is placed across part of the potentiometer resistance from which the bias is obtained. This short, of course, removes the bias, since no voltage drop can then be obtained. The 1.0 mfd. condenser is an arc absorption unit connected in shunt with the contact points of key relay (17). Large potential surges, due to keying the circuit, are absorbed and dissipated by the 6.0 mfd. condenser (20).
ICW telegraphy is accomplished by modulating the output of the power amplifiers with an audio-frequency current obtained from the audio oscillator circuit consisting of three capacitors labelled (23) and the secondary winding of the iron core transformer (22). The tube functioning in conjunction with this circuit is known as the audio oscillator tube, the first tube on the left in the schematic diagram. The production of an oscillating current in the audio-frequency range is possible through the feed-back of power from the plate or primary winding of (22) to the grid or secondary which action takes place due to the changing magnetic flux permeating the iron core which always accompanies any variation in the strength of the plate current. The plate and grid circuits are made resonant to a low frequency current by employing large condensers of high capacitance and building up the inductive reactance of the circuit through the use of windings composed of a large number of turns together with an iron magnetic circuit. The grid of the audio oscillator connects to one side of the secondary winding of (22) and receives its excitation from the alternating voltage of low frequency induced in this winding from the fluctuating plate current in the primary. The opposite end of the secondary is joined to the negative 1000 end of the potentiometer (18) at point "X".

In order to carry on ICW telegraphy with this transmitter the "CW - ICW" switch on the panel is thrown to position marked "ICW", thus closing switch (21) in the schematic diagram. The closing of this switch supplies power to the audio oscillator tube plate from the d-c. generator, while at the same time switch (21A) opens and removes the short circuit around resistor (13) and the secondary winding of transformer (22). The audio oscillator grid return is completed at point "X" which provides this tube with a blocking bias for keying similar to the conditions existing in the grids of the other tubes in the transmitter when the sending key is up. An inspection of the diagram shows that when switch (21A) is open the grid leak current of the six power-amplifier tubes must flow through resistor (13) and the secondary of transformer (22). Because of this interrelation between the radio and audio circuits the low frequency a-c. voltage induced across the secondary by the fluctuating plate current in the primary is effectively applied on the grids of all the radio power-amplifiers because these tubes are arranged in parallel, i.e., all of the grids are connected to one common junction which leads to condenser 12, and also to grid leak circuit consisting of choke (14) and leak resistor (15).

When the sending key is depressed the output of the audio oscillator is impressed upon the grids of the amplifiers, while these tubes are at the same time continuing to step-up the strength of the continuous oscillations received from the master oscillator. It follows that for any change in grid potential at an audio rate the amplitude heights of the continuous oscillations will be forced to vary in exact accordance with the wave form of the audio energy. It is then said that the CW energy is modulated with the frequency of the audio oscillating circuit. The CW energy is known as the "carrier" frequency and it will be recalled that this frequency was generated in the circuits of the master oscillator and amplified through the power tubes. Hence, an ICW signal or better, a modulated wave signal, is transmitted which produces a signal in the distant receiving set having a characteristic spark tone. The term "tone modulation" may also be applied to this variety of telegraphic transmission.

The audio oscillator circuit can be adjusted to three different tone frequencies by varying its capacitance. Three condensers marked (23) and a switch making suitable connections is provided for this purpose. By proper selection of condensers, two of which are rated at .5 mfd. each, the third at 1.0 mfd., the tube grid bias can be made to vary at a 500, 700, or 1000 cycle rate, approximately.

When operating ICW, overloadi of the audio oscillator with d-c. current from the power- plifier grids is prevented by resistor (13) which also acts as a grid leak resistance for the plifiers addition to resistor (15).

The grid ret n of all tubes te i tes at a tapped point on the filament balancing resistor shown in the diagr . T insertion of t s small o t of resistance in the grid circuit requires the use of t .5 d. by-pass condenser (24) in order to ovide a path of low reactance to t radio-frequency energy. ile the audio oscillator tions normally d i ICW tr smission, a negative bias of correct value is intained upon its grid by t 5.0 d. grid condenser and 3000-o le resistor rked (25) on the diagram. D ing CW operation t a io oscillator ceases to ction because switc s (21) d (21A) are open, d at this t e t rid leak circuit for the power plifier tubes is thr gh grid leak resistor 15), r.f. choke (14) and switch (21A) which is then closed and t nce to the negative l -volt side of potenti ter resistor (18) indicated on the diagr at point "X".

The instruments on t transmitter panel are labelled on the sc matic diagr as foll s: Al is the antenna c rent ammeter (0-15 amps.) which is necessary to ascertain when res ance is establis d between t closed a open circuits on any of the transmitting waves while adjusti t tenna variometer controls; A2 is the plate current ammeter (0-5 amps.) which records the amount of direct current flowing from the d-c. generator to the plates of all eight tubes; V1 isthe plate voltmeter equipped with a 0-1500 volt scale and used in conjunction with the multiplier resistance to indicate the positive plate potential applied to the plates, and V2 is the filament voltmeter with a range of 0-15 volts used to indicate the input e.m.f. applied to the filament terminals which provides the correct filament temperature. The radio-frequency chokes 1, 8 and 14 are 400 turn duolateral wound coils.

Troubles and Emergency Measures. It will be found that a majority of the suggestions contained in the following paragraphs are applicable to various types of vacuum tube transmitters.

Defective Tubes. Should any of the tubes become inoperative and no spares are available, the transmitter may still be operated with three or four amplifier tubes in place of the usual six. The plate voltage should be reduced to prevent overheating of the plates of the tubes. Care must be taken that the tube plates do not exceed a dull red. The master oscillator tube, (the front left hand tube), must always be used. ICW transmission cannot be accomplished without the left hand rear tube which is the audio oscillator, because this transmitter is not equipped with a chopper.

Plate Radio Frequency Choke Coil Burned Out. Should the master oscillator plate choke, marked (1) in Figure 7, burn out remove the defective plate choke and replace it with grid choke (8) being careful to put in a temporary wire jumper to close the grid circuit. This provides an immediate remedy, but it will be observed that the efficiency of the master oscillator will be impaired. A 400-turn honeycomb or duolateral coil may be used for the plate choke if one is available.

Shorted Plate or Grid Blocking Condenser. This difficulty may be remedied by removing the defective condenser and substituting one of the large condensers in the other wavelength band. The substitute condenser can be easily mounted in a temporary position by lengthening the connecting leads.

Filament Voltmeter Inoperative. The filament rheostat should be adjusted until the tubes begin to heat or the antenna current drops quickly. When this effect is observed the rheostat should be adjusted slowly in the opposite direction until the temperature of the tubes becomes normal and the antenna is not rising rapidly.

No Indication on the Antenna Ammeter. The antenna circuit may not be in resonance or the trouble may be due to loose connections. Examine the antenna variometer and coupling transformer in the wavelength range that is inoperative. Also, look for open switch blades in the transfer switch. If this trouble is thought to be due to a burned out ammeter place a wire jumper between the meter terminals and note the results. If this is found to be the seat of the trouble without an ammeter reading the only alternative is to adjust the circuits in accordance with the tuning record and observe the plate current ammeter for final resonance.

Burned Out Plate Ammeter or Voltmeter. If the voltmeter is burned out no temporary repair is possible, therefore it is suggested that the generator field rheostat be adjusted to its usual position and the tubes watched closely to prevent overheating of the plates. In the case of a burned out plate ammeter a 150-watt lamp can be connected to the meter terminals, and for normal operation the lamp should not exceed full brilliancy.

Burned Out Filament Transformer: Filament Rheostat in the a-c. Supply Discontinued From the Two Slip Rings on the Motor Armature. The filament circuit should be disconnected from the filament transformer secondary and then connected to the terminals of a storage battery as follows: Connect five cells in series and then attach the filament terminals across the five cells. The connecting leads should be capable of carrying 30 amperes. The cells should be of the lead-acid type. A rheostat control will not be required because the voltage of the five cells is practically correct, i.e., 10 volts.

Burned Out Grid Leak. Should the grid leak of the power amplifier burn out it may be replaced by an equal value of resistance approximately 4000 to 10,000 ohms. A satisfactory substitute may be made up with a rubber hose about 10 inches long, filled with water and plugged at each end with a connecting wire passing through each plug and protruding a short distance in the water to form suitable electrodes.

Motor Generator. If the machine fails to start when the "start" button is pressed, look for an open main switch on the starter panel or a defective main fuse. The operator should ascertain if there is line voltage at the main switch and if it is of the correct value. A test for line voltage may be easily made by depressing the telegraph key which should cause the relay key to work, providing the ship's power is on.

If the contactor in the automatic starter closes when the "start" button is pressed, but the motor generator armature fails to rotate the trouble might be due to a burned out starting resistance on the back of the starting panel, or look for loose connections.

A frozen bearing will prevent any movement of the armature. To ascertain this condition first open the main switch and, with the power off, turn the armature over by hand and at the same time inspect the oil wells and rings to see that they have plenty of oil.

Tube Filaments do not Light. If the motor generator starts up satisfactorily, but the filaments fail to light look for blown fuses on the terminal board which might happen provided a tube filament has been previously short circuited. Also look for defective brush or insufficient brush tension on the motor slip rings, or loose connections.

Tubes Overheating. It is possible that a low voltage bias caused by a defective potentiometer resistance will not block the tubes sufficiently. Or, the bias voltage may be partially short-circuited by an amplifier tube which has become soft, this condition being generally evidenced by the troublesome tube showing a blue haze and heating more than the other tubes.

If, on the other hand, the tubes only overload while the key is down the master oscillator tube may be defective, that is, oscillations are not being generated in the oscillator's tuned circuit. In order to localize the possible reason for this trouble remove the six amplifier tubes from their sockets, but keep the master oscillator and audio oscillator tubes in place. When the key is now depressed the oscillator tube will heat excessively if the tube or circuit is defective. However, if the amplifier plates exceed a dull red glow with the key down and the antenna in resonance it may be assumed that an incorrect number of plate turns is used or the antenna coupling transformer is defective.

Audio Oscillator Circuit Fails to Operate. For the location of this trouble look at all connections on the "CW - ICW" switch, audio transformer (22) and condensers and switch (23) indicated on the diagram in Figure 3. The audio oscillator tube may be defective and the remedy in this event is obvious. One of the three condensers (23) may have broken down. Should the plate current rise excessively when the key is pressed while the audio oscillator seems to function properly the trouble may be due to either a shorted amplifier grid leak or audio oscillator grid leak, both of which have a rating of 3000 ohms.

Observe the Following Precautions. Never clean commutators with the motor generator set running as the high voltage is dangerous. Do not change tubes, make adjustments, or come into contact with the wiring while the set is in operation.

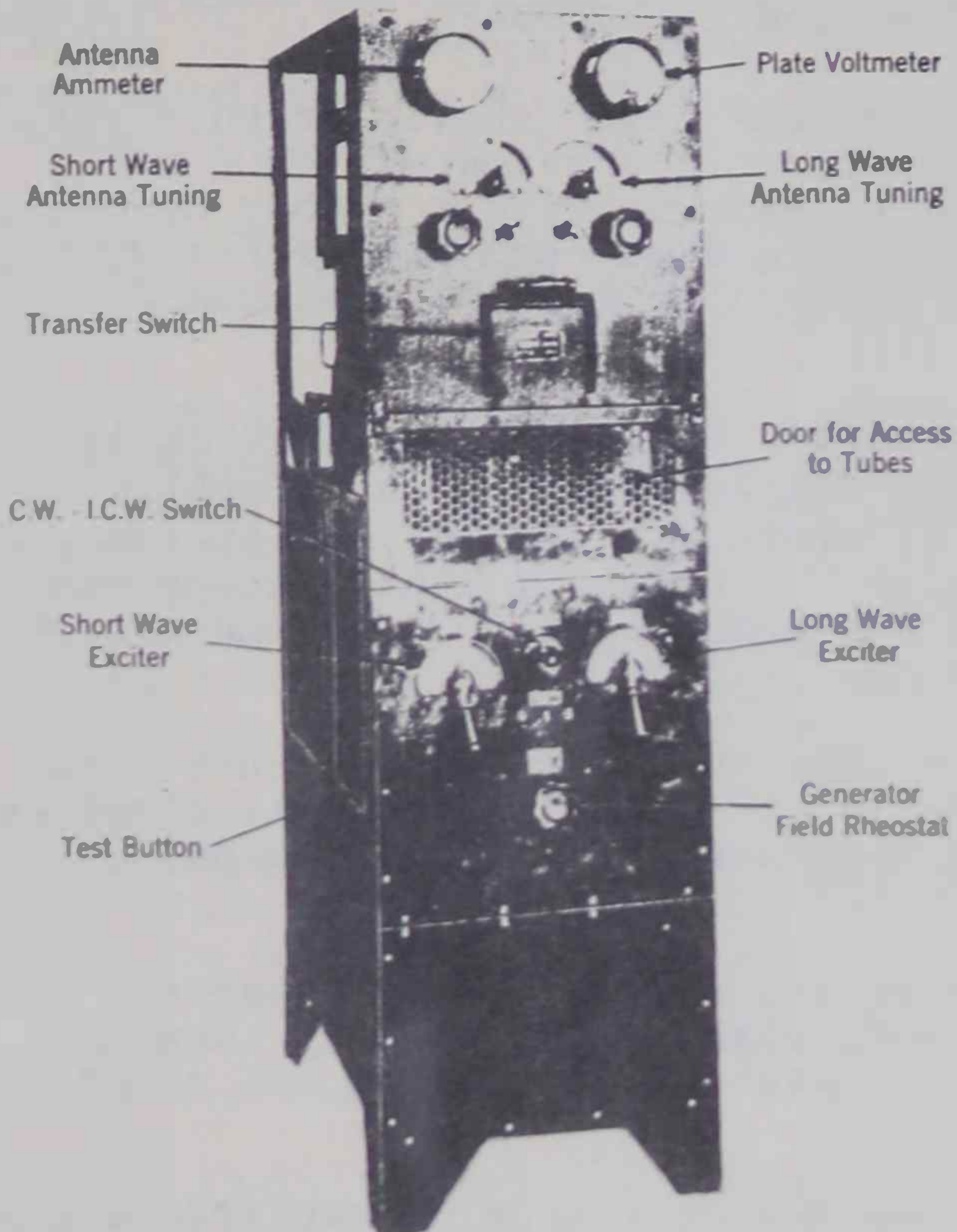

Figure 4

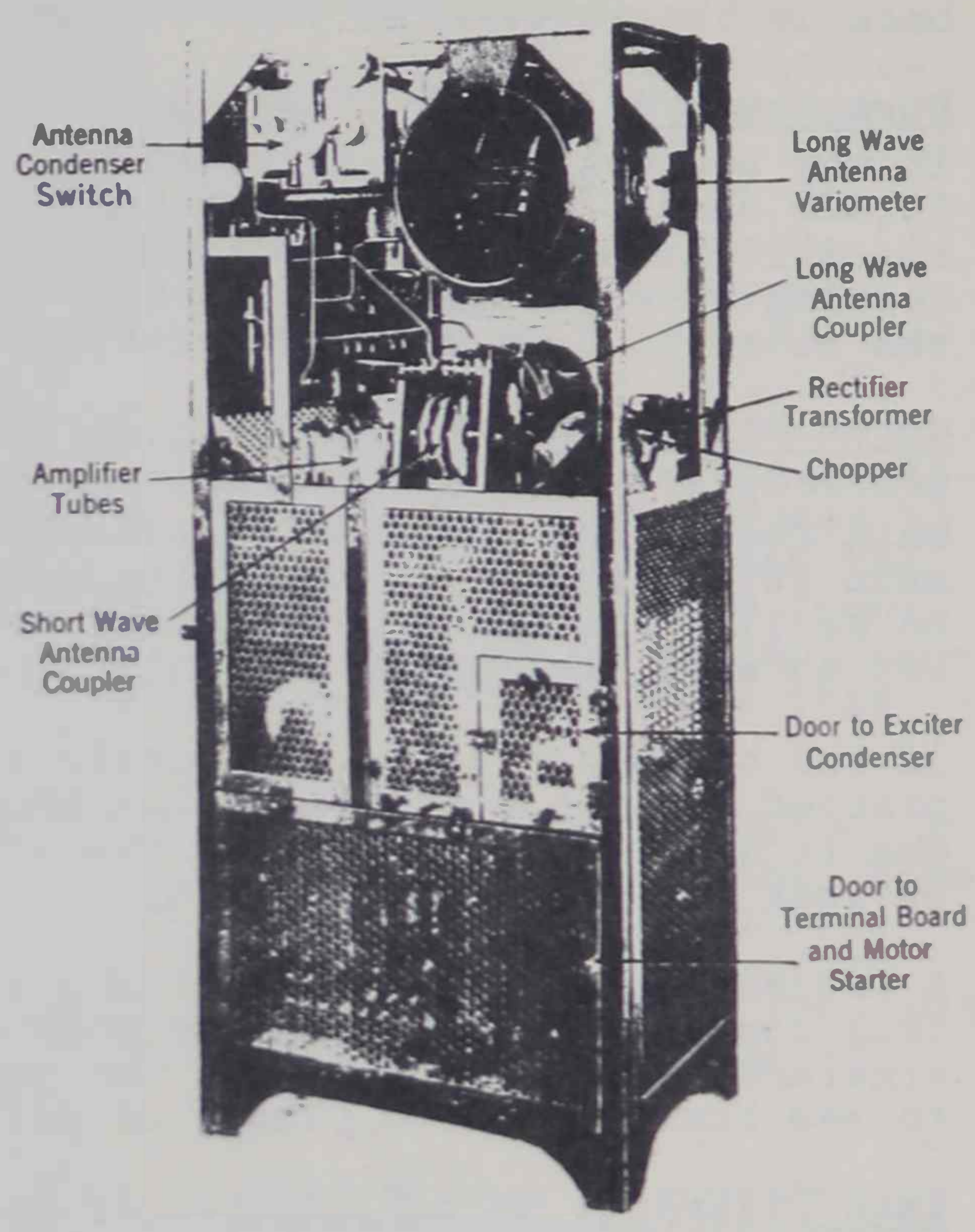

Figure 5

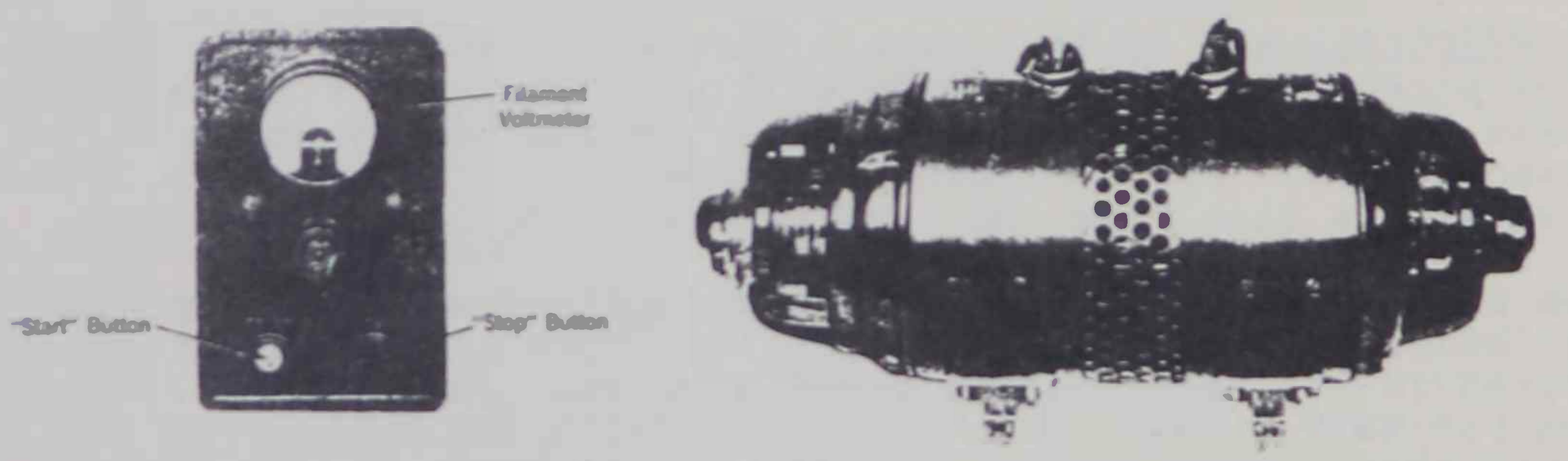

Figure 6

E.T. 3626 Telegraph Transmitter 750 watts. The front view of this transmitter is shown in Figure 4 and a side view in Figure 5. The motor generator and operator's control panel are illustrated in Figure 6. Transmission on two wavelength bands are provided through the use of a transfer switch and two independent sets of tuning elements. These bands are 600 to 1250 meters and 1250 to 2500 meters. Interrupted continuous wave transmission is obtained by a chopper system which causes the radiated signal to have the characteristic tone of a 500-cycle spark transmitter.

A total of eight UV-211 fifty- tt tubes are utilized in this equipment. Six t s connec d allel a as p r lifiers which feed their out- t to t tenna stem t a coupl tr sformer. tube is employed as the master oscillator or exciter. Facing the panel the master oscillator is the left hand front tube; it utilizes the split inductance or "Hartley" method of feed-back to produce oscillations. Another tube located directly in back of the master oscillator, i.e., in the left hand rear corner of the tube rack, is used as a rectifier. This tube charges a 1.0 mfd. condenser to a potential of approximately 250 volts. Power for this circuit is obtained from the 77-volt, 30-cycle filament supply and passes through a small transformer which steps up the voltage to 250 volts and the tube rectifies this voltage for introduction to the keying circuit. While the sending key is up a negative potential of 250 volts is applied to the grid circuits of the master oscillator and the power amplifiers to stop oscillation and insure continued blocking of the plate current. The grid bias voltage is automatically controlled by the manipulation of the hand key which in turn actuates a relay with two pairs of contacts. The relay contacts are arranged in such a manner to first open the grid circuit, stopping oscillation, and immediately after permitting the negative 250-volt bias to be applied while the key is up as previously mentioned. A second relay device provides break-in operation by connecting the receiving set to the antenna when the key is up.

The motor armature of the motor-generator is provided with two slip rings from which the a-c. power is obtained for filament heating. The filament transformer receives the 77 volts, 30 cycles, single phase power through a rheostat and steps down this voltage to the value required by the filaments, i.e., 10 volts. The power for plate excitation is delivered by a two-pole compound wound generator giving a d-c. potential of 1000 to 1200 volts.

The fundamental oscillator, power amplifier, and tuning circuits in this transmitter are quite similar to those in the E.T. 3626-B equipment. The theory of operation and other information relating to the main circuits may be fully understood by making reference to the discussions on transmitter E.T. 3626-B given in previous paragraphs. The principal change that has been made is in the method employed for obtaining the 250-volt grid negative bias. In the E.T. 3626-B it is obtained from the voltage divider or potentiometer connected across the positive and negative 1000 volts of the generator, whereas, in the E.T. 3626 this potential bias is furnished by one tube which functions as a rectifier as explained in the foregoing paragraph.

Since this transmitter does not contain an audio oscillator circuit it requires the use of a chopper system in order to provide ICW transmission. The motor driven chopper commutator interrupts the tube grid circuits at a 500-cycle rate, approximately, to give tone modulation or modulated CW signals. However, in commercial service signals of this type are called ICW. The chopper is placed in operation by the "CW - ICW" switch on the front of the panel. It should be noted that the antenna current will be somewhat less than when straight CW is used.

<u>E.T. 3626-A 750-Watt Transmitter</u>. This transmitter uses a total of eight tubes of the UV-211 type. Six of these tubes are connected in parallel and operate as power amplifiers while the remaining two, also connected in parallel, are the master oscillators. The front and rear tubes at the extreme left of the tube rack are the oscillators. An audio oscillator circuit is not included hence a motor driven chopper is used to give ICW transmission. Keying is uni-wave and the negative 250-volt keying bias is supplied from a potentiometer. The circuit arrangement of the oscillator, power-amplifier and antenna circuits are similar to those in models E.T. 3626 and E.T. 3626-B.

<u>200-Watt Model E.T. 3627-A Transmitter</u>. Figure 7 shows a front view of this continuous wave and interrupted continous wave vacu tube transmitter. A rear view is shown in Fig e 8. The amental circuit of this transmitter is sho in Figure 9. An adjustable positioning device for the master-oscillator variometer permits any five frequencies within the 300 to 312 kilocycle

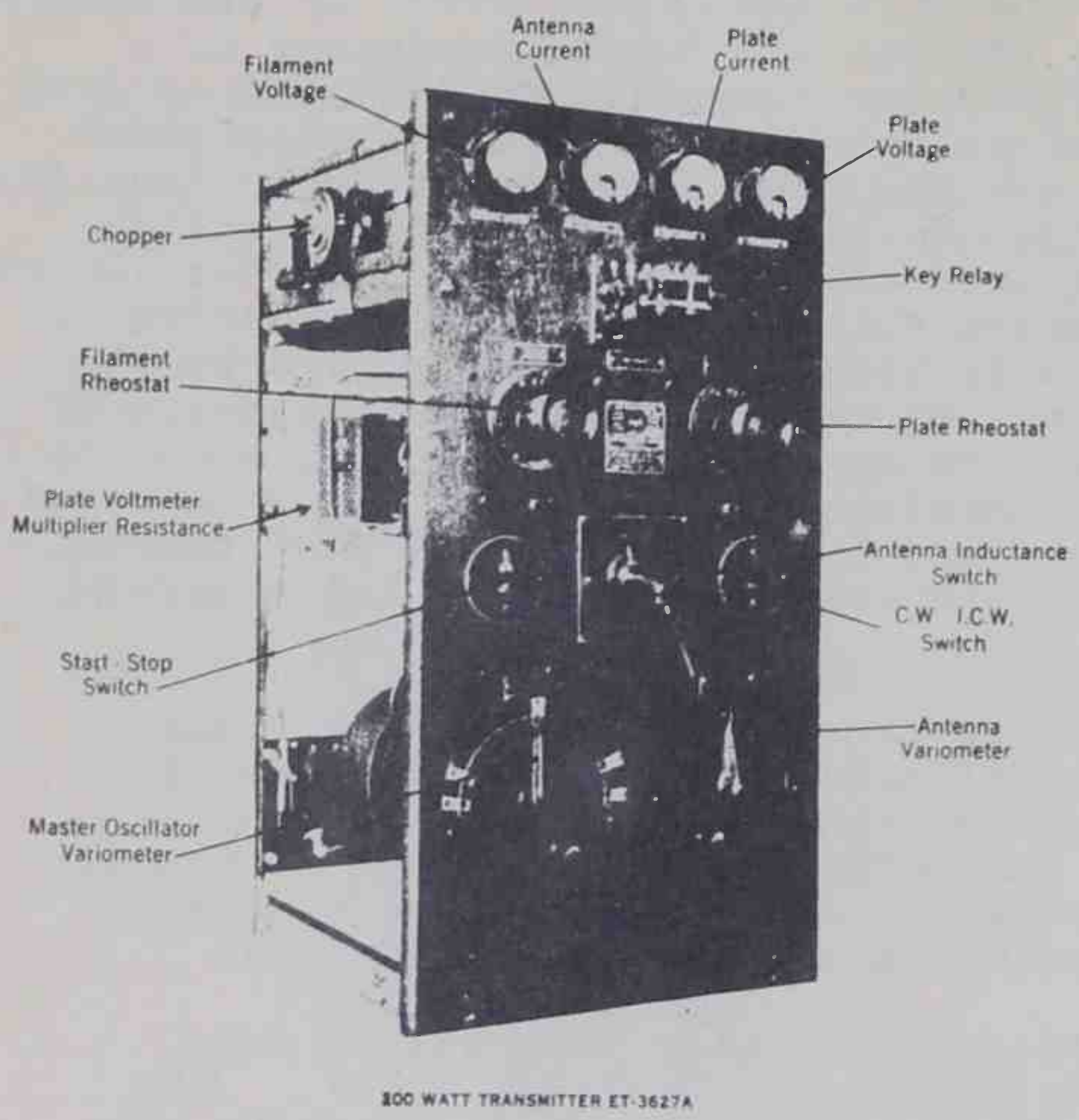

Figure 7

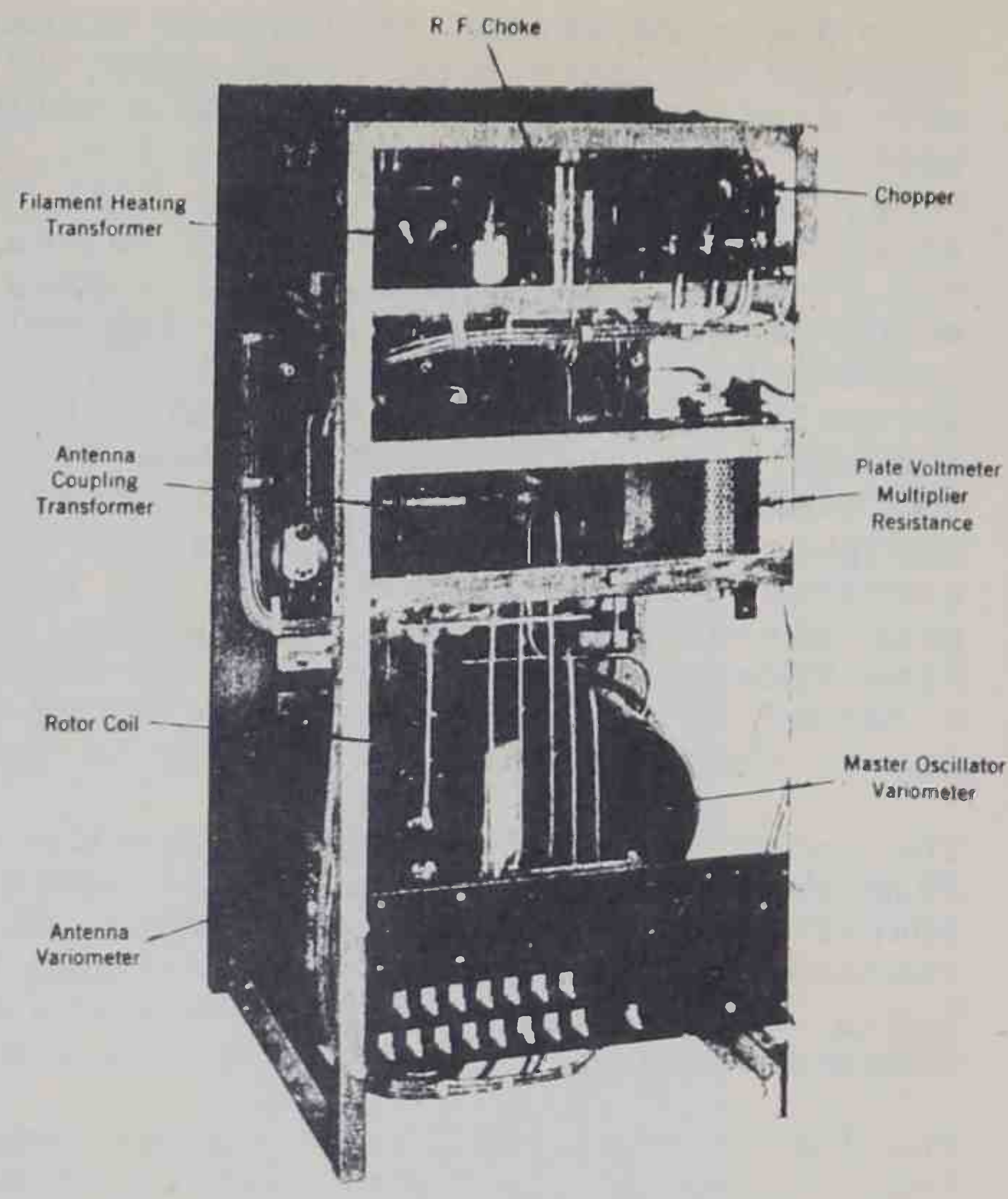

Figure 8

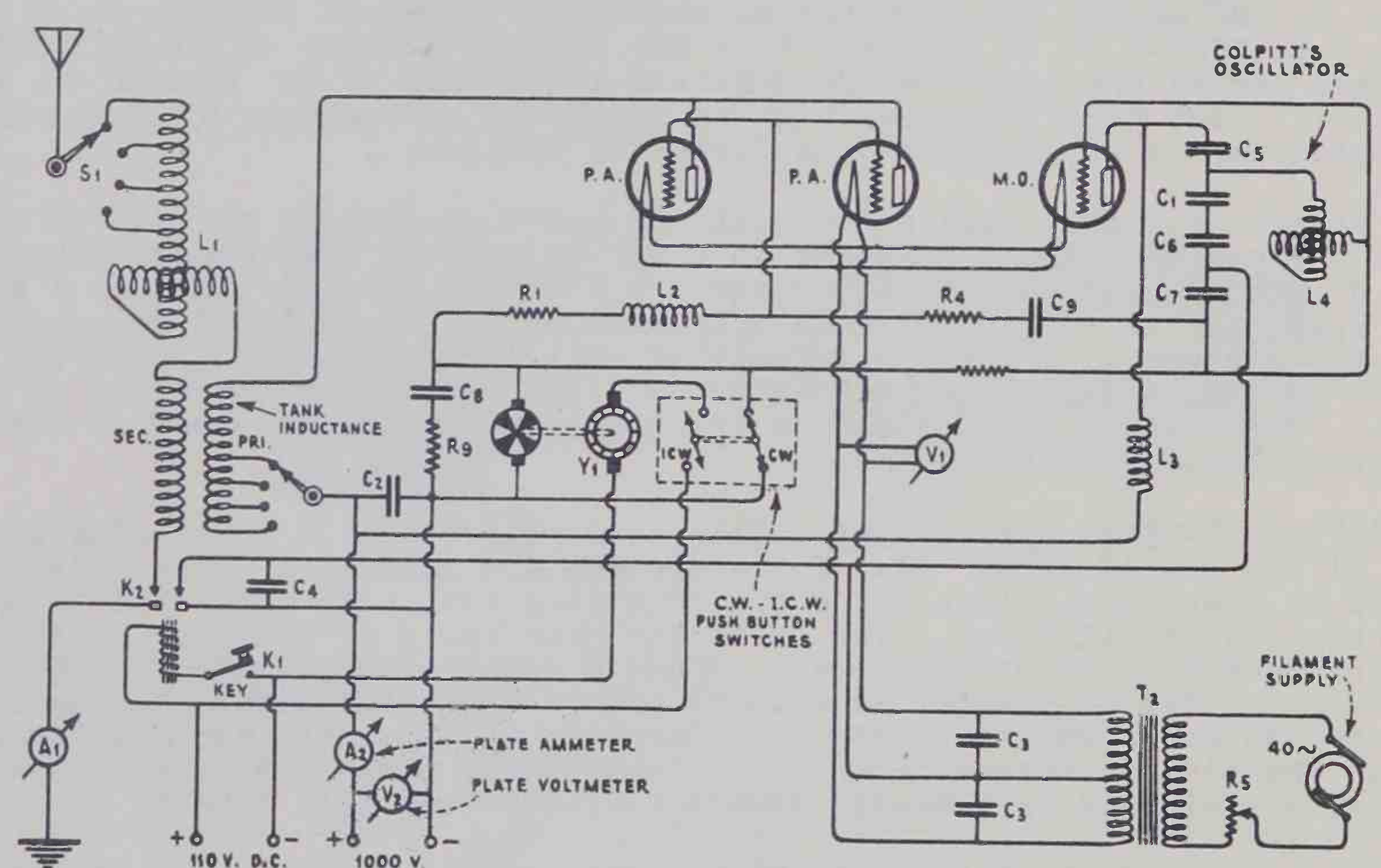

Figure 9

band to be selected and kept in a permanent adjustment. This provides a convenient arrangement, for in changing from a calling to a working frequency the operator is not required to make careful adjustments to locate an exact position on the scale with the master-oscillator pointer.

Theory of Operation. The theory of operation of the 200-watt E.T. 3627-A transmitter may be understood by referring to the schematic diagram in Figure 9. The frequency of the UV-211 master-oscillator tube is controlled by the variometer L4 which operates in a capacity-coupled (Colpitt's oscillator) circuit. The grid alternating e.m.f. necessary for the promotion of continuous oscillations is obtained from the voltage drop across condenser C7. The values of capacitance of the three condensers C1, C6 and C7, and the inductance of variometer L4, are carefully selected because they represent the circuit constants and therefore determine the frequency range of the transmitter. Condenser C5 is the usual plate-blocking condenser and serves to keep the d-c. plate voltage off the grid and oscillatory circuit of the master-oscillator tube. This condenser, of .003 mfd. capacitance, provides a low reactance path for the radio-frequency component of the total plate current, allowing it to flow into the oscillatory circuit for the requisite feedback of plate energy into the grid. Radio-frequency choke L3 keeps the plate high-frequency component from backing into the 1000-volt generator circuit. The grids of the two UV-211 power-amplifier tubes are directly connected and these grids are excited by radio energy through condenser C9 and resistance R4, at the frequency of the oscillatory circuit. Grid leak resistor R1 maintains the correct negative bias on the amplifiers, and radio-frequency choke L2 prevents losses of the high-frequencies through the grid leak circuit. The grid leak on the master oscillator tube is resistor R3. The high-frequency ener in the power amplifier plate circuit feeds into the primary (pri.) or plate coil of t te transfo r. This coil is also called the "ta i uct ce". The te is set into excitation thro h the transfer of this high- ncy t t of t radio plifier tubes t ou the antenna transformer. T pr y of this transformer carries the ICW and CW switch. It will notic that in the case of interrupted continuous waves the o t of in ctance u will ver as at as for straight CW. This feature allows the radiated ve of the v iety to possess sharp characteristics. The frequency of the ster-oscillator is re at in the out t of p r- lifiers, the antenna cir t is justed for resonance to t s q ncy by the f taps and io ter the te a l i i uctor L1.

Ke Rela . A rapid c -o r from send to receive is provided by t - ly operated bre - relay w ch is sh mounted on t front of the l in F 7. T s relay is s t as in the sche tic diagram. Modern radio traffic conditions req this feat e to be provided in t transmitter; keying speeds up to 40 words a ute are possible with t relay, it bei equivalent to a double-pole, s le-t relay. l side of the te a contains one ir of contacts c cted in series a d i the tr smitti periods they serve to short cir t the in t to t radio receiver. order to prevent sparki at the antenna c tact and also to re ce the dist bance from clicks in the radio receiver, t sec pair of contacts key the transmitter proper are adj ted to close slightly after a open slightly before the antenna circuit contacts.

i Cir it. The expl ati of t a ntal keyi cir it will be erstood reference to the schematic diagram where it is seen t t the negative lead from the 10 -volt rator c cts to one of the key contacts on the e -in relay. The gative plate circuit is co leted t the upper right contact to t mid-tap on the fil ent heati transfor r T2. grid ret n leads of both t p er a lifiers ster oscillator are ret ned to this tive side of the plate circuit t h grid le resistors R1 and R3, res ctively. Both t tive plate circuit and the grid circuit oken by t action, with t result that a high negative potential is impressed upon the grids of the tubes whenever the contacts open. The relay contacts will interrupt a large current with minimum sparking.

Legend and Function of Component Parts of E.T. 3627-A Transmitter, Figure 9.

A-1 Antenna ammeter (0-10 amperes) is used to indicate resonance between the tank inductance, or plate coil Pri and antenna system.

A-2 Plate ammeter (0-2 amperes) indicates direct current drawn from the plate generator by the three tubes.

C-1 Master oscillator plate condenser, .003 mfd. is used for plate excitation of this tube.

C-2 Filter condenser, 1 mfd, acts to smooth out any ripples in the d-c. from the 1000-volt generator due to commutation.

C-3 Filament by-pass condensers, .5 mfd. each, furnish a low reactance path for the radio-frequency oscillations from grid to filament. Without these condensers the filament heating coils on the iron core transformer T2 would form the only path which would obviously impede the flow.

C-4 Key condenser, .015 mfd. functions to absorb and dissipate transients of potential surges set up while keying. This condition is manifested by arcing.

C-5 Master oscillator plate blocking condenser, .003 mfd., permits the high-frequency oscillating component of the plate current to flow through readily, but prevents the d-c. component of the plate supply from being impressed on the oscillator grid or passing to the a-c. tuned circuit.

C-6 Master oscillator plate condenser, .002 mfd., functions similarly to C1 and forms a part of the oscillatory circuit.

C-7 Master oscillator grid condenser, .002 mfd., is the grid input or excitation condenser and from across its plates is obtained the requisite voltage drop to be applied between grid and filament for maintaining the master oscillator and associated circuits in a state of generating continuous oscillations.

C-8 Chopper condenser, .003 mfd., used in conjunction with resistor R9 helps to smooth out any uneveness in the chopper note in order to produce a clear and distinct tone in the telephone receivers.

C-9 Power amplifier grid condenser, .003 mfd., permits the high-frequencies generated in the master oscillator circuit to pass through and excite the grids of the two radio-frequency power tubes.

F-1 Plate fuse rated at 2 amperes (not shown)

F-2 Receiver antenna fuse, .5 ampere (not shown).

K-1 Hand key used for interrupting the stream of radio oscillations generated in the transmitter into dots and dashes for the dispatch of radio telegraphic messages.

K-2 Break-in relay (Key relay) permits a rapid changeover from send to receive, it being magnetically operated by the hand key.

L-1 Antenna variometer and four-tap inductance used for loading the antenna in order to establish resonance with the tank circuit.

L-2 Power amplifier grid leak radio-frequency choke. To prevent losses in the grid leak circuit of the high frequencies flowing from the master oscillator through amplifier feed resistance R4 and condenser C9. These radio frequencies are intended to build up a high value of excitation voltage on the amplifier grids.

L-3 Master oscillator plate choke is in series with the positive lead of the 1000-volt generator and functions to prevent losses by blocking out the radio oscillations from this circuit. These oscillations will flow readily through the low reactance path of C5.

L-4 Master oscillator variometer permits any five frequencies within the 312 to 500-kilocycle range to be selected.

R-1 Power amplifier grid resistance, 500 ohms, furnisnes correct grid bias for stable operation of the two UV-211 tubes.

R-3 Master oscillator grid resistance, 7500 ohms, maintains grid at correct bias or negative potential.

R-4 Power amplifier feed resistance, 150 ohms, used to maintain the radio-frequency voltage supplied to the power amplifier grids from the master oscillator at a normal value.

R-5 Filament rheostat, 20 ohms, permits a close control of filament terminal e.m.f. of all tubes for working the filaments at their rated temperature.

R-6 Master oscillator parasitic resistor, 15 ohms, (not shown) is used to suppress the generation of ultra high-frequencies caused by the plate-to-grid capacity of vacuum tubes and coupling leads which give such a circuit a definite oscillation period.

R-7 Plate field rheostat, 250 ohms, allows a fine control of the positive voltage applied to the plates of all tubes.

R-8 Power amplifier parasitic resistor, 15 ohms, (not shown) functions similarly to R6.

R-9 Chopper resistor, 50 ohms, works in conjunction with C8 to smooth out any uneveness in I.C.W. energy.

R-10 Key relay resistor, 400 ohms, (not shown).

S-1 Antenna inductance switch permits convenient change of wavelength from calling wave to communicating (working) wave.

T-1 Antenna transformer consists of tank inductance (plate coil) Pri and antenna coil S, and is used to provide magnetic coupling between the closed and open oscillatory circuits for the transfer of radio power. The tapped tank inductance connects to CW and ICW switch allowing the proper selection of inductance for either form of transmission.

T-2 Filament transformer, .125 K.V.A., is a mid-tapped step-down iron core transformer which receives power from a 40-cycle supply from collector rings attached to the windings of the motor, and delivers an alternating current of 10 volts, when regulated, for heating the filaments resulting in an adequate electron emission.

V-1 Filament voltmeter, 0-15 volts a-c. should read 10 volts after completing the voltage adjustment by means of the filament rheostat R5.

V-2 Plate voltmeter, 0-1500 volts d-c. indicates the positive plate potential applied to each of the three plates.

Y-1 Chopper motor is rated at 1/50th horse power and is driven from 110 V. d-c. supply. When ICW transmission is desired the signal switch should be placed in ICW position closing one pair of contacts which starts the chopper motor and opening a second pair which removes the short circuit maintained around the chopper during CW transmission. A brush resting on the chopper wheel alternately makes contact with a copper and fibre segments thus causing the grid circuits of the master oscillator and power amplifiers to be broken at the rate of approximately 1000 times a second to radiate a wave having the general characteristics of the note produced by a 500-cycle spark transmitter.

Vacuum Tubes. Facing the transmitter panel, the tube at the left is the master oscillator and the remaining two tubes to the right are the power amplifiers, both being connected in parallel. In the schematic diagram, Figure 9 , this order is reversed, where it may be seen that the master oscillator is drawn at the ri t the two power a lifier t rd the left.

Fi e 10

eval tions given in the follow table will enable the rator to ascertain the practical relati between the operat wavele ths and the c rents in vari s circuits. The positions of the e variometer pointer on the scale, icated in de es, the te a inductance switch, are also given.

n t E.T. 3627-A was used with an ante a havi a capacitance of 0.0008 d. resist e of f o the followi res ts were observed, both for d I tr smission.

vele h	te rent. res	P ate in	rent res	Readi os on o Ante I uctance itch.	ca osition of t a Vario ter Switch.
		9		55 d	
0				55	
				41 d e	
				41	
				1 2	
		1		1	

A different set of results was obtained with the transmitter working into an antenna possessing the following characteristics, namely, a capacitance of 0.0004 mfd. and resistance of four ohms.

CW 600	6.1	0.5	45 degrees	2
ICW 600	4.0	0.33	45 degrees	2
CW 800	6.4	0.5	70 degrees	3
ICW 800	4.0	0.32	70 degrees	3
CW 960	6.25	0.55	79 degrees	4
ICW 960	3.5	0.32	79 degrees	4

2-KW. Model E.T. 3638 Telegraph Transmitter. A front and rear view of this transmitter are shown in Figure 10 and 11, respectively, and the schematic diagram in Figure 12. An inspection of the diagram shows that the general arrangement of the master oscillator (M.O.) and power amplifier circuits are

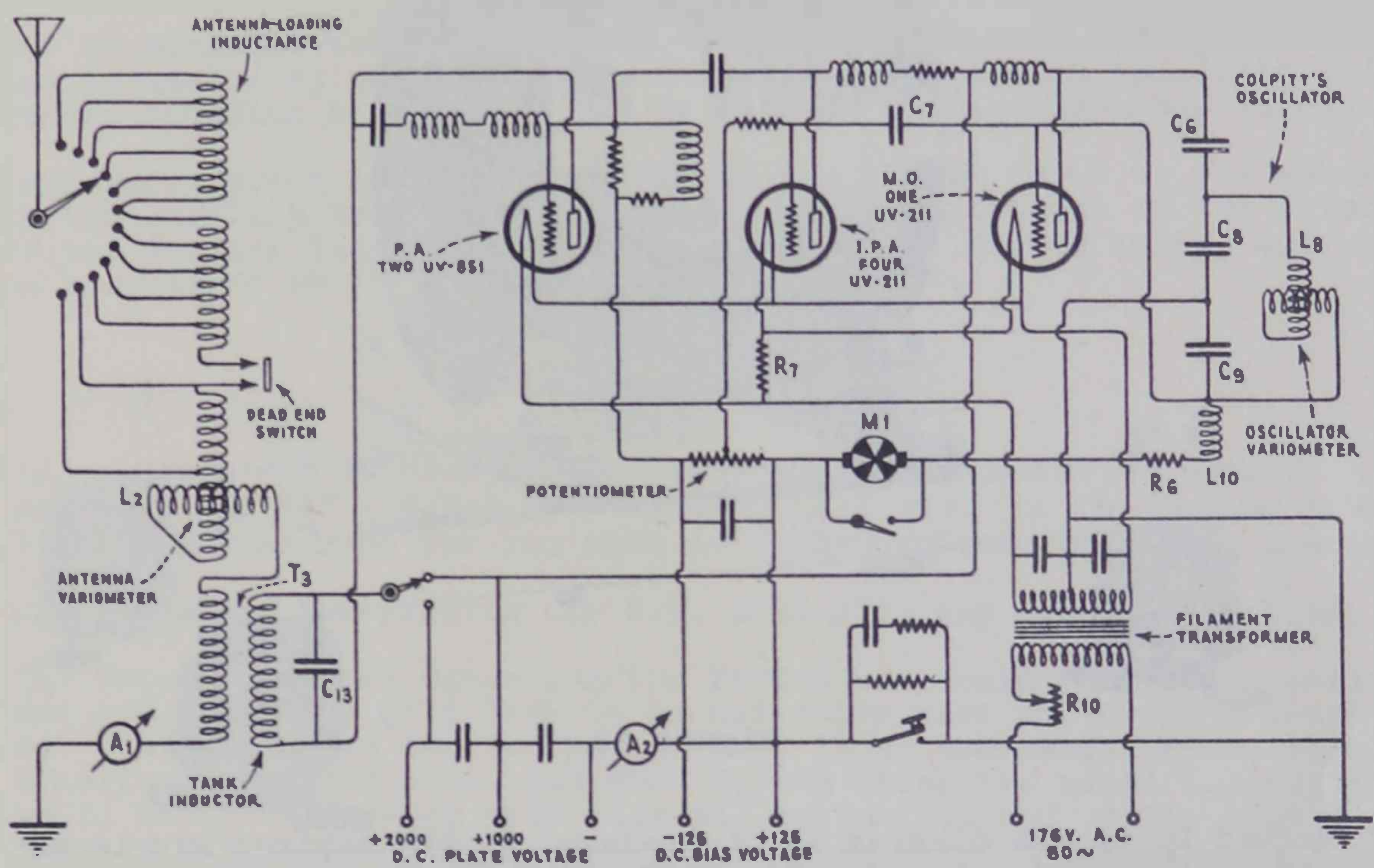

Figure 12

somewhat similar to those employed in the E.T. 3627-A transmitter. The E.T. 3638 equipment, however, utilizes four vacuum tubes connected in parallel as intermediate power amplifiers (I.P.A.) and an "antenna loading inductance" in order to increase the frequency range of the transmitter. A ship's antenna with a low capacitance requires the use of an external loading inductance in order to permit transmission on the higher wavelengths. A photograph of the external loading inductance is illustrated in Figure 13. When this transmitter is used on an antenna with the proper characteristics it will cover a continuous wavelength band of 600 to 2400 meters, or a frequency range of 125 to 500 kilocycles.

The transmitter employs seven vacuum tubes, one 50-watt UV-211 as a master oscillator, four similar tubes arranged in parallel as intermediate amplifiers, and the remaining two tubes, type UV-851, as main power amplifiers. The two UV-851 tubes are shown in the front panel view protected by the screen door. These main a lifiers are rated at 1-kw., require a plate potential of 2 0 volts d-c. obtained by adjusti t plate rheostat, and t filaments each draw 15.5 peres a-c. w n supplied with the specified te inal voltage of

Y-1 Chopper motor is rated at 1/50th horse power and is driven from 110 V. d-c. supply. When ICW transmission is desired the signal switch should be placed in ICW position closing one pair of contacts which starts the chopper motor and opening a second pair which removes the short circuit maintained around the chopper during CW transmission. A brush resting on the chopper wheel alternately makes contact with a copper and fibre segments thus causing the grid circuits of the master oscillator and power amplifiers to be broken at the rate of approximately 1000 times a second to radiate a wave having the general characteristics of the note produced by a 500-cycle spark transmitter.

Vacuum Tubes. Facing the transmitter panel, the tube at the left is the master oscillator and the remaining two tubes to the right are the power amplifiers, both being connected in parallel. In the schematic diagram, Figure 9 , this order is reversed, where it may be seen that the master oscillator is drawn at the right and the two power amplifier toward the left.

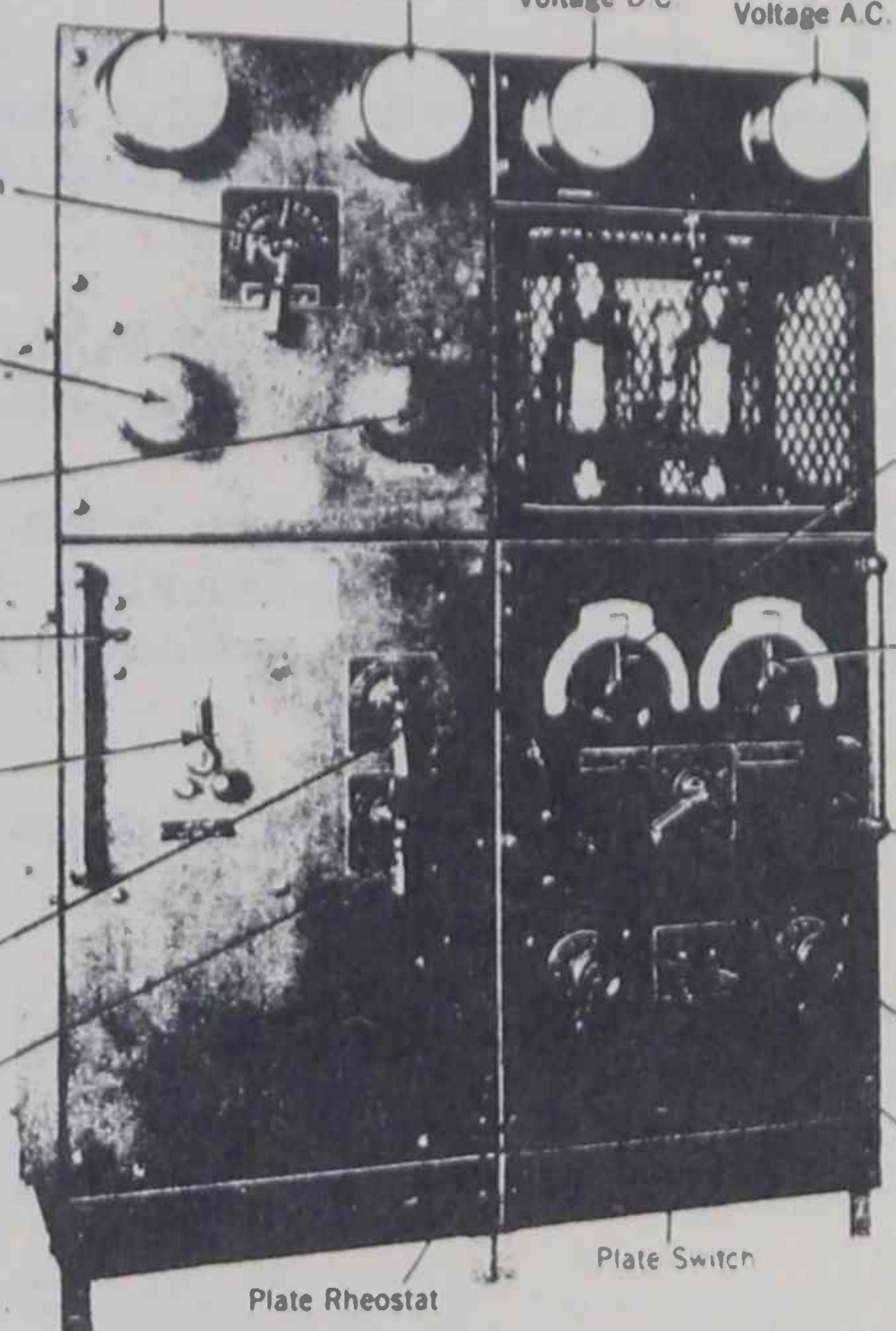

Figure 10

The evaluations given in the following table will enable the operator to ascertain the practical relation between the operating wavelengths and the currents in the various circuits. The positions of the antenna variometer pointer on the scale, indicated in degrees, and the antenna inductance switch, are also given.

When the E.T. 3627-A was used with an antenna having a capacitance of 0.0008 mfd. and resistance of four ohms the following results were observed, both for CW and ICW transmission.

Wavelength	Antenna current. Amperes	Plate current. in Amperes	Reading on Scales	
			Position of Antenna Inductance Switch.	Position of Antenna Variometer Switch.
CW 600	7.1	0.59	55 degrees	1
ICW 600	4.75	0.39	55 degrees	1
CW 800	7.1	0.6	41 degrees	2
ICW 800	4.6	0.39	41 degrees	2
CW 960	7.25	0.61	102 degrees	2
ICW 960	4.6	0.41	102 degrees	2

A different set of results was obtained with the transmitter working into an antenna possessing the following characteristics, namely, a capacitance of 0.0004 mfd. and resistance of four ohms.

CW 600	6.1	0.5	45 degrees	2
ICW 600	4.0	0.33	45 degrees	2
CW 800	6.4	0.5	70 degrees	3
ICW 800	4.0	0.32	70 degrees	3
CW 960	6.25	0.55	79 degrees	4
ICW 960	3.5	0.32	79 degrees	4

2-KW. Model E.T. 3638 Telegraph Transmitter. A front and rear view of this transmitter are shown in Figure 10 and 11, respectively, and the schematic diagram in Figure 12. An inspection of the diagram shows that the general arrangement of the master oscillator (M.O.) and power amplifier circuits are

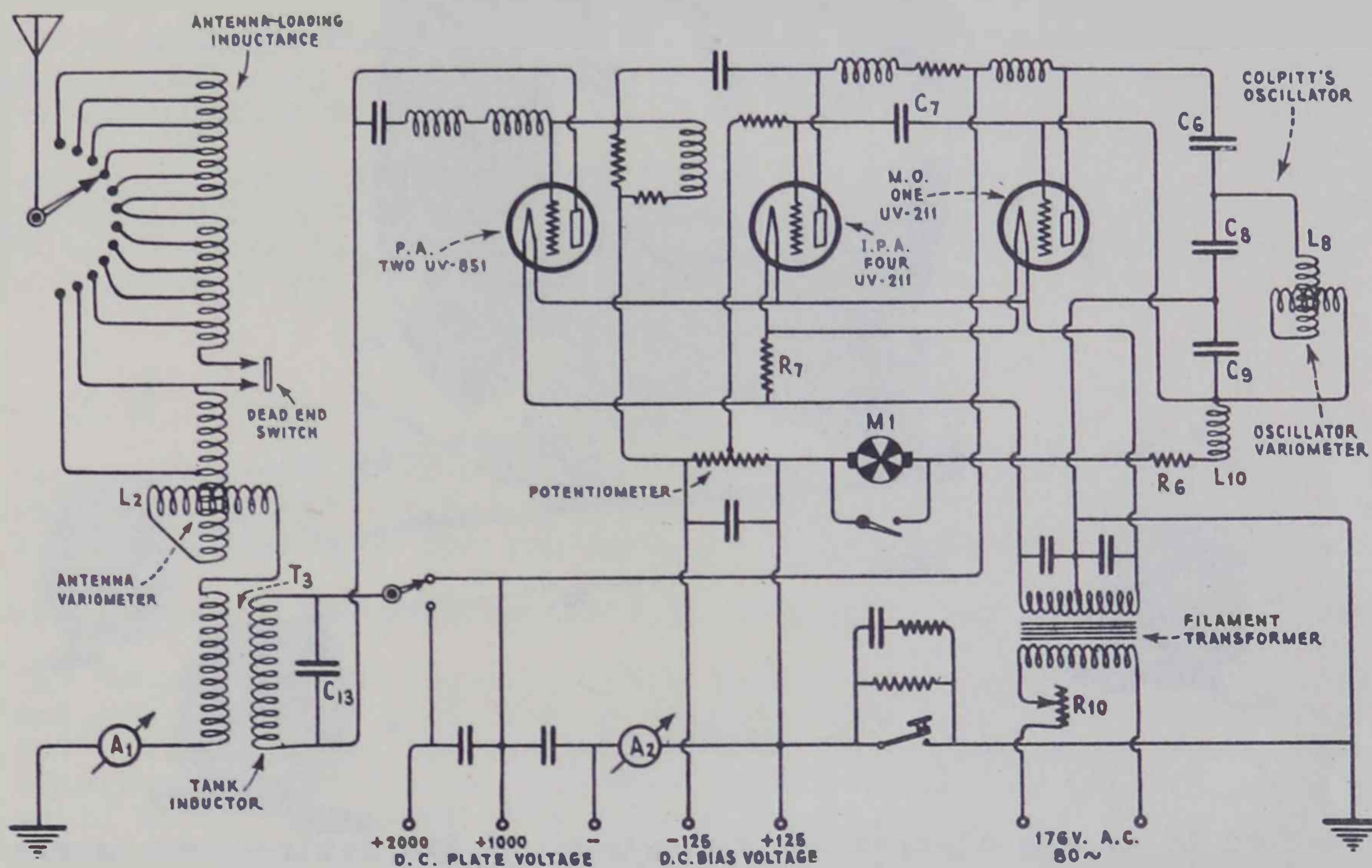

Figure 12

somewhat similar to those employed in the E.T. 3627-A transmitter. The E.T. 3638 equipment, however, utilizes four vacuum tubes connected in parallel as intermediate power amplifiers (I.P.A.) and an "antenna loading inductance" in order to increase the frequency range of the transmitter. A ship's antenna with a low capacitance requires the use of an external loading inductance in order to permit transmission on the higher wavelengths. A photograph of the external loading inductance is illustrated in Figure 13. When this transmitter is used on an antenna with the proper characteristics it will cover a continuous wavelength band of 600 to 2400 meters, or a frequency range of 125 to 500 kilocycles.

The transmitter employs seven vacuum tubes, one 50-watt UV-211 as a master oscillator, four similar tubes arranged in parallel as intermediate amplifiers, and the remaining two tubes, type UV-851, as main power amplifiers. The two UV-851 tubes are shown in the front panel view protected by the screen door. These main amplifiers are rated at 1-kw., require a plate potential of 2000 volts d-c. obtained by adjusting the plate rheostat, and the filaments each draw 15.5 amperes a-c. when supplied with the specified te inal voltage of

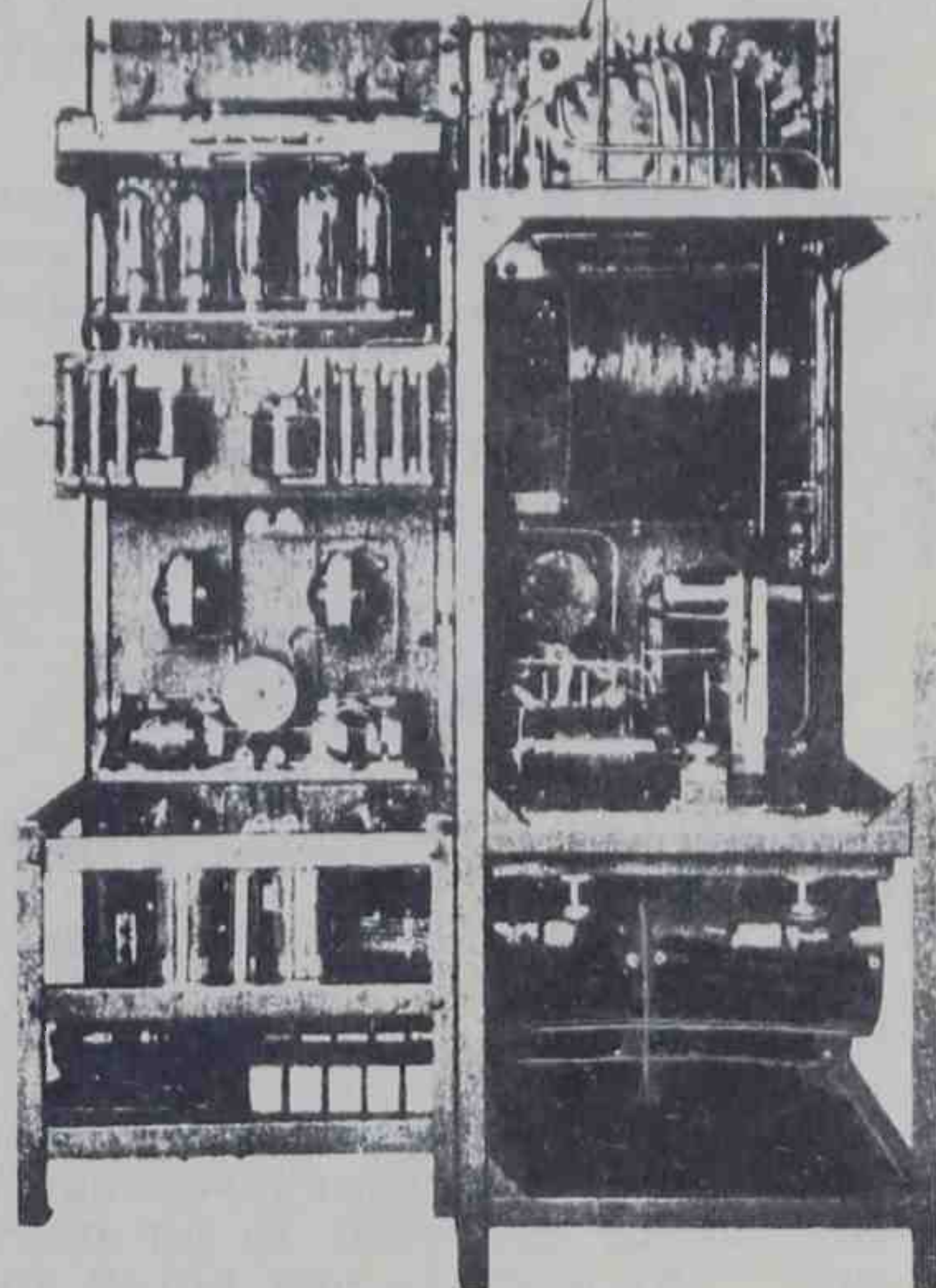

Figure 11 —Rear View of 2KW. Model E.T.3638
Telegraph Transmitter

RCA INSTITUTES INC

COMMERCIAL LONG
and
SHORT WAVE RECEIVERS

Lesson Text V36-15

(3405-X1)

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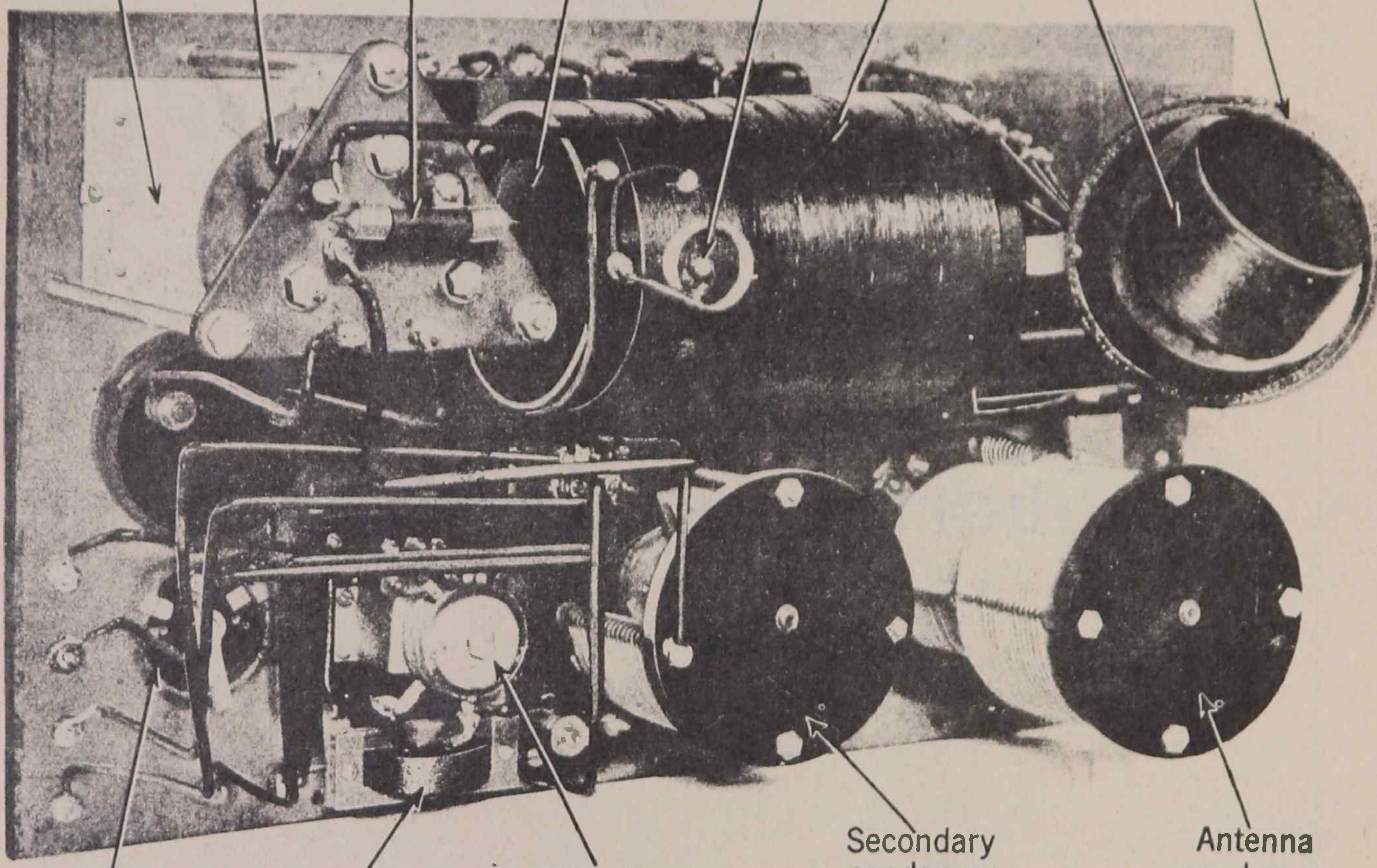

Fig. 1--Rear View of Type IP-501 Receiver

COMMERCIAL LONG AND SHORT WAVE RECEIVERS

Type IP-501 Receiver. The Type IP-501 receiver is designed for operation as a regenerative detector circuit to receive the signals sent out by spark stations, and for regenerative beat reception to respond to continuous wave (C.W.) signals.

The vacuum tube detector is mounted on the panel with the tuning apparatus, a rear view of which is illustrated in Figure 1. The complete circuit diagram is shown in Figure 2. A front view of the panel showing the tuning controls, filament voltmeter and filament rheostat control, is illustrated in Figure 3. A schematic diagram of the IP-501 is shown in Figure 3A.

A crystal detector may be connected to the two binding posts marked "Crystal" for the reception of spark signals or modulated C.W., and the four-pole double-throw switch permits a quick changeover from crystal to vacuum tube operation. When the switch handle is in the center position, marked "Send," the receiving circuits are disconnected from the detector which should be the adjustment when signals are being transmitted.

The wavelength range of the receiver is from 300 meters to 8000 meters.

External loading inductance coils may be inserted in the primary, secondary and tickler circuits to reach the maximum range of the receiver. The "long wave loading unit" is shown mounted over the main receiver cabinet in Figure 4, while the schematic wiring diagram of this same unit is shown in Figure 5. The binding posts on both panels are placed exactly opposite to allow convenient and accurate connection between the circuits. When the loading coils are used the metal straps attached to the three pairs of binding posts on the receiver panel must be removed. Connection between the lower antenna post of the loading unit and the antenna post of the receiver is required.

A three-position rotary switch on the loading unit panel connects the circuit to a low, medium and high wavelength range. When the switch is in "Low" position all of the loading coils are short-circuited and the receiver is then in a condition for the regular adjustments which are carried out when additional inductance is not used. In "Medium" position the primary and tickler coils are added to the circuit while only a portion of the secondary loading inductance is cut in. On the "High" position all of the loading coils are added to the respective circuits.

The coupling between the primary and secondary loading coils is variable, with a lock provided to hold the adjustment. The tickler coil coupling is also variable and likewise provided with a lock.

The receiver is an inductively coupled type having independent primary and secondary circuits which must be in tune with the wavelength of the signals desired.

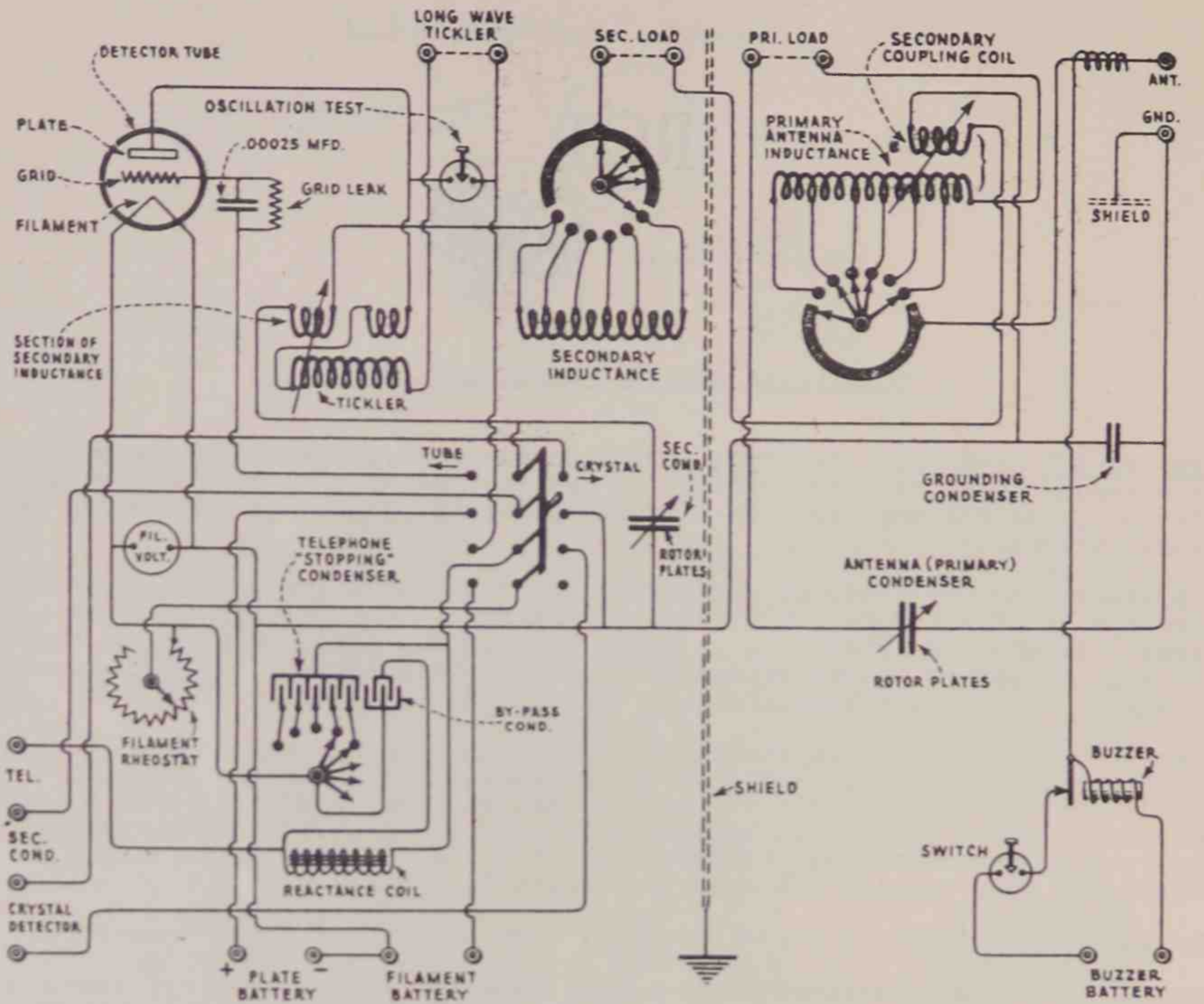

Fig. 2--Circuit Diagram of IP-501 Receiver

To the right of the main receiver cabinet in Figure 4 is shown the two-step audio amplifier unit. Five-volt tubes of the 201-A type are employed in the detector and amplifier circuits, the filaments being energized by a 6-volt storage battery. The receiver and amplifier units are electrically connected by attaching a jumper wire from each "telephone" binding post to each "input" binding post, the corresponding binding posts of the two instruments being exactly opposite. Separate filament rheostat controls are provided for each tube, and each plate circuit is equipped with a phone jack, to allow for reception of signals directly from the detector, or after the signals have passed through one or two stages of amplification.

The amplifier unit is provided with terminals for connecting the 6-volt "A" battery, the "C" battery to furnish a negative bias to the grid circuits, and the "B" battery to supply the positive plate potentials. The e.m.f. of the "B" battery may range from 90 to 135 volts, and the potential of the "C" battery should be between 4.5 and 9 volts depending upon the amount of "B" voltage used. The main receiver unit is also provided with battery terminals for the detector tube only. Leads can be connected to the filament posts from the storage battery supplying the amplifier. The "B" battery may be tapped at the 45-volt terminal and a lead carried to the "positive plate battery" binding post.

A small protective spark gap is mounted on the extreme left of the receiver panel directly in the center, and a thin card should be slipped in between the two angle-shaped posts occasionally as a test to make sure that the gap is not short-circuited.

Antenna Circuit or Primary Circuit. The antenna or open oscillatory circuit consists of the antenna, the primary cylindrical loading coil, the primary inductance bank-wound on threaded tubing, the antenna inductance switch, the variable air type condenser, and the ground conductor.

The primary inductance is tapped and made variable in six steps with connections to the rotary control switch indicated on the panel from A to F. This switch is equipped with an arrangement for dead-ending the unused portions of the inductance. The diagram shows how the end switch automatically connects and opens, or entirely disconnects and short-circuits the sections of inductance when the five switch blades make different contact with the studs.

The primary inductance is mounted at an angle to the main secondary inductance with a heavy sheet metal shield placed between the coils to neutralize electrostatic coupling effects. The coupling between the circuits is purely electromagnetic as provided by a movable coupling coil which is part of the total inductance of the secondary.

By the switch arrangement for short-circuiting the unused sections of the inductance, interference is minimized. If the unused turns were allowed to remain in the circuit the self-capacity (distributed capacity) and inductance of these turns would of themselves form an oscillatory circuit and there would be a loss of high-frequency current. At the same time the resulting magnetic field would react upon the main inductance to change its self-inductance. This would tend to destroy the resonant setting of the circuit and broaden the tuning.

The primary condenser remains in series with the antenna circuit at all times. It has a capacity of between 0.00008 mfd. and 0.0045 mfd. being also of the self-balanced type with suitable gearing to provide a vernier motion. When the condenser is rotated between 0 and 180 degrees a very fine variation in capacity is obtainable by means of the vernier control. When the inductance switch is moved, a mechanism attached to it moves a pointer to successive circles which are engraved on the condenser dial, and the wavelength calibrations may then be marked on the dial for future identification.

Secondary or Closed Circuit. The secondary oscillatory circuit consists of the secondary inductance, also bank-wound, on a form of threaded bakelite dilecto tubing. Also the secondary variable air type condenser shunted between one end of the inductance and the inductance switch, and the small coil inserted within the primary tubing which provides the coupling between both circuits. The secondary loading inductance in the "long-wave unit" becomes a part of this circuit, providing this long-wave unit is used.

The secondary inductance is tapped and made variable in six steps, the sections being added to the circuit in progressive order when the secondary inductance switch is rotated from point 1 to point 6. This switch also is equipped with the automatic arrangement for cutting out and short-circuiting the unused sections of the coil. The capacitance of the secondary condenser is rated from about 0.00006 mfd. to 0.0032 mfd. and it is also equipped with vernier control. The condenser dial is engraved with rows of concentric circles across which the pointer moves when the inductance switch is rotated, similar to the mechanical arrangement of the primary condenser.

Coupling the Primary and Secondary. The transfer of radio-frequency oscillations from the primary to the secondary is obtained by the mutual inductance between a movable coupling coil, which is part of the secondary inductance, and the low wavelength end of the primary inductance. The photograph shows the movable coil mounted within and toward one end of the primary inductance.

The variable magnetic coupling between the two circuits enables the primary and secondary to be adjusted individually to a given wavelength, thus affording sharp tuning to one wavelength.

When the windings of the two coils are parallel the coupling is maximum and it is then that the induced signal oscillations reach their highest current strength, but under these conditions selectivity is reduced. If the coupling

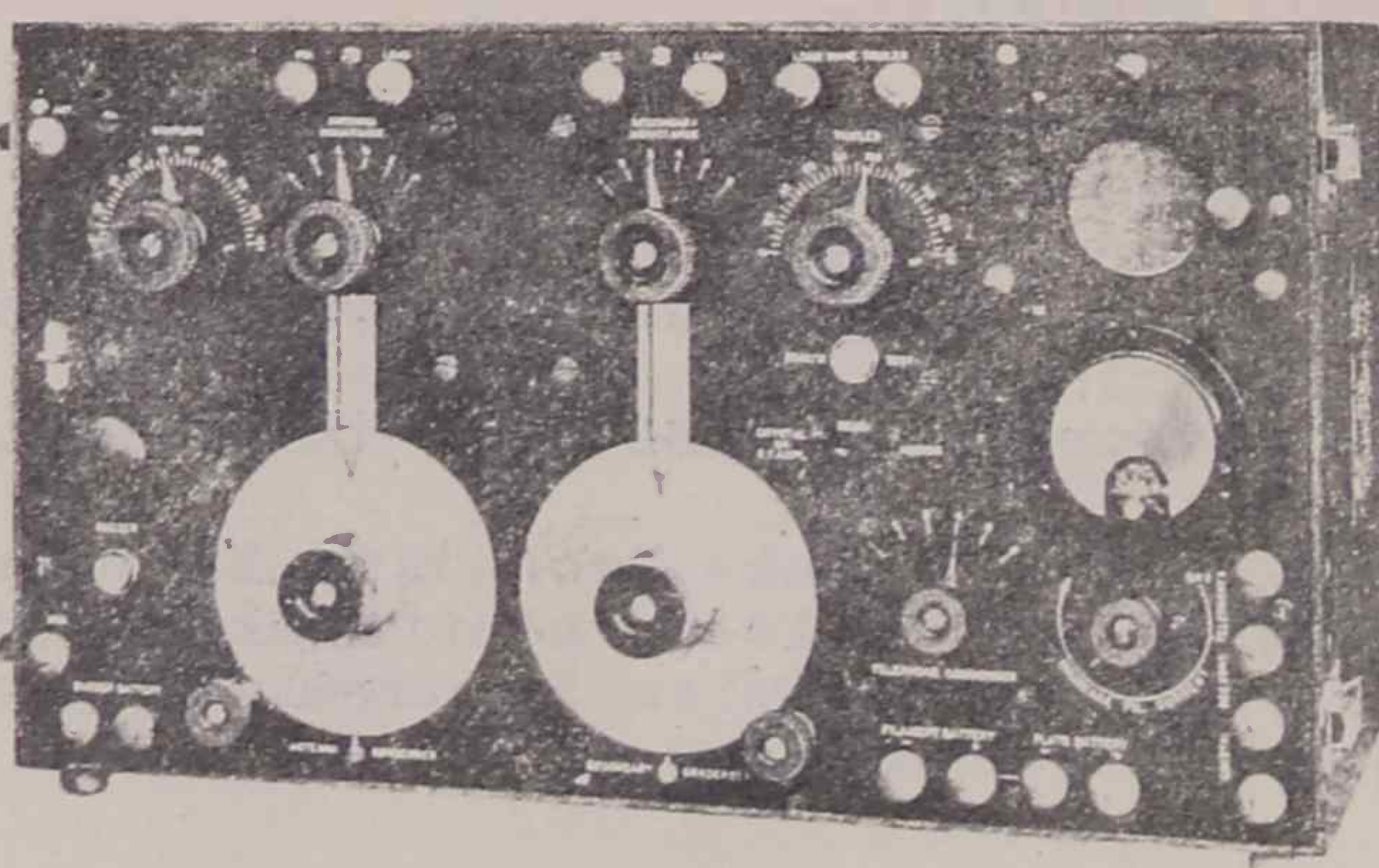

Fig. 3--Front View of IP-501 Receiver

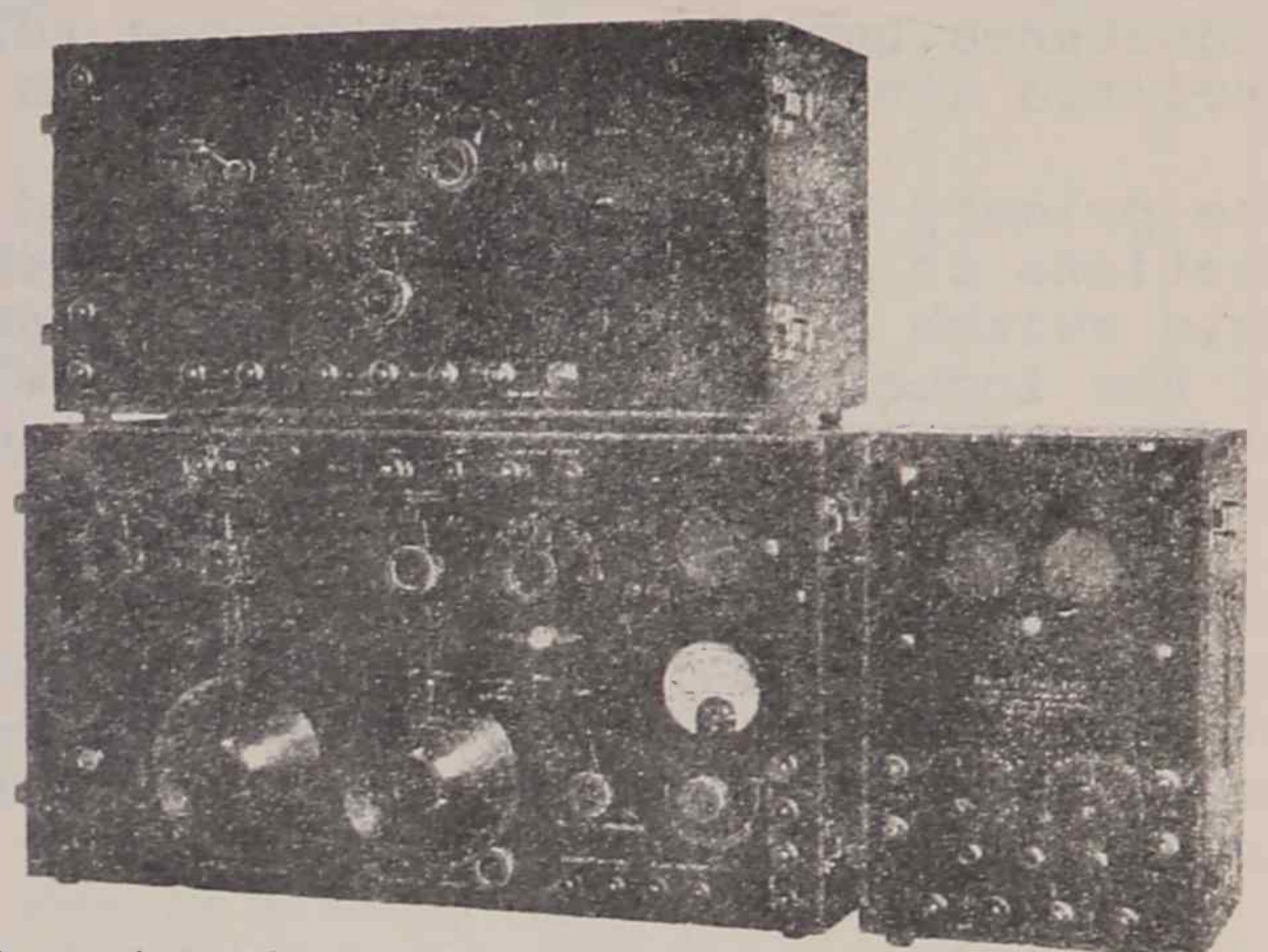

Fig. 4--View of "Long Wave Loading Unit" Mounted on Top of Main Receiver Cabinet

coil is rotated to occupy a position where its windings are in a plane at right angles to the primary turns then the coupling is loosest or at minimum (zero). The coupling coil may be rotated a few degrees beyond this point of zero coupling where the respective windings are at an angle of 90 degrees to what is called a small reverse coupling. By utilizing reverse coupling it is possible in practice to secure a point of minimum coupling between the primary and secondary circuits on all wavelengths within the range of the receiver.

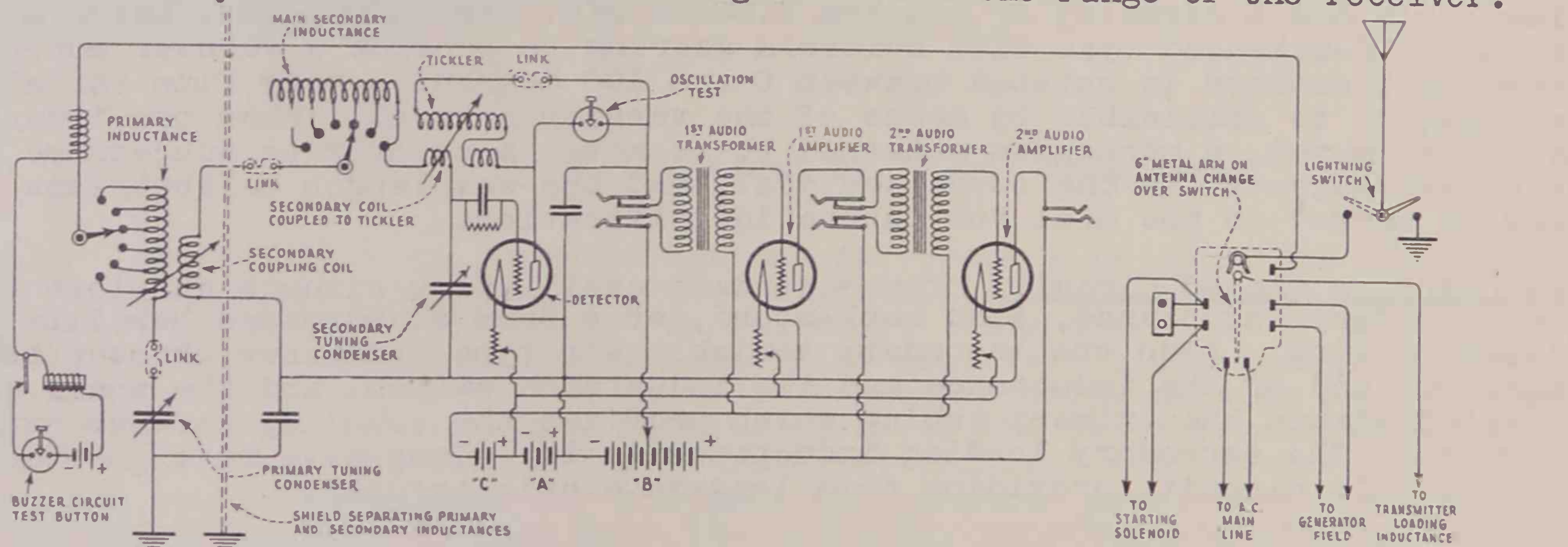

Fig. 3A--Schematic Circuit Diagram of IP-501 Receiver

Capacity coupling between the circuits is neutralized by means of the small reverse coupling which has the effect of sharpening the tuning considerably, and thereby reducing interference. As we have previously explained the capacity coupling between the circuits is entirely eliminated by enclosing the elements forming the primary and secondary in separate heavy sheet copper boxes. The metal sheets act as a shield in blocking and absorbing static energy and are grounded as indicated by the diagram. The coupling between the circuits is purely electromagnetic and depends upon the degree of coupling as determined by the angular relationship existing between the movable secondary coil and the primary inductance.

Tickler Coil for Regeneration and Beat Reception. The tickler coil is connected in series with the detector tube plate circuit and is mounted at the short wavelength end of the secondary inductance. The tickler inductance, sometimes known as the rotor, is wound on a ball-shaped form, small enough in diameter to rotate within the tubing on which the secondary turns are wound. The coil is mounted on a shaft controlled by the rotary switch knob on the panel marked "Tickler," with the scale graduated from 0 to 180 degrees.

The inductive relation between the tickler and secondary being controllable, and being dependent upon the relative position of the two windings, allows a close regulation of the amount of energy which feeds back, or is transferred

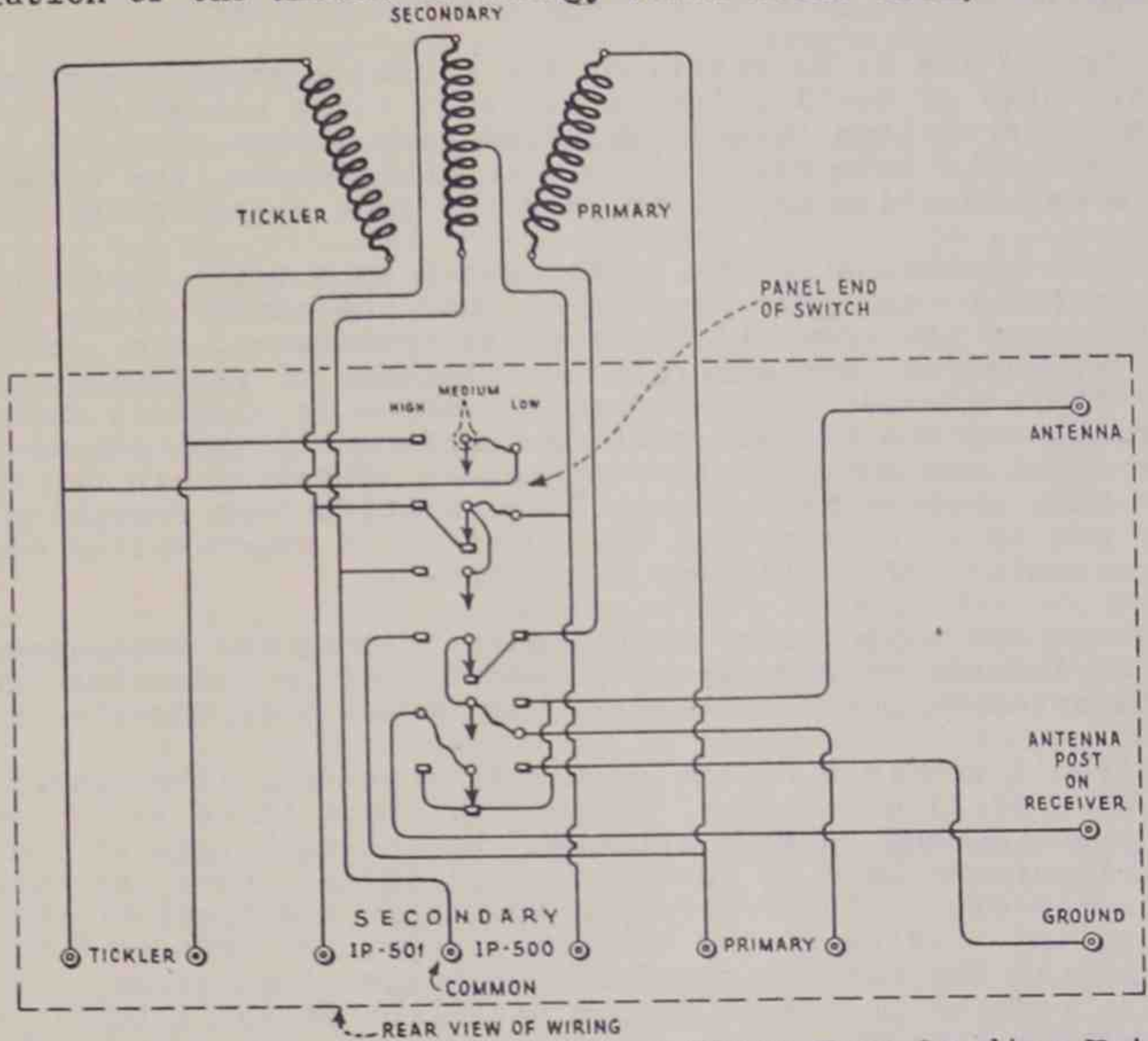

Fig. 5--Schematic Wiring Diagram of "Long Wave Loading Unit."

back, from the plate circuit to the grid circuit. The action of the tickler coil is briefly as follows: When signal oscillations are induced into the secondary circuit from the primary, the grid is charged with an alternating voltage which causes the plate current to pulsate at a similar frequency. The rise and fall of plate current in the tickler coil induces an alternating e.m.f. in the secondary because of the mutual inductance existing between the two circuits. The mutual inductance is variable by changing the angular positions between the coils when the tickler is rotated.

The signal energy is now re-introduced into the grid circuit. The e.m.f. induced in the secondary charges the grid with an alternating e.m.f. causing the plate current to again rise and fall, but at a much greater value, for we know that a small grid voltage variation will be repeated in the plate circuit with correspondingly large plate current pulsations. This is due to the inherent amplification characteristics of the vacuum tube.

The functionof the tickler coil may be classified according to the two processes that take place, namely;

First, to provide for amplification of the signal by transferring part of the the power in the plate current alternations produced by the incoming oscillations back into the grid circuit. This process is called "regenerative amplification" and the circuit will respond efficiently, when in this condition, to damped waves of the spark transmitter, or modulated continuous waves (C.W.)

If a regenerative detector is set into self-oscillation when damped oscillations such as those generated by spark transmitters are being received, only partial beats are formed by the combining of the two sets of oscillations. Although amplification is secured, complete beat formations, such as are produced from continuous wave signals, cannot be obtained because of the damping and discontinuity of the spark wave. The normal note of the spark transmitter is distorted, and a beat note of a rough quality is heard.

When spark signals are to be received, the coupling should be carefully adjusted to the verge of oscillation; i.e., only close enough to re-enforce the plate current alternations through the feed-back action, but not sufficiently great to set the tube into oscillation. In other words, the circuit should be operated as a regenerative amplifier, and not as a regenerative beat receiver.

Secondly, if the tickler coupling is increased to a point where the plate energy transferred to the grid is greater than the energy which is lost in the grid circuit due to its oppositions, such as resistance, etc., then the tube will become retroactive, and generate oscillations of radio-frequency. If the frequency of these locally generated oscillations is slightly different from the signal frequency the two alternating currents will combine or heterodyne to produce a "beat current," which will set up vibrations in the telephone diaphragms. This process is known as "regenerative beat reception," and enables the receiver not only to carry out the function of regenerative amplification, but permits reception of continuous wave signals.

The explanations and suggestions relating to primary and secondary coupling and proportions of inductance and capacity used to secure selective tuning, which have been discussed in previous lessons, are equally applicable to this circuit.

The buzzer circuit consists of the push button switch, (the buzzer mounted at the left of the panel) an external battery of about three volts connected to the binding posts marked "Buzzer Battery," and a small coil of inductance coupled to the antenna lead as shown in the diagram. When the current flowing in the buzzer circuit is interrupted at each make and break of the circuit, as by the opening and closing of the contact points, the induced e.m.f. of self-inductance excites the circuit carrying the buzzer inductance, causing the latter coil to radiate groups of damped oscillations sufficiently strong to affect the antenna circuit.

Each impulse causes the antenna or primary circuit to oscillate at its own natural frequency, which of course depends upon the tuning adjustments, and a buzz or note will be heard in the receivers. The buzzer may then be used to adjust a crystal, if one is used as in the case of an emergency, or it will serve to indicate when the vacuum tube is oscillating, in which case a low hissing sound will be heard.

The "stopping" or telephone condenser is a mica condenser, variable in five steps by the rotary control switch mounted on the panel. When the correct capacity is found the groups of damped oscillations from a spark transmitter will discharge through the telephones with a large cumulative effect.

The grid condenser of 0.00025 mfd. capacity and the grid leak resistance shunted across the condenser allows the excess accumulation of electrons stored up on the grid during a group of oscillations to leak off and restore the grid to its normal negative potential. The function of the grid condenser is to place a negative potential bias on the grid to produce a large audio-frequency average variation of plate current, resulting in a greater deflection of the telephone diaphragm.

The impedance or iron core reactance coil shown in the diagram is connected in series with the telephone windings and it acts to build up the e.m.f. of self-induction caused by the audio variation of current passing through the telephone circuit, thus giving a strong signal. However, with very high resistance telephone receivers it is possible to accomplish this result without the reactance coil, but such head-sets possessing the proper impedance are not always available.

A small fixed condenser acting as a "by-pass" condenser is shown in the diagram to the right of the variable stopping condenser. By following out the continuity of the circuit it can be seen that when the four-pole double-throw control switch is in the "Crystal" position the fixed condenser and stopping condenser are connected in series and shunted across the reactance coil. Refer to Figure 2.

Let us observe the circuit arrangement when the control switch is moved to the "Tube" position. Both condensers are still connected in shunt with the reactance coil, but from the common point, which joins them in series, another lead is carried to the filament circuit. This places the condensers across all of the external impedance in the plate circuit represented by the reactance coil and the magnet windings of the receivers. The function of the condensers is to provide a low reactance path for the high-frequency alternating component of the plate current to flow through and dissipate this energy. By removing this oscillating energy, or high-frequency alternating component immediately after the incoming signal oscillations have acted upon the detector tube, it allows only the direct current, carrying the audio-frequency variations, to pass through either the telephone receivers, or a two-stage audio amplifier unit.

If, however, there is no means provided for the dissipation of the high-frequency component it will pass through the path formed by the distributed capacity of the windings. Under such conditions these parasitic currents, which they now become, may be carried along with the audio-frequency currents and perhaps mar the perfect reproduction of the original signal wave, or create disturbances in the audio circuits.

Practical Operation of the IP-501 Receiver

(1) When the vacuum tube detector is employed move the control switch to the right, to "Tube," (sometimes marked "Audion.")

(2) The rheostat should be in the "Off" position before operation (1) is performed. Now increase the filament current by moving the control handle in the direction marked "Increase" until the filament voltmeter indicator is on 5 volts.

(3) For short wave work set the secondary inductance pointer at division 2, and for long waves at division 4, and for the reception of Spark signals the Tickler should be set at about 120 degrees. In any event the tube should not be oscillating, but in a condition for regenerative amplification when receiving spark or modulated C.W.signals.

(4)* To pick up a signal, increase the coupling and adjust the Antenna Inductance in steps and for every change swing the Antenna Condenser entirely across the scale. After the signal is heard, loosen the coupling, and tune the secondary circuit to resonance with the primary by means of the Secondary Inductance and Secondary Condenser.

(5) Adjust the telephone condenser until maximum signal is heard, bearing in mind that the highest selectivity on spark signals is obtained by using a minimum amount of capacity in this condenser.

(6) Note, that for "Stand-By" adjustment, or pick-up work, the coupling between primary and secondary should be close, but for selectivity the coupling should be reduced to a point consistent with satisfactory reception.

Operation For Continuous Wave (C.W.) Reception

(1) Throw the control switch to "Tube" and increase the filament current until the voltmeter reads 5.0 volts.

(2) Adjust the Tickler coupling control to about 45 degrees and set the stopping or telephone condenser at point 3 or 4 cutting in about half of its capacity.

(3) The tube should now generate oscillations, which can be easily determined when a clicking sound is heard in the receivers while applying the following tests:

(a) When the push button marked "Oscl'n Test" is depressed the tickler coil is shorted and consequently no inductive feed-back action will take place; hence, every time the button is pressed the oscillations will cease, being manifested by the phone click.

(b) When the antenna circuit is brought into resonance with the secondary by tuning with a medium amount of inductance coupling between the circuits.

(c) When the tickler coupling is tightened (periodic click).

(d) If the tube is oscillating and the test buzzer is operated, a soft hissing sound will be heard.

(4) Set the coupling control, marked "Coupling," at about 80 degrees.

(5) Adjust the Antenna Inductance and vary the Antenna Condenser until the antenna system is in resonance with the desired signal wave, following the general procedure for tuning in spark signals. However, in C.W. reception the signal is often tuned in and out with a small variation in capacity and therefore the condenser should be rotated very slowly. For every change in the capacity of the primary or antenna condenser, the secondary condenser should be slowly rotated back and forth and each time the point is reached when the secondary is tuned to resonance with the primary it will be marked by a slight click heard in the phones. Continue varying the primary capacity slowly and for every change swing the secondary condenser back and forth past the resonant point until the characteristic C.W. note of the station is tuned in. The pitch of the note can be altered to suit the individual ear, but in practice it is found that the best note, one that is not too highly pitched, is heard at a setting slightly above or below the resonant point.

(6) Loosen the tickler coupling as much as possible to obtain selective reception of C.W. signals and also use the loosest (minimum) inductive coupling between the primary and secondary.

(7) Failure to obtain oscillations may be due to insufficient tickler coupling or the polarity of the "B battery connection may be reversed.

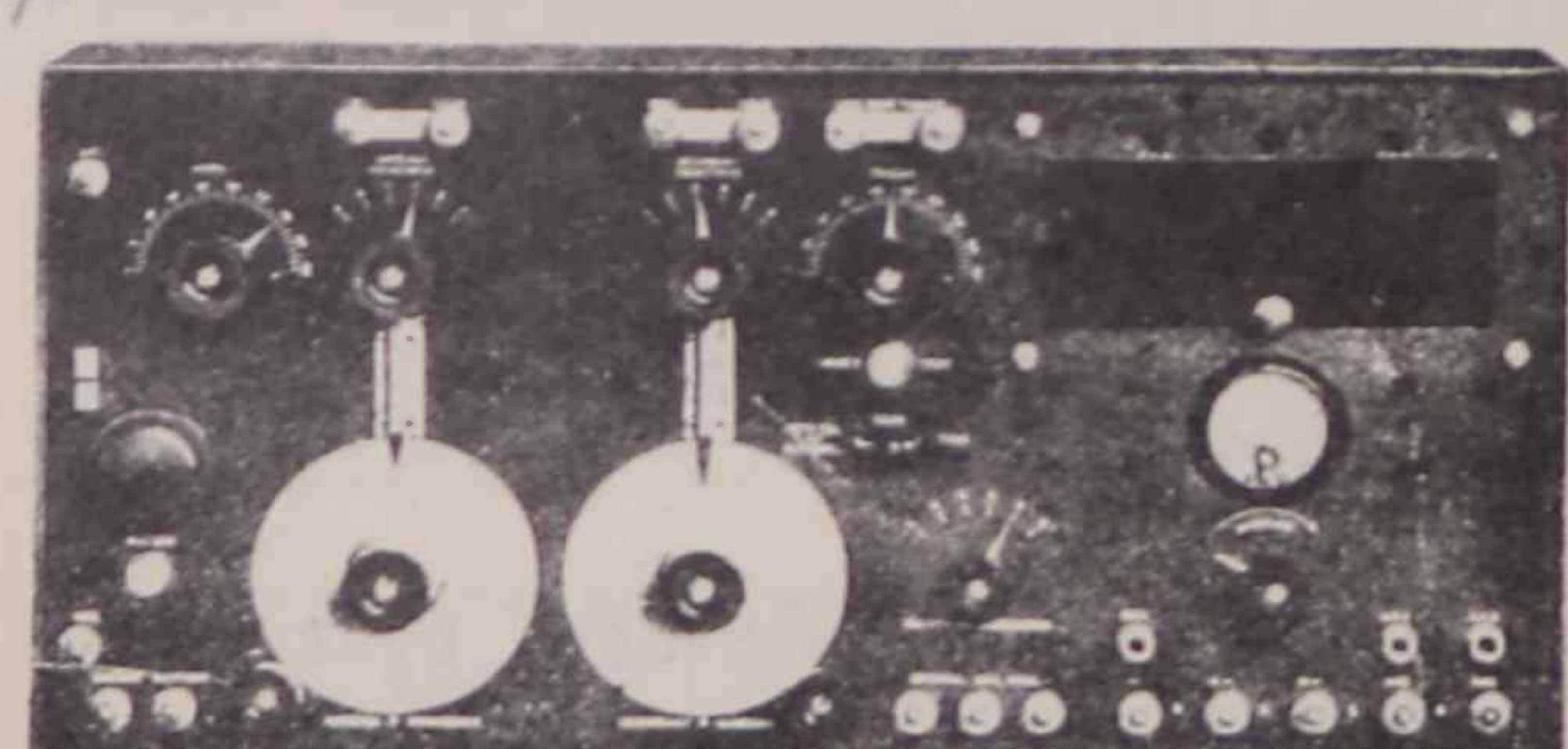

Fig. 6--Front View of the IP-501A Type Receiver

T e 501A Receiver. This receiver, the ron v ew o c s shown in Fig. 6, c rises an inductively co led tuner, a vacu tube detector, and two-stage li- fier. Except for the compact rou ing of these components in one cabine , t is receiver differs only slightly f the well known IP 501 receiver.

Model AR-8500 Radio Receiver —Several important features not heretofore available are provided by this receiver, designed primarily for marine application. A frequency range of 15 K.C. to 17,500 K.C. may be covered by the use of plug-in coils. In addition the receiver is provided with a built-in or fixed coil system which may be quickly connected in circuit by operating a switch and which provides coverage of the band from 230 to 520 K.C. (1304 to 577 meters). Variable mu pentode tubes are used permitting high sensitivity and considerable freedom from interference. A single control for the tuning elements of the receiver is provided.

The receiver should be installed so that the various controls on the front panel are within convenient reach. Sufficient space should be available above the receiver to permit access to the tube door and removal of the coil assembly.

The A and B battery leads to the receiver should preferably be run in lead covered or sheilded wiring and the shield thoroughly grounded so that supply circuits will not pick up excessive interference from the local radio transmitter.

The B supply should consist of a 135-volt battery made up of three heavy duty 45-volt units. A tap from this battery at 22-1/2 volts and a second tap at 45 volts are required. The total drain from the 135-volt battery is approximately 7 milliamperes.

A 6-volt storage battery should be used for the A supply. The drain on this battery will be 1.2 amperes. The negative terminal of the 6-volt battery and the negative terminal of the 135-volt battery are common and should be connected to a good ground. This connection will then ground the chassis of the receiver.

Unless there is considerable vibration it is not necessary to use any form of shock mounting as the receiver tubes are non-microphonic.

A total of four pentode tubes are used in the receiver consisting of 3 RCA Radiotrons 239,and 1 RCA Radiotron 238. The arrangement of these tubes in the circuit is as follows: One 239 as radio frequency amplifier; one 239 as regenerative detector; one 239 as first audio amplifier; one 238 as second audio amplifier. These tubes are indirectly heated cathode or heater type tubes, the heater operating at 6 volts and .3 amperes per tube. The heater or filament will function satisfactorily with an A supply voltage ranging from 5.5 to 8.5 volts. This allows for a variation in the charge and discharge cycles of the storage battery and makes it unnecessary to use a filament rheostat in the receiver.

The receiver is designed to cover a frequency range of 17,500 to 15 K.C. (17.1 to 20,000 meters). For average marine service the following coils may be supplied:

Coil	Frequency—K.C.	Wavelength—Meters
A	11000-17500	27.27-17.14
B	8200-12900	36.59-23.3
C	5500-8900	54.45-33.71
H (built-in fixed coils)	230-520	1304-577
I	110-230	2727-1304
J	55-110	5455-2727
K	30-55	10000-5455
L	15-30	20000-10000

Coils E,F and G are not listed above, these coils being reserved for any special frequency bands which may be desired.

The combination of a tuned radio frequency amplifier, screen grid detector and pentode audio amplifiers permits a high degree of sensitivity to be obtained.

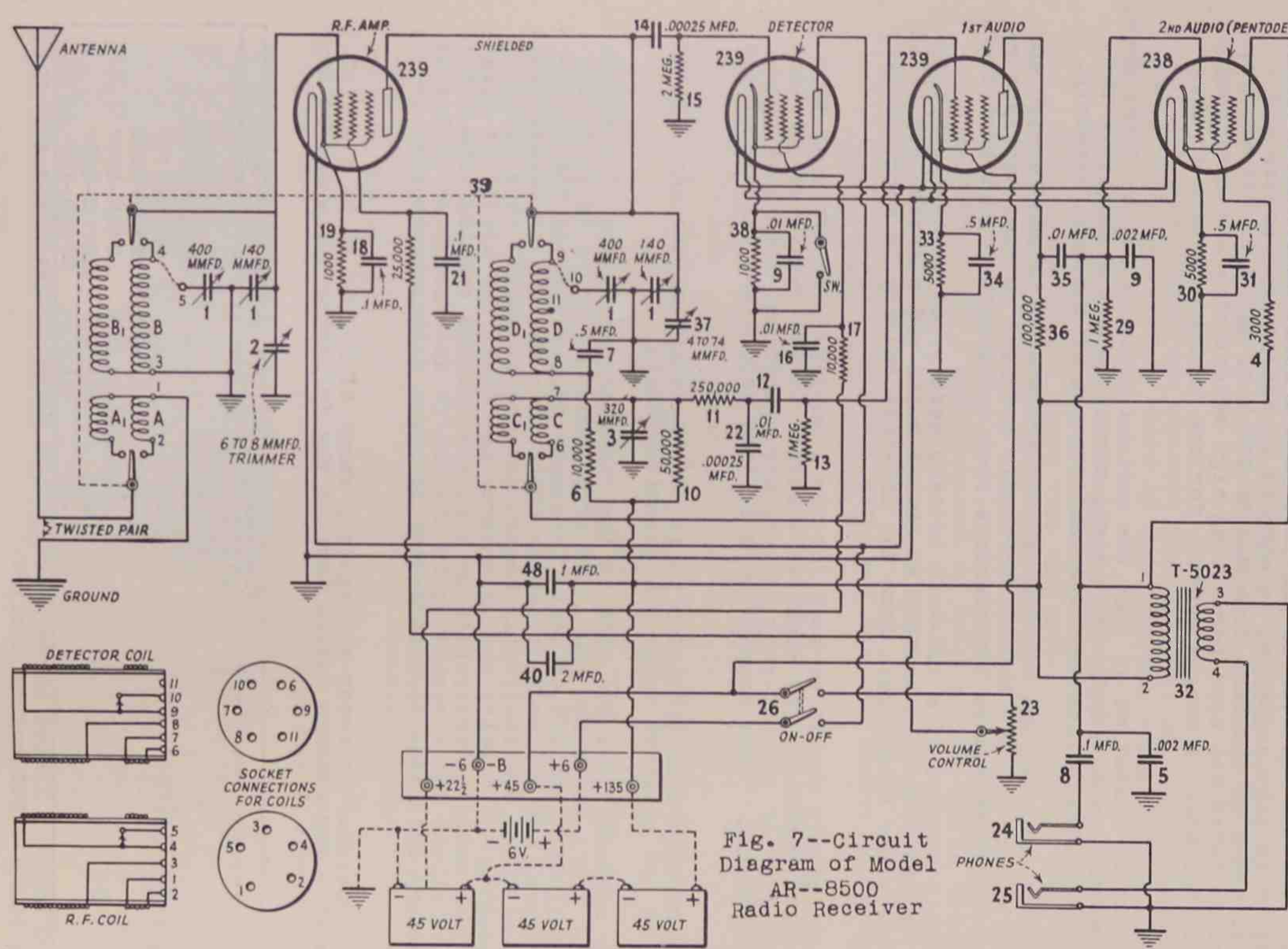

Fig. 7--Circuit Diagram of Model AR--8500 Radio Receiver

1.- Variable Tuning Condensers
2.- Trimmer --Trimming Condenser
3.- Regeneration Condenser
4.- Second Audio Screen Grid Resistor
5.- Second Audio Control Grid-By-Pass Cond.
6.- R.F. Amplifier Plate Resistor
7.- R.F. Amplifier Plate By-Pass Condenser
8.- Second Audio Plate By-Pass Condenser
9.- Detector Cathode By-Pass Condenser
10.- Detector Plate Resistor
11.- Coupling Resistor
12.- Audio Coupling Condenser
13.- First Audio Grid Leak
14.- Detector Grid Condenser
15.- Detector Grid Leak
16.- Detector Screen Grid By-Pass Condenser
17.- Detector Screen Grid Resistor
18.- R.F. Cathode By-Pass Condenser
19.- R.F. Cathode Resistor
20.- R.F. Screen Grid Resistor
21.- R.F. Screen Grid By-Pass Condenser
22.- R.F. By-Pass Condenser
23.- Volume Control
24.- Low Phone Jack
25.- High Phone Jack
26.- On-Off Switch
27.- Phone Coupling Condenser, First Audio
28.- Plate Filter Condenser
29.- Second Audio Amplifier Grid Leak
30.- Second Audio Cathode Resistor
31.- Second Audio Cathode By-Pass Condenser
32.- Output Transformer
33.- First Audio Cathode Resistor
34.- First Audio Cathode By-Pass Condenser
35.- Audio Coupling Condenser
36.- First Audio Plate Resistor
37.- Filter Condenser
38.- Detector Cathode Resistor
39.- Band Selector Switch
40.- First Audio Filter Condenser
48.- First Audio Filter Condenser

In the high frequency range of the receiver an input of 1 to 2 microvolts* will provide a good headphone signal. In the intermediate frequency part of the range where modulated signals are frequently used the receiver will provide a readable output with a 60% modulated signal having a value of 2 microvolts. At the low frequency portion of the range satisfactory C.W. reception may be obtained with signals having a level of only 2 to 4 microvolts. Since the noise level due to static, induction, etc., is usually greater than the input values mentioned above, it will be evident that the receiver provides ample sensitivity.

The selectivity characteristics of the receiver may be determined by considering the following typical examples. Assume the receiver is adjusted to 500 K.C. with critical regeneration to receive a 3 microvolt modulated signal. An interfering signal 10 K.C. lower than the desired signal must have a field strength approximately 50 times greater than the desired signal before it begins to produce barely audible interference. Under the same conditions as above, but with the interfering signal 20 K.C. lower, it must have a field strength 400 times greater than the desired signal.

At 125 K.C. with the receiver adjusted for best regeneration and with a 1 microvolt input, an interfering signal removed only 5 K.C. must have a field strength 200 times greater than the desired signal before it produces audible interference.

At 8250 K.C. receiving a modulated signal, an interfering signal 20 K.C. off resonance must be approximately 6 times stronger than the desired signal before it produces audible interference. At 40 K.C. off resonance the interfering signal must be approximately 20 times as strong as the desired signal to produce noticeable interference.

All of the above data is based on an adjustment where the detector is not oscillating. In the case of an oscillating detector such as is necessary for C.W. reception the selectivity will, in general, be even better than that indicated above.

The component units of the AR-8500 receiver are mounted on a cast aluminum chassis to which is attached the main front panel. This complete assembly is then arranged to fit in metal box which completes the shielding. The four vacuum tubes are mounted on the upper right section of the chassis and are accessible through a door in the top of the cabinet. Small removable shields are provided for the radio frequency amplifier and the detector tubes. Each plug-in coil assembly consists of 2 coils mounted on a common plate and are arranged to plug into a shielded compartment built on the center of the chassis. To the left of the shielded compartment for the coils there is mounted a four-section variable condenser so arranged that more or less capacity is automatically connected in the circuit when the various coils are plugged in. In order to minimize difficulties from noisy contacts long connection plugs are used to carry the circuits from the plug-in coils to the chassis. These connectors introduce some friction and a coil ejector is provided in the handle of each coil assembly. To remove a coil the round button above the handle should be held down while the coil is raised by pulling up on the handle.

The fixed coils (coils H) for the six-hundred meter band are built in a shielded compartment on the under side of the chassis. To connect these coils in circuit it is simply necessary to pull out the switch handle at the left of the regeneration dial. When this switch is pushed toward the panel it will connect in circuit whatever plug-in coil is in the top of the receiver. By means of this ar-

*The microvolt is used in measuring radio field intensity which is the effective (root-mean-square) value of the electromagnetic field intensity at a point due to the passage of radio waves of a special frequency. The electric field intensity is usually expressed in terms of microvolts per meter or millivolts per meter.

rangement the operator may instantly change from the 600-meter band to the 2400-meter band in case coil I is plugged in, or he may change to the 36-meter band if coil C is plugged in.

On the front panel there is provided a vernier tuning control which is a cable drive for the main tuning condenser, a trimmer condenser, regeneration control, and volume control. There is also a band selector switch to the left of the regeneration dial as explained in the preceding paragraph. The antenna and ground posts are mounted to the left of the panel. The ground post is not connected to the frame of the receiver so that whenever desired a doublet* receiving antenna may be used. This will be found to be of value in reducing local interference for short wave reception. The volume control is a voltage divider used to apply a negative voltage to the control grid of the radio frequency amplifier. Volume control obtained in this manner permits a wide range to be covered and at the same time affords considerable freedom from overload and cross modulation effects due to the variable mu feature of the R.F. amplifier tube.

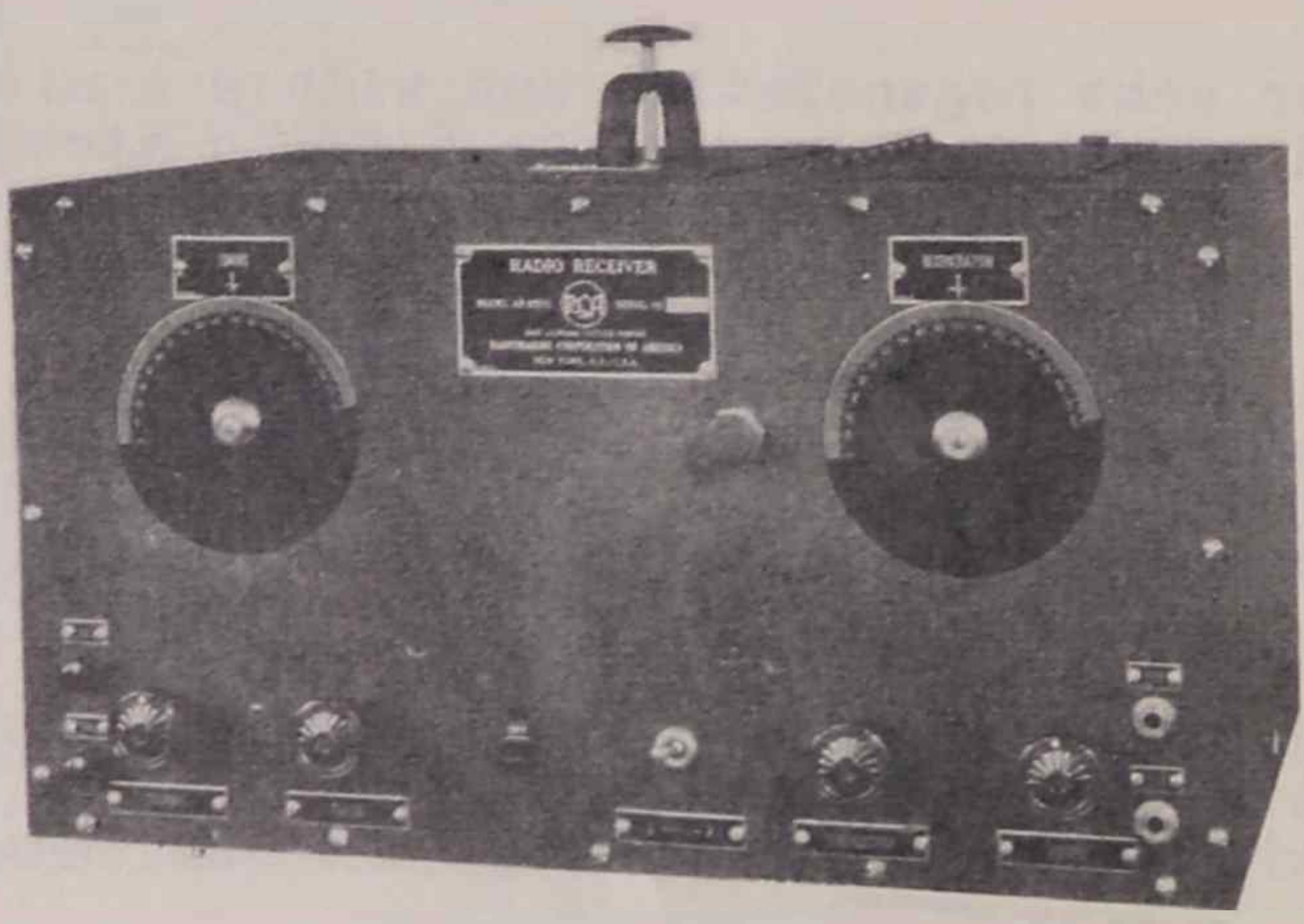

Fig. 8--Front Panel View of AR--8500 Radio Receiver

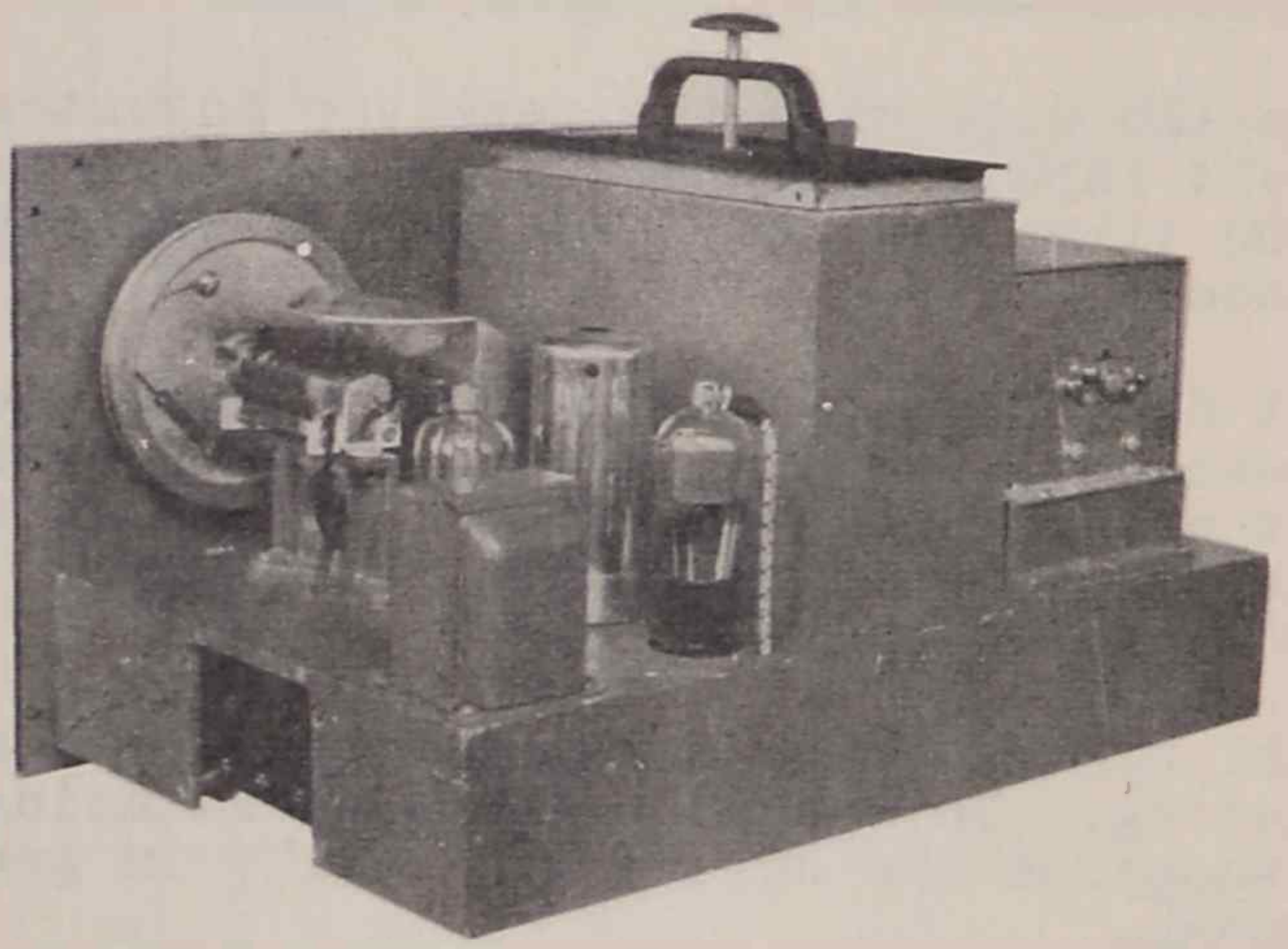

Fig. 9--Rear Chassis View of Model AR--8500 Radio Receiver

The "on-off" switch in the center of the panel controls the 6-volt heater circuit and the volume control potentiometer. It requires approximately 20 seconds for the heaters to bring the cathodes of the tubes up to the normal operating temperature and for this reason the switch should not be turned to the "off" position while transmitting.

The telephone jacks are provided in the right-hand section of the panel, the jack marked "High" being connected to the second stage of audio amplification, while the jack marked "Low" is connected to the first stage. The output impedance for the High jack is 600 ohms and in general it is recommended that low resistance (120 ohms D.C.) phones be used. For installations where a loud speaker is used it is recommended that the speaker be plugged into the High jack and 2200-ohm phones used which may then be plugged into the Low jack or the High jack.

All control knobs on the panel are arranged to rotate in the same relative direction. Turning the tuning knob to the right (clockwise) increases wavelength and decreases frequency. Turning the regeneration control clockwise increases regeneration. The trimmer condenser and volume control operate in the same manner. It will be observed that the low numbers on the tuning and regeneration dials correspond to the low frequencies and the higher numbers to the high frequencies.

*A doublet antenna is an antenna consisting of two elevated conductors substantially in the same straight line, of substantially equal length, with the power delivered at the center.

The complete circuit diagram of AR-8500 is shown in Figure 7 and the front and rear views of the Receiver are presented in Figures 8 and 9. The input coil for the grid of the R.F. amplifier contains a coupling coil and a tuned grid coil. The coupling coil is designed for each frequency band so that the coupling increases with wavelength. The plate circuit of the R.F. amplifier is also tuned and is coupled through a condenser to the grid of the detector. The range selector switch, Item 39, controls the various circuits for the plug-in coils and the fixed coils. A tickler coil is coupled to an amplifier plate coil and regeneration or detector oscillation is controlled by means of variable condenser, Item 3. Particular care has been directed in the design of this part of the circuit with the result that smooth regeneration is obtained and the use of excessive regeneration will not cause undesirable howling in the headphones. The audio voltage built up in the detector plate circuit appears across a 50,000-ohm resistor, Item 10, and is then coupled through a low pass filter network to the grid of the first audio amplifier.

Resistance coupling is used between the plate circuit of the first audio stage and the grid circuit of the second audio stage. The output from the 238 second-stage amplifier is connected to the "High" telephone jack through an output transformer, Item 32. The output of the first audio stage is connected to the "Low" jack through a coupling condenser, Item 27. No D.C. voltages exist on either phone jack.

While the general operation of the Receiver is quite similar to that usually employed in regenerative receivers, there are certain points in the AR-8500 which deserve special attention.

Careful adjustment of the amplifier trimmer condenser and the regeneration condenser will be found to produce excellent performance when receiving weak signals under conditions of interference. In any receiver used for C.W. work with an oscillating detector it is necessary, of course, for the detector to be adjusted to a frequency differing by 500 or 1000 cycles from that of the R.F. amplifier. In other words the detector circuit is never tuned to exactly the frequency of the incoming signal, for if this were done zero beat* reception would result. Consequently the AR-8500 has been provided with a trimmer condenser for the amplifier grid so that this circuit may always be tuned exactly to the desired signal while the detector is tuned slightly off to produce an audible beat note.

It will be found that the best setting for the regeneration condenser is influenced by the adjustment of the trimmer condenser. The rule to follow is always to use sufficient regeneration so that the amplifier trimmer condenser may be tuned through maximum without causing the detector to stop oscillating or drop into zero beat. When searching for a signal the correct adjustment of the regeneration control and the trimmer condenser may be checked easily by noting the increase in noise level as the trimmer condenser is turned through resonance.

On the front panel of the Receiver to the left of the regeneration knob will be observed a small switch marked G-P. This switch controls a resistor in the cathode circuit of the detector and provides in the "G" position grid leak detection and in the "P" position grid bias detection for small input signals. In general for maximum sensitivity this switch may be left in the "G" position. When operating on intermediate or low frequencies under conditions of interference it will be found that the selectivity is improved by throwing this switch to the "P" position. When used in the "P" or grid bias position the damping effect of the detector grid circuit on the preceding tuned circuit is reduced and the selectivity thereby improved.

Reasonable care should be exercised in removing or replacing the plug-in coils so that they are not damaged by rough handling. When removing a coil it should

*Zero beat occurs when two frequencies, such as the incoming and the locally generated, are of the same frequency, resulting in no beat frequency.

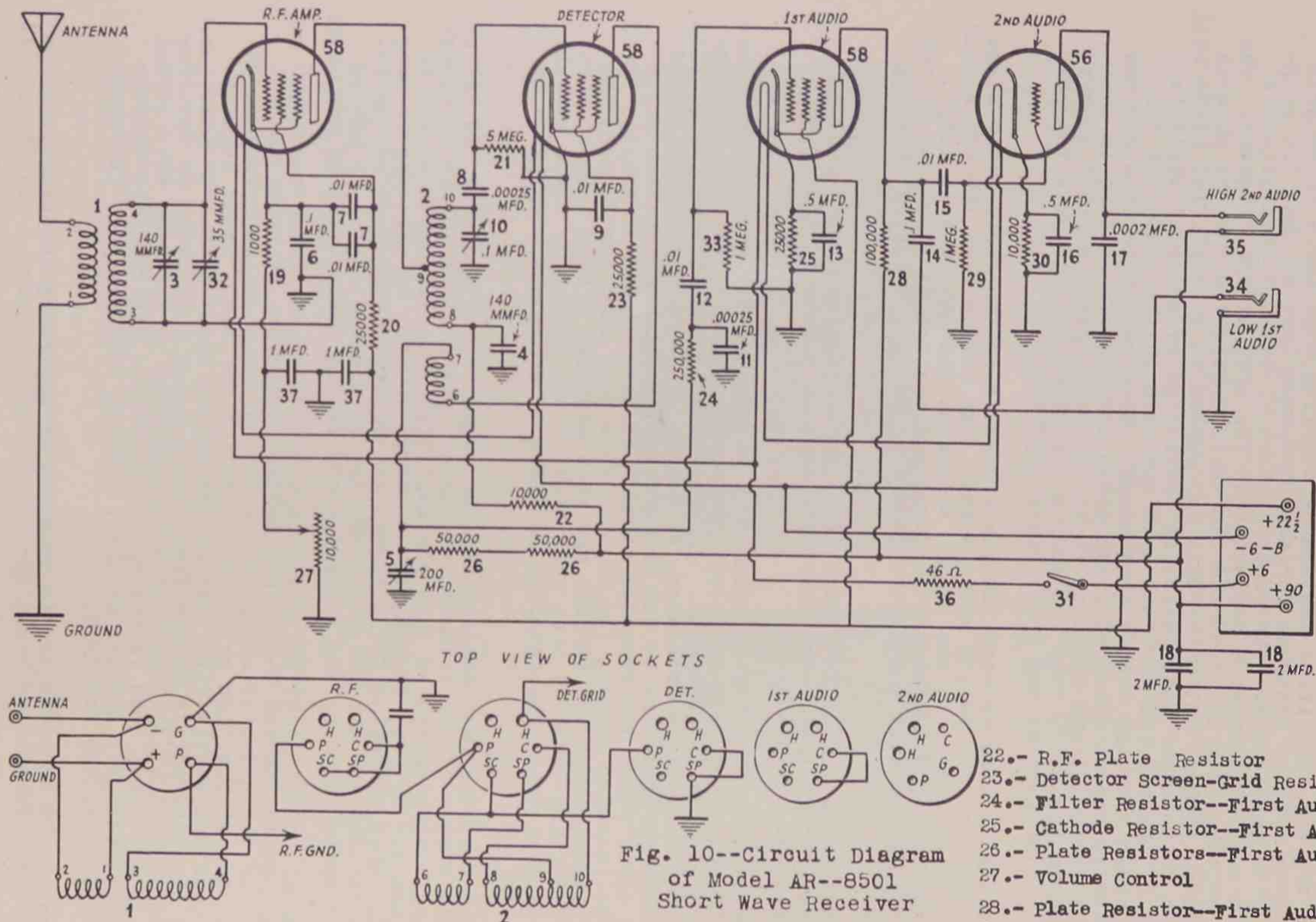

Fig. 10--Circuit Diagram of Model AR--8501 Short Wave Receiver

1.- R.F. Amplifier Coil 2.- Detector Coil
3.- R.F. Amplifier Grid Tuning Condenser
4.- R.F. Amplifier Plate Tuning Condenser
5.- Regeneration Condenser
6.- R.F. Amplifier Cathode By-Pass Cond.
7.- R.F. Amplifier Screen-Grid By-Pass Cond.
8.- Detector Control-Grid Condenser
9.- Detector Screen-Grid By-Pass Condenser
10.- Detector Plate By-Pass Condenser
11.- Grid By-Pass Condenser --First Audio
12.- Grid Coupling Condenser -- First Audio
13.- Cathode By-Pass Condenser --First Audio
14.- Phone Coupling Condenser
15.- Coupling Condenser
16.- Cathode By-Pass Condenser --Second Audio
17.- Plate By-Pass Condenser --Second Audio
18.- Filter Condensers. 19.- R.F. Cathode Res
20.- R.F. Screen-Grid Res. 21.- Det. Grid Leak
22.- R.F. Plate Resistor
23.- Detector Screen-Grid Resistor
24.- Filter Resistor--First Audio
25.- Cathode Resistor--First Audio
26.- Plate Resistors--First Audio
27.- Volume Control
28.- Plate Resistor--First Audio
29.- Grid Leak--Second Audio
30.- Cathode Resistor--Second Audio
31.- On-Off Switch
32.- Trimming Condenser
33.- Grid Leak--First Audio
34.- Phone Jack--First Audio
35.- Phone Jack--Second Audio
36.- Filament Resistor
37.- By-Pass Condensers

be lifted vertically until completely out of the cabinet. When inserting a coil it should be held so that the name plate is toward the front panel. Dowel pins are provided so that the coil cannot be inserted in the wrong position.

Looking down through the tube door the three tubes in a row are Type 239. The fourth tube to the right is the 238 second audio amplifier tube. The shields over the R.F. and detector tubes should always be replaced when tubes are changed and care taken not to ground the control grid connection at the top of the tube.

Due to variations in tubes it will sometimes be found that better control of regeneration is obtained with a selected tube. If it is found that insufficient regeneration is obtained over the range of any one coil or if the regeneration is excessive, changing detector tubes will correct the trouble.

Model AR-8501 Radio Receiver—The following instructions cover a short wave receiver designed primarily for marine applications. Several important features not heretofore available are provided by this receiver. A frequency range of 5 to 18 megacycles* (60 to 16.6 meters) is covered by the use of three pairs of plug-in coils wound on Isolantite forms. Special coils to cover other frequency bands may also be furnished if ordered. Variable mu pentode tubes are used, permitting high sensitivity and considerable freedom from interference. A single control for the tuning elements of the receiver is provided.

The receiver should be installed so that the various controls on the front panel are within convenient reach for the operator. The input binding posts are located in the receiver at the extreme left end and may be connected to a suitable doublet or a conventional antenna and ground. It is preferable to use a doublet with the lead-in portion inside the radio room shielded, and this shield brought down and clamped to the receiver case by means of a metal clamp located near the input binding posts.

The A and B battery leads should preferably be run in shielded cable and the shield thoroughly grounded. Five conductors are required for the power supply, consisting of plus 6, minus 6, minus B, plus 22-1/2 and plus 90 volts. The receiver terminal board is located in a horizontal position in the rear right corner of the chassis and is readily accessible.

The B supply should consist of a heavy duty 90-volt battery with a tap at $22\frac{1}{2}$ volts. The total drain from this battery is approximately 2 milliamperes.

A 6-volt storage battery should be used for the A supply. The drain on this battery is 2 amperes. The minus 6-volt supply should be well grounded.

The receiver cabinet is furnished normally with four Lord rubber shock mounts.

A total of 4 tubes are used in the receiver, consisting of 3 RCA Radiotrons 58 and 1 RCA Radiotron 56. The arrangement of these tubes in the circuit is as follows:

One 58 as radio frequency amplifier.
One 58 as regenerative detector.
One 58 as first audio amplifier.
One 56 as second audio amplifier.

These tubes are the indirect heated cathode type, each heater requiring 2.5 volts and 1 ampere. The 4 heaters are connected 2 in series and 2 in parallel, requiring a supply of 5 volts and 2 amperes. A small fixed resistor is mounted underneath the chassis to provide a 1-volt drop, thereby permitting a 6-volt storage battery to be used. Due to ample emission from the cathodes and the very small plate current required by the receiver no regulation of the filament circuit is necessary over the normal charge and discharge cycles of the storage battery.

*One megacycle equals 1,000 kilocycles.

Normally 3 pairs of plug-in coils are supplied to cover the following frequency bands:

Coil	Frequency—M.C.	Wavelength—Meters
A	12-18	25-16.6
B	9-14	33.3-21.4
C	5-9	60-33.3

For reception of the marine high frequencies at present used by coastal stations, it is recommended that the coils be used as follows:

Use Coil "C" for 5, 6 and 8 megacycle reception.
Use Coil "B" for 11 and 12 megacycle reception.
Use Coil "A" for 16 megacycle reception.

The circuit diagram of this receiver is shown in Figure 10, and the front cabinet and rear chassis views appear in Figures 11 and 12. The input circuit for the grid of the R.F. amplifier contains a coupling coil and a tuned grid coil. The coupling coil is designed for each frequency band so that the coupling increases as the longer wave coils are placed in circuit. The plate circuit of the R.F. amplifier is tuned and is coupled through a condenser to the grid of the detector. A tickler coil coupled to the amplifier plate coil permits regeneration, which is controlled by means of a variable condenser. Particular care has been directed in the design of this part of the circuit to

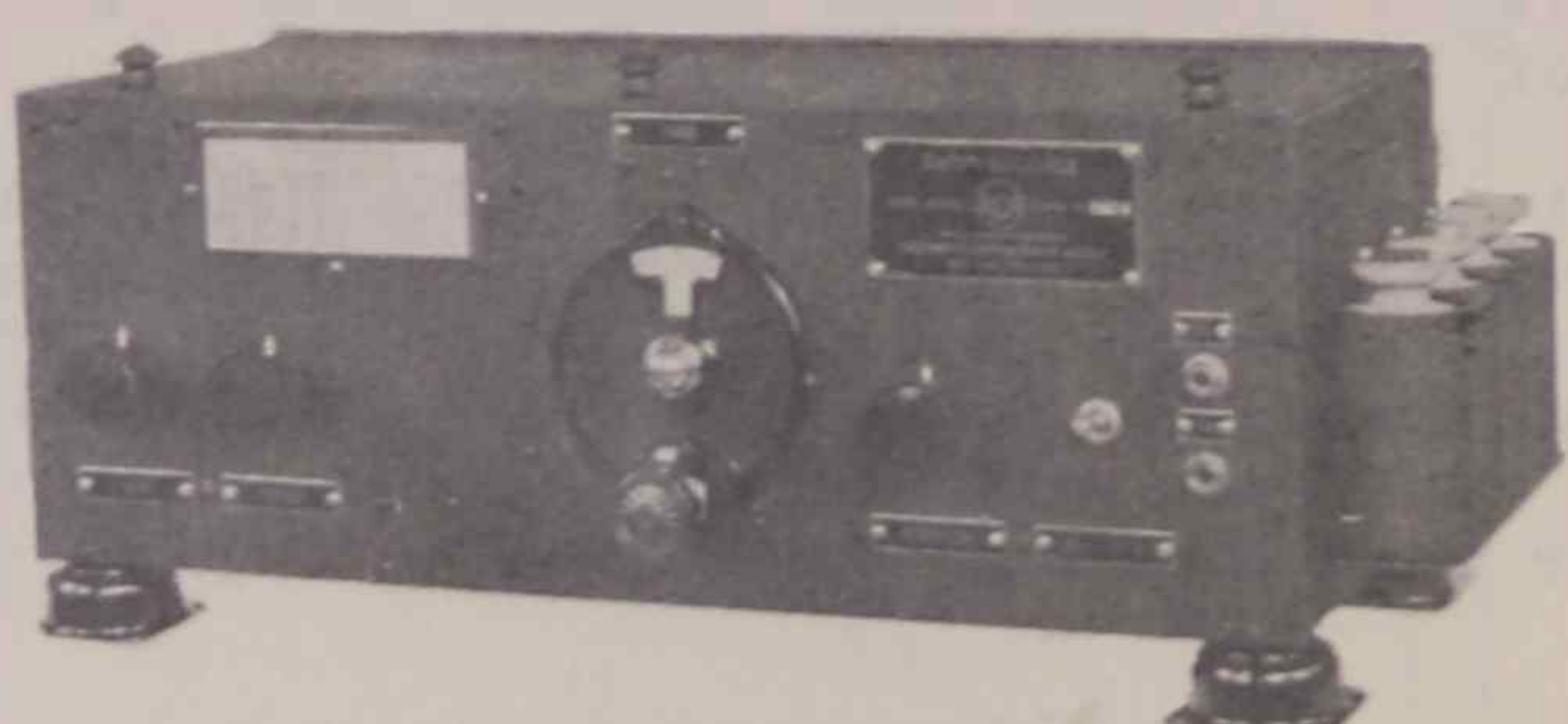

Fig. 11--Front Cabinet View Of Model AR--8501 Radio Receiver

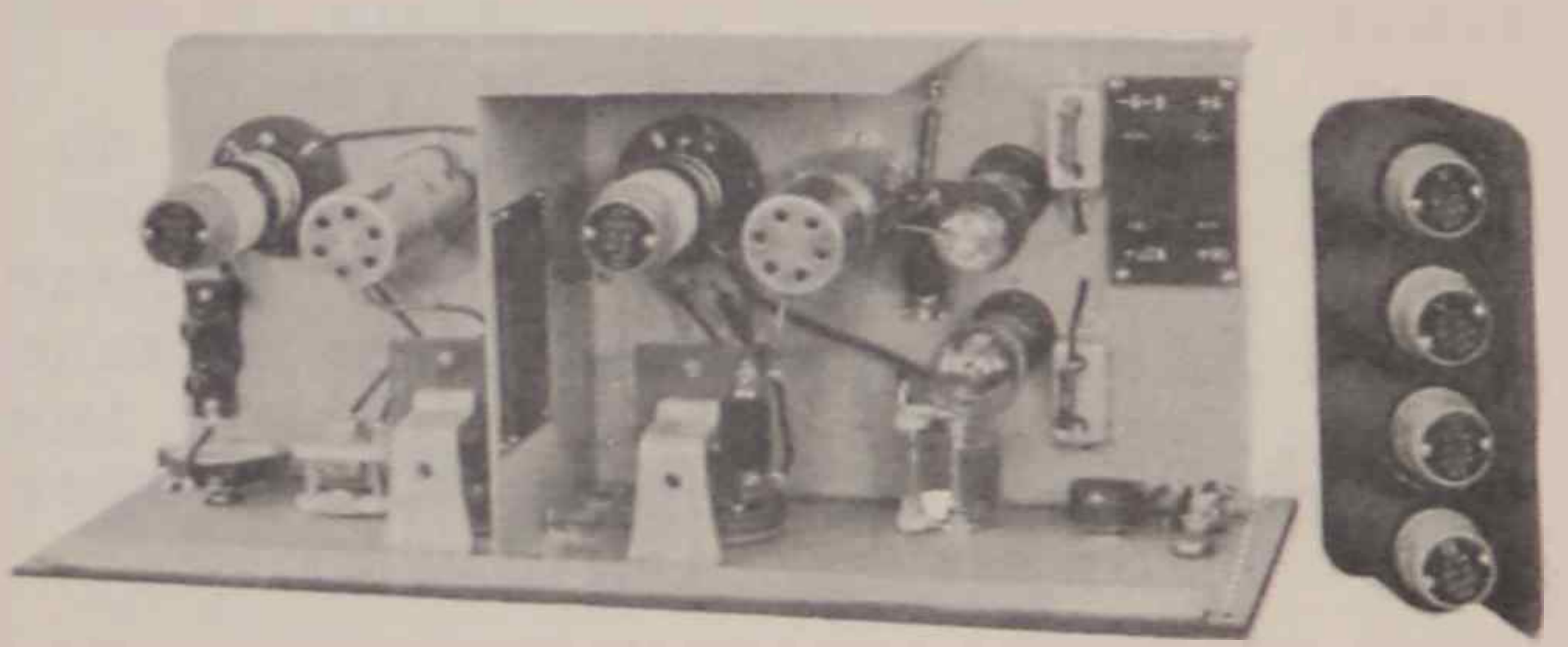

Fig. 12--Chassis View of Model AR--8501 Radio Receiver

obtain smooth regeneration with freedom from backlash. The audio voltage built up in the detector plate circuit appears across two 50,000-ohm resistors connected in series, Item 26, and is then coupled through a low pass filter network to the grid of the first audio amplifier.

Resistance coupling is used between the plate circuit of the first audio stage and the grid circuit of the second audio stage. The plate circuit of the second audio tube is connected through the telephone receivers to plus 90 volts. The tip of the second stage telephone jack connects to plus 90 volts and the sleeve of this jack connects to the plate of the tube. The polarity of the cords from the headphones should be arranged with this point in mind so that the second stage plate current passes through the phones in the correct direction. 2,200-ohm headphones should be used with this receiver for best results.

A trimmer condenser is provided on the panel and is connected in parallel to the R.F. tuning condenser so that exact line-up may be maintained between the two tuned circuits.

Volume control is accomplished by means of a 10,000-ohm variable resistor connected in the cathode of the R.F. amplifier. As this resistance is cut in circuit it increases the negative grid bias on the R.F. amplifier, thereby reducing amplification.

Shields are provided for the R.F. and detector tubes. These shields should be kept in place for best results.

A time interval of approximately 20 seconds is required for the cathodes to reach their normal operating temperature. The filament switch, therefore, should not be turned off during transmission.

Wavelength is increased by a clockwise motion of the tuning dial, which corresponds to a counter clockwise motion of the Vernier driving knob. Regeneration increases in a clockwise direction and volume increases in a like direction. Higher numbers on the tuning dial correspond to higher frequencies.

The top door of the cabinet which provides access to the tubes and coils swings through a radius of 8". When the receiver is mounted on shock supports the height is increased approximately 1-1/4". The weight of the receiver is approxmately 20 pounds.

A four-compartment coil box is provided so that two pairs of coils may be stowed. This coil box is designed so that it may be mounted on the bulkhead, on the right end of the receiver cabinet or on the lid so that the four coils face the operator.

A card-holder for a calibration chart is provided on the front panel. The various marine frequencies should be recorded and the various dial settings entered on this chart.

EXAMINATION QUESTIONS

1. Draw a schematic diagram of the type IP-501 commerical receiver and label the parts.

2. In concise tabulated form write all of the steps necessary to place the IP-501 receiver in practical operation to receive a C.W. signal.

3. In brief, how should the receiver be adjusted first to tune in a spark signal, and second, to tune in a C.W. signal?

4. (a) How is the tickler coil connected and in general what position should it occupy to provide maximum "feed-back" of plate energy? (b) If the circuit failed to oscillate what might be the probable cause or causes? (c) Suppose you are on a radio watch and your receiver is tuned to pick up a distant spark station and the signals came in with considerable distortion. What do you think would be accountable for this condition and how would you remedy it?

5. (a) Are there any practical considerations in regard to the amounts of inductance and capacity to be used in the tuned circuits when manipulating the control knobs to tune in a signal? (b) Is it of any particular advantage to know the theoretical operation of a tuned circuit in order to be capable of adjusting such a circuit to the best advantage in commercial operating? Explain briefly.

6. (a) Is it always necessary to employ extreme close coupling between primary and secondary to obtain a good readable signal? Why? (b) When is the series antenna condenser used and how may it be cut out of the circuit?

7. Give some general advice in regard to tuning a commercial receiver to a certain incoming signal. (Be brief in your reply, but answer this question as though you were instructing a fellow-operator in the best practical methods necessary to accomplish this important assignment).

8. (a) What is meant by "stand-by" adjustment? (b) How is coupling altered? (c) What causes the "double-click" heard in the phones and how does this test for critical coupling?

9. Draw a schematic diagram of the Model AR-8500 Radio Receiver.

10. In what respect does the AR-8501 Radio Receiver differ from the AR-8500?

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America's Oldest Radio School

RCA INSTITUTES INC.

A Radio Corporation of America Subsidiary

HOME OFFICE
75 Varick Street, New York

Self Rectifying Type Tube Transmitter

Vol.35#7

Dewey Classification R350

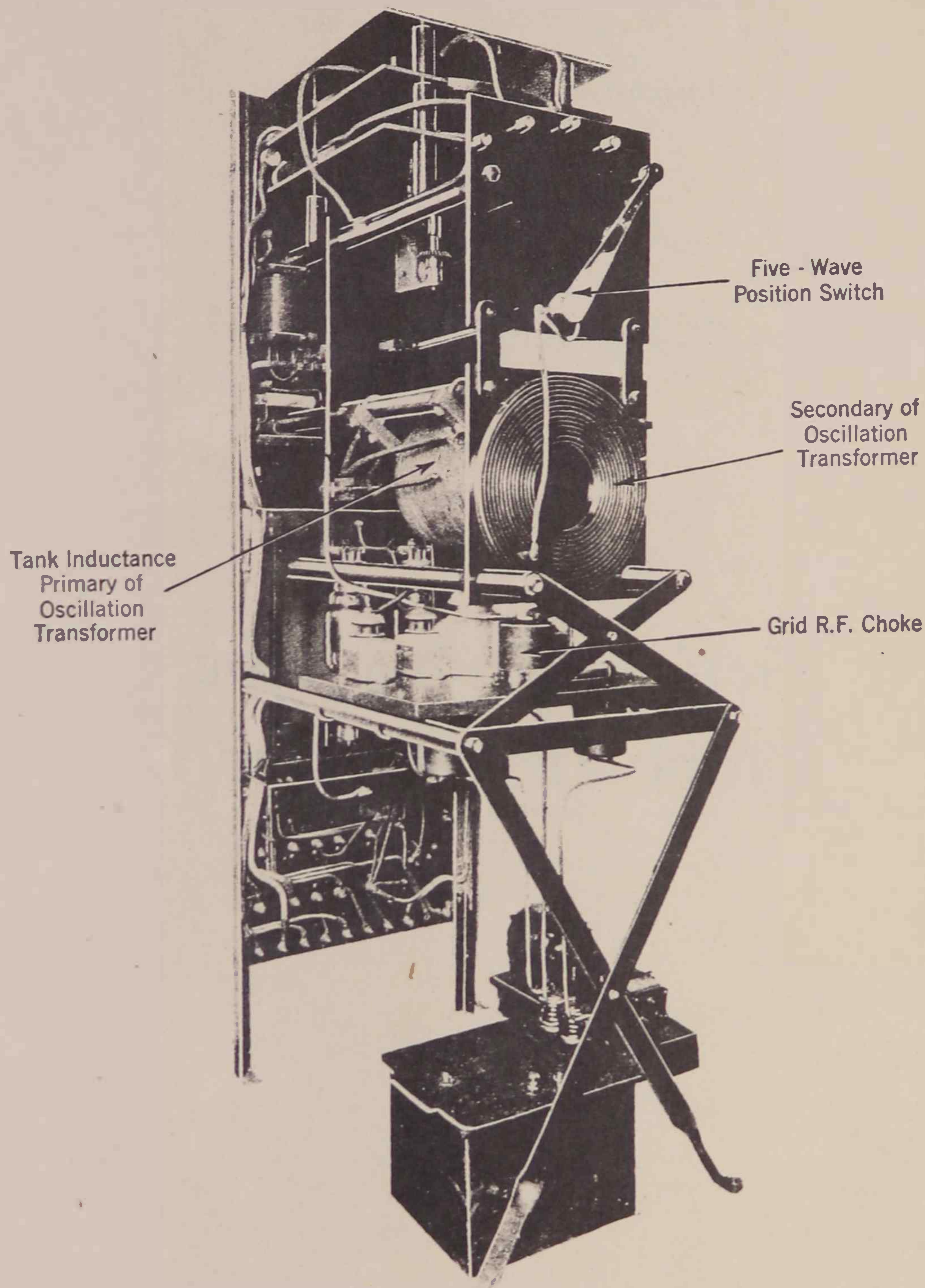
Five - Wave
Position Switch
Secondary of
Oscillation
Transformer
Tank Inductance
Primary of
Oscillation
Transformer
Grid R.F. Choke

Figure 1

America's Oldest Radio School

RCA Institutes Inc.
A Radio Corporation of America Subsidiary
HOME OFFICE
75 Varick Street, New York

SELF RECTIFYING TYPE TUBE TRANSMITTER

Type E.T. 3628 Tube Transmitter. Vacuum tube transmitters are rapidly replacing spark and arc sets because of two reasons:

1. They are capable of covering much greater distances with less power.
2. They emit a sharper (less interfering) wave than either the spark or arc.

A-2

The E.T. 3628 is one of the standard transmitters now in use on many ships and in a few coastal stations. A vast amount of radio transmitting apparatus has been installed on ships since the birth of radio communication and while the advancement in radio has progressed, there was a limitation set, naturally, in the discard of older types to accommodate the more efficient newer types. Towards the relief of such an expensive change the Radio Corporation of America designed the E.T. 3628 tube set which utilizes much of the apparatus used in the old standard P-8 spark transmitter that we have just recently studied. The E.T. 3628 is often referred to as the "Converted P-8". In this lesson we show the changes made and if the student will study this assignment with the lesson on spark transmitters the instruction will be clear.

All connections to the motor-generator and automatic starter are the same as for the P-8 spark set. The method of Keying, (by breaking the primary circuit of the power transformer) is exactly the same as used with the P-8 installation. Power regulation by means of generator field and motor field rheostats is the same. The connections to the wattmeter and antenna ammeter are also the same as used with the P-8 spark set. Instructions and diagrams given in the lesson on spark transmitters should be followed so far as any of the above mentioned circuits are concerned.

The conversion of the P-8 spark transmitter is made by removing the following parts: The quenched gap panel, airduct, primary condenser rack, coupling shaft and scale, rotary gap disc and muffler, change-over switch and adjusting handle, and all upper contact studs on the wave-changer panel. Also the primary reactance is permanently cut out and the primary inductance (pancake coil) is removed and replaced with the drum wound helix type called the "tank inductance", as shown in the photograph, Figure 1.

The tube cradle holding the two UV-204-A's is then installed and protected by a panel screen as shown in Figure 2. The filament by-pass condensers are mounted on the rear of the panel in a position directly in back of the filament voltmeter as shown in Figure 3. A large board holding the choke coil and condenser assembly is put in the place formerly occupied by the spark condenser rack. On this board are the grid leak resistor of 4,000 ohms, grid r.f.

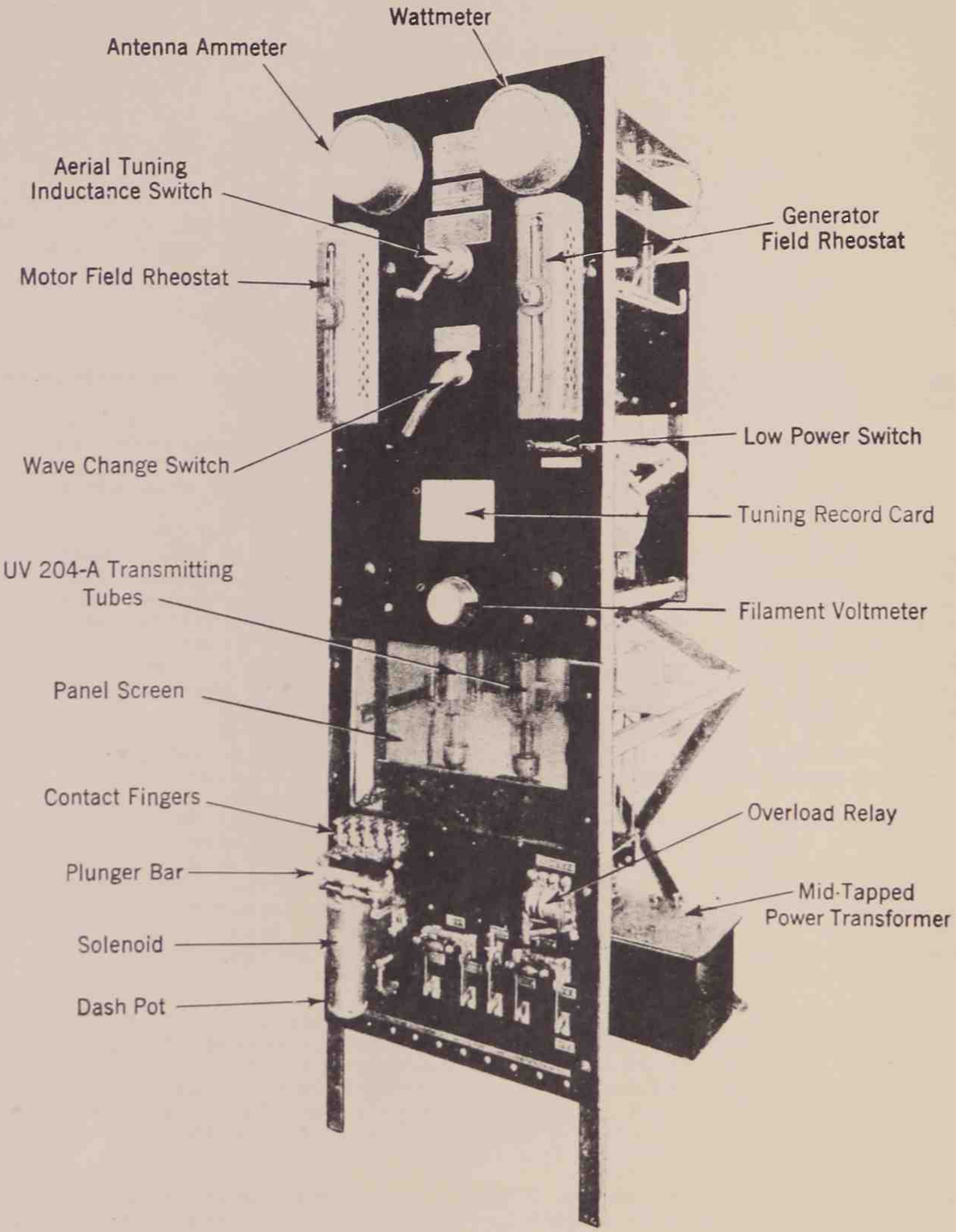
Wattmeter
Antenna Ammeter
Aerial Tuning
Inductance Switch
Generator
Field Rheostat
Motor Field Rheostat
Low Power Switch
Wave Change Switch
Tuning Record Card
UV 204-A Transmitting
Tubes
Filament Voltmeter
Panel Screen
Contact Fingers
Overload Relay
Plunger Bar
Mid-Tapped
Power Transformer
Solenoid
Dash Pot

Figure 2

choke and the large plate excitation condenser on either side of which are mounted the two smaller plate blocking condensers. The two plate r.f. chokes are secured to the bottom of the board toward the rear.

The primary wave-changer panel is drilled for two additional contact studs and five flexible leads are connected, thus providing for a five-wave position holder. The circuit is the conventional Colpitt's oscillator type using flexible inductance leads making five wavelengths available as indicated in the schematic diagram of Figure 4.

The open oscillatory circuit of the E.T. 3628 is substantially the same as the P-8 except that the secondary inductance has only one variable tap which, after calibration, remains in a fixed position for all wavelengths. The

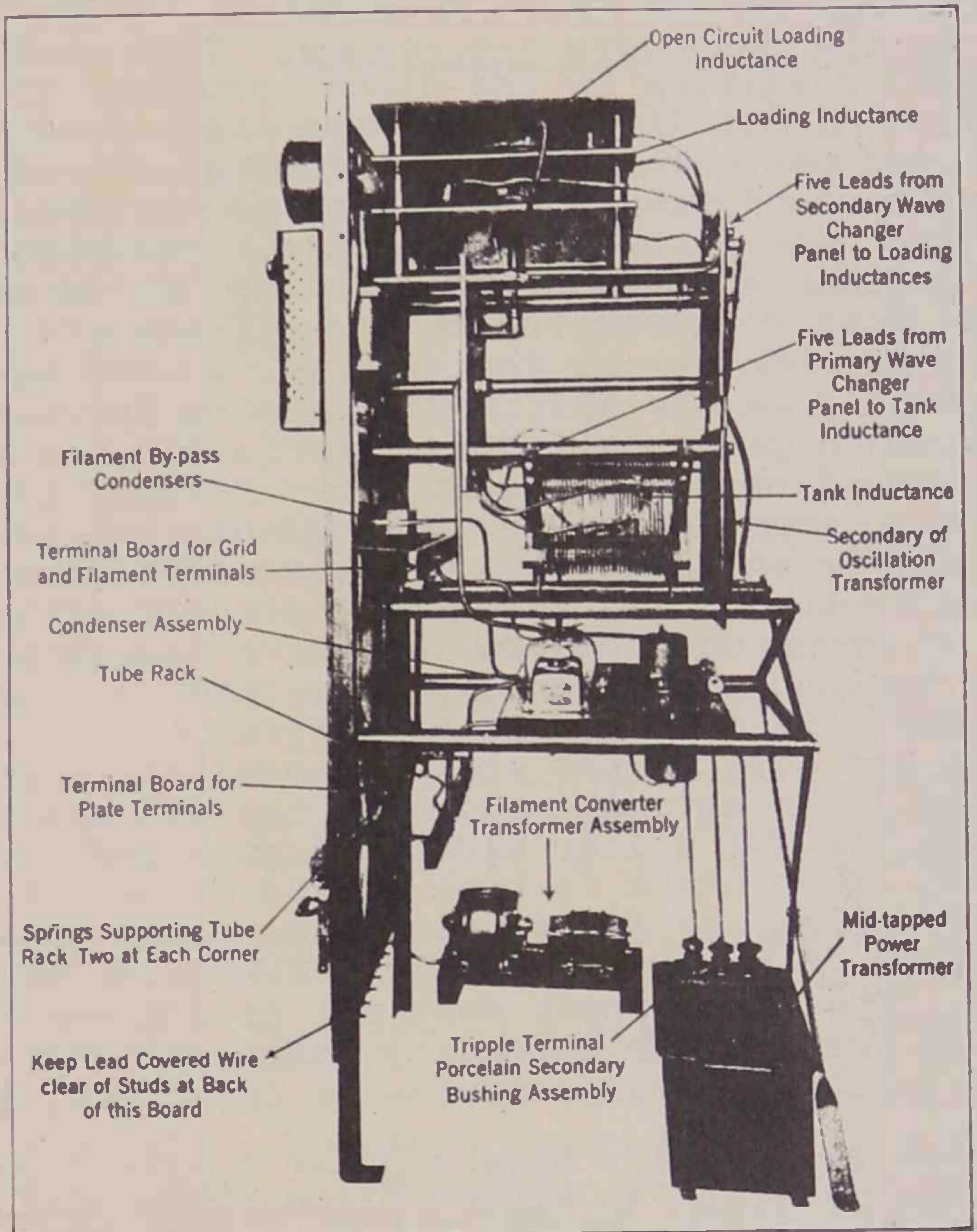

Figure 3

spark transformer is replaced with a mid-tapped transformer. A filament voltmeter is mounted on the panel whereas the filament rheostat which controls the output of the a-c. rotary converter is usually placed on or near the operator's table. The mid-point of the filament transformer and mid-point of the plate transformer are joined with a heavy No. 12 gauge lead-covered wire which is connected to the ground.

Theory of Operation. Self-rectifying Tube Transmitter. The self-rectifying circuits may be divided into the following two classes:

1. Those employing one tube and utilizing only one-half of the a-c. cycle.
2. Those using both halves of the a-c. cycle by employing two tubes arranged symmetrically so that each tube operates alternately during the positive alternations of the a-c. cycle. The latter type is utilized in the E.T. 3628 described in subsequent paragraphs.

Tuning. The transmitting key is depressed and the power adjusted to ½-kw. while watching the tubes for heating and sparking. If any one of the tube plates heat up badly, shut down the motor-generator and check over all connections, ascertaining if they are made to proper points and if they are clean and bright. This applies particularly to the wave-change switch arms. If trouble still persists, check through each unit of the transmitter. When clean, place the wave-changer switch on the first position and measure the wavelength with a wavemeter coupled to the tank inductance. Vary the clip on this coil until the desired wave is found. Then resonate the open circuit in the usual manner, using about two turns in the secondary inductance. The resonance point indicated by maximum antenna current is much sharper than is the case with a spark set and may be passed over unnoticed if the tuning is not done slowly and carefully.

The Number of Turns in the Secondary Inductance. Care must be taken not to include too many turns, resulting in too close coupling, in order to avoid the undersirable effect of "split" tuning. When this condition obtains radiation may be low and the wavelength will "swing" sharply from one value to another without warning or visual indication to the transmitting operator as the radiation is the same in both frequencies. The receiving operator, however, gets only the dots and dashes transmitted on the wavelength to which he is tuned and does not hear the others. There are two indications of split tuning to be watched for by the observer as outlined below. If the radiation increases evenly as the ATI (aerial tuning inductance) is brought slowly up to the resonance point by turning the handle and radiation decreases evenly as the ATI is moved past this point, then the set is radiating on one wave. If, however, radiation falls off suddenly and sharply as the critical point is passed, it is an indication that two waves are being emitted and that the coupling is too close. A change in coupling is obtained by altering the number of turns used on the secondary inductance by going over the ribbon wire inch by inch with the clip very carefully, until a suitable point is found. Coupling is not changed by varying the distance between the two inductances as in the case of the spark transmitter. Another method of detecting split tuning is to note the point on the ATI scale at which resonance is reached. Move the ATI slider along the wire perhaps two or three turns past this point. Then bring it back to resonance. If the second resonance point differs from the first, reduce coupling until they agree. Antenna current of 10 to 12 a res y be expected with average conditions on 1½ . power in t. The power input m st not be allowed to exceed 1 . The safety gaps on the transformer secondary terminals should ve 3 clearance. Make all calibration adjust nts on low power, ¼ to ½ .

S estions. The three cho coils ve s ilar characteristics and are intercha eable. If trouble develops in either plate choke coil remove the choke in the grid le cir it d install it in place of the defective plate choke. T grid leak choke terminals may be j ped as this choke may be dispensed with for e rgency o ration. Emerge y choke coils y made up of two 400-t n honeycomb coils in series, or their equivalent.

If the ante a has not already been reinsulated with standard porcelain insulators, this should be done as the old hard rubber straps and rods are not satisfactor for CW. One porcelain insulator should be used in each halyard and rod insu ators in the spreader guys. If a two-wire ante a is used, one porcelain insulator sh ld be placed in each end of each wire, which will ma it unnecessary to use any insulation in the bridles or ys.

Go over all co ections periodically. It is of the utmost ortance that the resistance of the te a and gro d system be reduced to a minim . If the te a wire is not in good co ition it should be renewed and all connections made thor y tight. Instances of swi i signals from E.T. 3628 transmitters have been traced to faulty antenna const ction, unnoticed on spark transmitters, but show up very badly with CW transmitters. The ante a should be secured as rigidly as possible to eliminate capacity changes and consequent swinging of signals. If the regular standard deck insulator is not in first class condition, it should be replaced with a porcelain type deck insulator. The ground connection should be given special attention. It is suggested that at least three ground leads be run to different points in the hull or bulk-head, making sure that there is a direct metal connection between the bulk-head to which the ground lead is attached and the hull of the ship. Full advantage should be taken of all conduit pipe, heating system piping, and so on, utilizing these to supplement other ground points.

In any emergency due to failure of the motor-generator set or component parts the Converted P-8 transmitter can be operated from the 120-volt storage battery bank by placing the six-pole double throw switch, located in the charging panel, in the "discharge" position which is to the operator's right when facing the charging panel.

Communication could be carried on with this transmitter in the event of either one or both oscillator tubes becoming damaged and spares unobtainable. A damaged tube could be removed from the rack and the set operated with the remaining tube functioning as a half-wave oscillator. In case both tubes were found to be destroyed the circuit could be easily altered to take the form of a typical antenna spark discharge, where the antenna system is excited through direct connection to the outside terminals of the plate transformer secondary; the whole being connected across a small open gap. In order to accomplish this changeover, the vacuum tube circuit is completely removed from the plate transformer by disconnecting all three leads, the two attached to the outside ends and the one coming from the mid-tap. The safety gap remains connected across the secondary to serve in the capacity of a plain-antenna spark discharger. The antenna is attached to one end of the transformer and the ground to the opposite end. The mid-tap is left free. Each time the transformer voltage builds up sufficiently high to overcome the resistance of the gap a spark discharge takes place causing radio-frequency oscillations to traverse the open radiative system. However, the distance between the electrodes of the safety gap must be adjusted so that a spark discharge will occur at the "peak" voltage of the transformer secondary output.

Placing the E.T. 3628 Into Operation. Before starting the 2-kw. motor-generator be sure that the motor and generator field rheostat controls on the panel are at lowest points and also adjust the filament rheostat resistance for minimum voltage. To start the set close the main line d-c. switch on the panel and direct current will then flow to the motor field windings. Next press the automatic starter button or throw the antenna change-over switch to the transmitting position. The direct current line is now closed through the starting solenoid, marked on the photograph in Figure 2, causing the plunger bar of the automatic starter to raise. The plunger bar moves up slowly, short-circuiting each one of the motor armature starting resistances in succession as it touches the finger contacts. This operation is necessary in order to prevent an excessive current flow through the armature when starting. The starting resistances compensate for the lack of sufficient counter e.m.f. until the armature attains full speed. The direct current line to the motor armature coil is closed, however, only when the bar touches the first finger and at this moment the armat e will begin rotation. From this point on, the ar ture continues increasing in speed until the bar reaches its rmost position, after which the speed remains constant. The motor speed y be c nged by movi the slider of the field rheostat up or down, as the case may be. When the bar makes contact with the last fi er on t right, current flows to the nerator field t o h the low p r resistor (sh ted by a S switch the field rheostat). These latter devices re late t a-c. output of the generator. The rotary converter used for fila nt exci - tion is set into operation when the ante a change-over switch ("send-receive" itch) is placed in transmitti position. Adjust the fil nt rheostat until the filament voltmeter reads 10 volts. Now close the a-c. main line switch and place the wave-changer switch on the desired wave. This should be followed by depressing the transmitting key and at the same time turn the aerial inductance handle which controls the sliding contact, until a maximum deflection is recorded on the radiation ammeter scale. This method for fine tuning permits the best conditions of resonance, between the closed and open oscillation circuits, to be obtained. It is advisable to repeat this adjustment when operating on any of the five wavelengths. Do not change the wavelengths while the key is depressed. When the maximum antenna current is obtained and with the wave-changer on the desired wave, the key may be operated for the transmission of messages. The set is stopped by pressing the push button "start-stop" switch.

As previously mentioned the power is regulated by the generator field rheostat and in no case should the wattmeter be permitted to read higher than $1\frac{1}{2}$kw. The single-pole switch shunted across the low power resistor should be open when communication is established with nearby coastal stations in order to minimize interference.

The main line d-c. switch should be open when the set is not in operation because the motor fields are permanently connected across the line when this switch is closed. With the d-c. switch closed, current feeds to these coils continuously regardless of whether the motor generator set is running or idle.

FUNCTION OF PARTS

The antenna radio-frequency ammeter indicates maximum deflection when circuit resonance is established with the tank oscillatory circuit.

The loading inductances permit the antenna to be resonated with the closed circuit at the five wavelengths available.

The aerial tuning inductance is a continuously variable inductance having a sliding clip which can be moved by rotating the topmost handle on the front of the panel. The inductance can be increased or decreased inch by inch permitting a critical resonant adjustment to be obtained on all waves.

The primary inductance, called "tank inductance" or "plate coil", is used for obtaining the correct amount of inductance for a certain capacitance in the excitation condensers to [illegible]te the generation of continuous oscillations. Also, the tank inductance, being mutually related to the secondary inductance, functions to transfer part of its energy by electromagnetic induction to the open antenna circuit, thus setting the latter into excitation.

A plate excitation condenser of .[illegible] mfd. capacity is connected in series with the grid excitation condenser and tank inductance forming the closed oscillatory circuit. The plate condenser couples the output circuit or plate to the input or grid.

The grid excitation condenser of .014 mfd. capacity supplies the grids of the oscillator tubes with a radio-frequency alternating voltage obtained from the radio oscillations flowing in the tank circuit. This is known as the "feed-back voltage". It is seen from the diagram that the voltage drop impressed between grid and filament of the tubes is obtained through the two leads connected across only a portion of the total primary capacitance, i.e., the portion represented by the grid excitation condenser. This is a conventional Colpitt's oscillator circuit. The total capacity of the tank circuit is represented by both the grid and plate excitation condensers in series. Tuning this circuit to any required frequency is accomplished by varying the flexible leads on the primary inductance for any of the wavelength positions as designated.

The plate blocking condensers, of .001 mfd. capacity each, prevent the plate d-c. voltage supplied by the plate transformer from being applied directly to the grids of the tubes. These condensers are intended not only to isolate the d-c. circuit from the oscillating a-c. circuit, but they must offer a low reactance to the high-frequency component of the plate current and thereby serve as a by-pass path for this oscillating energy from the plates to the tank circuit. The plate supply system or power transformer secondary would be short-circuited if these condensers break down. The plate current flows through the plate r.f. chokes and the transformer secondary.

The plate radio-frequency choke coils keep the high-frequency current from backing into the power transformer circuit which would result in severe losses of energy. In this way the maximum flow of radio energy is maintained in the tank circuit.

It will be noticed that the radio-frequency chokes are not single-layer wound coils, but have a special form of winding. This construction was found necessary in order to prevent trouble due to burned-out chokes. The burning currents were frequencies of some even multiple of the fundamental or operating frequency of the transmitter. Because of the special winding, the chokes possess a greater amount of inductance and less distributed capacitance than the ordinary single-layer wound coil. To damage these special type chokes would require frequencies other than those that might possibly be generated in the circuits in which they are contained.

A filament heating transformer steps down the a-c. voltage to about 13 volts, no load. The filament rheostat permits the adjustment of the filament voltage.

A filament a-c. rotary converter receives d-c. power from the 110-volt d-c. line and delivers alternating current at 60 cycles to the primary of the filament transformer.

The grid leak resistance of 4000 ohms, connected in common to the grids of both oscillators, maintains the correct negative bias for stable operation.

A grid r.f. choke prevents losses through the grid leak circuit, i.e., high-frequencies which flow from the grid excitation condenser. The largest amount of this energy fed back from the plate circuit is necessary for building up a maximum alternating voltage on the grids to promote the generation of continuous oscillations. Also the grid choke will prevent ultra high-frequency or parasitic oscillations from being generated. The frequency of such oscillations, if allowed to occur, is governed by the plate to grid capacity of the two tubes in series and the inductance of the connecting leads.

The filament by-pass condensers allow the radio-frequencies to flow between the fil ent and tank circuit without opposition. With t these condensers the only other path provided would t o h the windi s of the filament heati secondary. These windi s t ally would offer a high inductive reactance due to their t ns and the presence of the iron core.

The plate power transformer is of the closed core t , and receives a l voltage -cycle c rent from its seconda , the opposite ends of which are co ecte o the plates of the oscillator tubes. Each tube alternately receives a positive a a negative voltage d ing successive cycles. Only the tube receiving a positive voltage at any particular t is active in permitti the flow of plate current. The plate voltage continually changes in stre th at the low frequency (5 cycles) causi the generated continuous oscillations to vary their plitude in like manner. This is called "tone or modulated" C.W. The primary circuit of the plate power transformer includes the transmitting key, wattmeter, and a-c. generator.

The hand transmitting key closes the generator a-c. circuit and energizes the plate transformer which in turn supplies the plate potentials necessary to set the vacuum tube circuit into oscillation.

The circuits of the motor-generator, automatic starter, and type "I" antenna switch are similar to those described in the lesson on spark transmitters.

A five-position wave-changer switch changes the wavelength of the closed oscillatory circuit or tank circuit simultaneously with the open radiative circuit; both contact arms are connected mechanically as indicated by the dotted line in the schematic diagram, Figure 4.

Tuning. Split-tuning Indications. Whenever calibration of the Converted P-8 is performed the power should be adjusted to about $\frac{1}{2}$ kw. and the tubes constantly observed during the process for heating and sparking. A rough tuning adjustment is first taken by placing the wavechanger switch on the lowest wavelength position and, with a wavemeter held near the tank inductance, measure the wavelength. (Note: The theory of operation of a wavemeter is given at the end of this lesson). The wavemeter condenser should be moved very slowly in order not to pass the exact point of resonance. The tank inductance is provided with only one clip which should be varied until the desired wavelength is obtained. This procedure is to be followed by resonating the antenna circuit to the primary or tank circuit. The adjustment is to be considered satisfactory when a maximum reading is obtained on the antenna ammeter. When tuning the antenna circuit care must be taken not to include too many turns on the secondary coil. It will be found that about two turns gives a sufficient amount of inductance for the proper transfer of power, and yet will not result in too close coupling between the primary and secondary circuits, a condition that usually produces an effect called "split tuning". It is essential that a transmitter be cleared of such an undesirable condition, providing it exists, because the frequency of the emitted signal will "swing" sharply from one frequency to another. The operator at the distant receiving station could only intercept the signals upon the frequency to which his receiver circuit is tuned and the other frequency, when the signal swings, could not be heard.

In order to detect the presence of split tuning the following two tests should be employed. First, the transmitter is in correct adjustment (i.e., only one frequency or wave is being radiated) when the ante a ammeter reading increases steadily while the open circuit is bro ht to resonance by t ning the handle on the front of the panel marked "aerial t i inductce", d if after the resonance point is passed the ter reading is again seen to decrease steadily. On the other d, it may be accepted t t two fre encies or waves are bei radiated (i.e. split t i) if t ammeter readi drops s denly after the critical point or highest reading is passed. It y be assumed t t the split tuning effect is d to tight co ling and t s trouble y be corrected by c n i the cou li . This is accomplished by alteri the amo t of secondary i uc ce use by very carefully goi over the ribbon wire inch by inch with the clip til a suitable point is found and not by varyi the distance between the two coils, they bei in fixed c ical relation to each other. The person perfo ing the calibration must not touch any wiring or clips when the tr smitting circuit is active. Second, anot r test for dete ining split t i is to rk the resonant point on the aerial i uctance scale while the handle is turned in one direction, a after pass the resonant point by two or t ee t ns of the h dle, reverse the direction ret n to reso nce and again mark the scale. If t two marks do not coincide the c ling should be reduced til they do.

After t calibration is co leted on low power, the power can then be increased to nor l and an ante a c rent of ab t 10 peres is us lly obtainable. In order to provide adequate protection to the transmitter apparatus the clearance between the safety gaps on the plate transformer secondary are to be set at 1/16th inch.

Practical Suggestions. The connections in the transmitter and power units should be gone over occasionally and at such times the antenna and ground system should also be inspected. While ordinary faults in an antenna system used with a spark transmitter do not lower the efficiency to any appreciable extent they do become troublesome with a C.W. transmitter. In order to maintain the resistance of the antenna at a minimum the ground lead should make a clean metal connection with the hull of the ship. Two or three ground leads are generally required and these may be easily traced to their actual locations whether they be made on the hull, bulk-head, conduit pipe or heating system piping.

The old hard rubber straps and rods which insulate the antenna are generally replaced with porcelain insulators whenever C.W. operation is to be employed. The porcelain insulators inserted in each end of the one or two wires forming the horizontal elevated portion of the antenna, those in each halyard, and the porcelain deck insulator should all be carefully examined for cracks or chips in their surfaces which would allow the insulators to absorb moisture.

In the transmitter proper all of the three r.f. chokes have similar characteristics and are interchangeable. If trouble develops in either plate choke coil remove the choke in the grid leak circuit and install it in place of the defective plate choke. The grid leak choke terminals may be jumped as this choke can be dispensed with for emergency operation. Emergency choke coils may be made of two 400-turn honeycomb coils in series, or their equivalent.

Maintenance. The filament rotary converter should be kept oiled and commutators clean. All parts of the transmitter must be protected from water and spray and kept clean and dry at all times. The bakelite panel and rods and the treated maple boards used in the set should, in particular, be wiped off with a dry cloth every day. Should the transmitter accidentally get wet, it should not be started until it has been wiped off and the insulation and choke coils have become thoro hly dry. The ari s of the 2 . motor-generator should kept oiled a t c .tators cle e of sparki .

Should it c necessary to c e tubes, t s should be done carefully to prevent breakage. Tubes t en the set should be immediately placed in the containers from w ch spare tubes re removed.

oubles dies. T circ t used is very stable and can be relied upon o o ra e sa sfactorily er all conditi w re the apparatus is not defective, except two co itions, as follows:

1. T oscillations will not start when the key is closed if t re is a poor co ction in the ta circuit or inte ittent bre i do of the t circuit insulation either to gr or in the condensers.
2. n the ante a coupl is too tight the m imum te a c rent ca ot be obtained as the t circ t will shift frequency when ap oac resonance of the ante a circuit.

n the te a is s ll, or t resistance very l , it will be fo d t t the ximum out t y not load t tubes to their full rati and, der these circ stances, no attempt sh ld be de to increase the loadi by over-voltage or cha e circuits ot r t n care l t ing and use of proper value of coupl .

The coupling is varied by means of cha i the n ber of t ns t secondary i uct ce instead of by varyi the distance tween the pr y and secondary coil.

Signals from these transmitters may swing slightly in rough weather due to the rolling of the ship, changing the antenna capacity. The antenna should be pulled taut to minimize this as much as possible. However, should excessive swinging be complained of, it will probably be because the secondary circuit is too closely coupled to the primary. The coupling should be loosened by decreasing the number of turns used in the secondary of the oscillation transformer. Usually not more than two or three turns are required on this coil for proper coupling. Any change in the number of turns used in the secondary coil must be compensated for by a corresponding change in the aerial inductance to bring the set back into resonance.

Burned Out Filament Converter, Filament Transformer, or Filament Rheostat. Disconnect all of these units and connect filament terminals directly to a five-cell lead-acid storage battery which will supply approximately the right filament voltage. Leads formerly connected to the mid-tap of the filament transformer should be connected to the negative side of the storage battery. The regular filament rheostat cannot be used with a storage battery as it will not carry the heavy current flowing directly in the filament circuit. However, the voltage of a five-cell storage battery should be so close to normal that no regulation will be required.

Burned Out Grid Leak. The resistance of the grid leak used on this transmitter is 4000 ohms. Should the grid leak become burned out with no spare available, a suitable resistance could be made up from material available on board ship by using a piece of rubber hose about a foot long, filled with salt water and plugged at both ends with wires extending through the plugs at both ends and making contact with the salt water in the hose. A little experimenting with the length of hose to be used should result in obtaining the proper value of resistance for satisfactory operation. Any suitable resistance having a value between 2,000 and 10,000 ohms may be used.

Another method which may be utilized in case a suitable material may not be found on board is that of the ordinary lead pencil - sharpening both ends to get the necessary contact with the lead. It can be shortened if necessary to approach the required resistance. This is, of course, an emergency measure.

Filament Converter Fails to Start. In some cases the filament converter may not start immediately when the circuit is closed if maximum resistance is cut in with the filament rheostat. In such cases the armature of the converter should be turned over immediately by hand.

Trouble in One Side of Circuit Which Cannot be Repaired at Sea Due to Lack of Material. Spare tubes, a spare plate choke, spare grid leak and spare transformer secondary sections should be aboard at all times. If these spares are available and the set is properly cared for it should be possible to keep it always operating at maximum efficiency. It should be borne in mind, however, that, if necessary, this set may be operated at reduced power with only one good tube, one good plate choke and one good plate transformer. Should there be available only one good tube, one good plate choke, one good plate blocking condenser, or only one-half of the secondary of the plate transformer, the defective part should be removed from the circuit and the lead to the plate transformer on that side disconnected. The set may then be operated at reduced power on one tube with about half the normal radiation. If only one tube is used, care should be exercised to reduce the filament voltage to normal.

In the event of irreparable damage, making it impossible to use even one side of the circuit, a "plain aerial" spark transmitter for emergency use only may be made by removing all connections from the three secondary terminals of the plate transformer and connecting the antenna to one outside secondary terminal of this transformer and the ground to the other outside secondary terminal. The safety gaps on the secondary terminals will then serve as a spark gap, as previously stated in this lesson. Necessary changes may be quickly made by disconnecting the flexible lead from the secondary of the oscillation transformer, lengthening this lead as much as necessary and connecting it to one side of the power transformer. The other side of the power transformer should then be connected to the piece of copper tubing leading from the secondary of the oscillation transformer to the thermo unit of the radiation ammeter. This will tune the circuit and permit of reading the radiation on the radiation ammeter. It is very improbable that it will ever be necessary to resort to the use of the plain aerial circuit and such circuit should never be used unless the vessel is in distress and the transmitter damaged so that it cannot be made to function normally.

NOTE: Porcelain, micalex, or glass antenna and deck insulators should be used with this type of transmitter. If other forms of insulation are used there is likely to be an excessive drop in radiation during wet weather.

The UV-204A tubes used in this transmitter are provided with an X-L or thoriated filament, the characteristics of which are low power consumption and high electron emission at low operating temperature. This low temperature very considerably increases the life of the tubes.

The UV-204A tube has a nominal power rating of 250 watts output. The current required for filament heating is 3.85 amperes per tube. The filament voltage must never exceed 11 volts. Satisfactory operation should be possible at all times with the filament voltage adjusted to between 9 and 10 volts.

In case of severe overload resulting in overheating of the tube, the electron emission may decrease and oscillations may not start when the key is closed. Unless the overload has liberated a large amount of gas, the activity of the filament may be restored by operating at rated filament voltage for 10 minutes or longer with the plate voltage off.

In the case of all tubes equipped with thoriated filaments, the end of the useful life of the tube is usually reached before the filament burns out. A tube may have lost its emission and be useless even though the filament lights and it is not otherwise defective. If a tube cannot be reactivated by the method described above within a reaso ble le th of time, it should be replaced by one of the spare tubes.

vemeter. The wave ter is one of the most portant measuri instruments in the radio field, and is used to calibrate a trans tter or receivi circuit to a definite frequency or wavele th, its principle of operation dependi upon the phenomen of resonance. Some wave ters are desi d to transmit a radio-frequency energy which can be detected in a receiver, and the receiver may be calibrated fr the own frequency of the wave ter. Transmitters radiate their o energy, a a wave ter held in close i uctive relation to the tr smitter oscillation transformer will ve the energy impressed upon its circuit.

A suitable ter will indicate, by a im c rent deflection of its needle, when the wavemeter circuit is adjusted to resonance. This is done, usually, by varying the capacity of the air condenser. The co enser scale is marked in divisions, either directly in wavelength, frequency, or in degrees. If the co enser scale divisions are marked in degrees, a graph or chart will accompany the ter. The c ves on the graph are so dra that for any de ee of setting of the condenser the corresponding frequency, or wavele th in ters, y be read.

The wavemeter consists essentially of variable condenser with its dial calibrated, and an i uctance, called an "exploring coil", previously calibrated from a o standard of inductance. The meter which indicates the m im c rent in this oscillatory circuit, comprising inductance and capacity, st so arr ged that the meter movement will not in any way impede the radio-

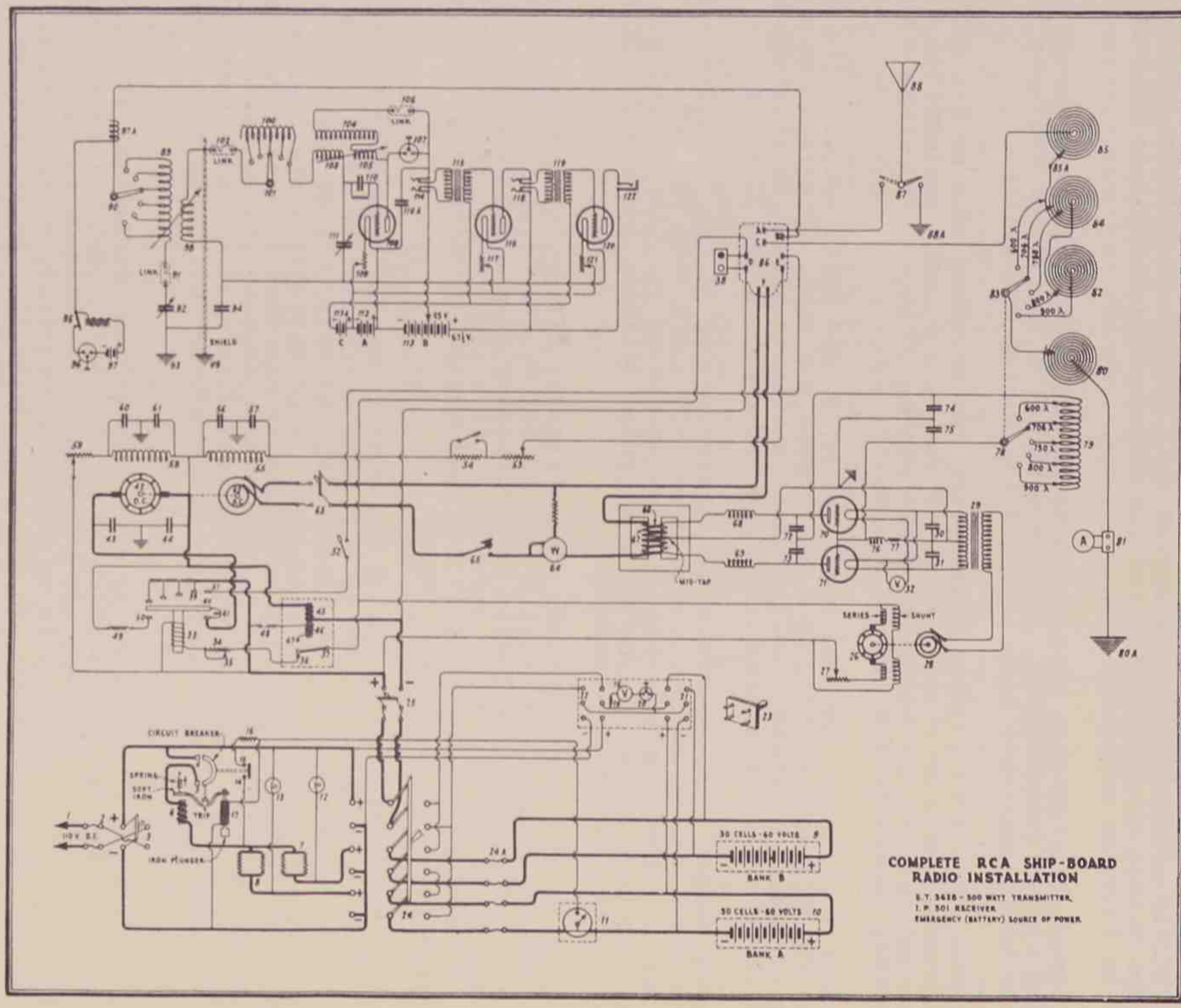
COMPLETE RCA SHIP-BOARD RADIO INSTALLATION
I.P. 501 RECEIVER
EMERGENCY (BATTERY) SOURCE OF POWER
CIRCUIT BREAKER
SPRING
SOFT IRON
TRIP
IRON PLUNGER
110 V. D.C.
30 CELLS - 60 VOLTS
BANK B
BANK A
SERIES
SHUNT
MID-TAP
SHIELD
LINK

Figure 4

frequency currents that flow. Therefore, there are two standard types in use, as follows:

The first type is the hot-wire meter consisting of a straight wire along which the currents flow. Since the heat dissipation increases and decreases with an increase or decrease of current the wire will expand and contract, and a small spool or bobbin is turned by any change in length of the hot wire. The spool is connected to the needle and a movement is imparted to the latter, causing it to deflect across the scale. Usually the divisions on the scale do not indicate the actual current flow, but are arbitrary divisions for comparative reading. The divisions are not uniform in length, but become gradually greater as the current intensity increases. This follows the current square law of alternating currents.

The second type in common use is the thermo couple. The oscillatory circuit is brought to a junction which is composed of two dissimilar metals, for example, bismuth and antimony, and current which flows across this junction will produce an e.m.f. much the same as though the junction were heated by a flame. A galvanometer connected to the junction will indicate the value of the current. This meter is constructed similar to a d-c. ammeter, in that its electromagnetic winding acts upon a permanent magnet to give movement to the needle. The radio-frequency currents only pass across the junction and not through the meter windings. The meter scale is generally calibrated in divisions from 0 to 100, each of equal length because the deflection depends upon the magnitude of the e.m.f. produced at the junction. The value of the direct current is directly proportional to the e.m.f.

Most wavemeters are supplied with several inductances or exploring coils, only one of which can be used at a time, to cover a definite band of frequencies. The different coils are designed so that the frequencies they cover overlap at the upper and lower limits in order to provide a continuous frequency range.

MAIN DIAGRAM LEGEND——FIGURE 4

1. D.C. supply, ship's generator.
2. Fuses.
3. Polarity reversing switch.
4. Main circuit contact of underload circuit breaker.
5. Main circuit contact of underload circuit breaker.
6. Circuit breaker overload electro-magnet.
7. Charging resistors.
8. Charging resistors.
9. Bank of 30 lead-acid storage cells.
10. Bank of 30 lead-acid storage cells.
11. Ampere-hour meter.
12. Trickle-charge lamp.
13. Trickle-charge lamp.
14. Low-voltage release coil.
15. Low-voltage release coil.
16. Limiting resistor.
17. Low-voltage release coil.
18. Voltmeter.
19. Voltage multiplier.
20. Voltmeter switch.
21. Voltmeter plug receptacle.
22. Voltmeter plug receptacle.
23. Voltmeter plug.
24. Six-pole charge-discharge switch.

24a. Fuses.
25. Transmitter panel D.C. supply switch.
26. Filament rotary converter. (D.C. end).
27. Filament rotary converter voltage regulator rheostat.
28. A.C. end of filament rotary converter.
29. Filament lighting transformer.
30. Filament by-pass condenser (.5 mfd.)
31. Filament by-pass condenser (.5 mfd.)
32. Filament voltmeter.
33. Automatic starter solenoid coil.
34. Solenoid coil protective resistor.
35. Short-circuiting contacts for protective resistor.
36. Solenoid contact of overload relay.
37. Movable contact of overload relay.
38. Starting button switch.
39. Starting resistors and contact fingers.
40. Contact bar.
41. Flexible connection.
42. Motor armature.
43. Protective condenser (1 mfd.).
44. Protective condenser (1 mfd.).

45. Overload relay coil.
46. Holding coil.
47. Holding coil contact.
48. Holding coil limiting resistor.
49. Dynamic brake resistance.
50. Dynamic brake contact.
51. Generator field contact.
52. Generator field switch.
53. Generator field rheostat.
54. Low power resistor and switch.
55. Generator field.
56. Protective condenser (1 mfd.).
57. Protective condenser (1 mfd.).
58. Motor field.
59. Motor field rheostat.
60. Protective condenser (1 mfd.).
61. Protective condenser (1 mfd.).
62. A.C. generator armature.
63. A.C. output switch.
64. Wattmeter.
65. Hand key.
66. Primary of plate transformer.
67. Secondary of plate transformer.
68. Plate choke coil.
69. Plate choke coil.
70. U.V. 204-A radiotron.
71. U.V. 204-A radiotron.
72. Plate blocking condenser (.001 mfd.).
73. Plate blocking condenser (.001 mfd.).
74. Plate coupling condenser (.002 mfd.).
75. Grid coupling condenser (.014 mfd.)
76. Grid choke coil.
77. Grid bias resistor, 4000 ohms.
78. Wave changing switch ("tank" circuit).
79. Primary or "tank" circuit inductance of aerial transformer.
80. Secondary inductance of aerial transformer.
80a. Ground.
81. Aerial ammeter and thermo-couple
82. Aerial load coil.
83. Wave changing switch (secondary circuit).
84. Aerial load coil.
85. Aerial tuning inductance.
85a. Aerial tuning inductance switch.
86. Aerial change-over switch.
A. Aerial connection.
B. Receiver connection.
C. Transmitter connection
D. Motor starter contacts.
E. Generator field contacts.
F. Key contacts.
87. Lightning switch
88. Aerial.
88a. Aerial ground.
89. Primary winding of receiving transformer.
90. Primary inductance switch.
91. Long wave attachment link.
92. Primary series condenser (.0008-.0045 mfd.)
93. Ground connection
94. Grounding condenser.
95. Buzzer tester.
96. Buzzer push button switch.
97. Buzzer battery.
97a. Buzzer pick-up coil.
98. Coupling of secondary inductance.
99. Shield.
100. Secondary inductance.
101. Secondary inductance switch.
102. Long wave attachment link.
103. Coupling coil of secondary inductance.
104. Tickler coil.
105. Coupling coil of tickler inductance.
106. Long wave attachment link.
107. Oscillation test button switch.
108. Detector tube U.X. 201-A.
109. Filament rheostat.
110. Grid leak and condenser.
110a. Plate to filament by-pass condenser.
111. Secondary tuning condenser (.00006-.00032 mfd.).
112. "A" battery (filament).
113. "B" battery (plate).
113a. "C" battery (grid).
114. Detector jack.
115. First stage coupling transformer.
116. First stage amplifier tube U.X. 201-A.
117. Filament rheostat.
118. First stage amplifier jack.
119. Second stage coupling transformer.
120. Second stage amplifier tube U.X. 201-A.
121. Fil ent rheostat.
122. Seco stage amplifier jack.

O ATION OF APPARA S

<u>The E.T. 3628 Transmitter</u>. The transmitter y be operated from the ship's generator or, in an emergency, from the storage ttery, by throwi the six-pole switch (24) to the left or right, respectively. n using the ship's generator the storage battery panel circuit breaker should be open, disconnecti the stor e batteries.

When the D.C. supply switch (25) on the transmitter is closed current will flow through the motor field (58). When aerial switch (86) or the starting button (38) is closed current will flow through the starting solenoid (33), through the protective resistor (34), through the lower contact of overload relay (36), through contact bar (37), and back to the negative line. This will cause the contact bar (40) to move upward. As soon as the bar touches the first contact finger current will flow through the starting resistance (39), through the flexible connection (41), through the motor armature (42), through the overload coil (45), and to the negative side of the line. The motor will now start and, as the contact bar continues to rise, the motor speed will increase until the bar reaches the top contact at which time the motor will be running at maximum speed. At this point the protective resistance (34) is automatically cut in the circuit by the contact (35) which is operated mechanically. The bar now touches the generator field contact (51) and current flows through the generator field (55). The output of the generator is controlled by the rheostat (53). Low power is obtained by opening switch (54) which cuts in the series resistance. As a safety measure switch (52) is used to open the generator field while the motor generator is running and the transmitter is not being operated.

The input to the primary (66) of the power transformer is controlled by the hand key (65) and measured by the wattmeter (64). The secondary (67) of the power transformer is center tapped (mid-tapped) and is connected to the plates of the two U.V. 204-A tubes. Plate choke coils (68 and 69) prevent R.F. currents from flowing in the transformer. The condensers (72 and 73) prevent the low frequency supply current from flowing in the R.F. circuits. Condensers (74 and 75) couple the plate and grid circuits respectively, and with the tank inductance (79), constitute the oscillatory circuit. Coil (76) is a grid choke for preventing the flow of parasitic currents, i.e., ultra high frequencies.

Switch (78) changes the wavelength of the tank circuit. It is mechanically connected to the secondary switch (83) thereby permitting the inductance of both circuits to be changed at the same time. The inductance of the secondary coil (80) remains fixed after the transmitter is tuned and it should not be changed. The thermo-coupled ammeter (81) measures the aerial current. Coils (82 and 84) are aerial load coils. Coil (85) is the aerial tuning inductance. The aerial change-over switch (86) transfers the aerial from the transmitting to the receiving position and vice-versa. The lightning switch (87) should be grounded when the operator is not on duty.

The filaments of the U.V. 204-A radiotrons (70 and 71) receive their current supply from the step-down filament transformer (29). The condensers (30 and 31) by-pass R.F. current around the transformer. The meter (32) measures the filament voltage. The filament transformer is supplied from a small 100-watt rotary converter, the output of which is controlled by the rheostat (27).

The generator (62) output is increased by means of the field rheostat (53) until the safety spark gaps on the tank circuit condensers begin to spark over. The voltage is then decreased to a point just short of ere sparking occ s; t wattmeter (64) should read about 1.5 k.w., the for oi adjustment is for maximum out ts; lower outputs y be obtained by adjusting the generator field r ostat (53).

The key (65) houl ot essed while cha i wavel ths in order to av id arcing at e swi c con ac s.

To stop the transmitter t aerial ch ge-over switch (86) is t o to the receivi position. This not only shifts the aerial fr the tr smitter to the receiver, but opens the key, generator field and starter circuits as well, el inati the possibility of accident due to live circ ts.

The I.P. 501 Receiver. When the aerial switch (86) is thrown in the receiving position received signal energy will flow from contact (B) to the primary inductance switch (90), thence through inductance (89) through the antenna series condenser (92), and to ground (93). The variable coil (98), a part of the secondary inductance, is employed to provide coupling between the primary and secondary circuits. Condenser (94) is used to ground the filament side of the secondary. When the primary and secondary are in resonance current will flow through the main secondary coil (100), the inductance of which is adjustable by means of switch (101). The purpose of condenser (111) is to tune the secondary. Coil (103) is a part of the secondary and is used to couple the tickler coil (105). Coil (104) is the main tickler coil.

The grounded shield (99) prevents undesirable induction between the primary and secondary circuits. When the oscillation test button (107) is closed the tickler coil is short circuited; this enables the operator to ascertain if the circuit is in a state of oscillation. A click indicates that the circuit is oscillating.

The remainder of the receiving circuit consists chiefly of a standard two stage audio amplifier with jacks (114-118-122) in each stage, and individual filament rheostats (109-117-121). Either the detector, first stage, or two stages, may be used for reception of signals. A crystal detector may be employed by connecting it to binding posts on the panel provided for that purpose, (not shown in the diagram). To aid in adjusting the crystal detector, and to test the set in general, the buzzer circuit (95-96-97) has been provided. It is inductively coupled to the aerial by the pick-up coil (97A).

In operating the I.P. 501 receiver the filament rheostats should be turned on, and the small "send-receive" switch on the receiver panel placed in the "receive" position. The coupling should be tightened, maximum primary condenser capacity used, and minimum secondary condenser capacity and minimum tickler coupling employed. These adjustments place the receiver in the "listen in" or "stand by" position.

When t ing for spark signals or I.C.W. the pri ry and seconda inductance switches are turned til the des d si l is heard, and both inductance capacity are adjusted for signal stre th. The coupl bet en the primary d seco ary should be loosened as much as possible. When t i for C.W. si als the tickler knob should t d til the circuit is oscillati . The li s 91, 102 106 are ovided so that extra induct ces y be used for lo ves (a long wave attac nt is usually provid fo with this receiver).

Stor e Batte C r i P el. To char e t batteries switch 3 i d the s -pole switch (24) is t to t left. T circuit bre n closed with the left d and, at t s e time, t iron pl ger is pushed up with t ri t d to release t trip. C rent will flo the positive side of the line t h contacts 4 a 5 , t h the load coil (6), s lt ously t h the two battery b s 9 a 10 t o h the ampere-hour er (11 , a back to the negative side of t If the supply voltage c s too low en c ging, t circuit break trip thereby preventing the batteries from discharging. Current will fl thr h t contacts (14 a 15 on t rear of t panel, t l iti resistor (16), thr h the overload coil 17 and back to the tive l .

If the supply voltage bec s too high when c gi , t circuit brea will trip because the c nt fl t o h coil 17 will stro to pull t iron lever downw .

When the batteries become fully charged the black needle on the ampere-hour meter (11) will reach the vertical position thereby short circuiting coil (17), releasing the iron plunger, causing it to trip the circuit breaker. A small amount of current will then flow through the trickle charge lamps (12 and 13) keeping the battery on a very slow (trickle) charge, otherwise the batteries will slowly discharge. To discharge the battery the six-pole switch (24) is thrown to the right. This connects both banks (9 and 10) in series giving 120 volts.

EXAMINATION QUESTIONS

1. What could be done in an emergency if the E.T.3628 transmitter became temporarily inoperative?

2. What causes swinging signals?

3. Why are plate radio-frequency choke coils used?

4. What are the advantages of vacuum tube transmitters as compared to other types?

5. What is meant by the term "split-tuning"?

6. Where are the ground connections usually made on shipboard?

7. In this lesson there is a statement that reads, "The loading inductances permit the antenna to be resonated with the closed circuit at the five wavelengths available". What is meant by this statement?

8. (a) Of what is the closed oscillatory circuit composed? (b) What is a "tank inductance"? (c) How is the filament voltage obtained for the U.V.204A tubes?

9. If the ship's generator should fail from what source of supply would the transmitter motor-generator receive its input?

10. (a) Why is a grid r.f. choke coil used? (b) Why is a grid leak used?

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VACUUM TUBE OSCILLATORS

Lesson Text V13-9

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VACUUM TUBE OSCILLATORS

The vacuum tube is conceded to be the most important single factor which has contributed to make the art of radio attain its present proportions. In this lesson we will be concerned with the use of the vacuum tube as a generator of radio frequency energy or "R.F." oscillations.

The vacuum tube is able to act as an oscillation generator due to its ability to amplify, that is, a voltage change on its input circuit (grid-filament) will produce a larger change in voltage built up in its output circuit (whatever is connected between the plate and the filament). In order for the tube to produce sustained oscillations, certain conditions must be fulfilled.

FIRST an "oscillatory" circuit must be provided to roughly fix the frequency of oscillation and whose energy storing capacity is sufficient to supply coil losses between impulses of plate current. Thus the coil and condenser combination is known as the "tank circuit", since energy is stored due to the high circulating current. This gives the circuit a "flywheel" effect like a flywheel on a steam engine or on an automobile engine since impulses from the cylinders are not continuous, but occur periodically and it is the inertia of the flywheel that keeps the crankshaft turning between impulses.

SECOND it is necessary to feed back energy from the output (plate) circuit to the input (grid) circuit if the tube is to be a "self excited" oscillator. This is always accomplished by either electromagnetic or electrostatic coupling between the output and input circuits.

THIRD the fed-back energy must be in the correct direction, that is, in the correct phase to make the tube oscillate.

Let us first consider the circuit of a regenerative detector of radio frequency signals (Figure 1) as used in certain types of receivers.

A radio wave sweeping by the antenna induces a voltage in the antenna (to induce a voltage in a conductor the conductor must move through a magnetic field or the field must change around a stationary conductor - the latter case applies to a receiving antenna). This induced antenna voltage which is alternating at radio frequency (the frequency of the radio wave that traveled across the antenna) causes an R.F. current to flow to ground through the antenna or coupling coil L_a. The current in L_a sets up a varying flux

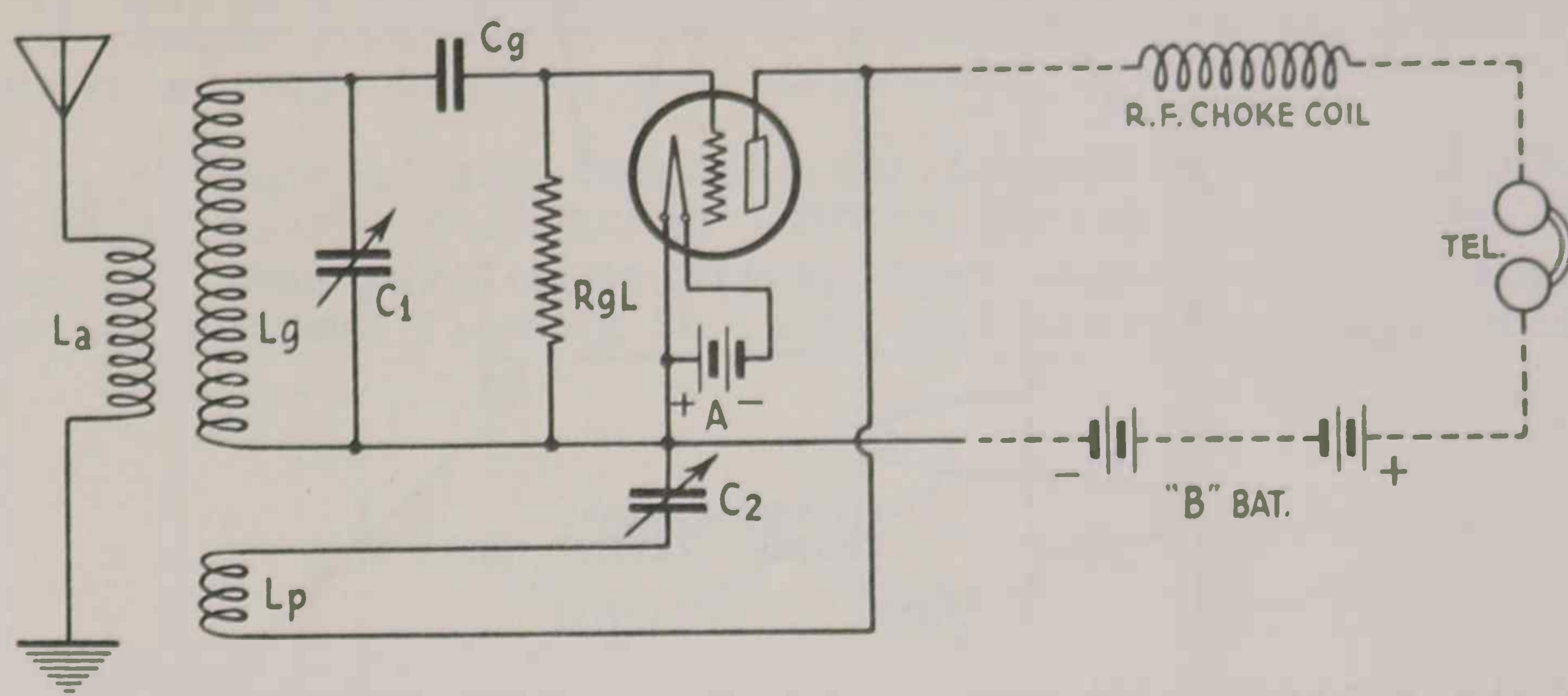

Fig. 1--Regenerative detector

of magnetic lines of force some of which thread through L_g and induce in L_g a voltage usually larger than the voltage across L_a since the turns in L_a are less than those in L_g and the two coils form a radio frequency (air core) "step-up" transformer. Since there is zero bias voltage between the grid and the filament of the tube with no signal input voltage an alternating (at R.F.) grid voltage will produce an alternating (also at R.F.) plate current. This is shown by Figure 2 which indicates the plate and grid current of the tube at some particular plate voltage.

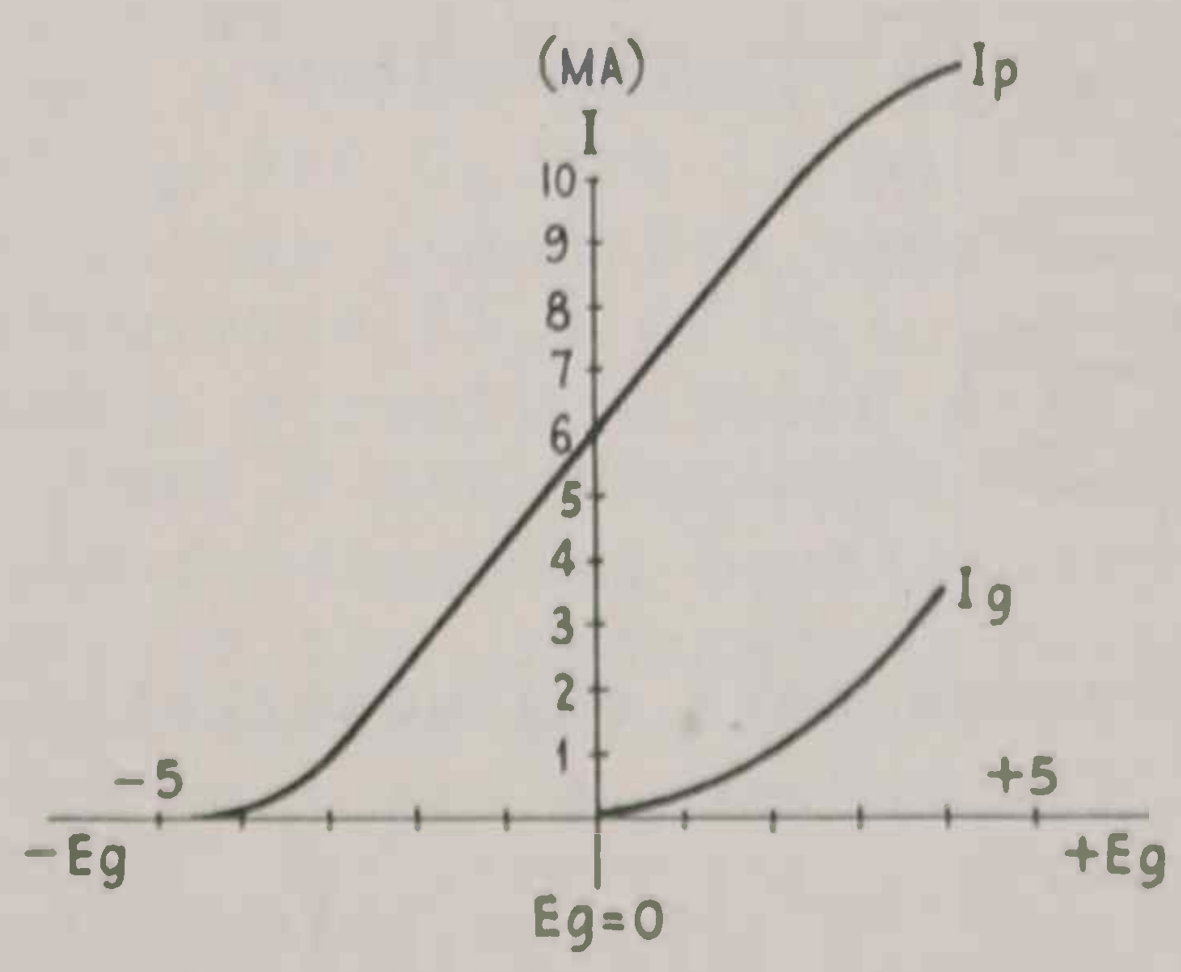

Fig. 2--Mutual characteristic curve

The plate current (I_p) grid voltage (E_g) curve (Figure 2) is sometimes called the mutual characteristic curve since it concerns both plate and grid elements of the tube. Note that the curve labeled I_g starts at $E_g = 0$ and occurs only in the region of plus values of grid voltage since the grid and plate only draw current when they are positive with respect to the filament.

When an alternating signal voltage appears on L_g (Fig. 1) the grid is plus with respect to the filament for half of the cycle and minus for the other half. This is shown in Figure 3.

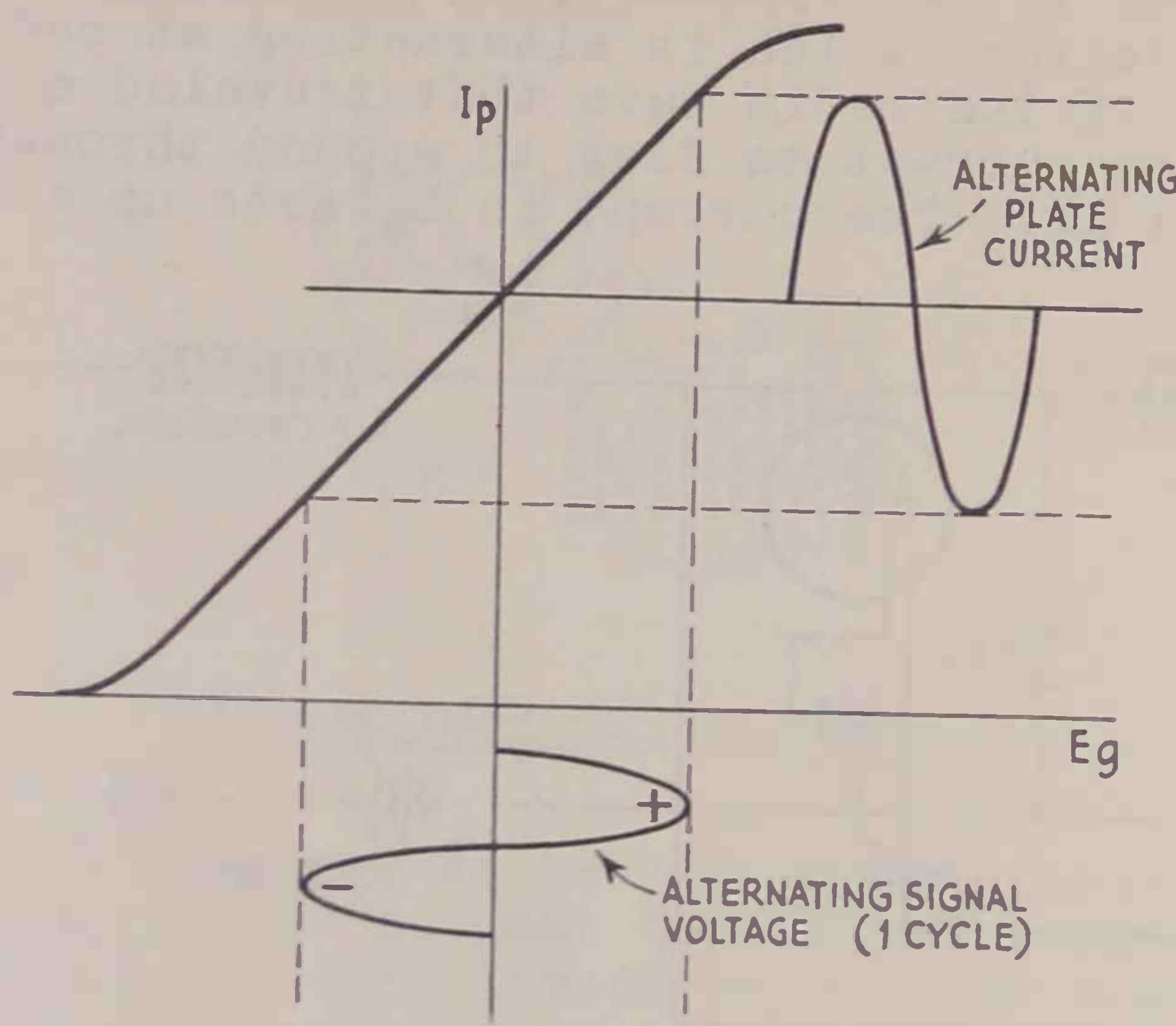

Fig. 3--Grid-voltage, plate-current characteristic curves

A continuous wave (CW) signal impressed on the grid would affect plate current as shown by Figure 4. Since the operating point of the tube changes when I_g flows through R_{gL} the IR drop on R_{gL} biases the grid negative with respect to the filament.

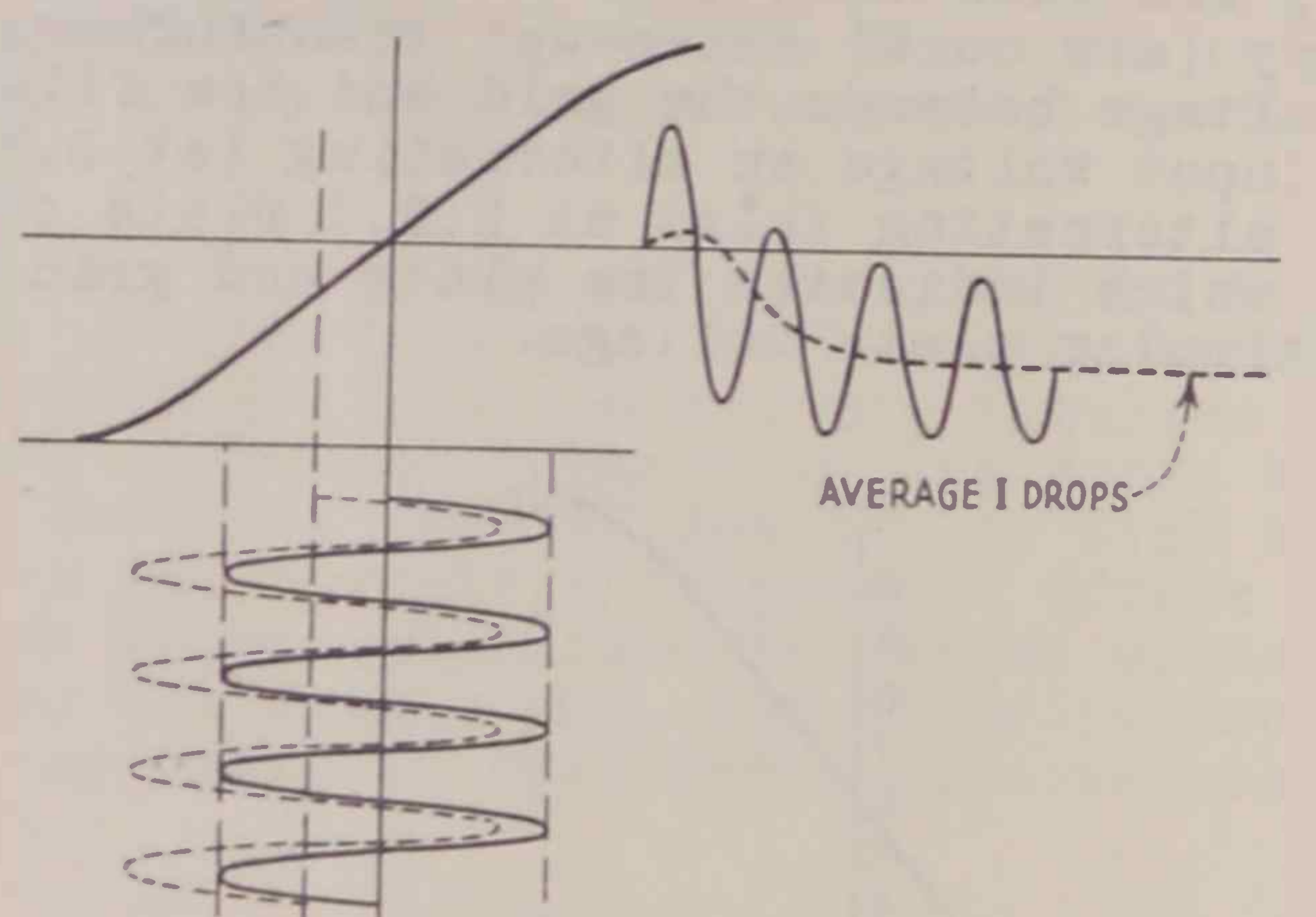

Fig. 4--Continuous wave characteristic

This would produce only a "click" in the telephones when the transmitter was turned on and another "click" when turned off. A modulated CW signal, which is a wave whose amplitudes are being changed at the modulation frequency would produce a result as shown in Figure 5.

This would produce a tone in the telephones equal to the frequency of the pulses of DC through the telephones, that is, the modulation frequency, whatever that might be.

It should be quite apparent from Figures 3, 4, and 5 that there is present in the plate circuit of the tube an alternating current at the frequency of the signal voltage impressed on the grid by coil L_g (Figure 1). If this current is choked out of the telephones and is made to flow through a coil L_p coupled to Lg (Figure 1) before its return to filament it will produce a new voltage in L_g which will reinforce the signal voltage present in L_g and therefore produce a larger plate current wave than was present before this plate circuit energy was returned to the grid circuit. Such action is called regeneration, which of course produces stronger signals in the telephones and is also known as regenerative amplification.

L_g and C_1 (Figure 1) are tuned to the frequency of the incoming signal and it is of course well known that by tuning L_g by C_1 to the desired frequency of some particular signal that signal will produce more circulating current flowing in Lg C1 and therefore more voltage

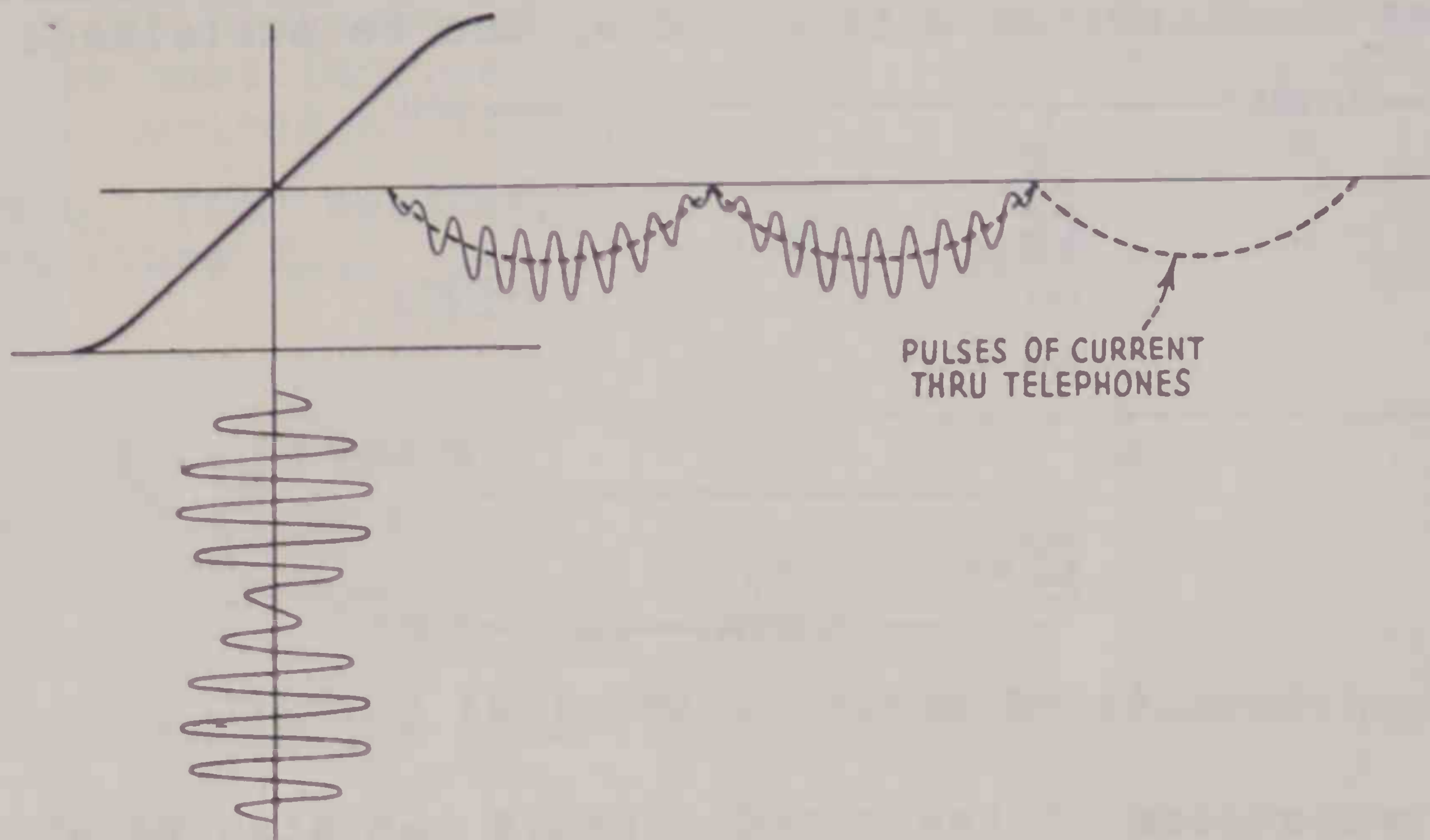

Fig. 5--Modulated CW characteristic

across L_g and C_1 than a signal having a slightly different frequency, in other words we get selectivity and amplification by tuning the circuit. Such a tuned circuit is known as a "parallel resonant" circuit since L_g and C_1 are in parallel and tuned to resonance, which means that the inductive reactance (X_L) of L_g is equal to the capacitive reactance (X_c) of C_1. It can also be shown that the impedance of such a circuit between grid and filament is equal to L/CR, where L, C, and R are constants of the tuned circuit L_g C_1. Referring to the fundamental oscillatory circuit, having only a coil and condenser, if the condenser C is charged by a DC voltage and then connected to the ends of a coil L the condenser will discharge through the coil and a current will flow from the (—) to the (+) terminal of the condenser through the coil. This current sets up a magnetic field around the coil. When the condenser is discharged current stops flowing and the magnetic field collapses, which induces a voltage in the coil of the opposite polarity and the condenser is then charged in the reverse direction. The condenser then discharges again and this process would continue indefinitely were it not for the presence of one thing, the resistance (R) of the LC circuit. The resistance "damps out" oscillations and each successive reversal builds up a smaller voltage until all oscillation ceases.

Any LC circuit can be made to oscillate if the effective resistance is zero. When additional voltage is present in the grid coil L_g (Figure 1) due to regeneration, more circulating current flows around the L_g C_1 circuit. This circuit originally had a certain AC resistance since no circuit is physically possible that does not have resistance. It is true that coils may be constructed of large wire, space wound and a good quality of insulation used for the coil form, all of which makes the AC resistance smaller, but of course never equal to zero. Since more current is now flowing in the grid circuit due to the increased voltage from regeneration it may be considered that the Resistance of the circuit has been decreased. Ohms Law states that current in a circuit may be increased by either increasing the voltage applied or by decreasing the resistance of the circuit. It should be quite apparent then that if regeneration is increased sufficiently the resistance of the L_g C_1 circuit will be decreased to zero or may even become a "negative" resistance, which means that oscillations will build up and be sustained.

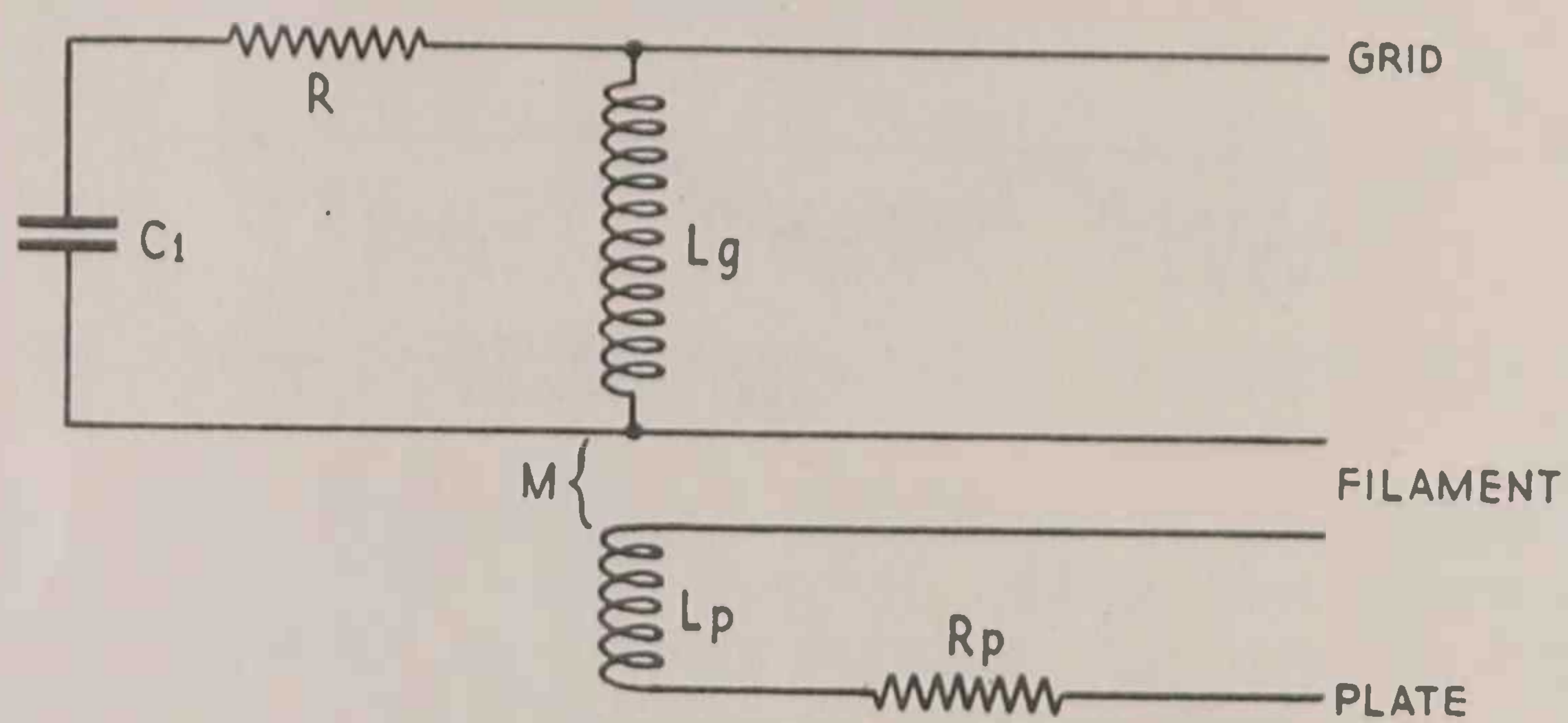

Fig. 6--Schematic of resonant parallel circuit

The change of resistance of the tuned circuit can also be shown mathematically as well as by the above reasoning.

Let R = AC resistance of the L_g C_1 circuit.
L_p = Self inductance of the plate coil.
M = Mutual inductance of the plate and grid coils.
$\omega = 2\pi f$.
R_p = AC plate resistance of the tube.

Figure 1 is reproduced in the "equivalent circuit" form in Figure 6.

By an analysis of a resonant parallel circuit the total impedance of the grid-filament circuit is L_g/C_1R when considered alone. However, coil L_p is coupled to L_g and from coupled circuit theory the "coupled-in" resistance of the plate circuit to the grid circuit is equal to $\frac{\omega^2 M^2}{R_p}$. Therefore the expression for grid-filament impedance will be

$$\frac{L_g}{C_1\left(R \pm \frac{\omega^2 M^2}{R_p}\right)}$$

The ± sign before the M meaning the mutual inductance is positive or negative depending on whether the turns of L_p are aiding or opposing the turns of L_g. If M is (+) the total resistance of the tuned circuit L_gC_1 is increased and regeneration cannot be accomplished, in fact "degeneration" occurs. If however, M is made (—) by connecting it properly the total resistance of the circuit L_g

C_1 is made less and regeneration obtains. Now if regeneration is increased to a point where $-\frac{\omega^2 M^2}{R_p}$ is greater than R of the tuned circuit L_g C_1 then oscillation will result which will roughly be at the resonant frequency of L_g C_1. There are three ways of determining when resonance exists in a parallel circuit, namely: (1) When maximum circulating (tank) current flows. (2) When minimum line current flows. (3) When the capacitive reactance X_C equals the inductive reactance X_L.

The above methods of determining resonance are not exact and none of the three give the same result, but the difference in frequency by the three methods is such a small fraction of one per cent that practically the answer is the same. Of course for calculation purposes the third method is used. The other two are used in actual transmitting circuits, particularly the second. The third method of determining the frequency of a parallel (or series) circuit results in one of the most important equations in the theory of radio circuits and is derived as follows:

If $X_C = X_L$ (for resonance)
then since $X_C = \frac{1}{2\pi fC}$ and $X_L = 2\pi fL$ $\quad 2\pi fL = \frac{1}{2\pi f C}$

and $(2\pi fL)(2\pi fC) = 1$
or $(2\pi)^2 f^2 LC = 1$
from which $f^2 = \frac{1}{(2\pi)^2 LC}$

And abstracting the square root of both sides of the equation,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Where f = cycles per second
L = inductance of coil in henries
C = capacity of condenser in farads
$2\pi = 6.28$

The practical form of this equation is,

$$f = \frac{159.2}{\sqrt{LC}}$$

Where f = kilocycles per second (kc)
L = inductance in microhenries (μh)
C = capacity in microfarads (μf)

In the actual oscillator circuit the L and C of the above equation must respectively include the inductance of the connecting leads and the stray capacities of wiring etc., as well as the inter-electrode capacities of the vacuum tube itself.

In receiving continuous wave signals it is necessary to use either the heterodyne method, a separate oscillator coupled to the detector or the autodyne method, an oscillating detector. The latter is the more common and is the circuit shown in Figure 1. There are many ways of controlling regeneration and oscillation for the autodyne detector which are outside the scope of this lesson. In Figure 1 however, control of oscillation is effected by condenser C_2 usually known as the "throttle" condenser since by changing its reactance more or less alternating plate current (at the signal frequency) is allowed to flow through L_p which controls the amount of negative resistance coupled into the grid circuit and hence gives the operator control over the strength of regeneration or oscillation depending on whether the received signal is of a modulated character or just a continuous wave.

The circuit under discussion (Figure 1) is known as the "Tickler Feedback Circuit", the plate coil Lp being the "tickler" coil. This circuit may be used for transmission, in fact an oscillating detector if coupled to the antenna acts as a low power transmitter and modern receivers using an autodyne detector incorporate a stage of tuned radio frequency amplification using a screen grid tube to stop the radiation from the receiver since this is a very obnoxious form of "man made" interference.

There are many forms of oscillator circuits, but the most important and the ones with which you should become familiar are set forth in the remainder of this lesson. It is truthfully said that the vacuum tube is the heart of the present day radio art and likewise the oscillator circuit is the foundation of all radio transmitters since it is the source of radio frequency energy.

THE HARTLEY OSCILLATOR CIRCUIT

You will note the similarity of Figure 7 to that of Figure 1 which was used to explain regeneration and oscillation. The coils L_g and L_p are no longer separated but are one continuous winding with a

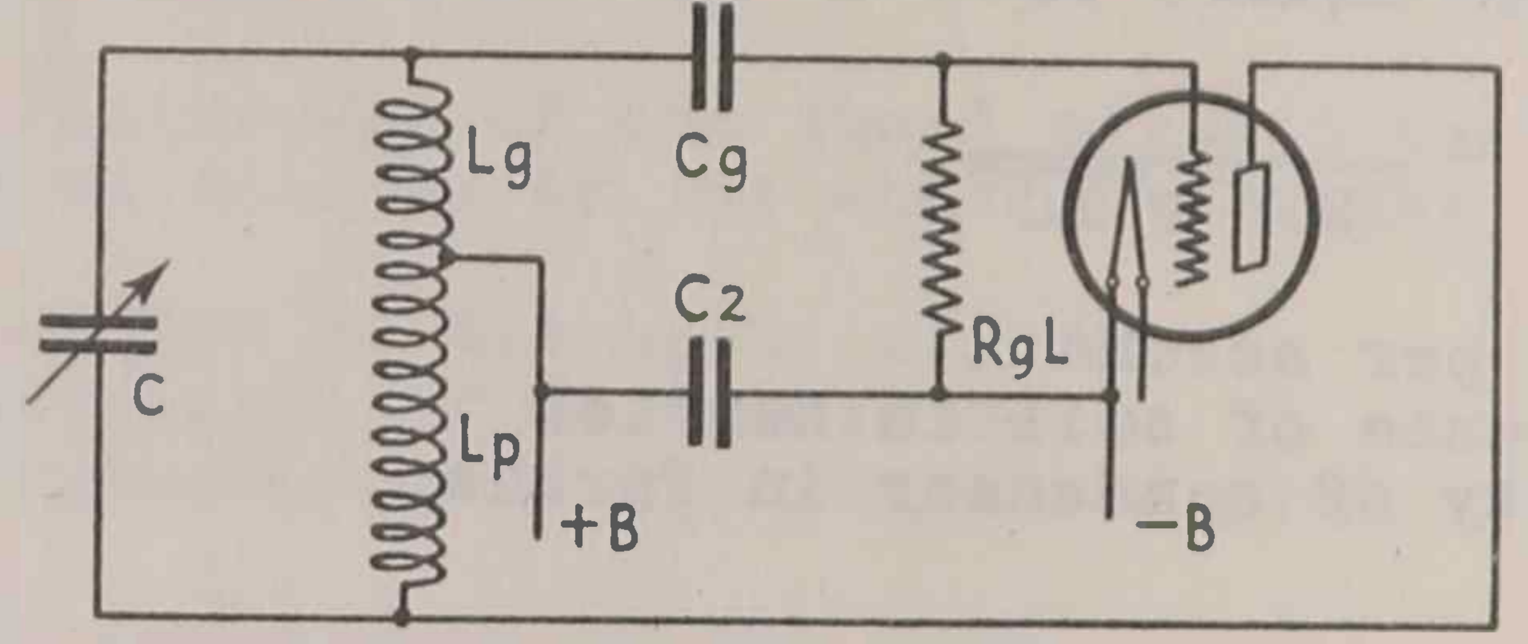

Figure 7--Schematic of Hartley oscillatory circuit

tap connected to filament, and the condenser C approximately tunes the total inductance, $L_g + L_p + 2M$, to the oscillation frequency. Instead of C_2 being the regeneration and strength of oscillation control it is moved to position as shown and is called a "plate blocking" condenser since it blocks the positive DC from flowing to filament and minus B thus shorting the high voltage supply.

The action of the circuit in Figure 7 is identical to the action of Figure 1 with the exception that Figure 7 is that of a strong oscillation generator while Figure 1 is of a regenerative or oscillating detector which is most sensitive to continuous waves when the regeneration condenser C_2 is set just above the oscillating point.

Assuming that the tube filament is "on" and proper adjustment of circuit constants has been made, when plate voltage is applied, a surge of plate current will flow from —B through the tube from filament to plate, through the coil L_p and back to +B. This initial "transient" current will be rather high since there is no bias voltage built up across the grid leak R_{gL} as yet. Since the initial flow of plate current represents a transient condition, a voltage will be induced in L_g due to the changing flux lines from L_p cutting through coil L_g. As the current through L_p increases the voltage across L_g will also increase and will be 180° out of phase with the voltage set up across L_p, that is, if the plate end of L_p is — then so is the grid end of L_g. This causes the plate of grid condenser C_g connected to L_g to also be — and the other plate which connects to the grid of the tube to be + or meaning that it has a deficiency of electrons. Since the grid of the tube is connected to the + plate of C_g it will be charged + and will attract electrons from the filament which will neutralize the + charge on the grid side of C_g. The electrons from the filament continue to pile up on the condenser plate, but are allowed to leak off back to

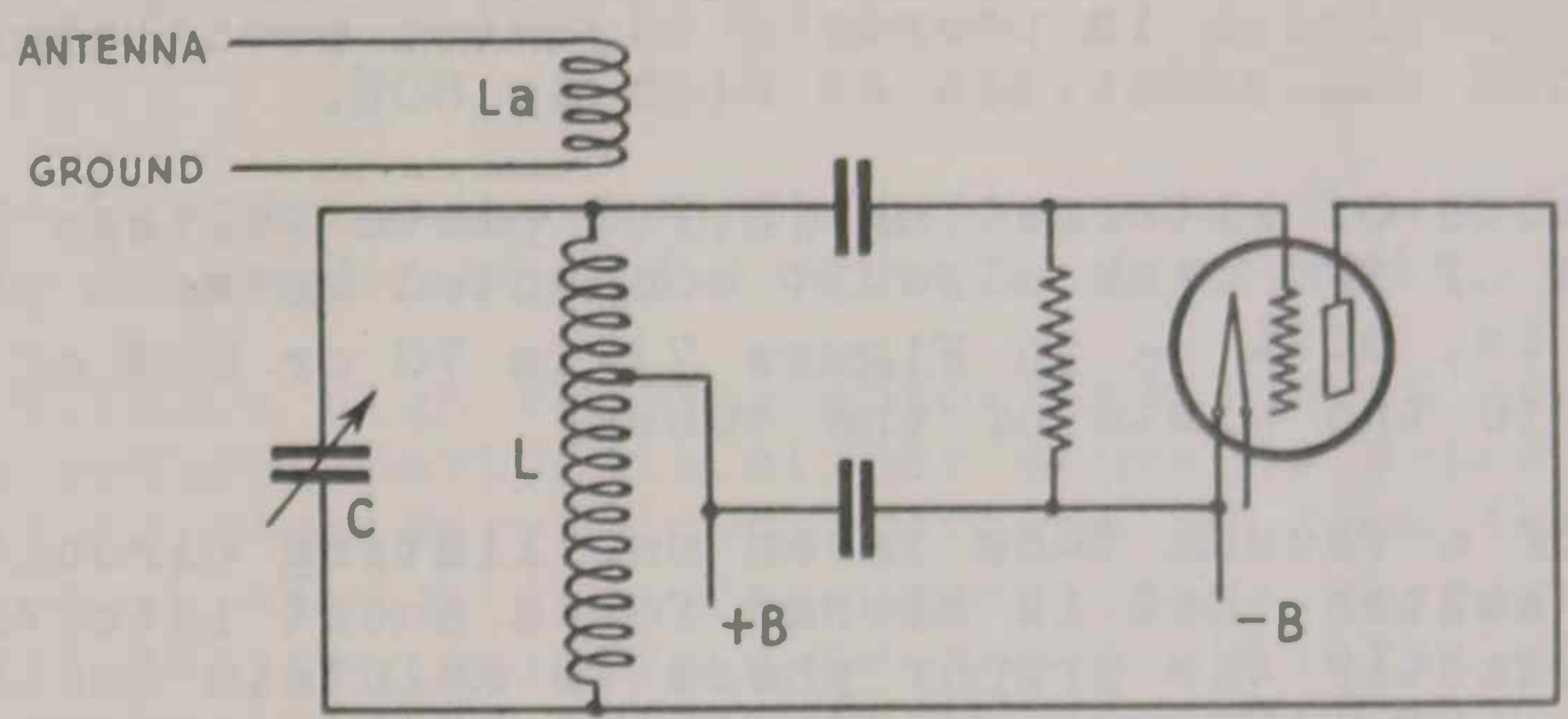

Figure 8--Schematic of an inductively coupled oscillator circuit

filament through the grid leak R_{gL} which then constitutes a flow of grid current and develops a voltage across R_{gL} with the polarity of this grid leak being — at the grid end and + at the filament end of the grid leak. This voltage biases the grid negative with respect to the filament and the plate current will then decrease. It should be clear then that the total current flowing through L_p is composed of two components, a steady DC which may be considered to have an alternating component superimposed on it. The alternating component induced in L_g acts just like the signal voltage induced in L_g from the antenna coil L_a in Figure 1 and due to the amplification of the tube a larger alternating voltage will be built up on L_p which again induces more voltage in L_g and energy is thus <u>fed back</u> from the plate to the grid circuit and oscillations are built up if the resistance of the LC circuit is decreased to a zero or negative value. Since LC is a parallel resonant circuit, a large R.F. "tank" current flows around the LC circuit and a smaller amount of R.F. "line" current flows. The circulating current or "tank" current flowing <u>around</u> the LC circuit times the R.F. voltage set up <u>across</u> the circuit represents the fly-wheel on an engine and even though plate current impulses occur only during a fraction of the R.F. cycle the circulating current or tank circuit volt-amperes represent a constant "tank" of R.F. energy.

Since power is required to excite or "drive" an antenna or the grid circuit of an R.F. amplifier tube the oscillator must be capable of furnishing this power. The simplest radio transmitter is shown by Figure 8 which indicates an oscillator circuit inductively coupled to an antenna for purposes of radiation of radio energy.

The antenna resistance is coupled into the LC tank circuit by L_a. This increases the series resistance of the LC circuit and hence more feedback is required so the total series resistance of LC with the antenna coupled may be reduced to the necessary value for oscillations to exist. The ratio of volt amperes in the tank circuit to the watts dissipated in the coupled-in resistance or the "load" must be at least 10 or 12 for good operation. Usually this ratio is made even higher.

The voltage and current relations in a "self excited" oscillator such as has been described are such that the grid bias developed by the rectified grid current flowing through the grid leak is more than enough to reduce the plate current to zero except for only a small portion of a cycle (usually about 1/4 to 1/6 of a cycle) and hence plate current flows in impulses and the tube is operated as "Class C" which makes for high efficiency of conversion of DC power to R.F. power; the express purpose of an oscillator circuit. The efficiency of conversion in properly adjusted oscillator circuits is at least 50% and sometimes as high as 80%.

Usually the peak value of alternating (R.F.) plate voltage built up across that part of the tank circuit connected between plate and filament (that is, coil L_p in Figure 7) is 70 or 80% of the DC voltage applied to the plate of the tube.

The plate circuit of a vacuum tube in an oscillating circuit acts like a synchronous switch that is closed for a short interval during each cycle in exactly the proper phase to maintain oscillations in the resonant LC circuit. The opening and closing of this fictitious switch is accomplished by the alternating voltage applied to the grid, and the portion of the cycle over which the "switch" remains closed depends on the amount of the grid bias.

In an efficiently adjusted oscillator circuit the plate current impulses are far from being of the "half sine wave" shape and in fact are called square topped waves. Such a wave is full of "harmonics" and use is made of this fact in actual transmitters.

If the oscillator in a transmitter functions on 2000 kc the oscillator coil will have present across its terminals voltages (of smaller amplitudes) representing harmonic frequencies of the fundamental, that is 4000 kc — the second harmonic, 6000 kc — the third harmonic, etc each harmonic being consecutively weaker. If the plate circuit of an amplifier tube coupled to the oscillator circuit is tuned to one of these harmonics the amplifier tube will amplify this harmonic and the amplifier is called a "doubler" or "tripler", etc, depending on whether the second, third, etc, harmonic is amplified. The strength of the harmonics is always greater the more square topped the plate current wave is, therefore a large bias on the tube produces harmonics better than a low bias.

SERIES AND SHUNT FEED

There are two ways in which the + DC plate voltage can be applied to the tube. If the DC plate current from the high voltage source flows through the tuning coil (as in Figure 7 and Figure 8) then the circuit is said to be a series fed one while if the + DC is fed to the plate through an R.F. choke coil and is blocked away from the tuning coil by a plate blocking condenser the circuit is known as a shunt fed one. Both methods are used in modern transmitters. When the shunt method is used it is very important that the R.F. choke coil be so constructed that its own "natural period"— the frequency to which the distributed capacity between turns and the inductance of the coil tunes - will be different from the oscillator frequency. Since the coil with its distributed capacity forms a parallel resonant circuit similar to the "tank" circuit a high circulating current would flow in the choke coil which would rob energy from the tank circuit as well as heat and very likely damage the choke, since it is usually wound with small wire to conserve space and only the DC from the high voltage supply flows through it - a matter of a few milliamperes usually. While the

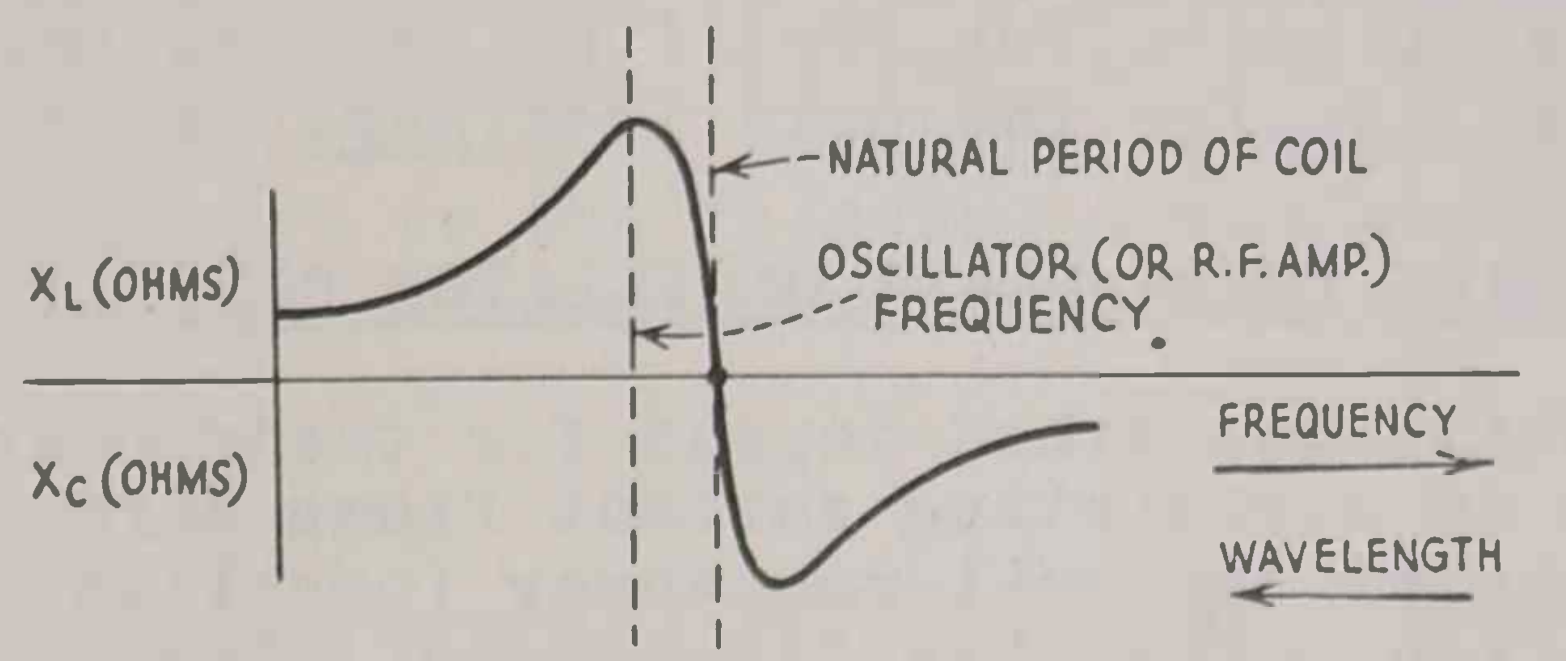

Figure 9A— Relative reactance values of a choke coil on each side of its natural period

choke will offer a high reactance to the flow of the R.F. current if its natural period is either above or below the oscillator frequency it is considered good practice to have the natural period of the choke at a higher frequency than the oscillator since it then offers inductive reactance to the oscillator plate circuit rather than capacitative reactance which would act as a by-pass condenser from plate to ground. The relative reactance values of a choke coil on each side of its natural period are shown in Figure 9A which also indicates the best point of operation.

THE COLPITTS OSCILLATOR CIRCUIT

The Colpitts oscillator circuit, Figure 9B, is no less important than the Hartley. When the plate supply voltage is applied to the tube a

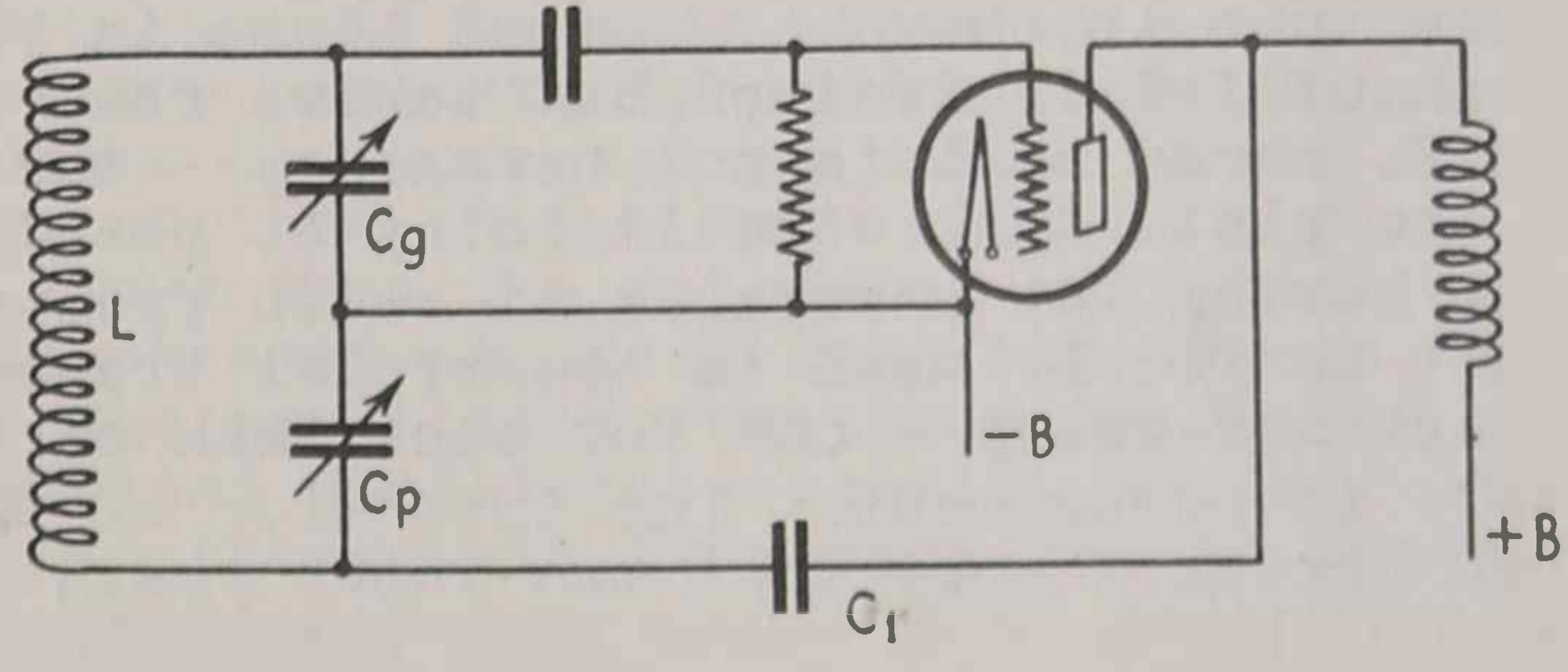

Figure 9B—The Colpitts oscillator circuit

transient condition of plate current exists which impresses a varying voltage drop across the plate-filament elements of the tube and the plate condenser C_p of the oscillatory circuit. The voltage across C_p causes a circulating current to flow in the tank circuit and therefore a voltage approximately 180° out of phase with that across C_p is developed across C_g and the grid-filament circuit from which point the action of the tube is the same as any self excited oscillator. Any oscillator "starts" oscillating due to transient currents when turned "on".

You will note that this type of circuit requires that the plate be shunt-fed, since there is no filament or "zero R.F. potential" tap taken off the coil through which to feed the +B current as in the Hartley circuit and a plate choke coil would be necessary if the +B connected to either end of the coil, both ends being at R.F. potential. Since a choke must be used it might as well connect to the plate and +DC. It can be blocked from the coil by condenser C_1. Also there is no choice between connecting the grid leak "across" the grid condenser, or from the grid to filament as there is in the shunt-fed Hartley, since in the Colpitts circuit the coil has no DC path to filament for rectified grid current, and the grid to filament connection for the grid leak must be used.

THE TUNED-GRID, TUNED-PLATE OSCILLATOR CIRCUIT

The two previous circuits described depend for their operation on the fact that tank or circulating current flows through both grid and plate portions of the coil-condenser (oscillatory) circuit. The T.G.T.P., often called the "Armstrong" circuit, how-

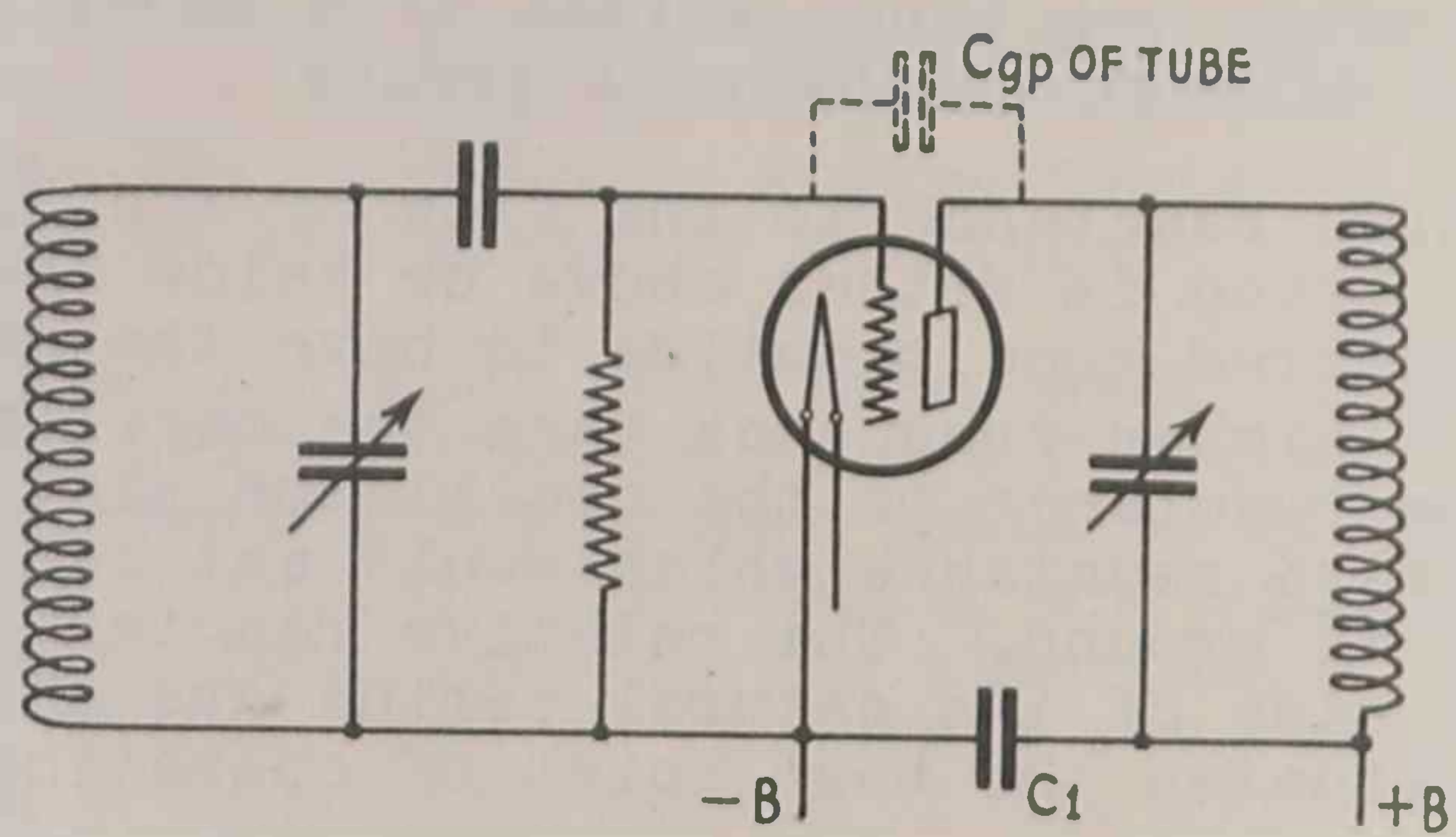

Figure 10--Tuned-grid, tuned-plate oscillator circuit

ever depends on feedback taking place through the grid-plate capacity of the tube itself since there is practically no coupling between the separate grid and plate tuned circuits. The grid-plate capacity of the tube is shown by dotted lines in Figure 10. The plate could be shunt fed if desired, but series feed is more simple because an R.F. choke coil is not necessary - the lower or filament end of the plate tank circuit being at practically ground potential, C_1 having low reactance at radio frequencies. The Armstrong circuit is rarely used in commercial transmitters since two controls are necessary - one for each tank circuit, and it requires more care in adjustment. The operation of the T.G.T.P. circuit is explained on the theory that the input resistance of a vacuum tube depends on the type of plate load used. In this case the plate tank is tuned to a slightly higher frequency than the grid tank in order that the tube's input resistance will be negative and cancel out the positive series resistance of the grid tank, thus allowing oscillations to be sustained. Changing the setting of either the grid or plate tuning condenser will cause the frequency generated to vary. It is quite apparent that in certain types of commercial transmitters where the operating frequency is being changed several times a day this would necessitate a waste of time in adjustment, besides the cost and mechanical complications of another tank circuit, whereas the Hartley and Colpitts circuits require only one tank circuit and one tuning control.

THE ELECTRON-COUPLED OSCILLATOR CIRCUIT

In the electron-coupled oscillator circuit the filament or cathode must be above ground potential. Figure 11 accomplishes this by using an indirectly heated cathode tube. If ordinary filament type tubes are used in this circuit the filament must receive its current through heavy R.F. choke coils or if AC is used on the filament, the transformer may be a special one having more than the ordinary spacing between secondary and primary windings so that the capacity between windings is low. Another alternative is to use copper tubing for coil L_1 and run the filament wires inside the tubing to the lower end of L_1 which is grounded. The filament wires may then connect to the filament transformer and the actual filament is maintained above ground potential.

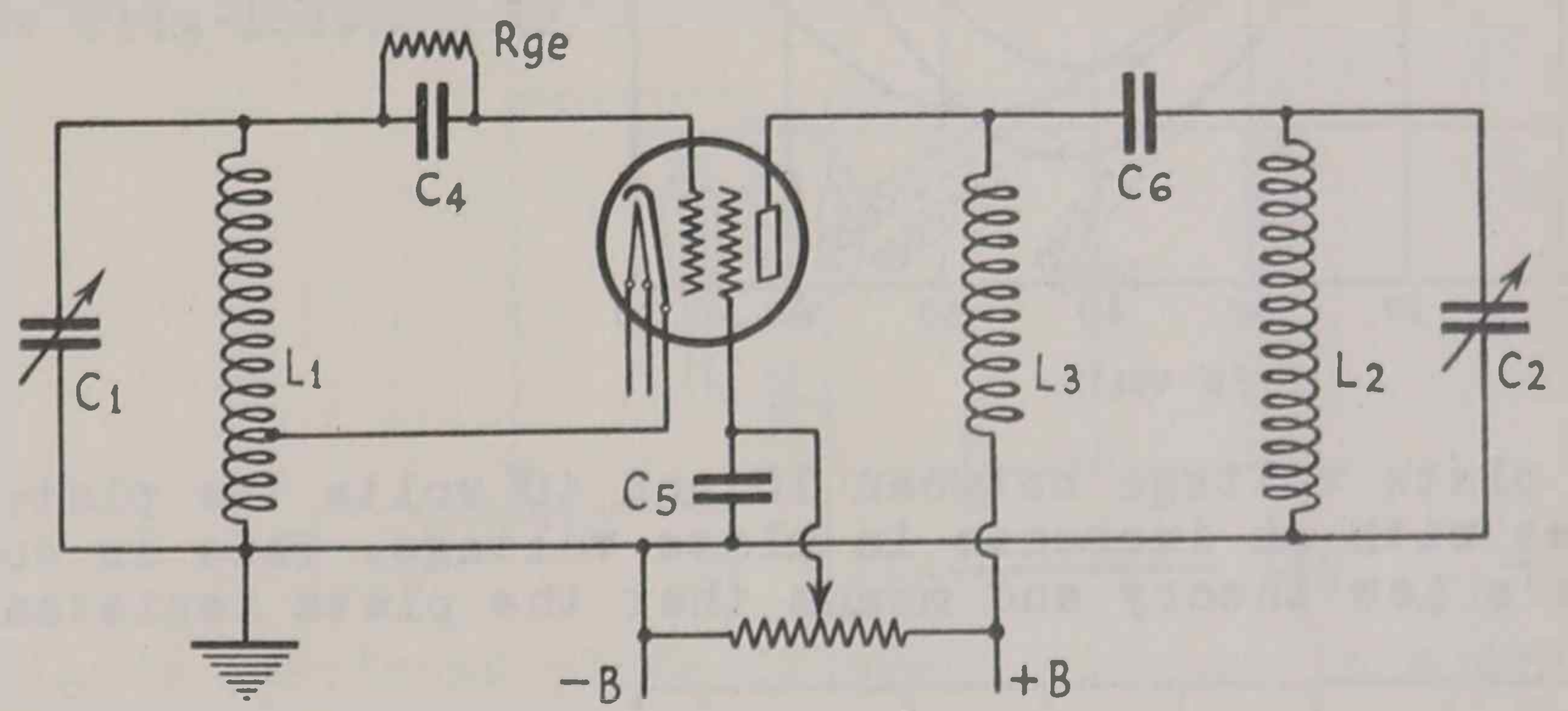

Figure 11--Electron-coupled oscillator circuit

The L_1C_1 combination is the frequency determining portion of the circuit and L_2C_2 is the "work" circuit. Since the screen is maintained at ground R.F. potential by condenser C_5 the coupling to the plate or work circuit depends on the electrons flowing through the screen, hence the name "Electron-Coupled". This circuit has a number of desirable characteristics one of which is the small effect of a change of load on the work circuit L_2C_2 on the frequency of oscillation. Thus when the following amplifier stages are keyed or modulated the changes in their load impedances do not reflect back and change the oscillator frequency nearly as much as in the ordinary self excited oscillator circuit. Another desirable characteristic is that changes in frequency due to plate voltage and screen voltage variations are opposite to each other. Thus if proper plate and screen voltages are used as much as a 20% change in supply voltage will cause very little frequency shift. It will be noted that the work circuit L_2C_2 is coupled to the plate through capacity C_6 and the plate is shunt-fed through choke L_3. If C_6 is made as small as practicable, consistent with the desired output, the result of load variations on generated frequency will be very small. This type of circuit is finding favor as an oscillator in Master-Oscillator Power-Amplifier Transmitter circuits and as a heterodyne frequency meter in addition to its use as an oscillator in superheterodyne receivers.

THE DYNATRON OSCILLATOR

To explain the "Dynatron" it is necessary to consider the curves on a four-element (S.G.) vacuum tube such as the 222 or 224 type. The E_p-I_p curves for various plate, screen and control grid voltages are shown in Figures 12 and 13 for the 224 tube.

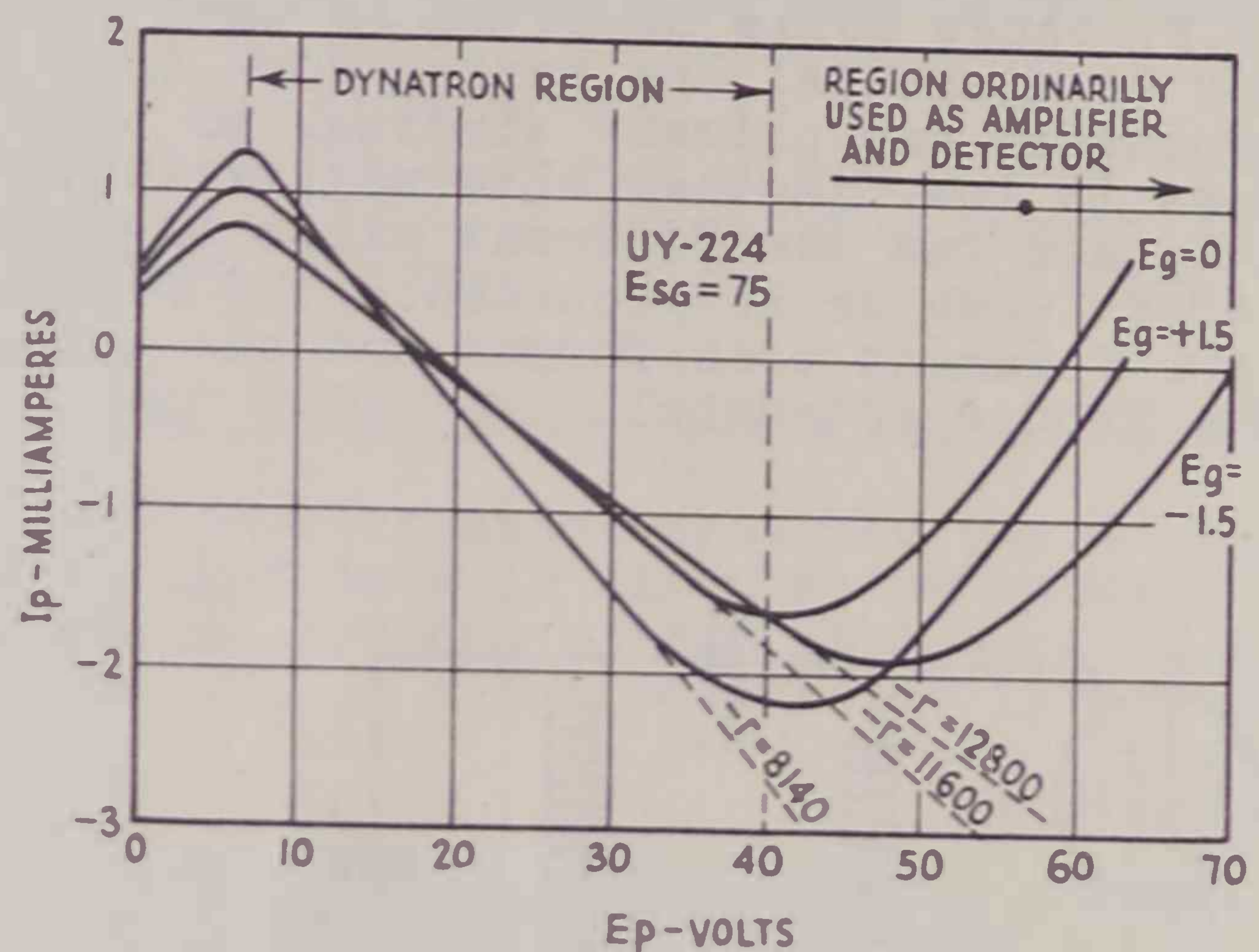

Fig. 12--Plate-voltage, plate-current characteristic of a screen-grid tube in the dynatron region with constant screen-grid voltage and three different values of control-grid voltage

In the range of plate voltage between 10 and 40 volts the plate current decreases with an increase in plate voltage. This is contrary to all Ohm's Law theory and means that the plate resistance

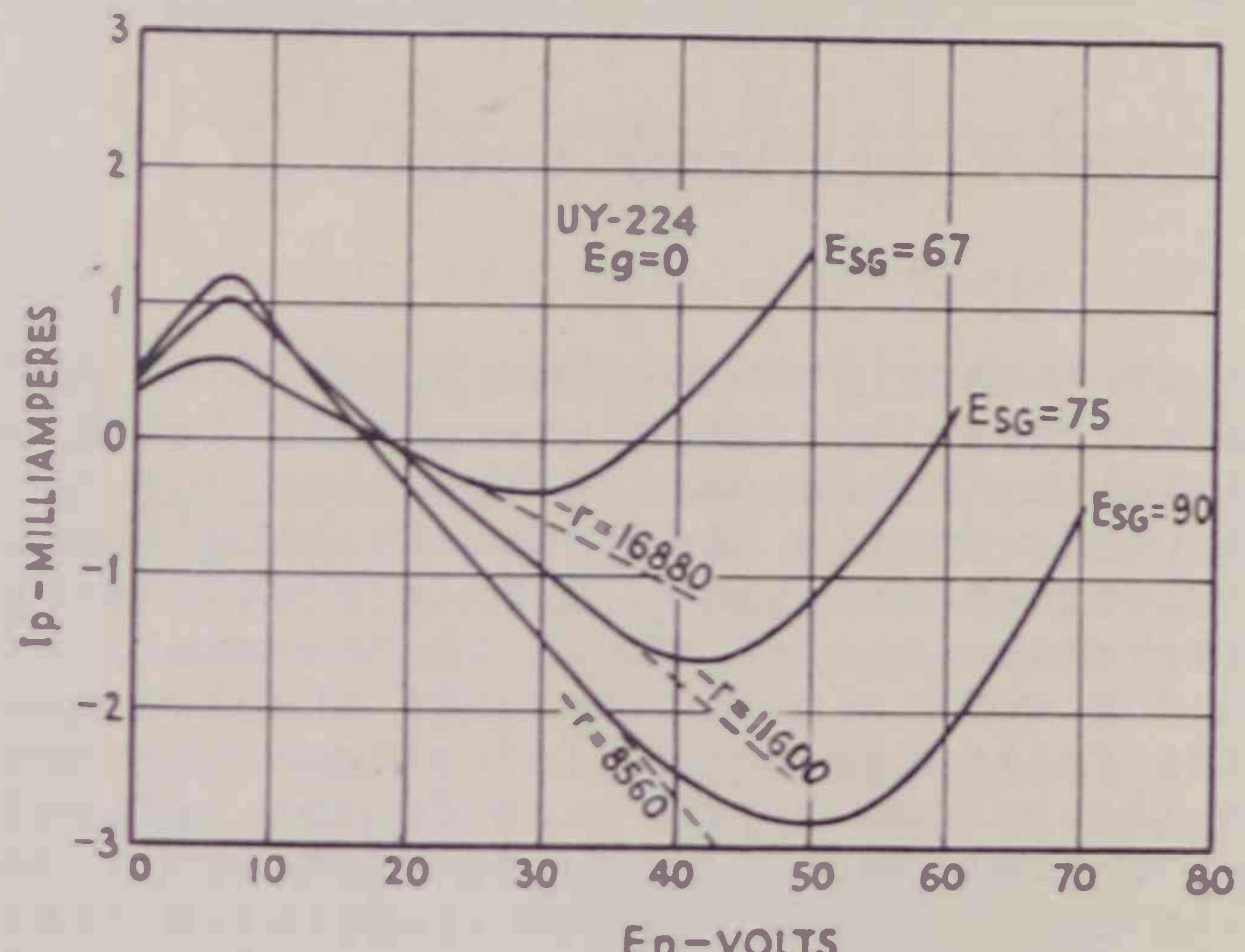

Fig. 13--Plate-voltage, plate-current characteristic of a screen-grid tube in the dynatron region with fixed control-grid voltage and three different values of screen-grid voltage

of the tube is negative. This phenomena is easily accounted for since when E_p is less than E_{sg} the secondary electrons resulting from the primary electrons originating at the filament and striking the plate are attracted by the more highly charged screen and a reversed current flows from plate to screen which is the secondary electron stream. In the dynatron region of the tube characteristic an increase in plate current due to an increased plate voltage produces an increase in primary electrons flowing from filament to plate, but a still greater flow of secondary electrons occurs between plate and screen and the net change in the plate current is less.

Any device which possesses this negative resistance characteristic can be used as an oscillation generator. The "Arc Transmitter" is another example of the application of this phenomena to oscillation generators. The negative resistance of the arc between the carbon and copper electrodes cancels out the positive resistance of the antenna-ground oscillatory circuit and sustained oscillations result. The dynatron has a tuned circuit connected between plate and filament which will oscillate if the series resistance of the tuned circuit can be made zero. The circuit is shown in Figure 14 using a 224 tube.

The parallel impedance of the tuned circuit is L/CR, where R is the series resistance. If r, the negative resistance of the dynatron is of such value (8000 to 16000 ohms) and L/CR is of the same order, but somewhat more than r the circuit will oscillate. For a given tube negative resistance and values of L and C to resonate at a specific frequency the value of R will determine

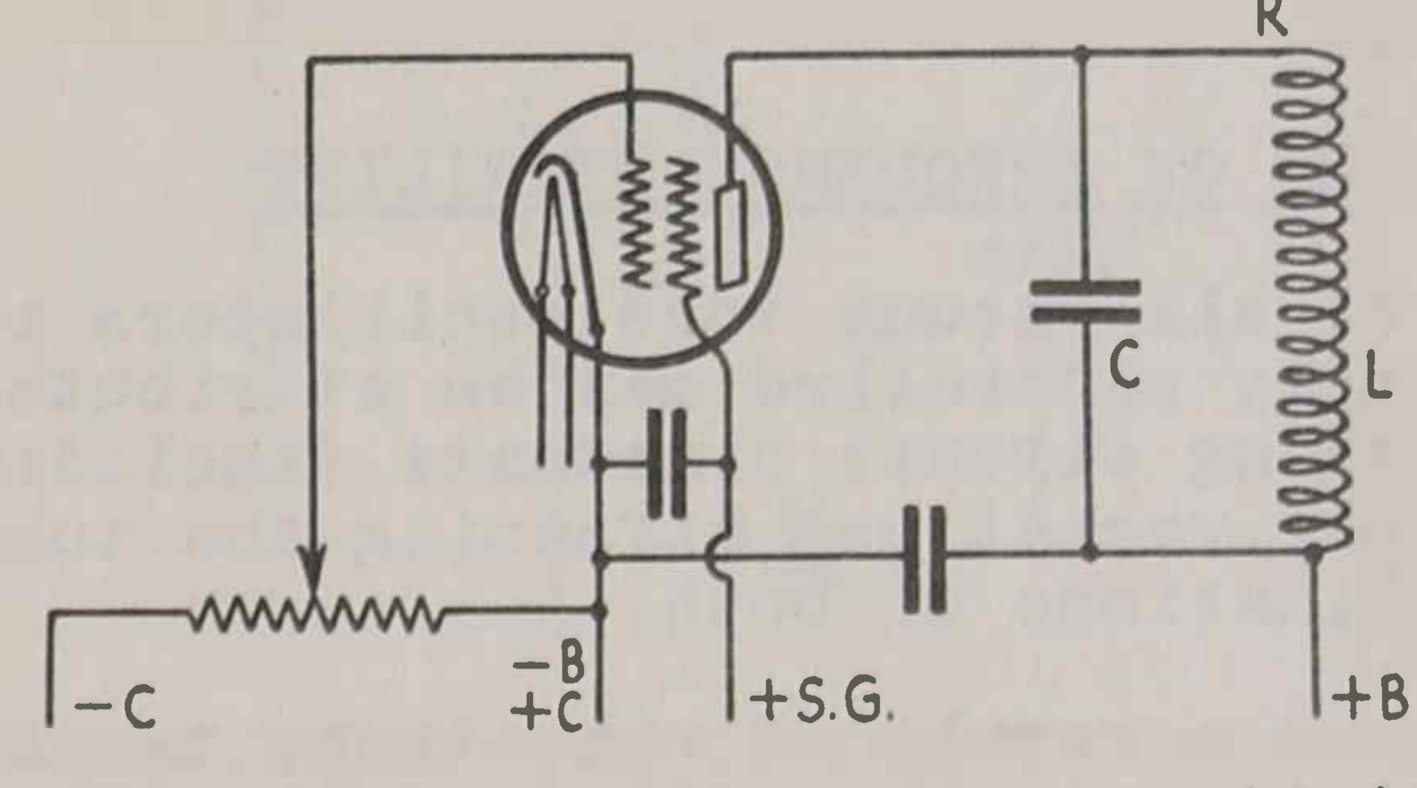

Figure 14--Tuned plate-filament circuit in a dynatron

whether or not the circuit will oscillate. The dynatron will oscillate over a wide frequency band, of a few cycles to approximately 20,000,000 cycles by merely changing the tuned circuit.

Any resonant circuit wavemeter can be used as the tuned circuit and the sharpness of resonance will be improved since the positive resistance of the tuned circuit is almost cancelled out by the tube negative resistance. If telephone receivers (or the primary of an A.F. transformer coupling to an A.F. amplifier) are connected in the screen grid lead beats may be heard between any other oscillator and the dynatron at harmonics of the dynatron frequency as well as the fundamental, which makes for a wide frequency monitoring band without changing the tuned circuit.

METHODS OF OBTAINING CONSTANT FREQUENCY

Oscillation generators readily fall into two classes, considering vacuum tube oscillators only which may be further subdivided as follows:

(1) Electrically Controlled Oscillators.
- (a) Simple circuits.
- (b) Special stabilized circuits.
- (c) Long line frequency control.

(2) Mechanically Controlled Oscillators.
- (a) Piezo crystal.
- (b) Magneto striction.
- (c) Tuning fork control.

The first class includes the simple Hartley, Colpitts, T.G.T.P., etc., and possesses the advantage of a continuously adjustable frequency. The special stabilized circuits make use of extra coils and condensers, and the long line method of frequency control uses the constants of a long transmission line to control the stability of oscillations.

The second class, or mechanically controlled oscillators, includes different types of mechanical vibrating systems of which the most satisfactory one to date is the quartz crystal. The magneto striction oscillator makes use of a rod of magneto strictive material which changes its length at the frequency of an alternating magnetic field. This form of control is limited to values between approximately 1000 and several hundred thousand cycles. The tuning fork method uses a fork vibrating at audio frequency which is multiplied to radio frequencies. This method is very satisfactory for frequencies up to 1500 kc, but is not considered practical above that value due to the many frequency multiplication stages that would be necessary.

CONSIDERATIONS OF FREQUENCY STABILITY

Freq cy instabilit a va t e cillators ether self cont lled or ly t lled y be attributed to mech- ic variati ct circuit co ts (including tube capacities) or electrical v iations affecting the tube's dynamic c racteristics or co inations of both.

c ical riati a a t of vibration, t erat e ch ge d h idity cha . se be gligib by el- imi ti vib ti , by chani desi d construction, by u of itable tu s, by inta t rature and h idity constant and by the use of c tively large capacities in parallel with t tube ca cities (re f liarly known as the "High C" circuits).

The principal ca s of c instability are those affecting the d c te i dance of the tube. se e chiefly; variations in plate vol , d bi , over or er excitati and variatio in fi t s y v d plate load i da e. latter is t t i t f may be incorporated in an equati stati te L, C, R, a r_p the internal plate resis ce of as follows;

$$= \quad (1 + \quad _p)$$

ere ω = in cycles/sec.
R = series resist ce of resonant circuit.
C = tot pacity.
L = uc ce d c c t.
r_p = plate resistance.

It is obvious that the influence of a c nge in r_p on frequency becomes less as the ratio of R to r_p bec s less, therefore there are two reasons for using hi C circuits, the paralleling of tube capac ies by a large capacity to reduce frequency drift caused by cha es in tube inter-electrode capacities and to make R, the load series resistance, ll c red to the tube nternal plate resistance which kes the fraction R/r_p of s ll value. The use of a high C oscillator tank circuit for fre ncy stability more than compensates f the slight loss in ficiency.

THE QUARTZ CRYSTAL OSCILLATOR

Even when all the precautions as discussed above are taken the performance is inferior to that of an oscillator using quartz crystal stabilization and temperature control. For transmission on a fixed frequency and where high frequency stability is required the quartz oscillator is now standard practice. The familiar circuit is shown in Figure 15.

This circuit looks like the Armstrong T.G.T.P. except that the grid tank circuit is replaced by the quartz plate. Two types of quartz plate holders are used. In both types the crystal rests on a lower plate. If a light weight plate rests on the crystal slightly more power output is possible, but better practice is to have a small air gap between the upper plate and the crystal surface.

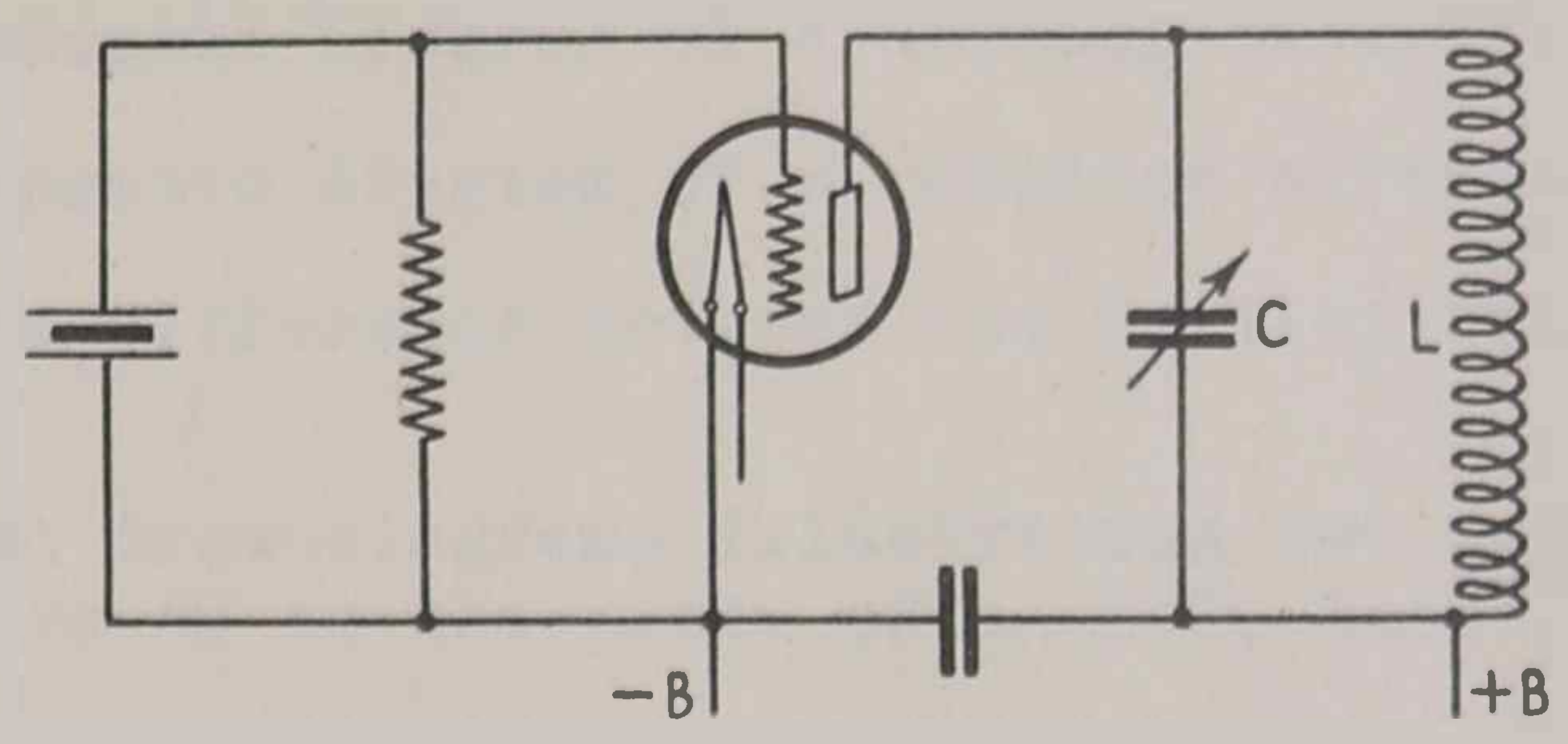

Figure 15--Schematic of quartz crystal oscillator circuit

The frequency of the crystal oscillator is dependent upon the temperature of the crystal to a large degree and upon the temperature of the associated circuits to a lesser degree. A constant plate voltage source is to be desired since voltage variations will affect frequency somewhat. Some precautions taken to maintain good frequency stability are:

1. Use of low plate voltage so variations in supply voltage do not change the power loss in the crystal enough to change the crystal temperature appreciably.

2. Tube impedances are made small and their effect minimized by using grid leak bias and loading the oscillator tube lightly.

3. The effect of filament voltage variations is minimized by using tubes with an electron emmission greatly in excess of that required.

4. When used to control a transmitter, the crystal oscillator must be protected from feedback by proper shielding and a buffer amplifier tube to reduce effects of changing load on tube impedance. Operating the amplifier tubes at a harmonic of the crystal frequency is also desirable.

Several circuits differing from Figure 15 are possible, but not as common. Figure 15 is merely a mechanical resonator (the crystal) connected between the grid and filament and a tuned circuit LC connected between plate and filament and tuned to a slightly higher frequency than the crystal resonant frequency so as to offer inductive reactance to the plate of the tube - a condition necessary for oscillation.

The oscillator, to repeat, is of course the most important part of a transmitter and can be likened to the hair spring on the balance wheel of a watch or any timepiece. The watch will not run without it and if something is slightly out of adjustment will either gain or lose time. Similarly, a transmitter with the oscillator missing would be of no earthly use as a transmitter and if the oscillator is producing the wrong frequency (more deviation than the tolerances allow) it is worse than no transmitter and might better be "off the air".

EXAMINATION QUESTIONS

1. Draw a schematic diagram of a Hartley circuit.
2. Draw a schematic diagram of a Colpitts circuit.
3. Explain the difference between the Hartley and the Colpitts circuits.
4. Explain and draw diagrams illustrating two methods of feeding positive DC to the plate of an R.F. tube — P. 10.
5. Contrast the Armstrong and Quartz Crystal oscillator circuits.
6. Explain how regeneration tends to cancel the series resistance of a parallel resonant circuit.
7. State three ways of determining if resonance exists in a tuned tank circuit.
8. If the inductance and capacitance were respectively .15 millihenries and .000169 microfarads, to what frequency would the "tank" circuit be tuned? — P. 7
9. How does feedback occur in self excited oscillator circuits?
10. (a) Name all the causes of frequency instability.
    (b) Why are self excited oscillators usually of the "High C" type?

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America's Oldest Radio School

RCA INSTITUTES INC.

A Radio Corporation of America Subsidiary

HOME OFFICE
75 Varick Street, New York

Thermionic Tubes

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CONTENTS

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THERMIONIC TUBES

INTRODUCTION — THE DIODE

This lesson shall concern itself with the two-element thermionic tube, or diode. The student is more familiar with the name vacuum tube, but the term thermionic is more correct, since many of the tubes we shall consider do not have a vacuum in them, but instead, gas or vapor at low pressure, such as the mercury vapor tube. The word diode means that there are but two electrodes or elements in the tube, hence the prefix "di", meaning two.

MATTER, ELECTRONS AND PROTONS

It will be well for the student to review the nature of matter before studying this text. The following facts will enable him to appreciate what follows. Matter is made up of molecules; molecules, in turn, of atoms, and the latter of electrons and protons — the fundamental building blocks of nature, as far as we know. Electrons each carry a negative charge of electricity, and protons a positive charge. Due to this, electrons repel each other, protons repel each other, but electrons and protons attract one another. This is in harmony with the well-known law that like charges repel; unlike, attract.

Another point about these particles is that the proton has a mass about two thousand times that of the electron, so that the latter is the more active of the two and produces most of the effects we note about us. Thus, an atom is a kind of miniature solar system composed of equal numbers of protons and electrons. All the protons and some electrons form the core or nucleus of the atom, and the remainder of the electrons form rings around this nucleus or core. In one hypothesis it is assumed that these outer electrons revolve in orbits about the nucleus, much as the planets — including our earth — revolve around the sun. These electrons are known as the orbital electrons, and account for the chemical behavior of the atom.

HEAT AND THE FREE ELECTRONS

We now digress for a moment to discuss heat. From a scientific viewpoint, heat is a random, haphazard motion or vibration of the molecules of the substance. The higher the temperature, the faster their motion, and at ordinary room temperature they execute several billion vibrations per second. It is inevitable that in doing so, these molecules should collide with one another, and in many cases this results in the more loosely held orbital electrons, which are lighter than the protons, being knocked out of their atoms. Previously the atom had as many electrons as protons, and was electrically neutral. When an orbital electron is dislodged, the atom has an excess proton, and therefore a positive charge. The dislodged electron is called a "free" electron, and the "bereaved" atom, a positive ion. (Ion means carrier of a charge).

In an ordinary piece of matter there are billions of billions of molecules, and where such large numbers are involved, it is to be expected — from the Law of Probability — that on the average a free electron finds itself surrounded by positively charged "bereaved" atoms which have lost electrons. The free electron is thus attracted to these on all sides, and hence does not of necessity return to the atom it left, but may join with some other "bereaved" atom, or else wander about in the material, the pull in any one direction due to one incomplete atom being balanced, on the average, by a pull in the opposite direction due to some other incomplete atom.

Of course this condition may last for only a fraction of a second, and then the free electron may happen too close to a "bereaved" atom and be absorbed by it. However — as mentioned before — where so many countless billions of molecules are involved, we may expect to find at any moment the same number of free electrons as at any other moment, and this number depends upon the nature of the material (electron and proton structure of the atom), and the temperature. The student should note that the free electrons are those that revolved in orbits about the nucleus. Those electrons that are in the nucleus and form a kind of cement or binder to hold the protons together, are not affected by heat or similar means. Until very recently no one could disintegrate the nucleus, whereas the orbital electrons could be removed in many ways, such as by heat, electronic bombardment (of which more will be said later under gaseous ionization) and ordinary chemical reactions.

THE ELECTRIC CURRENT

Not all substances, however, have free electrons at ordinary temperatures. Glass, for instance, has practically no free electrons, and every electron is locked up tightly in its atom. Copper, on the other hand, has many free electrons, as has silver, aluminum, and all other metals. Those substances which have free electrons are called electrical conductors, for under the impress of an electromotive force or push, these free electrons can be made to move, and this movement constitutes an electric current. It is usually stated in the more modern text book that an electric current is really the movement of electrons in the external circuit from the negative to the positive pole of the generator. While this is usually the case, it is possible to have an electric current due to the motion of positive charges (such as "bereaved" atoms) in the opposite direction. A small current of this nature occurs in an ionized gas, and in an electrolyte half of the current flow is due to the motion of positive ions towards the negative electrode. But in ordinary conductors, such as metals, the current flow is due to the drift or motion of electrons, and this is due to the relative immobility of the protons, whose mass is so much greater than that of the electrons. This point is mentioned here to avoid any confusion in the student's mind in the future.

We proceed with the discussion. It was shown that in certain materials there are present electrons which are free to wander about in the material because the pull of any "bereaved" atom is balanced by that of another in the opposite direction. What happens when an electron tries to pass through the boundary surface of the material into the open? To answer this question, the student must first visualize the conditions existing in the atom as described above. We have numerous electrons knocked out of their orbits in atoms. Surrounding any one electron are numerous incomplete or, — as we termed it, — "bereaved" atoms, all trying to pull the electron (and others in the vicinity) to themselves. As a result, each electron, being pulled about equally in all directions, is more or less free to move as it pleases within the material. In addition to all this we have the ceaseless vibration of the atoms as well as the electrons due to heat energy. Occasionally an incomplete atom recovers an electron, or more than one if it has lost more than one. Occasionally an atom loses one or more electrons due to an impact with another atom, or even an electron. On the average, there are a certain proportion of free electrons wandering about in the great open spaces of even the most solid material.

Now imagine an electron buffeted about until it happens to reach the surface of the material. Ahead of it looms empty space or else atoms that have their quota of electrons and require no more, (depending upon whether the material is in a vacuum or surrounded by an insulator respectively). Behind the electron are countless number of "bereaved" atoms that are trying to pull it towards themselves. It is obvious that the pull on the electron is now one-sided, that is, back into the material itself. Consequently the electron cannot escape through the surface: the incomplete atoms behind it all co-operate in pulling it back. We therefore see that the electron is really a prisoner in the material: as long as it remains within it, it is free to wander about as it pleases, but the moment it tries to leave the material it is pulled back with an overwhelming force.

In order to pull the electron out of the material we should require a correspondingly enormous force, of more than a million volts per centimeter. Such immense electromotive forces are not ordinarily available, and, as we shall see, other and more practical means are at hand to perform this task. The student will also perceive in due time why we wish to expel electrons from the material into space. He may — at this point — wonder how an electric current (circulation of electrons) can be established when the circuit is not made up entirely of one material. The explanation is as follows.

If we place in contact with the above material another piece of material which has free electrons and consequently incomplete atoms from which these electrons came, then any free electrons, from either material, when it comes to the boundary surface of that material, finds ahead of it positively charged incomplete atoms in the other adjacent material. These positive ions help to pull the free electron forward and balance the pull of the positive ions behind the electron in the first material, so that the electron can pass through the boundary surface into the second material without any difficulty. In this way an electric current can flow through switch contacts from commutators or slip rings to brushes, and similar parts of the circuit. It is only when a portion of the path or circuit contains a material having no free electrons and no positively charged incomplete atoms, that the electrons cannot proceed forward, and we have what we call an open circuit. At this point it is well to emphasize the important features of an ordinary conductive circuit, namely, — that such a circuit is characterized not only by free electrons that are capable of moving, but also by positive ions (from whence these electrons came) and which ions tend to hold the electrons in the material against their repulsive effect upon each other. Otherwise the electrons would repel each other out of the circuit into free space or even into the insulation surrounding the conductive material. It is thus evident that these incomplete atoms are just as important as the insulation in keeping the electrons confined to the path which we call a circuit: The incomplete positive ions hold the electrons within the conductive material, the insulation, having no incomplete atoms, exerts no counter pull on the electrons to pull them out of the material, and also tends to keep the circuit apart from any other conductive material whose positively-charged incomplete atoms would come in contact with the above circuit and lure the free electrons out of it. If the student grasps the full significance of the above, he is in a better position to understand the action of the vacuum tube.

THERMIONIC EMISSION

Now let us examine what happens when a piece of conductive material is heated. The atoms are caused to vibrate more intensely due to their greater thermal energy content, as are also the free electrons. Due to the random nature of their motion, it is evident that some of the atoms and electrons attain higher velocities at some moment than others, due to a series of collisions which happened to accelerate them continuously in one direction. Others would happen to collide with other electrons and atoms in such manner as to be stopped for the moment. Thus, the velocities attained by the particles are not all equal, but where so many are involved, we can imagine an average velocity, which the majority of the electrons, for instance, have, and also higher and lower velocities belonging to fewer electrons that happen to depart from this average velocity at some particular moment. As the temperature of the material is raised, the average velocity is increased, and a certain number of electrons may even reach extremely high velocities.

These latter electrons may happen to approach the surface at this high velocity, and the positively-charged incomplete atoms may be unable to bring them to a stop, so that they actually fly right through the surface out into the open. Once out, they may hover around the material like a vapor above a liquid, and thus form a cloud of electrons about the material. The material is thereby left with an excess of protons, i.e. a positive charge, and will try to pull the electrons back again. Those near the surface may therefore be actually pulled back into the material, but at the same time fresh electrons may be expelled from the surface, so that, on the average, as many electrons pass through the surface outward as well as inward, so that a balance occurs. Such a balance is known as dynamic (moving) equilibrium, and results in a certain number of electrons being present outside of the material.

Now suppose the temperature of the substance is increased. The thermal agitation of the atoms and electrons within it is increased, more electrons attain velocities sufficient to carry them out through the surface, and the electron cloud or vapor increases. We call this expulsion of electrons out of the substance "emission", and because it is due to heat, "thermal emission". There are other means of expelling electrons from a substance, such as by the action of light, but at the present time the thermal method is the best in that the greatest number of electrons can be expelled from a material by this means. The student should appreciate the importance of this action. Hitherto, in order to pull the electrons out of the material, extremely high potentials were required. Now, by the simple expedient of heating a suitable material to a dull red heat, the same effect can be had with far less trouble and expense, and it is for this reason that thermionic tubes have attained their present importance in science and industry.

THE EDISON EFFECT

The story of the discovery that conductors at high temperatures emit electrons is rather interesting. After Edison invented the incandescent electric lamp, he noted that the glass envelope of the lamp became coated in time with a black deposit. This action he attributed to the glowing filament, and so he placed a metal plate inside the bulb, and ran a wire from the plate through the glass outside to one terminal of a galvanometer. The other terminal he connected to one side of the filament. He found that a small current flowed (as registered on the galvanometer) between the cold metal plate and the hot filament. This was very strange, as hitherto extremely high voltages were required to cause a current to flow through an evacuated space. This current flowed only when the filament was hot (incandescent), so evidently the temperature of the filament played a most important role in the flow of this current. Moreover, current flowed only when the second terminal of the galvanometer was connected to the positive side of the filament. This phenomenon created a great deal of interest in scientific circles, and was known as the "Edison Effect". We now know that this current flow was due to the electrons emitted from the heated filament, and that the blackening of the bulb was due to another cause, namely, the condensation upon the relatively cool walls of the bulb of the carbon vapor which was also emitted by the incandescent filament.

The Edison Effect was investigated by Fleming, who introduced it to the art of radio, and employed it as a detector in the reception of radio waves. Others began to investigate the properties of this tube, both from a theoretical as well as practical standpoint, and the subsequent development was rapid indeed, until today we have scores of different tubes, each adapted for a specific purpose.

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If such a circuit be set up, it will be found that current flows in the plate circuit, as described above, only if the plate is made positive with respect to the filament. If the connections of battery "D" in the plate circuit be reversed, no current flows! The reason for this behavior is that the filament is emitting electrons due to its high temperature. Electrons are

Figure 1

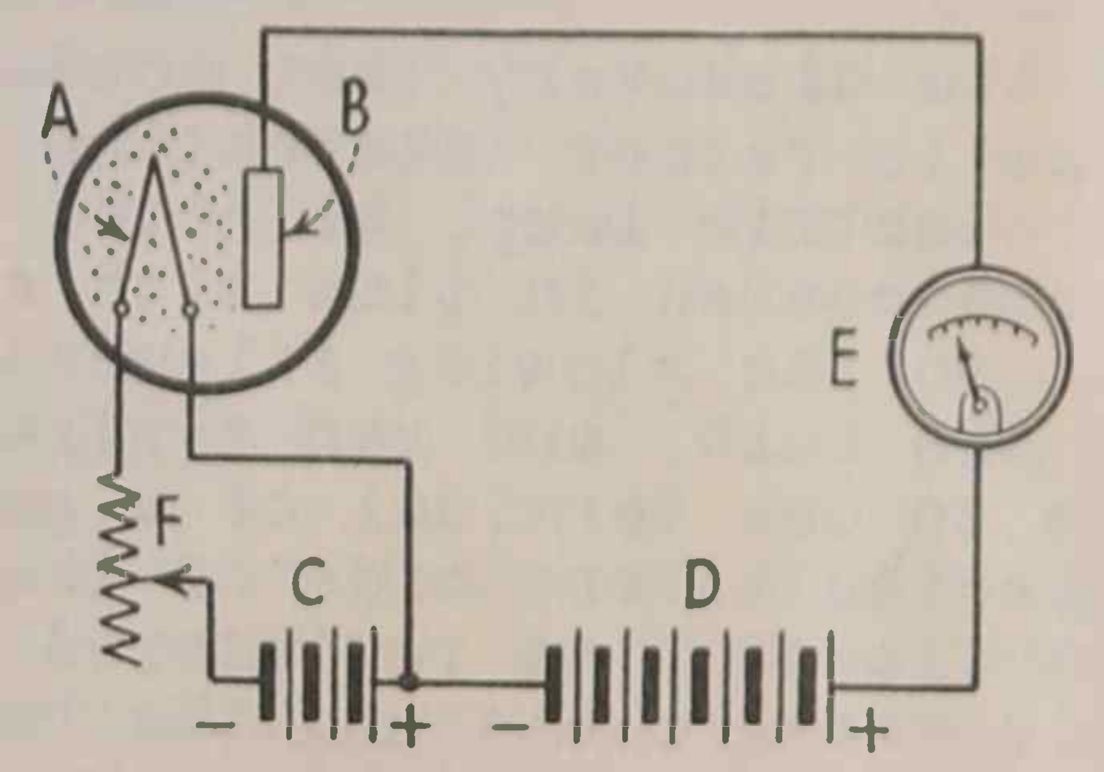

Figure 2

negatively charged particles, and will only be attracted to the plate when the latter is positively charged, i.e. when the positive terminal of the "B" battery (labelled "D" in Figure 2) is connected to the plate, and the negative side to some point of the filament (in Figure 2 we show it connected to the positive end of the filament, although the negative end could be used, or connection made to any intermediate point of battery "C"). This is the same thing as saying that the E.M.F. of the "B" or plate battery must be in such direction as to pull electrons within the tube from the filament to the plate.

Now suppose we reverse the plate ("B") battery. The plate is now negative with respect to the heated filament, and consequently repels the electrons emitted by the latter back into the filament again. Since the plate is cold, and therefore not emitting electrons, the plate battery cannot send electrons from the cold plate to the heated filament, i.e. no current flows. We therefore see that the tube acts as a kind of check-valve or one-way circuit: current can flow in one direction (electrons from the hot filament to the cold plate and thence around through the external plate circuit back to the filament again), but not in the opposite direction. While magnetic relays can be built to open the circuit when reverse current tends to flow, the action is not so quick as in the case of the above thermionic tube. There are, however, certain devices such as the aluminum rectifier which function like the above tube, but the latter is superior to these others in that practically no reverse current flows, even when the reverse potential (or inverse potential — as it is called by engineers) is very high. Other types of rectifiers usually allow a small reverse current to flow.

PLATE CURRENT CHARACTERISTICS
SPACE CHARGE AND SATURATION CURRENT

Before studying the practical uses to which this tube may be put, let us acquaint ourselves more thoroughly with its behavior. Let us employ the circuit shown in Figure 2, but so arranged that the plate can be connected to any terminal or tap of the plate battery, that is — the plate can be given any positive potential we desire. Let us see how the plate current varies with the plate potential. At first the student would think that as long as the plate is positive at all, it should attract every electron emitted by the filament to itself. This, however, is not the case, and is due to a property of the tube called the space

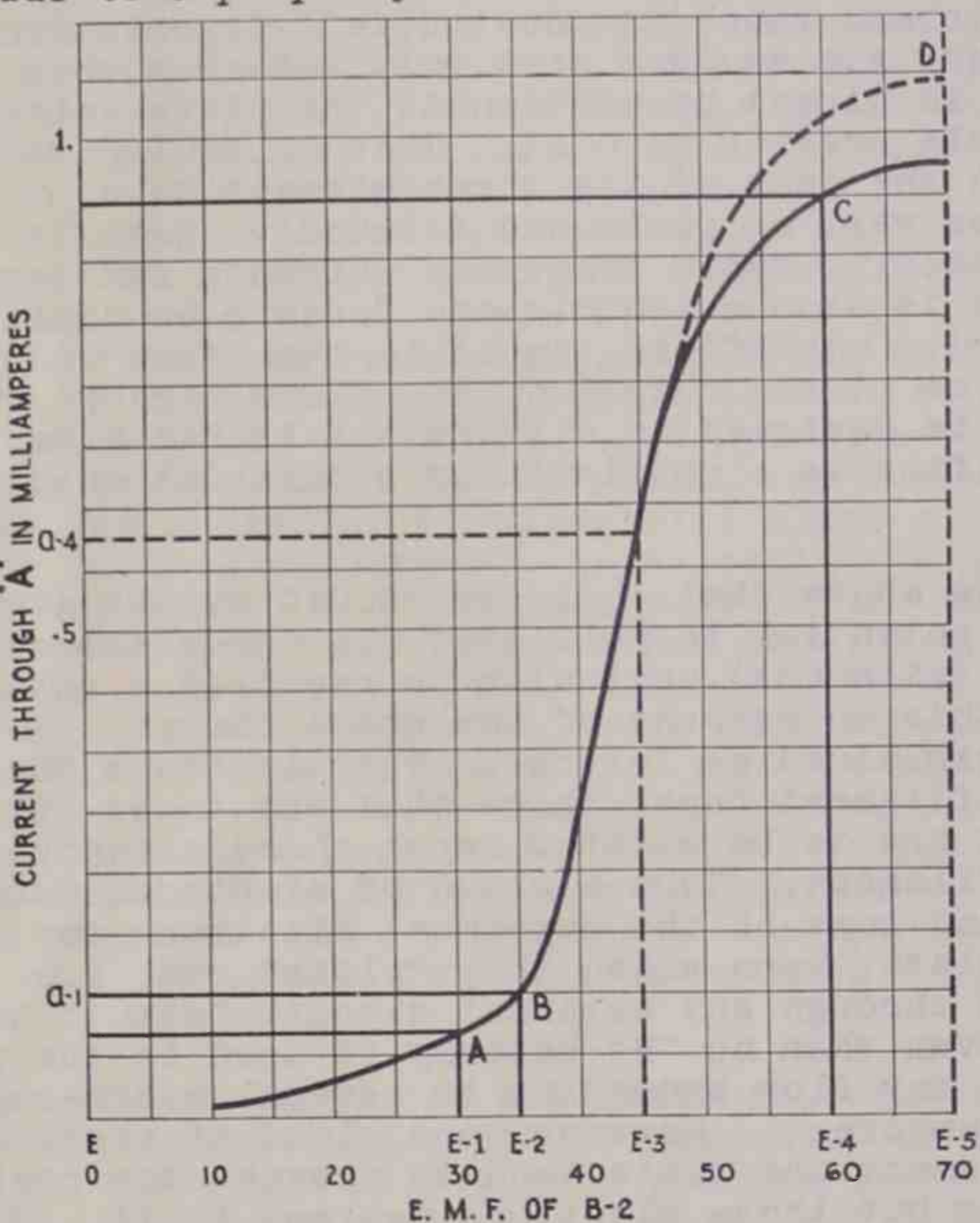

Figure 3

charge. As a result of this space charge, the plate current increases as the positive plate potential is increased, and Figure 3 shows this state of affairs. At first, as the plate potential is increased from +10 volts, the plate current increases very slowly to a value of "A". As we increase the plate voltage still further, the plate current begins to rise more rapidly until at about a plate potential of about 50 volts, it begins to taper off again, so that from point "C" its increase is less and less until at a plate potential of 70 volts and higher (not shown on graph), the plate current remains constant at a value of about 0.97 milliampere.

We shall now explain the curve. The first part of the curve shows that as the plate voltage is increased, the plate current increases. This is a condition encountered in ordinary circuits, namely, that the current increases with the voltage. However, in most circuits the current increases in direct proportion to the voltage, that is, twice the voltage produces exactly twice the current, and the ratio of the voltage to the current is a constant and called the resistance $R=(\frac{E}{I})$. This is nothing but a statement of Ohm's Law. If we examine the left-hand part of the curve in Figure 3 (up to point "C"), we find that the current increases at a rate faster than in proportion. From theoretical considerations it has been shown that the current is proportional to the three-halves power of the voltage, or, expressing it mathematically in equation form

$$I = kE^{3/2}$$

where k is a suitable constant.

However, the average tube, as constructed, departs from the above relation, so that the student need only remember that the plate current is not in direct proportion to the plate voltage, but increases at a rate greater than it. This is an important point, particularly in the case of the three-element tube, i.e. — a tube having a grid as well as plate and filament. Here this effect is utilized in detecting radio frequency currents and vacuum tube voltmeters. It is also a troublesome feature in amplifiers, particularly audio amplifiers, as it is the cause of the production of harmonics in the output of the plate circuit, and the amplifier must be designed to eliminate this bad effect. The push-pull amplifier is a particularly successful solution to this problem.

Mention was made above that while we should expect even a small positive plate potential to pull over all the electrons emitted by the cathode (filament), actually we required a rather high voltage to do this on account of the space charge. This latter effect can be explained as follows. The electrons that are emitted by the filament repel those that are to be emitted. In turn those that are to be emitted repel those already out further away from the filament. Thus a cloud of electrons forms around the filament, and some of the outermost electrons may even be repelled to the plate, upon which they "plate" out, i.e. are held and thence flow through any external circuit back to the filament again. Thus, even when no "B" battery is used in the plate circuit, a current may flow amounting to several micro-amperes (millionths of amperes). However, the cloud of electrons present between the filament and plate tend to prevent the positive plate from pulling any but those electrons nearest to it. The electrons may therefore be regarded as shielding other electrons from the pull of the positive plate.

A more detailed way of looking at the space charge is the following. The student is aware that a positive charge (produced by one or more protons) is attracted to a negative charge (produced by one or more electrons). Since the human mind cannot conceive of this action at a distance through empty space or vacuum, we imagine that between these charges there are lines of force, or strains in the ether pervading all space, called electrostatic lines of force, and that these, by their inherent tendency to contract, tend to pull the charges together. In the same way two like charges either both send out or receive lines of force (depending upon whether they are positive or negative, respectively).

Since these electrostatic lines of force have another innate property that they do not cross one another because they repel each other sidewise, it is evident that the field of one charge and that of the other are bent away from each other in an effort not to cross, and so repel one another and thus the charges producing or receiving them. We also imagine that there is one unit electrostatic line of force between each unit positive and negative charge. Therefore, if there is a preponderance of one charge or the other, there will be an excess of lines of force from these which cannot terminate on the opposite charge in the vicinity, and therefore must go off to other opposite charges, no matter how far away. We see therefore that only a portion of the greater charge will be affected by the lesser charge, and the remainder will not.

Now let us see how this applies to the vacuum tube. First we must ask ourselves, how does a "B" battery make the plate positive with respect to the filament? A battery develops an electro-motive force, (E.M.F.) which means a force on the electrons present in the battery circuit. When the positive terminal of the battery is connected to the plate, and the negative to the filament, a force is developed tending to pull the free electrons out of the plate and into the filament. The plate is thus left with an excess of incomplete, positively-charged atoms (from whence the free electrons came), and these send out electrostatic lines of force to the electrons emitted by the filament. If the battery has a low E.M.F., comparatively only a few positive charges are produced on the plate, and therefore only a correspondingly few number of electrostatic lines of force are sent out to the emitted electrons. As a result, only these are pulled over to the plate, and the remainder of the emitted electrons are unaffected and remain as a cloud about the filament. When the plate is made more positive (higher battery E.M.F.), more lines of force are established, more emitted electrons are acted upon and pulled over to the plate, and the plate current is therefore increased. Thus we find that the current flow is proportional to the plate potential, that is, of all the electrons emitted, not all are pulled over to the plate for low potentials, as might at first be expected, but instead, a certain definite high potential is required to move all the emitted electrons over to the plate.

The student should note that for all reasonable values of plate voltage — such as employed in ordinary operation of the tube — the potential is incapable of actually pulling the electrons out of the filament. Only the heat can do this, but once the electrons have been emitted, the plate potential can pull them over to the plate in amounts dependent upon its value.

We have thus explained the space charge effect, which prevents all the emitted electrons from being pulled over to the plate unless its potential is sufficiently great. Now let us see what happens if we make the plate voltage great enough. In this case all of the emitted electrons are pulled over to the plate, and the current has a definite value. Suppose we increase the plate potential. It is still far too low to affect the filament emission, so that the current is still limited to the above definite value determined by the rate at which the filament emits electrons. This in turn depends upon the temperature of the filament, so that we find that the plate current reaches a certain definite maximum value, and it does not increase thereafter even though the plate potential is increased many fold. This maximum value is called the saturation current, and is represented in Figure 3 by the right-hand bent portion of the curve after point "C". If the plate potential had been increased beyond 70 volts, the plate current would still have remained about 0.97 milliampere, the saturation current for the tube.

Suppose now we increase the temperature of the filament by passing more current through it from the "A" battery. The rate at which the filament emits electrons is now greater, and therefore we may expect the saturation current to be increased. Such is found to be the case, and in Figure 3, the dotted portion of the curve, terminating in point "D", shows how the current has in-

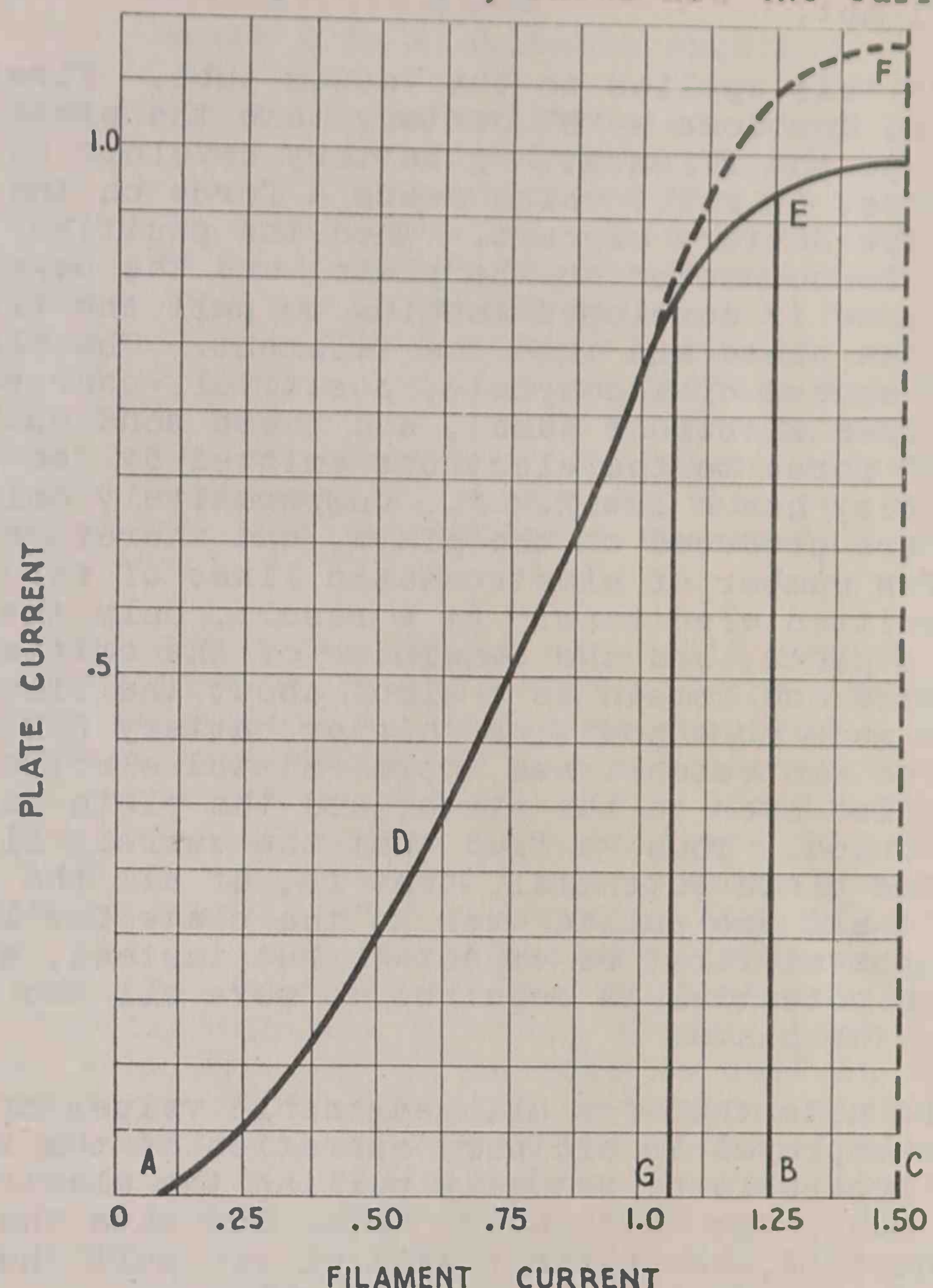

Figure 4

creased to a higher saturation value (at point "D") of about 1.05 milliamperes. Any further increase in plate potential will not result in any increase in plate current, the filament simply will not pass out any more electrons per second than that required to constitute the above plate current.

In Figure 4 the same facts are presented in slightly different form. Here we have filament current plotted along the horizontal axis (abscissa) instead of plate voltage. The vertical distances (ordinates) represent, as before, plate current. As the filament current is increased, the temperature of the filament goes up, too, so that the abscissa represent to some other scale filament temperatures. For the two curves (shown in solid and dotted lines, respectively), two values of plate voltage have been chosen which are high enough to produce saturation currents until the filament is near its maximum temperature. Consequently, for low temperatures, we see from Figure 4 that the plate current represents the saturation current, as the plate voltage is sufficient to pull over every electron emitted by the filament.

Let us examine the solid curve first. For values of filament current less than, or at most equal to "G", the curve represents saturation currents. As can be seen, the higher the filament temperature, the greater is its electron emission, and hence the greater the saturation current. For values of filament current greater than "G", however, the plate voltage is insufficient to pull over the additional electrons emitted and so the current approaches a limiting value which, under these conditions, is not determined by maximum emission, but by space charge. From point "E" on, the current remains fairly constant, because as the filament temperature, hence electron emission, is increased, the surplus electrons begin to form a cloud around the filament, the plate potential is inadequate to handle the excess, and the current therefore remains at the same value.

The student should study both Figures 3 and 4 very carefully. Although the curves in both figures resemble each other in form, they represent totally different conditions. In Figure 3, the left-hand part of the curve represents current limited by space charge. In Figure 4, the left-hand part of the curve represents saturation current. Similarly, the right-hand parts represent saturation and space charge currents, respectively, so that the two figures are in a sense, the opposites of each other.

Referring once more to Figure 4, let us examine the dotted curve. This curve shows the variation in plate current with filament temperature when a higher fixed "B" voltage is used. The left-hand part of this curve coincides with the solid curve. This is to be expected, as in this part of the curve the current is limited by the filament temperature regardless of the plate voltage. From point "G" on, however, the higher plate voltage prevents a space charge from forming because it is still great enough to handle all the electrons emitted, and it is not until point "F" is reached that the filament temperature becomes great enough to emit more electrons than the higher plate voltage can handle, so that the space charge can begin to form and limit the plate current to the higher value of "CF". Thus, the dotted curve lies above the solid one, since it requires a higher filament current to develop a space charge at the higher plate potential.

FACTORS INFLUENCING THERMIONIC EMISSION

Let us now study the action of the filament, or cathode, in greater detail. The first experimenters ran into all sorts of erratic results when studying the action of the vacuum tube, and many of these were traceable to the abnormal behavior of the filament. Mention was made earlier in the text that at normal temperatures the electrons cannot break through the surface of the material on account of the backward pull of the incomplete atoms within the material. Mention was also made that if another material having incomplete atoms were brought into contact with the first, the forces on the electron would be balanced, and it could therefore move through the surfaces of contact. When the electron is emitted from a substance by heat, its ability to pass out of the substance depends to a great extent upon what other substance is in contact with the first.

As a concrete example of this, let us take the case of tungsten in the form of a filament. Certain of the earlier tubes were found to be very erratic in their behavior. While in many cases this was due to the ionization of the residual gas in the tube, in other cases this was found to be due to the effect of certain gases upon the tungsten filament used. Thus, when water vapor was present, it seemed to poison the filament and prevent it from emitting electrons. From a scientific viewpoint, the amount of energy required to move the electron from within the tungsten to outside of it was increased by the presence of water vapor. An opposite case is that of platinum. The electron emission of platinum is greatly increased by the presence of hydrogen occluded in its surface. The amount of gas necessary to affect the emission may be so small that it will not show any ionization, even at high potentials. (Ionization will be explained in the text).

TYPES OF CATHODES

Due to the high temperature required for the emission of electrons, few materials are available for commercial use. The ones most commonly used at the present time are tungsten, thoriated tungsten, and oxide-coated filaments.

a) Tungsten

Tungsten is not a very profuse emitter of electrons, but due to the fact that it can be operated at a very high temperature without deteriorating, it is extensively used in the larger tubes which require intense heating of the elements during manufacture to drive out as much of the occluded gases in the tube as possible. Moreover, since the tungsten filament can be operated at incandescence, it is a fairly good emitter at this temperature.

b) Thoriated Tungsten

Thoriated tungsten consists of a tungsten filament to which has been added a reducing agent (usually carbon) and one to two per cent of thorium oxide. The filament is heated to a high temperature for one or two minutes (called flashing) and then glowed for several minutes at a lower temperature. Flashing causes the carbon to absorb the oxygen from the thorium oxide and reduce the latter to metallic thorium. Glowing then causes the thorium to diffuse from the interior of the filament to the surface, where it forms a coating or layer one molecule deep. It is this exceedingly thin layer of thorium on the filament surface that causes the emission of electrons for a given temperature to be many thousand times that of pure tungsten, and for a reasonable emission the thoriated filament can be operated at a far lower temperature than a tungsten filament. During normal operation the thorium at the surface is being continuously evaporated, but replenished by diffusion of thorium from the interior to the surface. If the filament is operated at too high a temperature (too much current through it), the rate at which the thorium is evaporated exceeds the rate at which it is diffused to the surface, and the filament ceases emitting electrons because the temperature is even then too low for appreciable emission from tungsten, which is what the filament really is when there is no thorium on the surface. The filament can be rejuvenated by "flashing" the filament for 20 to 30 seconds at three to four times normal voltage (with zero plate voltage) and then burning it for a half to one hour at 25 to 40 per cent overvoltage. Additional thorium oxide is reduced to metallic thorium by this process and then diffused to the surface to form a fresh monatomic layer of thorium.

Thoriated tungsten filaments are now used for moderate power tubes (for generating a few hundred watts as an oscillator). For this service they are somewhat better than the oxide-coated filaments to be described subsequently. For higher power tubes, requiring high plate voltages, this filament is subject to the same objection as the oxide-coated filaments; the positive ions formed from the gas tend to strip the surface layer of thorium as they bombard the filament at high velocities due to the high plate voltage.

c) Oxide-Coated Cathode

The oxide-coated cathode uses a mixture of barium and strontium oxides as a coating on a nickel alloy filament or base. In the manufacture a process of "forming" is employed, during which the emitter is glowed for several minutes at a temperature higher than the normal operating value, and then a strong positive electrostatic potential gradient is applied for several minutes (2 to 30 minutes). The emission during this latter period increases, and when it has reached a comparatively high value the electrostatic field and filament temperature are reduced to a lower value, which is maintained for an additional period. This process may vary somewhat between manufacturers, but is essentially as described above.

The initial high temperature causes some of the oxide to break down into ions, and the positive ions (of barium and strontium) are repelled by the positive electrostatic gradient into the oxide and up against the surface of the metallic core where they become atoms once more by taking up electrons from the core. They then diffuse to the surface of the oxide coating (which is porous) and gradually build up a surface layer of barium and strontium atoms. Here they emit electrons once more, and once again become positive ions. At the beginning of this lesson it was explained that electrons cannot leave a material because in doing so they would leave all the positively-charged "bereaved" atoms in the material behind them, and the pull of these latter would be so great as to prevent the electrons from leaving unless there were positive ions in front of them, too. That is the case here; an electron, upon leaving the metal core is pulled to the surface by the barium and strontium ions, so that a considerably lower temperature is required for the filament. Then, since barium and strontium are fairly high up in the electro-positive scale, they readily give up the electron to the region within the tube, i.e. emit the electrons. As in the case of the thoriated-filament, barium and strontium are being continuously evaporated from the surface of the filament, but also replenished by diffusion from within the oxide coating. Oxide-coated filaments operate at but a dull red heat, and are therefore very efficient, but, as mentioned above, are limited to tubes employing moderate plate voltages (no greater than 500 volts or thereabouts). The reason is that in the manufacture they cannot be heated to as high a temperature as other types of filaments or otherwise the oxide coating will be damaged. Consequently the occluded gases cannot be removed as completely as in the case of tungsten emitter tubes, for instance, and at high plate potentials this gas will ionize excessively, and produce various ill effects, among which is the stripping of the surface layer of the emitter by the bombardment of the high-speed positive gas ions.

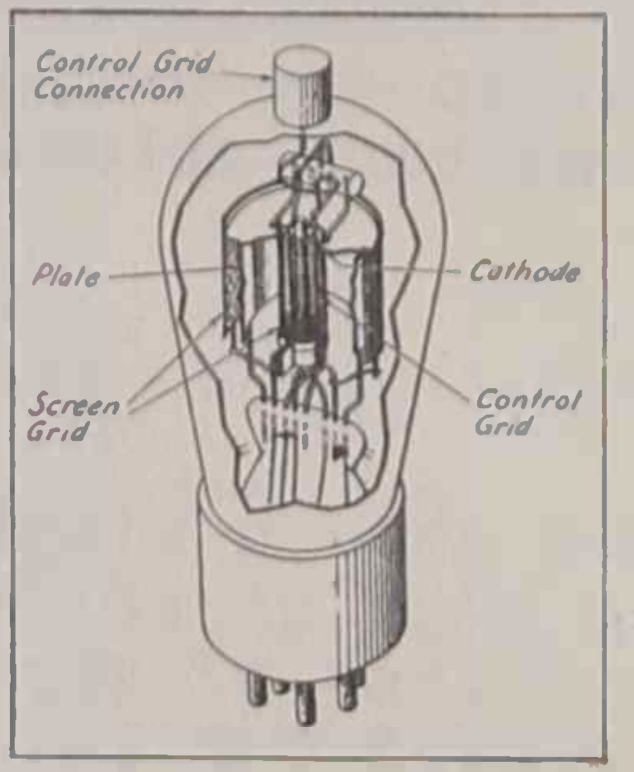

Figure 5

Indirectly heated cathode
type of vacuum tube

d) Indirectly Heated Cathode

The indirectly heated cathode is rarely used in diodes, but will be mentioned here. It consists of a heater element, or filament, (which is heated by passing a current through it), and an emitting surface surrounding the heater and heated to an emitting temperature by the latter. The heater element and the emitting surface (cathode) are usually electrically insulated from one another, so that one may be positive or negative to the other as desired. Figure 5 shows one form of construction. A heater filament of tungsten wire is inbedded in a tube of ceramic (porcelain) insulating material. Surrounding the insulating tube is a thin metal sleeve coated with the oxides of barium and strontium. Since there is an appreciable temperature drop in the ceramic insulator, and since the heater cannot be operated at more than a white heat, the cathode cannot be made to attain more than a red heat. Due to the use of the oxide coating, however, this is sufficient to give the required electron emission. The cathode sleeve not only furnishes electrons, but acts as a shield as well, and prevents alternating current in the heater from introducing variations in the plate current. This is of importance in the case of the three-element tube, etc, and explains the use of the indirectly-heated cathode type tube in spite of the greater heater power which it requires for a given electron emission.

TUBE MANUFACTURE

Brief mention will be made here of the manufacture of tubes. First a length of glass tube is fed through a machine which heats it progressively by means of a series of little gas jets until the end is at a bright yellow heat and therefore plastic. Hereupon a rotating core is pushed partly into it, spreading the end open, and the glass tube is now known as a flare. It is pushed on through the machine to another ring of gas flames which heat it at the proper distance from the flared end, and a revolving glass cutter then cuts it to the proper length.

It is then inspected and placed in the stem machine, where the metal supports and wires are inserted. (These are first cleaned of their tarnish by heating in an atmosphere of hydrogen). The parts are lined up very accurately in the flare by means of a metal jig, or template, and then a piece of glass tubing, for exhaust purposes, is automatically lowered into the center of the assembly. It is then carried through another series of flames which melt the glass above the flare at a point where it is to be welded to the wires. Since the coefficient of expansion for glass is different from that for ordinary metal, the latter has short sections of a special metal called "dumet" to which the glass is welded or squeezed by metal jaws. Dumet metal has the same coefficient of expansion as glass, so that the weld will not crack apart upon cooling. Previously the far more expensive platinum wire was used for this purpose. The assembly is now called a "press". While still hot, compressed air is forced through the exhaust tubing to blow a hole through the soft glass below the pinch. This hole will later serve for the evacuation of the glass bulb. The press is then annealed to remove any strains set up, inspected for imperfections, and then sent to the stem-forming machine, where the wire supports are bent to the proper shape to take the parts mounted thereon.

The plate, made upon another machine is mounted on its supports, as well as the filament, and the "getter" cup fastened. This contains pellets of magnesium, and is for the purpose of removing any residual gases, as well as subsequent maintaining of a vacuum. If a cathode type tube is to be made, the cathode, consisting of the heater wire enclosed in a metal sleeve from which it is insulated, is inserted after the plate has been mounted, and welded to the proper terminals. The active material is then sprayed on the sleeves, and great care is exercised to maintain a uniform coating and thickness. It is then baked and inspected.

The assembly is now called a mount, and is inspected for short circuits, etc., and then transferred to the sealing-in and exhaust machine. It is placed on a rotating support (sealing head), a glass bulb lowered over it, and a flame applied to the junction of the flare and the bulb. The rotation of the sealing head carries the tube into hotter and hotter flame areas, and the glass joint thereby fused. At the same time the bulb is annealed and thus relieved of any strains.

The tube is now brought to the exhaust section of the machine where exhaust pumps draw out all the air in successive operations. Usually an oil exhaust pump is used first to draw out the bulk of the air, and then a molecular type air pump for the remaining rarefied air. At the same time the metal parts are heated to drive out the gas that dissolves in the metal and also clings to its surface, as this gas would be evolved later during the operation of the tube and thus spoil the vacuum. The heating is done either by electronic bombardment within the tube, or, more usually, by inducing currents in the parts by means of a coil lowered over the tube, which coil carries high frequency currents. These induce, by magnetic induction (transformer action) currents in the metal parts, thus heating them and driving out the occluded gases, which the exhaust pump then removes.

When the exhaust is nearly completed, the getter is flashed by the coil being lowered to where the cup containing it is located. The getter is vaporized by the heat, and absorbs the residual gases that would be detrimental to the operation of the tube. Upon completion of the exhaust the tube is sealed off and transferred to the basing machine.

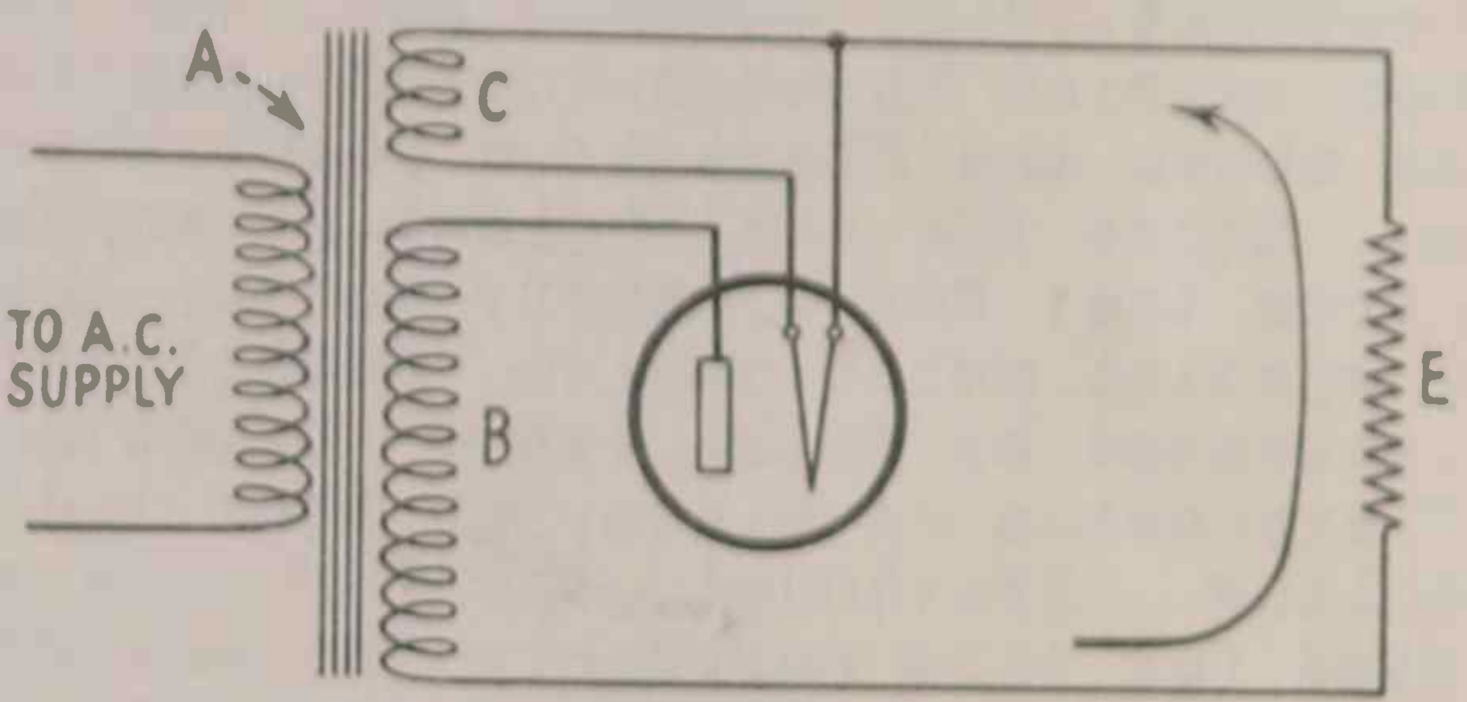

Figure 6

The connection wires are now threaded through the pins of the base, the tube passed through an oven to heat the cement on the inside of the base and harden it to the glass bulb, and then connection wires are cut off flush with the base pins and soldered to them. The tube is tested and then placed on a "seasoning" rack where the proper voltages are applied to it, and it is allowed to "season" until its characteristics become stabilized. It is then tested once again for defects, and if satisfactory, packed for shipment.

RECTIFYING CIRCUITS

Due to the property of the vacuum tube of allowing electrons to flow from the hot cathode to the cold plate, but not in the opposite direction (because the cold plate cannot emit electrons), it is eminently suited, especially in the diode form, to rectify alternating current. This means that when an alternating potential is applied between the cathode and plate (anode), current can only flow in the direction from the plate to the cathode, i.e. electrons flow from the cathode to the plate.

The point to be noted is that it is the current that is rectified, i.e. restrained to flow in one direction only. The applied potential is still alternating in character, When the rectified current is caused to flow through a resistance, in some part of the circuit it sets up an IR drop, the reaction to which is in the same direction as the current, that is, the potential in that part of the circuit is direct, whereas the applied potential is alternating in character. The action is very much the same as that of a D.C. generator. Here the voltage induced in the armature is alternating in character, but the commutator switches connections to the external circuit in such manner that the current here, and the potential across the load in the external circuit, is direct in nature. If these considerations are borne in mind, a great deal of confusion will be avoided as the discussion proceeds.

HALF WAVE RECTIFIER

In Figure 6 we see the circuit employed for this purpose. As a source of A.C. to be rectified we have the secondary "B" of a transformer "A". The other secondary, "C" is used to heat the filament of the diode, "D". It therefore performs the same function as an "A" battery, but is far more convenient to employ here. One end of secondary "B" is connected to the plate of "D", and the other end to the load "E" (here a resistance). The other end of "E" is connected back to the filament again, thus completing the circuit. It will be observed that the tube, together with secondary, "C", is in series between "B" and "E". Thus, due to its valve action, it permits electrons to flow only in the direction shown by the arrow, and not in the reverse direction, even though the potential in "B" reverses. It is evident, therefore, that the current flows every other alternation, or half cycle, as shown in Figure 7. Here the solid line denotes

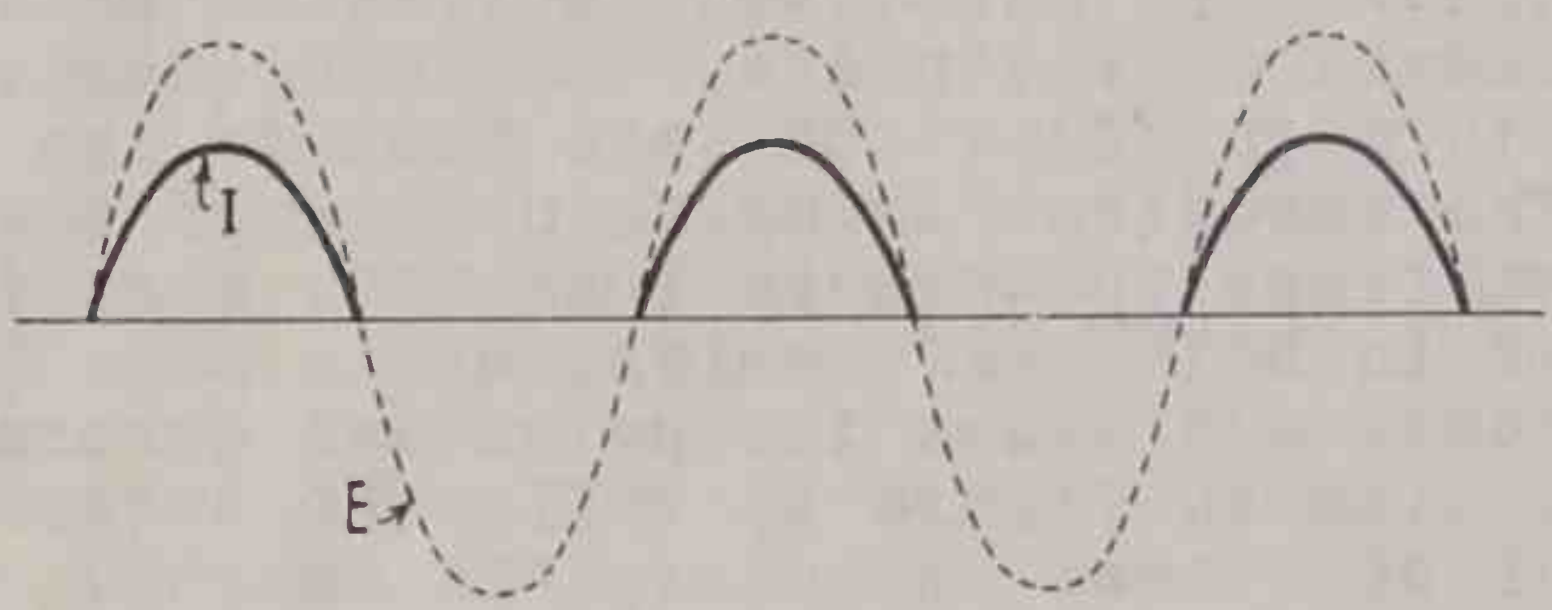

Figure 7

the current, and the dotted one the alternating voltage. For this reason this circuit is called a half wave rectifier, and the diode, a half wave rectifier tube.

Since the potential across "E" is equal at any instant to the instantaneous value of the current through "E" multiplied by its resistance, the voltage across "E" will have the same shape as the current wave, and will therefore be pulsating in character; in fact, it will be zero every other half cycle when the current through "E" is zero.

FULL WAVE RECTIFIER

In order to obtain a more uniform current flow, as well as put a more uniform load on the transformer, full wave rectification is more often employed. Figure 8 shows a circuit for accomplishing this. In this circuit a secondary of twice the voltage is used, i.e. secondaries "B" and "D" each would have the same potential of secondary "B" in Figure 6. Also, two tubes "E" and "F", are employed. Let us trace the electron flow during either half cycle. Suppose the top end of "B" is positive with respect to the center tap, and the bottom end of "D" consequently negative to the center tap. Electrons will then flow from the filament of "E" to the plate, thence through "B" around to "G", and up "G" to filament secondary "C" and thus back to the filament of "E" again. During this time tube F is inactive, since its plate

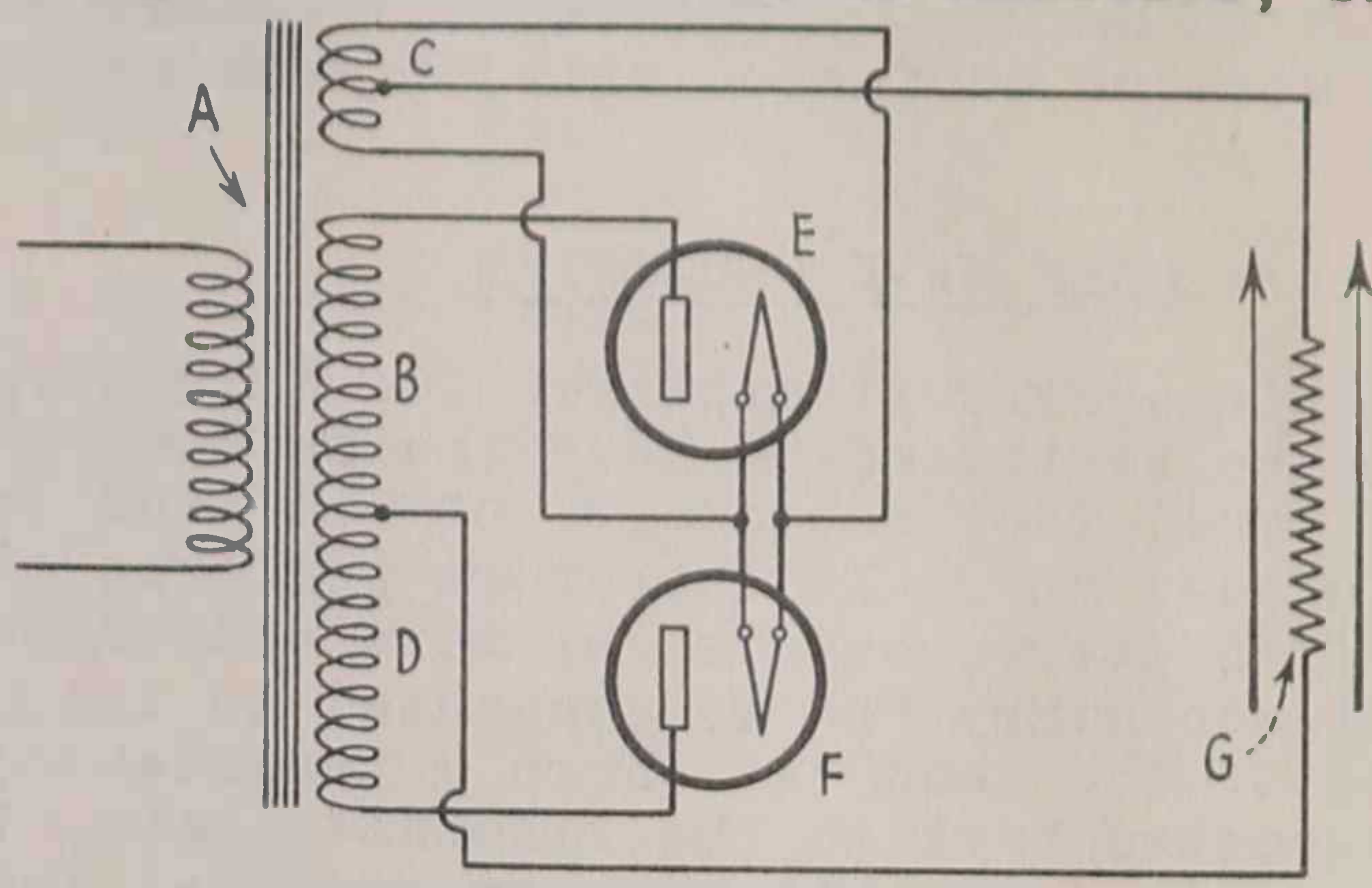

Figure 8

is negative with respect to its filament and cannot draw electrons from it. At the same time, neither can the current from "B" go through "D" and "F", but must go through "G" as described above. A half cycle later conditions are reversed. The plate of "E" now is negative with respect to its filament and thus draws no current (tube "E" inactive), while in "F" electrons flow from the filament to the plate, thence up through "D" to "G", and also up through "G" to "C" and back to the filament of "F" once more. The important thing to notice is that in either half cycle current flows up through load "G", i.e. it flows in the same direction in both half cycles, or is D.C. The wave shape of the current, and hence the potential across G, is now shown by the full line in Figure 9, while the dotted line shows the A,C. potential of either secondary "B" or "D".

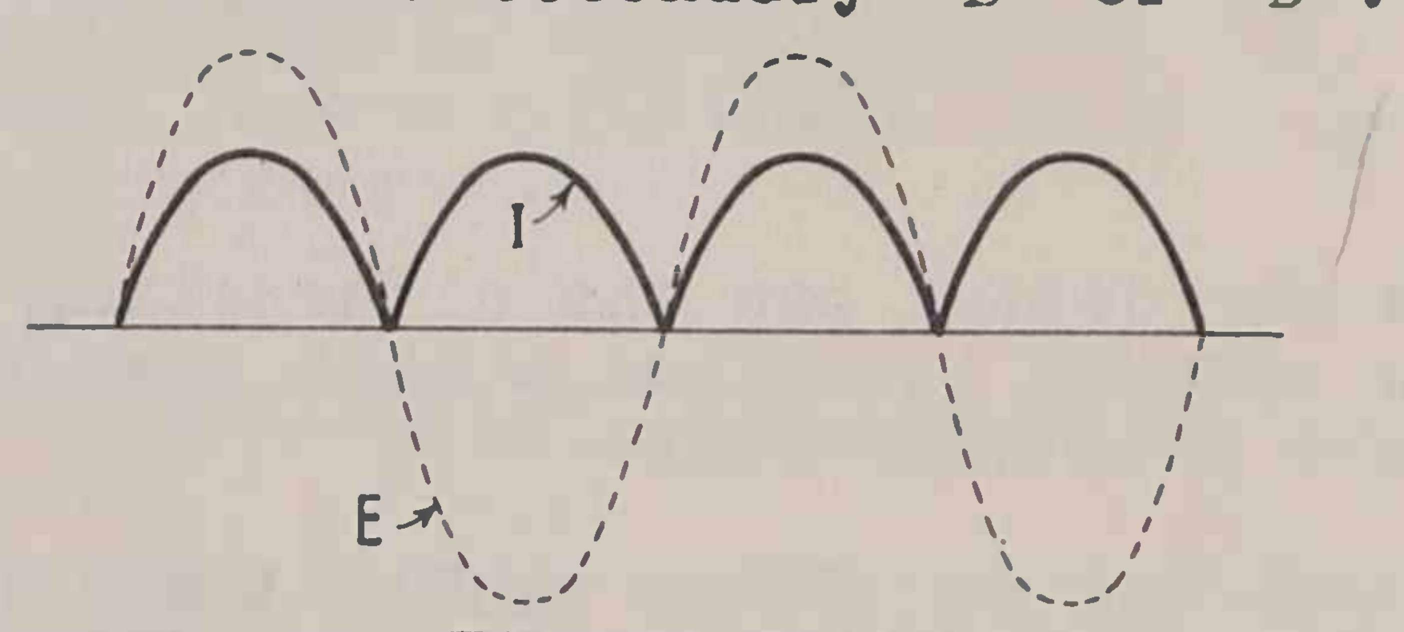

Figure 9

Twice as much current is passed, it is steadier in value (no gaps every other half cycle), and the number of peaks and zero values (ripples) have been doubled, which makes this current easier to filter, that is, smooth out until it is absolutely steady through the load. This is done by placing inductances in series with the load, and condensers across the D.C. circuit. A point to notice in Figure 8 is the use of a return from the top of load "G" to a center tap on secondary "C". This is equivalent to returning the current to the center of the filament of either tube, so that neither tube has a greater plate voltage acting on it than the other due to the filament voltage adding on to the plate voltage, This is of some importance in low resistance gaseous rectifier tubes, such as the mercury vapor type, but in the case of the high vacuum rectifier tube this center tap is often omitted, and the load return made to one side or the other of the filament secondary.

FULL WAVE RECTIFIER TUBE

For moderate voltages, say up to 500 volts, a single tube having two plates may be used in place of two diodes for full wave rectification. This follows from Figure 8, where it can be seen that the two tubes have their filaments connected to the same secondary. In the two plate or full wave rectifier tube, the filament comes in two sections connected in series, with a plate surrounding each section. Each plate is connected to a separate prong, and the two-section filament to two prongs.

INVERSE PEAK VOLTAGE

It must be remembered that in one direction the tube conducts current, and in the reverse it does not. In the direction in which it conducts current, the sum of the voltage drops in the tube and in the load must equal the impressed voltage between the plate and cathode. In a high vacuum tube the drop in the tube may be quite high due to the space charge. In the reverse direction the tube does not permit current to pass, so that at least the full A.C. voltage of the secondary connected to it is set up between the plate and cathode. If during this half cycle the load still has current flowing through it due to the circuit rectifying full-wave, or due to the use of a filter which maintains a continuous or steady current through the load, it can be seen that the voltage across the load is in series with that of the secondary, and, during this half cycle, in the same direction as the latter, so that the total voltage between the plate and cathode of the inactive tube is the sum of the two. The voltage across the load cannot exceed the peak of the A.C. voltage, so that the maximum voltage between the plate and cathode of this tube will be peak voltage (due to the secondary) plus peak voltage (set up across the load), or twice the peak voltage of the secondary. This voltage on the reverse cycle is called the maximum inverse peak, which name is self-explanatory, and is the highest voltage experienced within the tube. The insulation of the tube limits this to some value, and therefore also limits the maximum voltage that can be rectified by that particular tube.

HEATING OF PLATES

At this point it will not be amiss to mention something about the heating of the plate in a tube. The electrons emitted by the cathode are attracted to the positive plate, which exerts a force upon them. Under the impress of this force they are accelerated, and by the time they strike the plate they have attained very high velocities, and therefore considerable kinetic energy. The resultant collision with the plate causes them to give up this energy to the plate molecules, which are caused to vibrate, and this agitation, as we have seen, is heat. Consequently, if sufficient electrons strike the plate (large plate current), it may get red, and even white hot. It will then emit electrons too, so that the tube will cease rectifying. Moreover, the plate will eventually disintegrate, if not melt immediately.

Under normal operation, the plates are allowed to get red hot, at which temperature they will not emit appreciable electrons nor disintegrate.

Since there is a vacuum in the tube, the plate can get rid of its heat only by conduction through the lead-in wires, (which is a small amount) and by radiation to its surroundings (which is the principal means). It is therefore generally blackened with a graphitic deposit to increase its radiating properties.

EFFECT OF GAS

We now shall consider the effects of gas in a tube. For every pressure of gas there is an average distance that an electron can travel before striking an atom or molecule, and this is called the mean free length of path. Thus, as an electron proceeds from the cathode to the anode, it advances but the above distance before it strikes a molecule, and its motion is arrested and kinetic energy, in part—at least—transferred to the molecule. The speed the electron attains in this distance depends upon its acceleration, which in turn depends upon the anode potential, so that the higher this is, the higher the velocity and kinetic energy attained by the electron in its free length of path. An electron may attain so high a velocity that upon striking an atom it will disrupt the latter, knock some of its orbital electrons off, and leave the atom, as a consequence, with a positive charge. It is even possible for an electron to knock off as many as six electrons from an atom, so that the net result is that a great many more electrons, as well as positive ions are present in the space between the cathode and anode. This phenomenon is called "ionization by collision".

IONIZING POTENTIAL

Each kind of atom requires a certain force of impact to be ionized, which in turn means that the electron must attain a certain velocity to perform this task. For a given mean free path this requires that the electron "fall" through a certain potential, called the ionizing potential. This is usually low, and depends, of course, upon the mean free path. The latter in turn depends upon the pressure of the gas, for the lower the pressure, the more space between the molecules, the less potential is required for the electron to attain its necessary velocity in this greater distance, and hence the lower the ionizing potential. If, however, the pressure is too low, there may not be enough molecules present in front of the electrons to produce appreciable ionization, hence there is a lower limit to the rarefaction of the gas it is desired to ionize.

In some cases ionization may occur below the ionization potential of the gas for that pressure. This occurs when a molecule is subjected to successive bombardments by electrons. The first impacts are not sufficient to dislodge electrons from the atoms, but disturb the equilibrium of the latter, i.e. shift the orbital electrons from an orbit of lower energy level to one of higher level. In doing so, the bombarding electron yields some of its energy to the atom, and is deflected from it with a slower velocity — hence less kinetic energy. Such a collision is deemed inelastic, and the atom gains energy as a result. Consequently, if another electron strikes this atom with less than ionizing velocity, it may nevertheless cause ionization (dislodgment of an electron) to occur by merely continuing the work begun by the first electron or electrons.

In general, if the gas pressure is too high, the amount of ionization depends upon whether or not the collisions in the gas are elastic or inelastic in nature. If elastic, the electrons will rebound without loss of energy and thus may strike another molecule with greater impact than the first — in fact — sufficient to produce ionization. If inelastic, energy is absorbed by the atoms, and subsequent ionization may occur as above. Also, these atoms, upon absorbing energy may radiate it immediately in the form of light, giving rise to the glow seen in a gas when it is ionized.

EFFECT OF IONIZATION

The net result of ionization is that electrons and positive ions (bereaved gas atoms) are formed. These have a two-fold effect: 1) an increase in the number of electrons and (2) a reduction of the space charge around the cathode by the counter-acting presence of the positive ions.

The amount of additional electrons formed is usually small, particularly at high vacuum. But the reduction in negative space charge by the positive ions is very great, and the increase in plate current very marked when ionization sets in. The reason for this is that the positive ions formed are very heavy and immobile compared to the electrons and therefore they congregate near the cathode and "plate" out on it comparatively slowly. Consequently they remain interspersed between the cloud of electrons around the cathode for an appreciable period of time and neutralize the negative space charge to such an extent that very little positive potential is required between the cathode and anode to cause quite a current to flow to the latter. In this way the voltage drop in a rectifier tube is decreased considerably and more of the A.C. voltage is available across the load.

The above action is somewhat nullified by the formation of heavy negative ions due to neutral gas atoms sticking to electrons and moving very slowly towards the anode so that they, too, remain interspersed between the electrons in the cloud around the cathode and thus tend to neutralize the effect of the positive ions. Other secondary effects, such as the recombination of positive ions and electrons to form neutral atoms once more, photo-electric effects on the cathode and anode from the glow produced, and similar effects, are also produced.

DISADVANTAGES OF IONIZATION

Ionization may be desirable or undesirable, according to requirements. Thus, in a three-electrode tube (triode), where a grid is relied upon to control the anode current, the positive ions tend to interfere with the action of the grid and thus give rise to erratic effects. In such tubes a very high vacuum is employed, so that the probability of an electron striking a gas molecule in the path between the cathode and anode is rather remote. Hence sole control of the plate current is by means of the grid, as is desired, and reproducible effects can always be obtained.

ADVANTAGES OF IONIZATION

a) Tungar and Rectigon Tubes

Gas — as mentioned above — is of great value in diodes, particularly where employed for rectifying purposes. Here the voltage drop, hence power loss, in the tube is small, and much higher rectification efficiency can therefore be obtained. Examples of such a tube are the Tungar and Rectigon (trade names) rectifiers. Figure 10 shows the construction. "A" is the filament — of tungsten — and "B" is the carbon anode, connection to which is made at the top. The tube is filled with argon at a fairly low pressure, and this furnishes the positive ions.

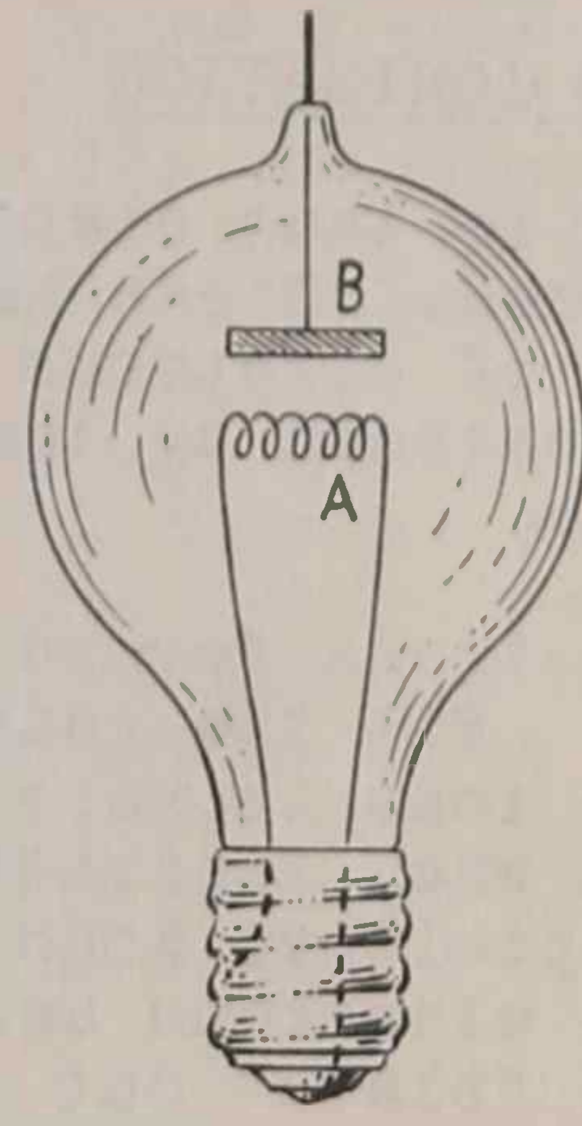

Figure 10

As a result, several amperes can be passed through the tube with only a moderate voltage drop, whereas if a high vacuum were employed, a much higher voltage drop would pass only milliamperes.

Argon is used because it has several advantages:

1) It has no surface effects upon the tungsten filament so as to decrease its emission.
2) It is chemically inert, and does not react with either filament or plate in any way.
3) It has very little tendency to form negative ion clusters i.e. groupings of electrons and neutral argon atoms, and hence its positive ions have full sway in reducing the space charge.

Tungar tubes are used to rectify A.C. at moderate voltages, up to about 150 volts. Above this voltage there is danger that the gas will break down on the inverse peak voltage and cause reverse current to flow thus destroying the rectifying action. An interesting feature is that after the action has started, the filament current can be shut off and emission still continues. This action is due to the bombardment of the filament by the positive ions, which raises the temperature of the filament and causes it to continue emitting electrons. The strong electrostatic field of the positive ions helps to pull electrons out of the filament, too. However, this action tends to get localized to one portion of the filament, since if that portion happens to emit more electrons than the other parts, it attracts more positive ions, which, in bombarding it, raise its temperature and cause it to emit more electrons, and so on until that part of the filament burns out. Therefore filament current is maintained to equalize the action, and to cause the filament to emit sufficient electrons to form a thin cloud about it just sufficient to protect its surface from the positive ions. The object here is to furnish electrons so fast that the positive ions are taken care of by the electrons and so cannot get to the filament itself and disintegrate it. This means that the plate current should not exceed the normal filament emission, and this is the normal operating condition for a gaseous conductor tube.

Figure 11

Full-Wave Mercury-Vapor Rectifier, Type RCA-82

b) <u>Mercury Vapor Tube</u>

Another type is the mercury-vapor tube in its many different forms. The Type 82 is shown in Figure 11. Mercury vapor has several advantages over other gases and vapors:

1) The vapor pressure of liquid mercury is sufficiently low so that the liquid itself may be introduced into the tube, and yet not give rise to too much vapor and excessive ionization and "back-flash" even under fairly high operating temperatures. As a consequence, any vapor absorbed by the parts of the tube is replenished from the pellet of mercury in the tube, whereas in tubes using fixed gases trouble is sometimes encountered in that the gas is absorbed by the elements of the tube and the amount available decreases to such an amount that insufficient ionization results.

2) The positive ions formed are very heavy and therefore immobile. Consequently they move very slowly through the electron cloud and thus help to overcome the space charge very thoroughly, instead of being neutralized very quickly by electrons in the cloud or directly from the filament.

3) The comparative immobility of the positive ions make it difficult for them to move to the plate on the inverse voltage. Consequently they cannot take electrons away from the plate during this half cycle, or no reverse current flows, even though the inverse peak-voltage, hence voltage to be rectified, is very high. Mercury vapor tubes can be used to rectify A.C. at thousands of volts potential.

4) Mercury vapor has less tendency than many other vapors or gases to form negative ion clusters. Therefore the neutralization of the space charge by the positive ions is not nullified by the presence of these negative ions. A point of interest in this matter is that the ionizing potential of mercury vapor under normal temperatures and pressure is about five volts. Sufficient negative ions are formed, even in mercury vapor, to raise the potential at which ionization is effective to about fifteen volts, which is the normal voltage drop in mercury vapor tubes.

5) Mercury vapor does not have any surface effect on tungsten or oxide coated filaments, i.e. — does not decrease their emission. However, no greater current should be drawn through the tube than the cathode emission, otherwise positive ions will be able to penetrate the electron cloud and strike the cathode in sufficient numbers to disintegrate it. In particular, they will strip the oxide coating off such type cathodes.

NEGATIVE RESISTANCE CHARACTERISTICS

Mention was made above that gas in a rectifier tube decreases the voltage drop in the tube by overcoming the space charge. Another important point is that the voltage drop is practically constant regardless of the amount of current drawn through the tube, at least up to the limit of cathode emission. This is because if more current (electron flow) is passed through the tube, the greater number of electrons increase the ionization by collision, thus further decreasing the space charge and increasing the number of electrons available by the amount coming from the gas. Thus the internal resistance is decreased, and the decrease is practically in proportion to the increase in current flow, so that the voltage drop, which is equal to the product of these two factors, remains practically constant. This is particularly important when the D.C. is to be furnished for Class "B" amplifiers, for here the requirement is that the voltage supplied to the amplifier be steady regardless of the amount of current drawn by the amplifier, and this is brought about by using a supply transformer whose regulation is low, filter chokes of low-resistance, and a gaseous rectifier tube — usually of mercury vapor type, whose voltage drop is only 15 volts regardless of the amount of current drawn.

OTHER APPLICATIONS OF THE GASEOUS CONDUCTOR TUBE

a) Thyratron and Grid Glow Tubes

There are some other applications of gaseous conductor tubes that are of interest. One is the type which is commercially known as the Thyratron (G.E.Co.) or as the Grid Glow tube, Figure 12, (Westinghouse). These are triodes; they have a grid or third electrode located near the cathode, and gas — such as neon or argon. Ordinarily the grid is given a negative potential and thus aids the space charge to such an extent that no appreciable electron flow to the anode occurs. As a consequence no ionization by collision forms and no positive ions are produced. Should the grid lose its negative charge by

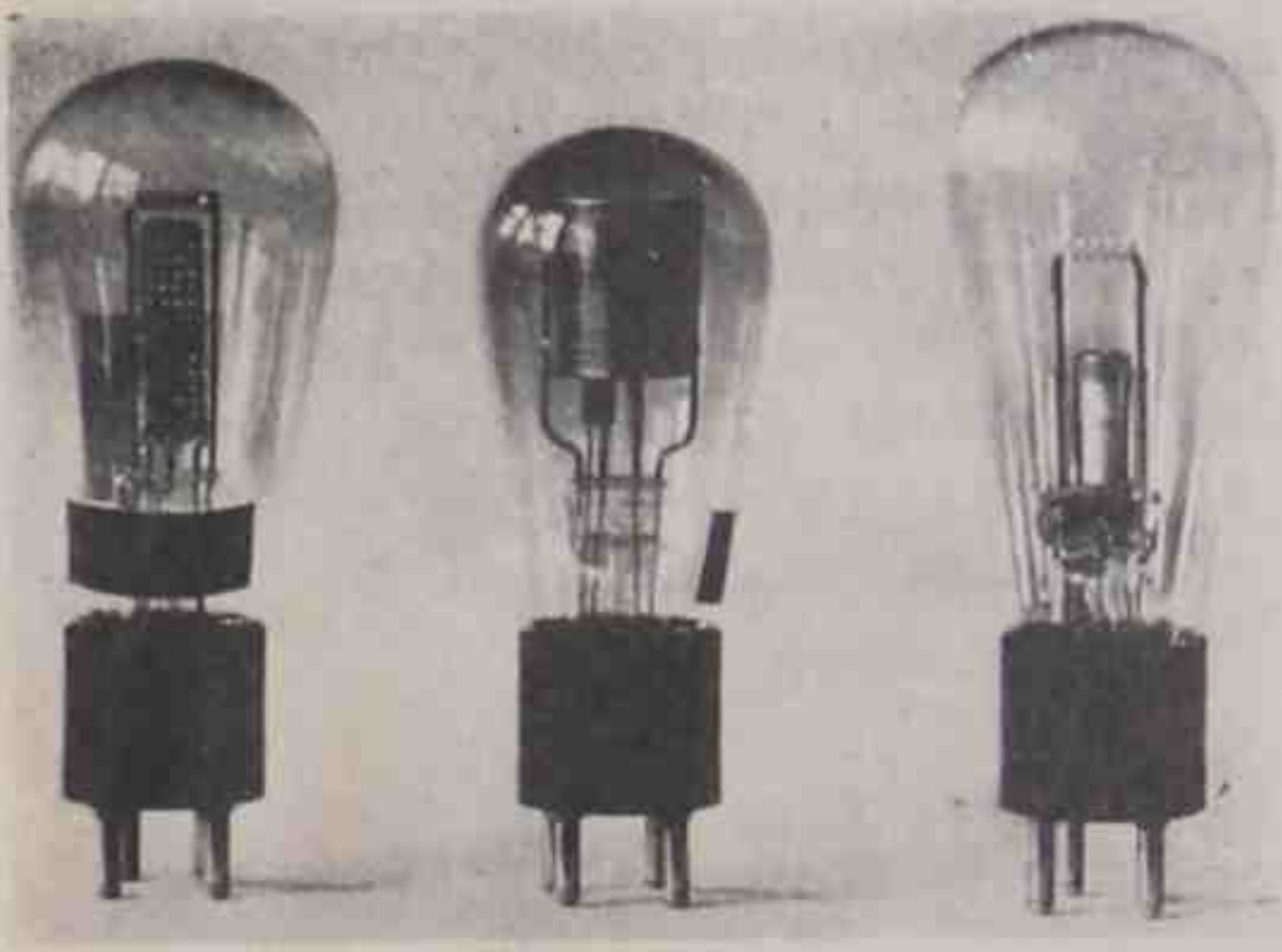

Figure 12
Three typical grid glow tubes of .64, .03 and .4 ampere capacity, reading from left to right. Tube in center is cold cathode type

suitable manipulation of the grid circuit, current starts to flow, ionization is produced, and the positive ions formed thereafter prevent the grid, even if it then go negative, from stopping the plate current until the plate voltage drops to zero. This, however, can occur every other half cycle if the plate be supplied with A.C. potential. If we also impress A.C. on the grid, and suitable means are provided to change the phase of the grid voltage with respect to that of the plate, we can cause plate current to start flowing at any point of its positive cycle. The later that this occurs in the positive cycle, the less total current flows in that cycle, or the less current is rectified. Thus we can control the D.C. in the anode circuit, or we have a rectifier which controls the current flow as well as rectifies it. This device can be used to actuate relays, or saturated core reactors, which in turn control A.C. for motors, lights, etc., and the initial control is the phase or magnitude of the grid voltage. The power in the grid circuit is very small and easily handled, the power under control may be large in amount.

b) Photoelectric Cells

Another use for gas is in the photo-electric cell. In this cell a cathode is used which is made of such material that it emits electrons when light strikes it. The electron emission is very small and the space charge comparatively high, so that for reasonable light intensities the plate current is on the order of one microampere or less. In order to increase the current, gas is introduced under low pressure, which gas ionizes in proportion to the number of electrons emitted, and this in turn is in proportion to the amount of incident light. The total current is therefore in proportion to the amount of incident light, but between five and six times as great as that normally flowing if no gas were present. The gas amplification (as it is called) is therefore about five or six. It is necessary that the quantity of gas introduced be not too great, nor the anode potential too high (in practice not above 90 volts) otherwise the ionization will get out of hand and cause current to flow whether light shines on the cathode or not. Under normal operating conditions, however, the ionization is very moderate and under control, so that its contribution to the anode current is in proportion to the initial number of electrons emitted, and consequently to the amount of incident light. All photo-cells used in sound motion pictures, television, and industry are of the gas-filled type, as the increased sensitivity reduces the required number of stages of amplification following the cell.

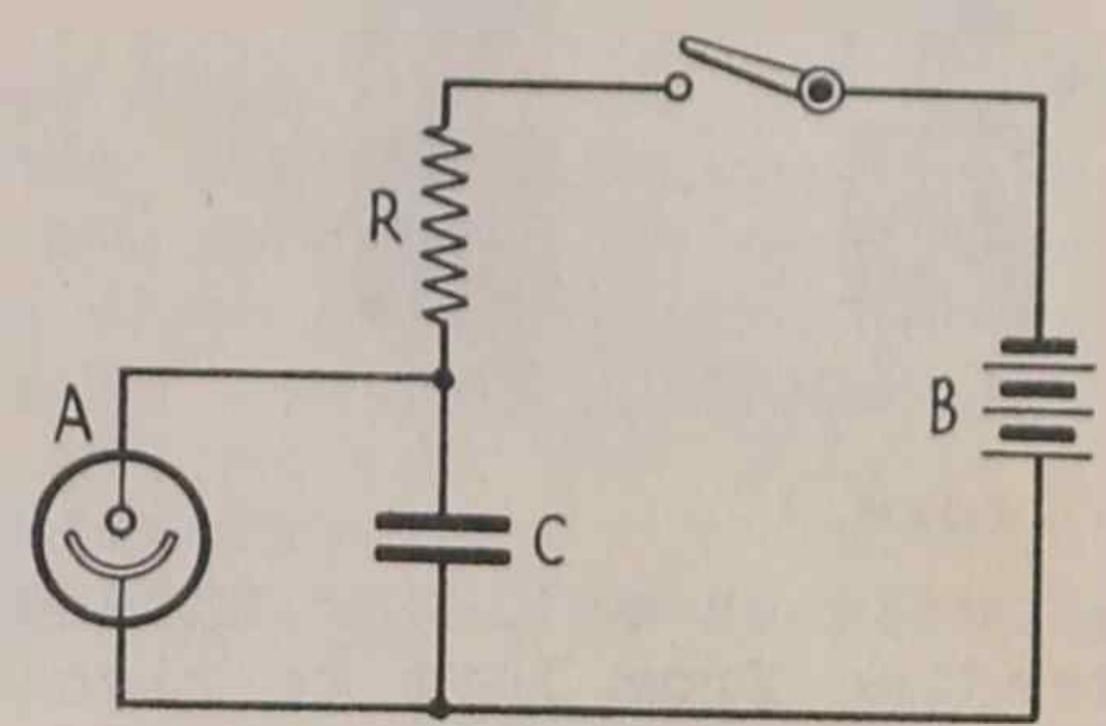

Figure 13

c) Neon Tube Oscillator

A third example is the neon tube oscillator. Figure 13 shows a circuit employing this tube. "A" is the gas tube (usually neon gas), R is a resistor, C a capacity, and B a source of D.C. potential, such as a battery. The neon tube consists of two electrodes immersed in neon gas under a low pressure. When the ionizing potential of the tube is exceeded, current flows through the tube, and the voltage drop in the tube decreases to a low value when ionization sets in. The voltage can drop to a much lower value before cessation of ionization and hence conductivity through the tube occurs. When this occurs, however, the voltage across the tube must build up to its original higher value before ionization and current flow starts again. Thus a higher voltage is required to start the current than to stop it. When the switch is closed, charging current for condenser "C" starts to flow through "R", and the voltage drop in the latter, when subtracted from B, leaves very little voltage across "C". Hence "A" does not ionize. As the charge in "C" builds up, current flow through "R" decreases, and the potential across "C" and "A" increases until "A" ionizes. Thereupon the resistance of "A" drops to a very low value — practically a short circuit on "C" — so that "C" discharges through "A" until the voltage across "C" drops to a low enough value to stop "A" from ionizing. When this occurs, "A" will not start ionizing again until its voltage builds up to a higher value, hence "C" starts charging through resistance "R", and the cycle repeats itself. The number of such cycles per second depends upon how fast "C" can be charged by "B" through "R". The larger "C" is, or the higher "R" is, the longer the charging cycle takes, or, as we say, the higher the time constant (=CxR). Thus, by varying "R" or "C", the number of current pulses per second can be controlled. By impressing this rising and falling voltage of "C" and "A" upon the input terminals of an amplifier, we can actuate a loud speaker to emit a note of any frequency we desire. Thus, this oscillator can be used as an electrical musical instrument. Furthermore, if we keep "C" constant, then we can calculate or measure "R" by means of the frequency generated by this oscillator. By making "C" sufficiently large, we can cause the frequency to be one or two cycles per second, which can easily be counted. Such a device is used to measure the moisture content of wood. Two nails are driven into the plank a fixed distance apart, and the intervening portion of the wood used as resistor "R". The greater the moisture content, the lower "R" is, and the greater the number of cycles per second.

SUMMARY

Let us now summarize the points brought out in this lesson:-

1) When a conductor is heated, electrons are emitted.

2) These electrons will be attracted to another electrode, called a plate, which is maintained positive with respect to the first, or cathode.

3) If the plate is made negative with respect to the hot, electron-emitting conductor, no current will flow, since no electrons can leave the cold plate.

4) This enables the tube to rectify A.C., and can be used in suitable circuits to rectify both halves of the wave (full-wave rectifier).

5) The cloud of electrons emitted by the cathode exert a mutually repelling effect upon one another and shield the electron nearer the cathode from the plate. This is known as space charge effect, and accounts for the fact that not all the electrons emitted are pulled over to the plate or anode until the anode potential is sufficiently high. When all the electrons emitted per second are pulled over to the plate we have saturation current — the maximum current that can be drawn from the cathode at that temperature.

6) By introducing gas into the tube, ionization by collision is produced, and the resulting positive ions help overcome the space charge, so that far less anode potential is required for a given anode current. This means — in the case of a rectifier tube — that more of the applied A.C. potential is available as D.C. potential across the load.

7) An important characteristic of gas-filled tubes is that as the current increases, the ionization and hence neutralization of space charge increases, so that the internal resistance of the tube decreases, and the potential drop across the tube (=IxR) remains substantially constant.

8) A moderate and controlled amount of ionization increases the current in a photo-electric cell for a given amount of light and hence increases the sensitivity of the cell.

9) In the thyratron the current is prevented from flowing by a third electrode or grid maintained at a negative potential with respect to the cathode. When the negative charge is removed, a very large current flows due to ionization. In this way a large amount of power in the anode circuit may be held in check by a very small amount of power in the grid circuit.

10) Due to the negative resistance characteristic of the gaseous discharge tube, sustained electrical oscillations may be maintained by the use of a suitable circuit, such as a condenser charging through a resistance. This is used in many ways, such as for electrical musical instruments, or for measuring high resistances.

EXAMINATION QUESTIONS

1. When an anode potential of 150 volts is applied to a diode a saturation current of 25 milliamperes flows. How much current will flow if the anode potential is increased to 180 volts?

2. Suppose now that more current is passed through the filament. How will the anode current vary?

3. Draw a full wave rectifier circuit and show how the current flows during each half cycle.

4. Does each tube carry current during the entire cycle?

5. Does each half of the secondary carry current during the entire cycle?

6. What is a disadvantage of the high vacuum type rectifier?

7. How does the gaseous type rectifier overcome this disadvantage?

8. Why is a mercury vapor tube used for Class "B" amplifiers?

9. Name three advantages of mercury vapor for rectifier tubes.

10. What is meant by the maximum inverse peak voltage?

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MODULATION

Lesson Text V10-19

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Modulation

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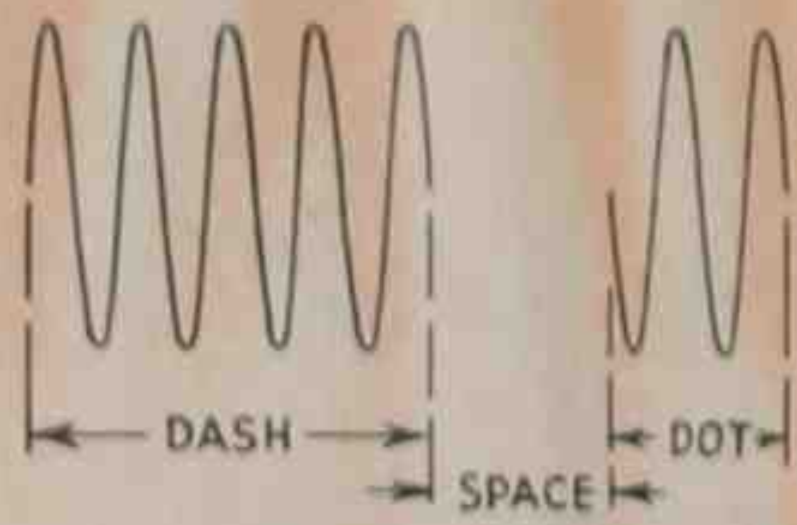

Fig. 1a--Diagram illustrating interrupted continuous waves

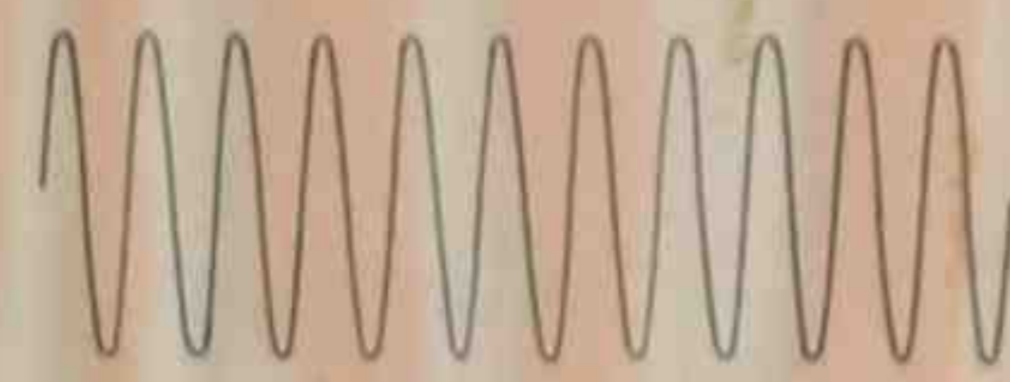

Fig. 1b--Diagram illustrating continuous carrier wave

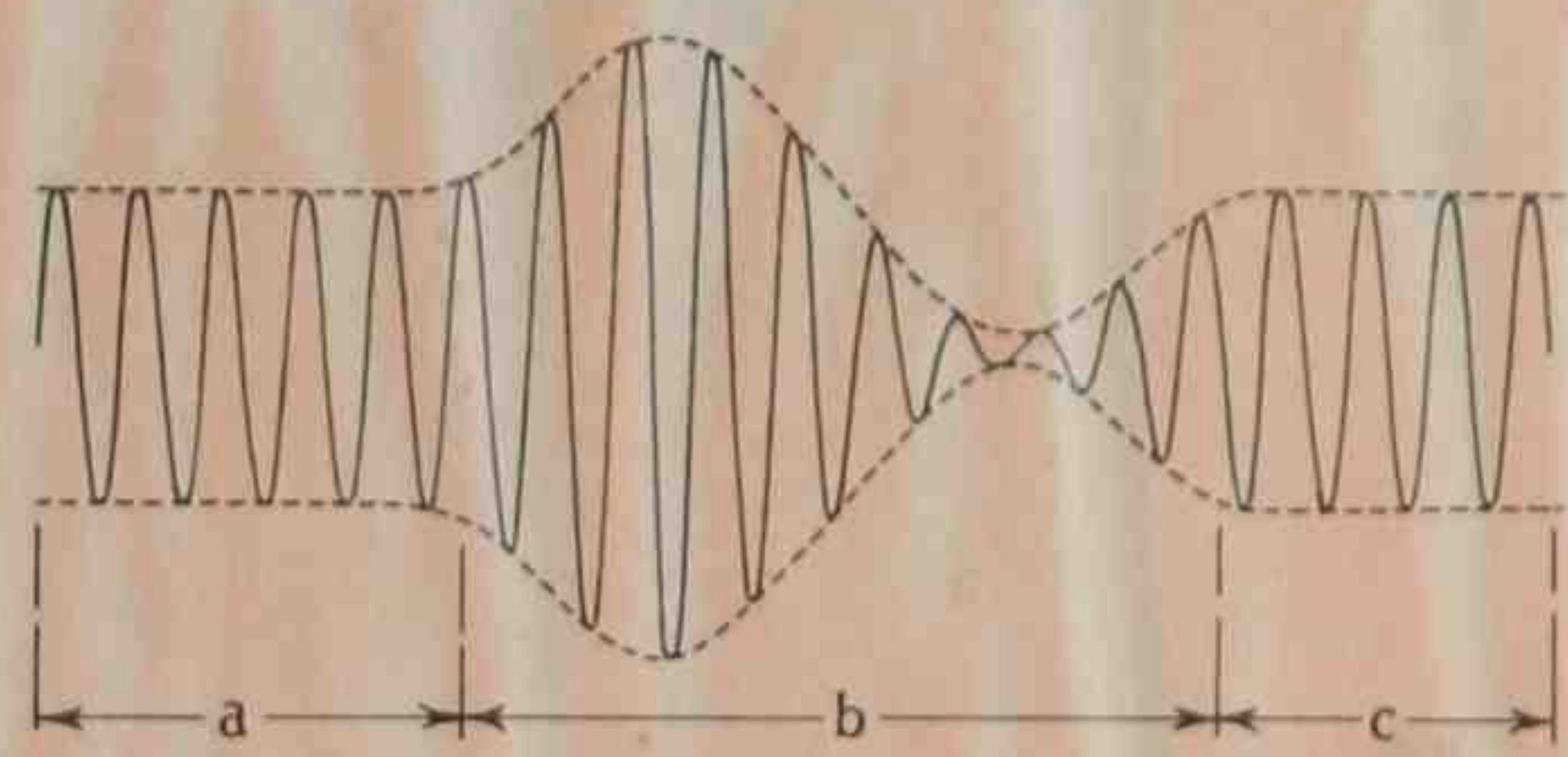

Fig. 2--Diagram illustrating modulated wave

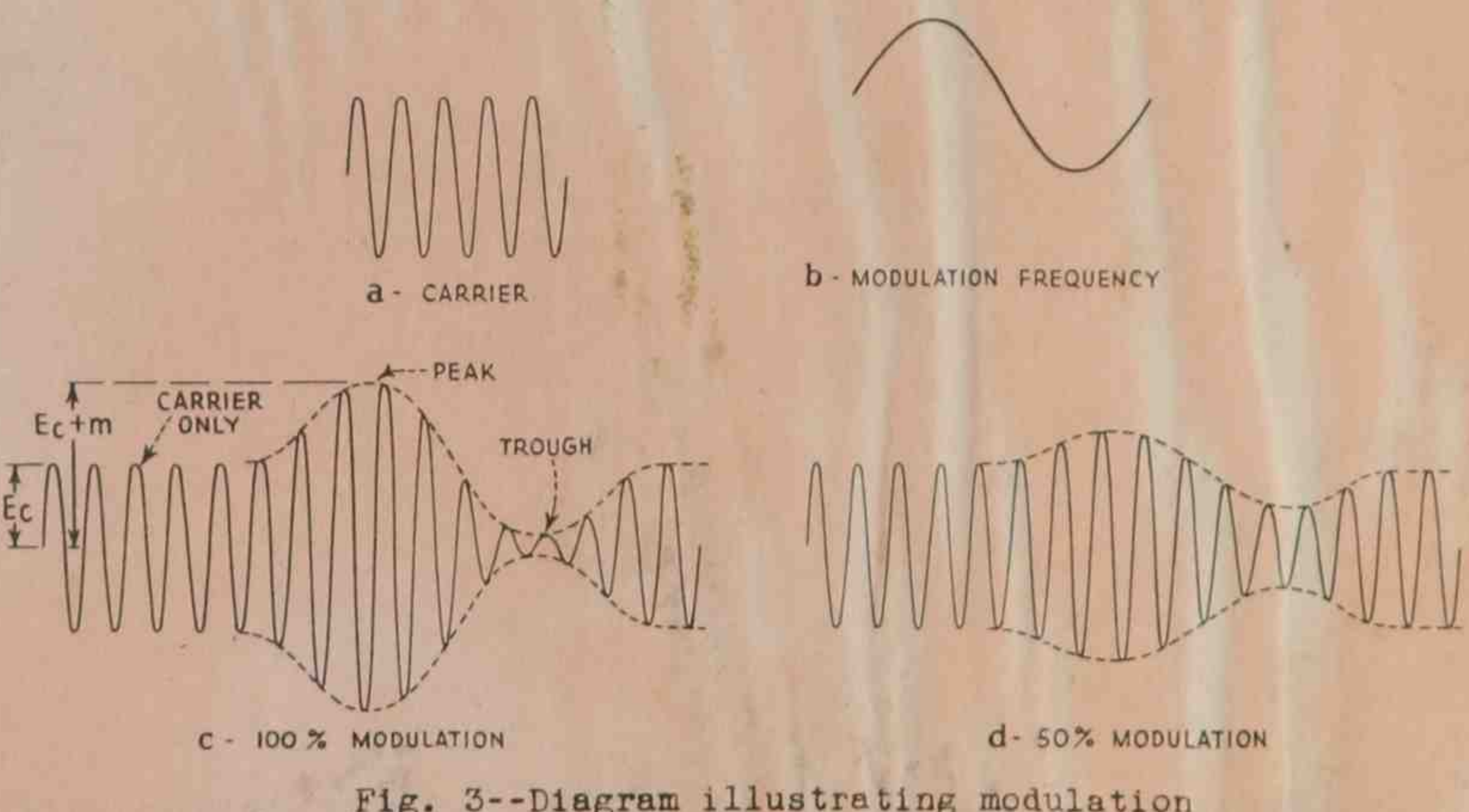

Fig. 3--Diagram illustrating modulation factor

MODULATION

The transfer of intelligence by radio requires that the transmission be controlled. In telegraph transmitters this is done by turning the transmitter on and off in order to form code characters, more familiarly known as "keying". A great many methods are available for keying, the most usual being the "blocked grid keying" that practically all modern vacuum tube transmitters employ. This is accomplished by applying a large biasing voltage to the grids of some or all of the tubes in the transmitter with the result that the grids are blocked by this high negative biasing voltage and plate current does not flow when the key is up. It is however not our purpose to study the methods of keying telegraph transmitters, but rather to become familiar with the more difficult processes of modulation as referred to telephone transmitters.

TYPES OF MODULATION

Vacuum tube transmitters emit or radiate a wave known as a continuous wave, more often abbreviated "CW". Figure 1 shows variations of antenna current or voltage of a radio wave, for example, when the key is held down in a telegraph transmitter or when a telephone transmitter is remaining idle, that is, without modulation. We call this the "carrier" when referring to telephone transmitters and it is also just as proper to say "telegraph carrier" since we actually modulate this carrier wave by keying.

Figure 1 (a) shows how the telegraph carrier is interrupted for keying purposes. Figure 1 (b) shows a continuous carrier. If a thermo-couple ammeter is placed in the antenna circuit it will register the keying (if at slow hand speeds) and will read a constant value in the case of Figure 1 (b). It should be noted however that the meter will read the effective or root mean square (RMS) value of current which in the case of a pure "sine" wave as represented in Figure 1 would be .707 x I_{max}. This is an important point to remember when considering effect of modulation on antenna current.

There are three types of modulation, namely, phase, frequency and amplitude. All practical systems use the latter type. To date the other two types are still in the experimental stage although some day they may replace amplitude modulation. At the present time, phase and frequency modulation do not enter into the picture except as by-products of the standard or amplitude type so they will not be considered in this lesson.

Figure 1 (a) is amplitude modulated since the wave's amplitude is changed from zero to a maximum etc, by operating the key. In a telephone transmitter the carrier runs continuously, but the amplitude of the peaks of the wave is being changed, that is, modulated.

Figure 2 shows a wave modulated for one cycle. (a) represents the carrier alone before modulation begins (before any sound is produced in front of the microphone). (b) shows how the peaks of the carrier wave are made to vary in accordance with the modulation frequency which is of course much lower than the carrier frequency of the station and is shown as a sine wave to further simplify explanation. The student should realize that a complex sound such as a spoken word or a musical note contains many harmonics, that is, several waves which added together give the total wave. It is convenient to consider modulation at only one frequency, however, although in an actual case there are many frequencies existing at the same time. (c) of Figure 2 shows "carrier only" again, the modulation having stopped and the peaks of the waves have returned to their constant or carrier value as in (a).

SIGNIFICANCE OF SIDE-BANDS

When two frequencies are combined in a circuit new frequencies are formed. These new frequencies are called side-bands and are very important. To cite an easily understood example, the method of heterodyne reception, used by certain radio receivers, uses this very principle. The waves of the transmitting station (CW) are of a certain frequency. If an oscillating detector in a receiver is adjusted to the same frequency as the transmitter no sound will be heard in the telephones, but if the detector tube is tuned to a slightly different frequency a note will be heard. This means that a new frequency is present. Actually two new frequencies are present, but only one is audible. The audible note is the difference between the transmitter and the receiver frequencies, which may be adjusted to any convenient value. The other frequency is the sum of the transmitter and receiver frequencies and is of course at radio frequency and can not be heard.

Applying this to a telephone transmitter, if the station frequency was 1000 kc/sec and the sound impinged on the microphone was 500 cycles/sec, the antenna would have present in it voltages and currents at frequencies of 1000 kc/sec or 1,000,000 cycles/sec, 1,000,000 plus 500 or 1,000,500 cycles/sec and 1,000,000 minus 500 cycles/sec or 999,500 cycles/sec. The first frequency represents the carrier and the other two side-bands. Thus there are two side-bands for every modulation frequency. What actually happens to antenna current can be shown best by resorting to mathematics. To understand the following statements, a knowledge of algebra, trigonometry and analytical geometry are essential, but the student without an understanding of these fundamental mathematical subjects can nevertheless appreciate the results as summarized.

The equation for a sinusoidally varying voltage may be written,

$$e = E_m \sin \theta \quad \text{where,}$$

e = instantaneous value.
E_m = maximum value.
θ = angle representing passage of time over the cycle. It is more convenient in our case to use the "cosine" function, however, so,

$$e = E_m \cos \theta \quad \text{or} \quad E_m \cos \omega t \quad \text{where,}$$

$\omega = 2\pi f$ and represents angular rotation, and t represents time in seconds. To set up equations for carrier voltage and modulation voltage, it is necessary to refer to Figure 3.

For a wave to be 100% modulated the peak value to the wave during modulation is double the carrier value and also the wave has a trough which is of zero amplitude at one instant during the cycle. Waves with a degree of modulation less than 100% have a peak value less than double the carrier and have a trough or "valley" that does not drop to zero. Such a wave is shown in Figure 3 (d) which represents a modulation of 50%. We do not always speak of modulation as a certain percent. It is usually more convenient to say the modulations factor "m" is 1.0 (meaning 100%), or m=.9 (meaning 90%), .7 for 70%, etc. It is apparent that the modulation factor depends on the size of the modulating wave. We can now set up equations for the two components which make up the final modulated wave.

Let e_c = instantaneous carrier voltage.
E_c = maximum value of carrier voltage.
m = modulation factor.
f_c = carrier frequency.
f_m = modulation frequency.

Then the carrier equals

$$e_c = E_c \cos 2\pi f_c t$$

and the modulating voltage equals

$$e_{mod} = mE_c \cos 2\pi f_m t$$

The total wave is the instantaneous sum of $e_c + e_{mod}$ or,

$$e = (E_c + mE_c \cos 2\pi f_m t) \cos 2\pi f_c t$$

Since the modulating voltage is superimposed on the carrier voltage, expanding:-

$$e = E_c \cos 2\pi f_c t + mE_c \cos 2\pi f_m t \cos 2\pi f_c t$$

Referring to trigonometry the product of the two angles may be written as follows.

$$2 \cos x \cos y = \cos (x+y) + \cos (x-y)$$
$$\text{or } \cos x \cos y = 1/2 \cos(x+y) + 1/2 \cos(x-y)$$

Applying this to our own equation,

$$e = E_c \cos 2(f_c)t + \frac{mE_c}{2} \cos 2\pi(f_c+f_m)t + \frac{mE_c}{2} \cos 2\pi(f_c-f_m)t$$

where f_c is carrier frequency
f_c+f_m is one side-band frequency
f_c-f_m is the other side-band frequency
and E_c is maximum value of carrier
$\frac{mE_c}{2}$ is maximum value of side-bands

For every voltage in the antenna there is also a current proportional to it, therefore there are currents flowing at the carrier and two side-band frequencies whose maximum amplitudes are,

I_c for carrier only.

$\frac{mI_c}{2}$ for each side-band.

An R.F. ammeter will read the effective or R.M.S. value of these three currents or,

$$I_{eff} = \sqrt{(I_c)^2 + \left(\frac{mI_c}{2}\right)^2 + \left(\frac{mI_c}{2}\right)^2}$$

Substituting actual values,

Let $I_c = 1$ ampere of carrier current.
$m = 1$ (100% modulation)

Then while modulation is occurring, the ammeter in the antenna will read,

$$I_{eff} = \sqrt{(1)^2 + \left(\frac{1 \times 1}{2}\right)^2 + \left(\frac{1 \times 1}{2}\right)^2}$$

$$= \sqrt{1 + \frac{1}{4} + \frac{1}{4}} = \sqrt{1.5}$$

$$= 1.226 \text{ Amperes}$$

Apparently the antenna current increases 22.6% for 100 percent modulation by a sine wave. For any other degree of modulation, $I_{eff.}$ could be found by substituting in the formula

Let $I_c = 1$ Ampere

$m = .5$ (50%)

$$I_{eff} = \sqrt{(1)^2 + \left(\frac{.5 \times 1}{2}\right)^2 + \left(\frac{.5 \times 1}{2}\right)^2}$$

$$= \sqrt{(1)^2 + (.25)^2 + (.25)^2}$$

$$= \sqrt{1 + .0625 + .0625}$$

$$= \sqrt{1.125}$$

$= 1.06$ or only a 6% increase in antenna current.

Figure 4 is a graph showing percentage increase in antenna current versus degree of modulation.

m	% increase
1.0	22.6
.9	18.5
.8	15.0
.7	11.6
.6	8.6
.5	6.2
.4	4.0
.3	2.1
.2	1.0
.1	0.2

Figure 4a

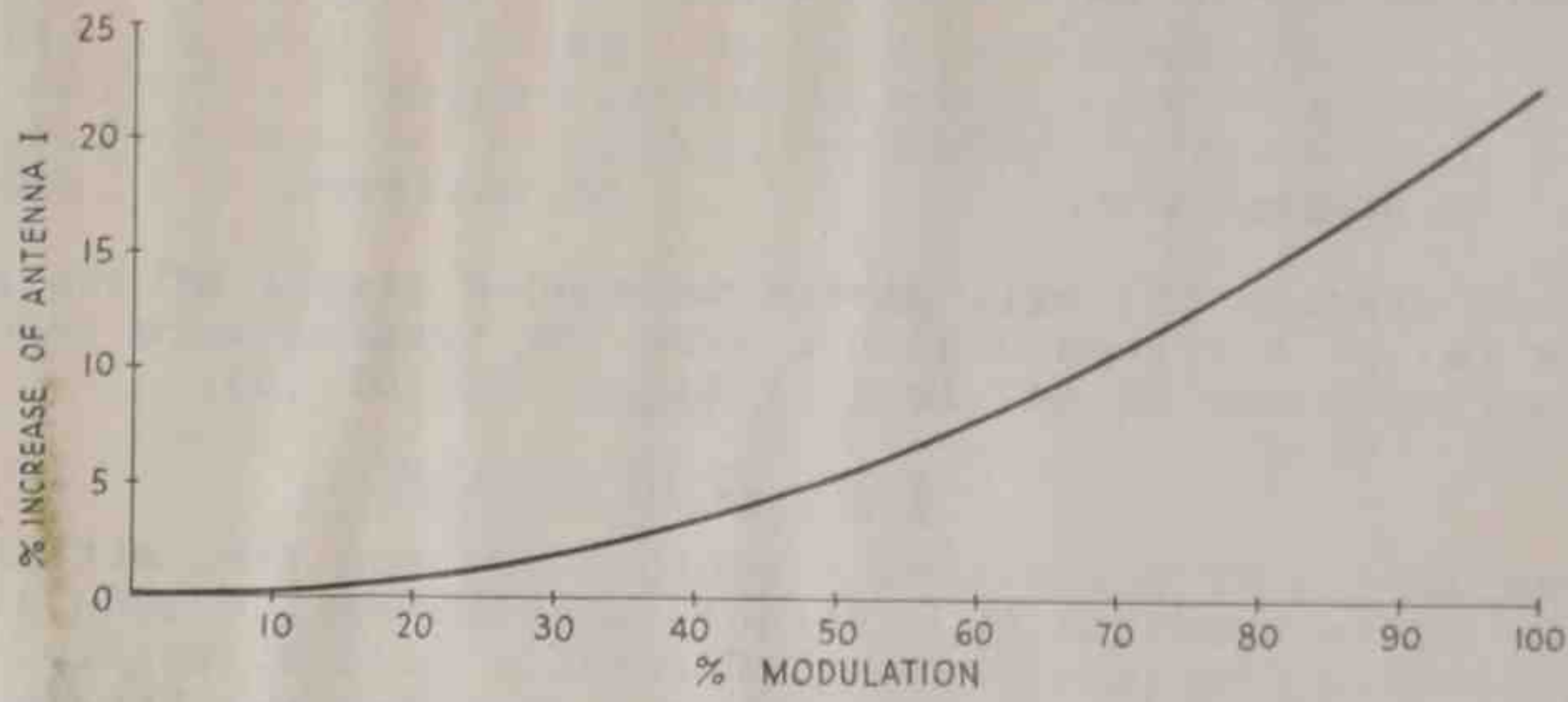

Figure 4b

For the lower degrees of modulation the antenna current hardly changes. It should, however, always increase and not decrease. A decrease in antenna current during modulation always means something is wrong in the transmitter.

SIDE-BAND POWER

Since all the intelligence in a modulated carrier is in the side-bands these bands should have as large an amplitude as possible, that is, high degrees of modulation should be employed if maximum range of the station is desired. The relative power of the side-bands to the carrier power may be determined by taking a simple case.

Assume $I_c = 1$ ampere.
$R_{ant} = 1$ ohm. (antenna resistance)

Then the carrier power $= I_c^2 R = 1$ watt, if $m = 1$.

$I = 1.226$ and total power during modulation is,

$$I^2 R = (1.226)^2 1 = 1.5 \text{ watts.}$$

The additional power is .5 watt and is in the side-bands. The data in Figure 4 may be used to calculate a table showing Side-Band Power versus Degree of Modulation on the basis of a one watt carrier. Such a table is shown in Figure 5.

m	P
1.0	.5
.9	.405
.8	.32
.7	.245
.5	.125
2	.02

Side-Band Power / Degree of Modulation for 1 watt carrier.

Figure 5

To use a specific example assume two stations using an identical antenna system have following powers and modulation factors.

	(a)	(b)
Carrier	400 watts	100 watts
m	0.5	1.0
Side-Band Power	50 watts	50 watts

Then station (b) will give a telephone signal of the same strength as (a) at the same distance from the transmitters even though the carrier power of (a) is <u>four times</u> that of (b).

WIDTH OF SIDE-BANDS

The amount of space that a radio telephone transmitter takes in the radio spectrum is a direct function of the modulation frequencies. Various classes of service need to handle modulation frequencies of different amounts. Thus for the broadcast of extra high quality music the audio equipment should be capable of handling frequencies up to 15,000 cycles/sec. as there are some musical instruments that produce these frequencies. In more technical words the audio system must have a flat frequency response up to 15,000 cycles/sec. Frequencies above about 5,000 cycles/sec., however, are not necessary for the complete appreciation of music; therefore the broadcast stations as a rule do not transmit side-bands having a frequency greater than 5,000 and hence are assigned carrier frequencies separated by 10 kc/sec. to allow 5,000 cycle or 5 kc modulation on each side of the carrier. If two stations in adjacent channels and in the same region were to broadcast using higher modulation frequencies than 5,000 cycles, then the two would overlap and severe interference would result. Stations having cleared channels (separated from other stations by 20 or 30 kc/sec.) can however use higher modulation frequencies, and such is done occasionally on some broadcasts from these clear channel stations.

For the broadcast of voice the frequency band need only be from about 250 cycles/sec. to 2700 cycles/sec. If all other frequencies are cut off or attenuated, it does not matter as the voice is plainly understandable, the average voice frequency being taken as 800 cycles/sec. This is quite a contrast to music which requires 50 to 5,000 cycles/sec. Transmitters in the "voice only" class are, for example, the transatlantic and transoceanic telephone circuits, aircraft radio beacon stations, aeronautical ground stations, airplane transmitters and amateur radiotelephone stations. The audio response curve for stations falling under the above classification need not be flat, therefore less expensive audio equipment may be used. On the other hand transmitters for visual broadcasting must handle modulation frequencies even higher than high quality music--up to 40,000 cycles/sec. depending on the detail required in the picture.

METHODS OF AMPLITUDE MODULATION

A great many methods for producing amplitude modulation have been devised most of which are now obsolete, but fall under the following four classifications.

1. Modulation by means of non-linear circuits.
2. Modulation by means of variable circuit elements.
3. Modulation of oscillators.
4. Modulation of R.F. amplifiers.

The last two, and particularly the last, are the most important.

THE PLATE-MODULATED OSCILLATOR or "HEISING" SYSTEM

This method was until a short time ago the most successful and most used method of modulation. The method is still used to a considerable extent, but as applied to an R.F. amplifier rather than the oscillator tube in a transmitter.

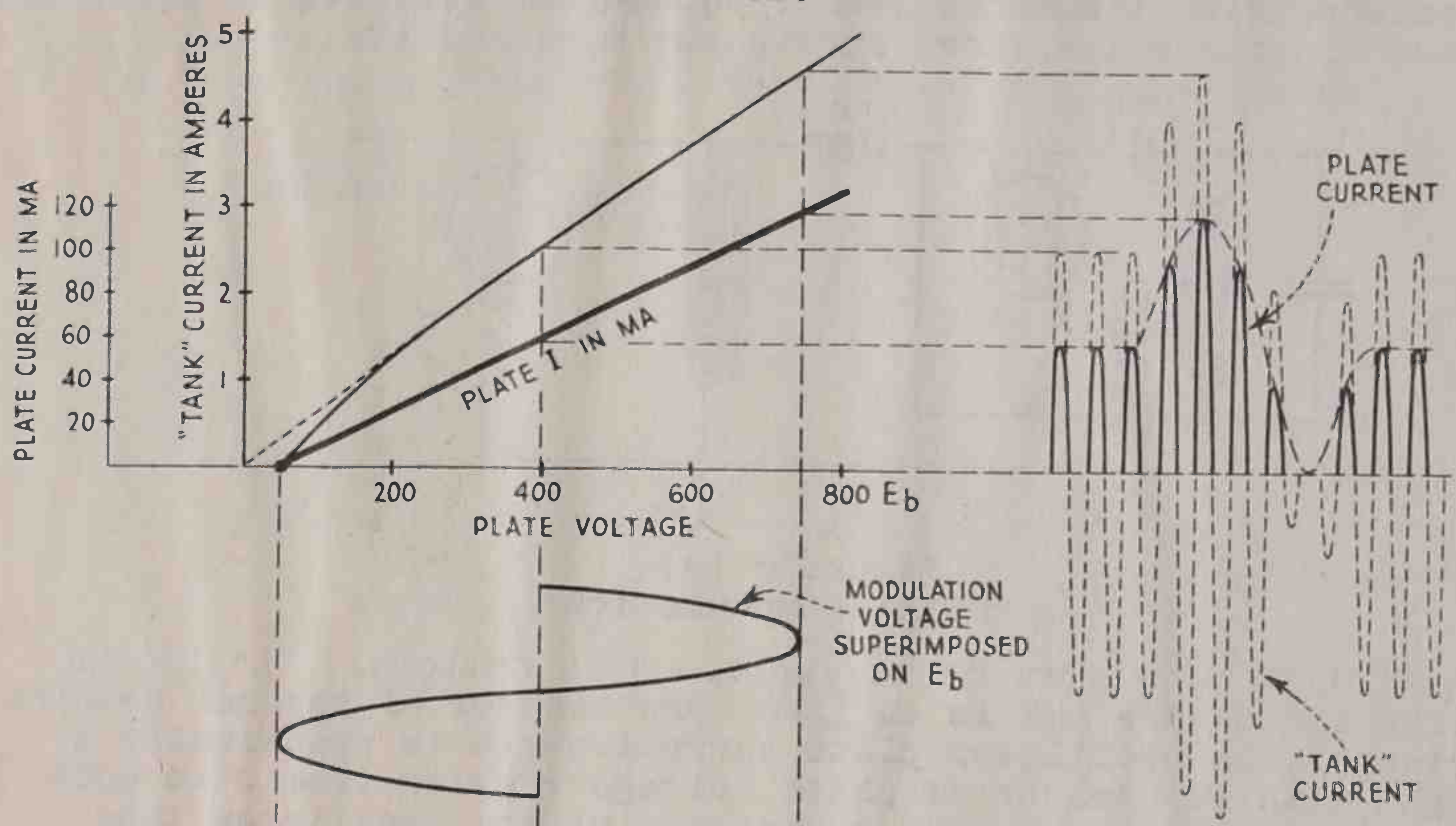

Figure 6

This system makes use of an oscillator in which the amplitude of oscillations and the plate current drawn by the tube are proportional to the applied plate voltage. Figure 6 shows the relations existing.

If the oscillator is coupled to an antenna, then antenna current will vary similarly to "tank" current and amplitude modulation has been produced according to Figure 3.

When I.C.W. transmission from a telegraph transmitter is desired it is sometimes accomplished by applying an alternating voltage of 350 or 500 cycles to the plates of the tubes. Transmitters of this type employ what is known as a self-rectifying circuit, two tubes being used. One tube has its plate shunt fed from one end of a

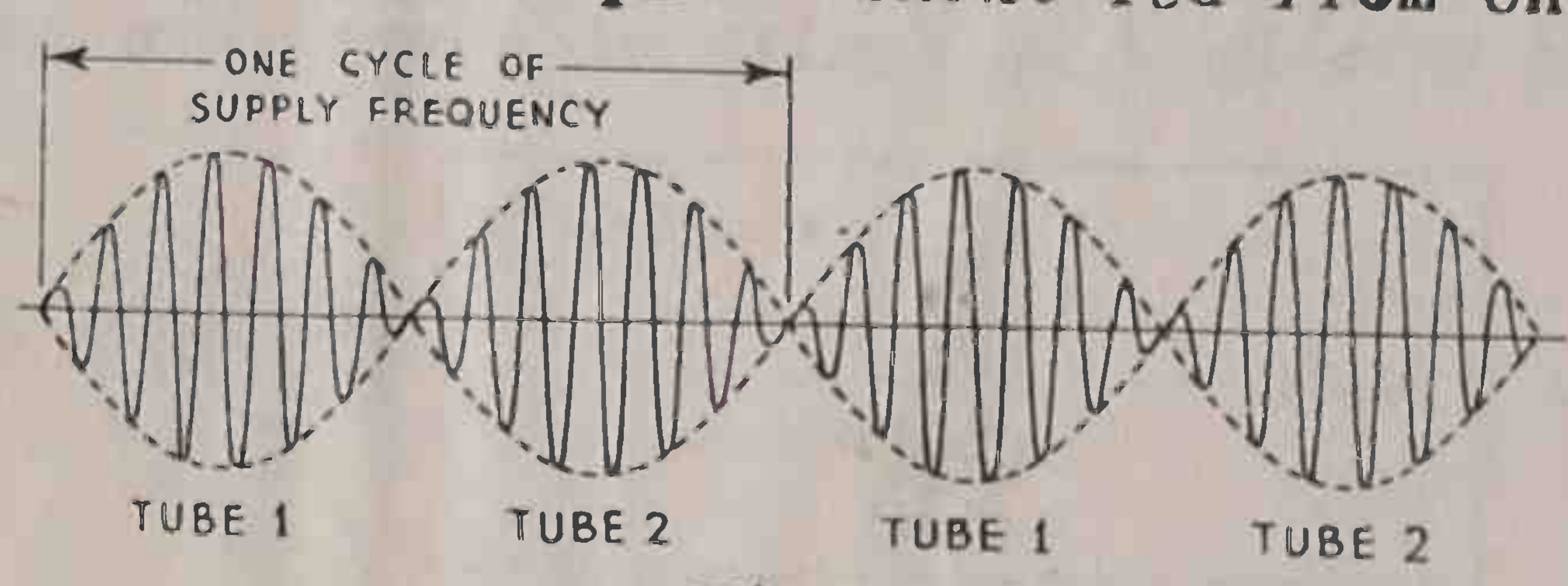

Figure 7

high voltage secondary on the power transformer (350 to 500 cycles) and the other tube plate is similarly fed from the other end of the transformer secondary. The center-tap of the winding connects to the tube filaments. In this circuit only one tube works at a time since the plate will only draw electrons when it is positively charged with respect to the filament. Each tube, then, works for only ½ a cycle and R.F. oscillations build up and die out as shown in Figure 7, which in effect is the same as modulating a continuous carrier at <u>twice</u> the supply frequency.

This system of course gives a modulated note of only one frequency. To produce relatively complex modulation by several frequencies at once it is necessary to employ an audio amplifier (modulator) tube whose output voltage is superimposed on the direct current supply voltage and thus makes the amplitude of oscillations vary in accordance with the modulation frequencies. Circuits to produce such an effect are shown in Figures 8, 9 and 10.

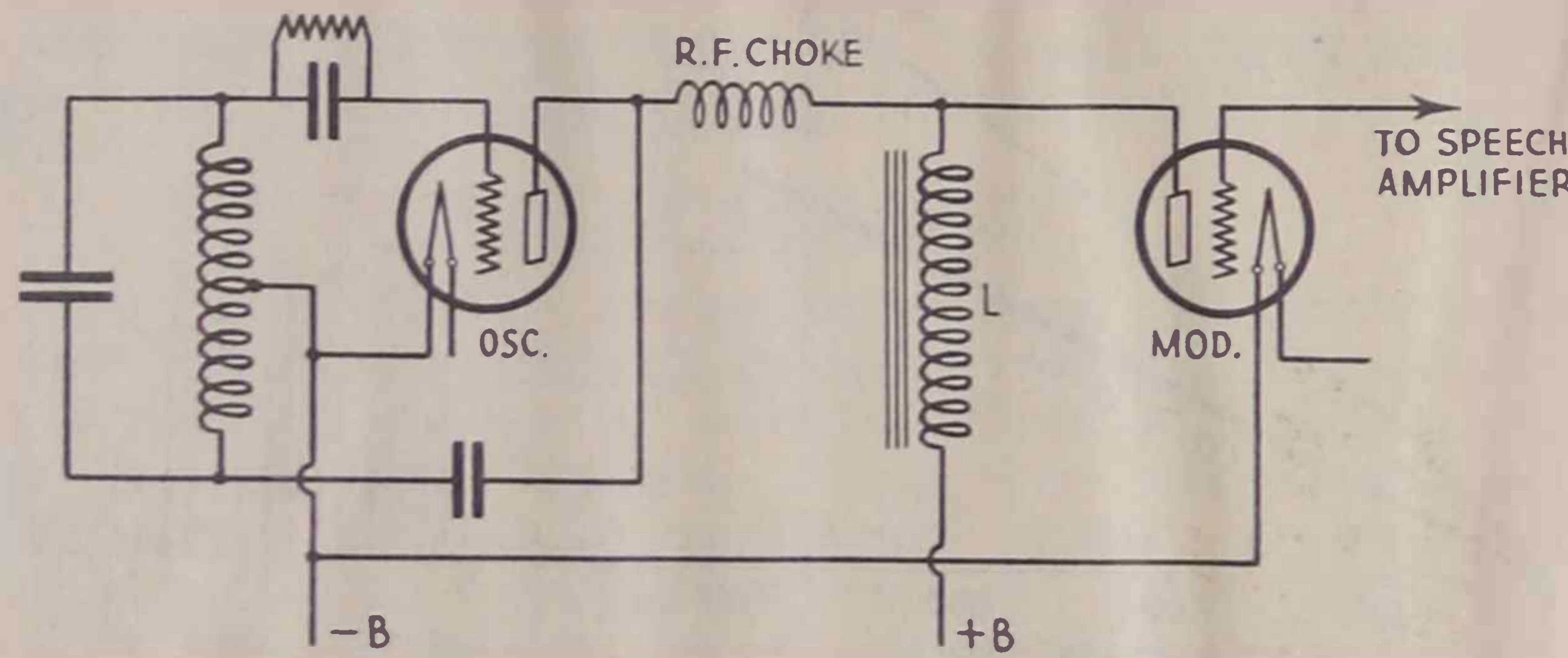

Figure 8 (a)
"Heising Modulation"

The operation of Figure 8a is explained as follows. "L" is the coupling inductance and is an iron core reactor of several henries inductance. The oscillator plate current curve is practically a straight line for values of plate voltage ranging from 0 to 200%. See Figure 6. This makes the resistance of the oscillator tube constant. It is this resistance which acts as the load for the modulator tube. For example, if the oscillator draws 50 ma of plate current at a plate voltage of 400 volts, the resistance is $R = E/I = 400/.050 = 8000$ ohms. If the plate current plate voltage curve is a straight line, then any voltage divided by the corresponding current will also give 8000 ohms which then is the modulator's load resistance into which the modulator tube delivers power. The purpose of the choke is merely to shunt feed the plate of the modulator, that is, act as a coupling impedance. Its inductance must be high enough so that at the lowest modulation frequency to be transmitted the reactance ($X_L = 2\pi fL$) will not fall to such a value that the total load impedance on the modulator tube is teri y red , in this case below 0 o s, otherwise serio dis ti of the low freque ies uld re t. In explaini t act l ration of the sys the equivalent circuit a ator / Ip f ly of c ves are used.

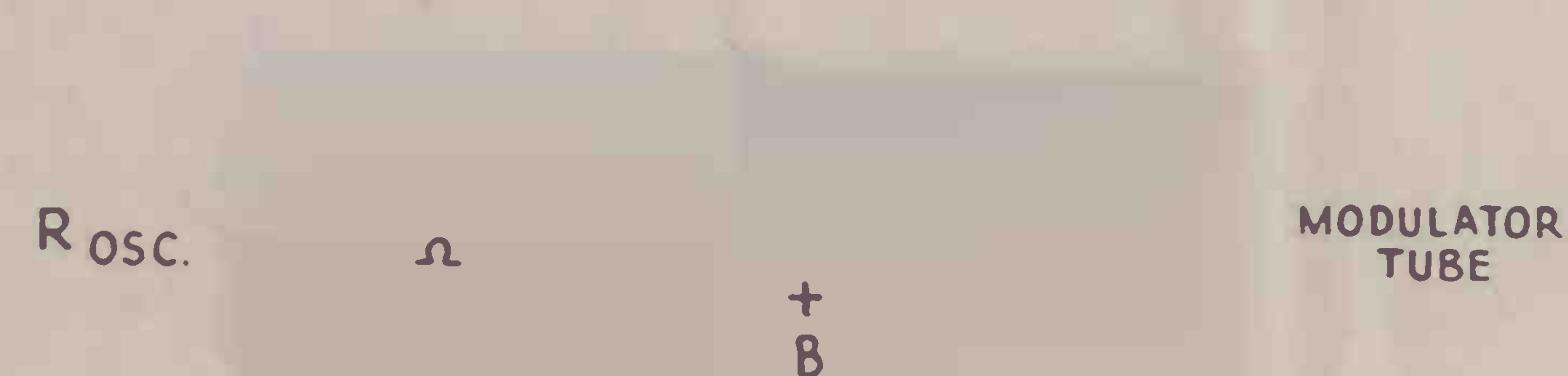

Figure 8(b)--Equivalent circuit of 8(a)

Fi re 8 (c) shows variati of dulator I_p the consequent voltage built up across R_{osc}. It is obvious that for one-half of the cycle this ta will be of the pol ity to add to the B supply voltage the oscilla d for the other e-half of the cycle wi ose t B volta and therefore cancel out so of it, thus acc lishing dulati . This is o as plate d a- tion since the plate e is modulated or d at an audio rate. It will also be obvious up inspection of Fi e 8 (c) t t while the modulator plate current is increasing the voltage across Rosc is of proper polarity to cancel out part of the B supply voltage and therefore the oscillator plate current decreases. This has led to the name "constant current" system, since the current flowing through the choke is constant as read on a milliammeter in series with the B supply voltage. It is well known that an audio amplifier will deliver maximum power when the load resistance equals the tube plate resistance. This, however, gives severe

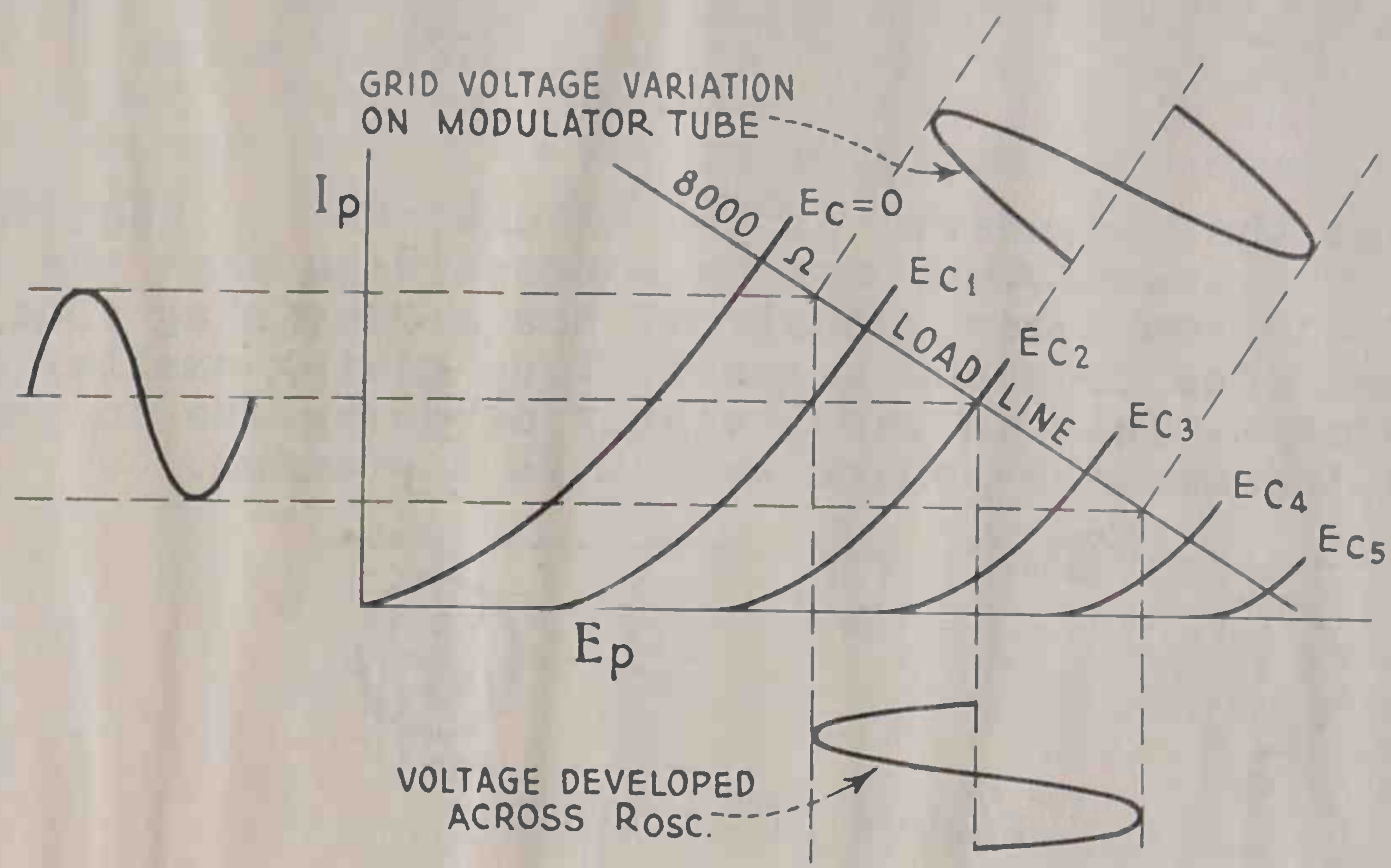

Figure 8 (c)

distortion and to limit distortion the amplifier load resistance is always made 2 to 3 times the plate resistance of the tube even though the power output drops to about 90% of the former value. Thus the modulator tube should have in this case a plate resistance of 3000 to 4000 ohms in order to keep distortion down to an unobjectionable amount when working into an oscillator whose resistance is 8000 ohms. This point cannot be stressed too much. In fact special circuits are used to match modulators and oscillators (or R.F. amplifier tubes). Such circuits are shown in Figures 9 and 10. The simple circuit of Figure 8 (a) is not capable of 100% modulation because, even though distortion was not a limiting factor, the peak value of alternating voltage can never be equal to the DC voltage of the oscillator and hence circuits of Figures 9 and 10 are also used to accomplish 100% modulation as well as match the tubes correctly.

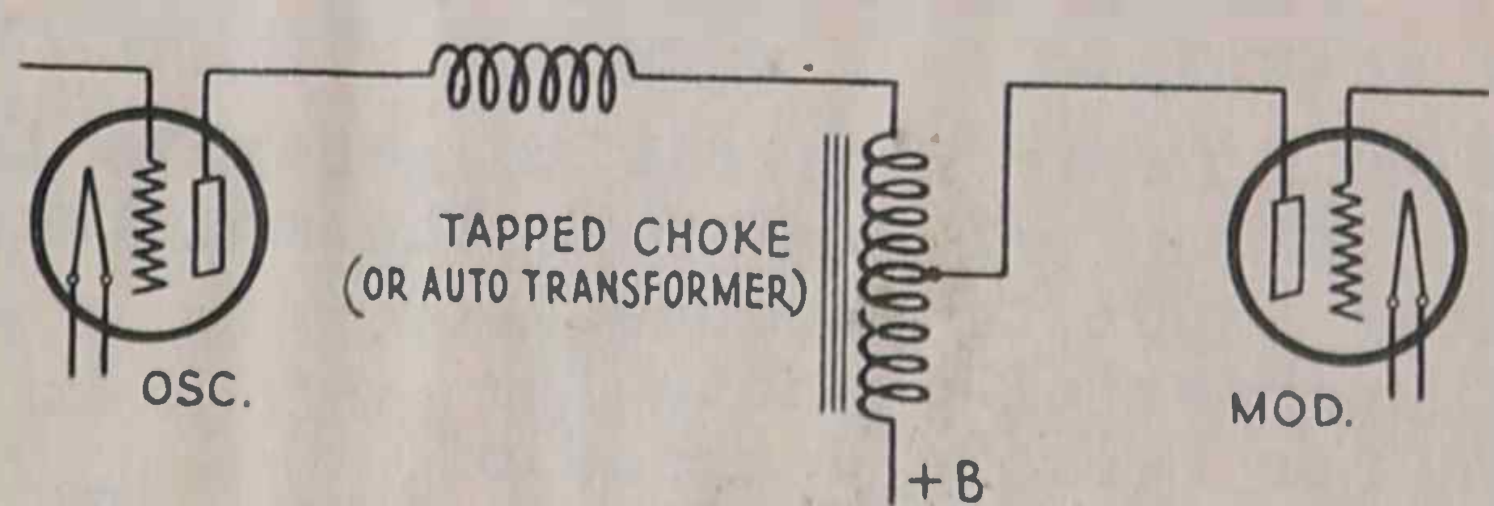

Figure 9

In Figure 9 the 8000-ohm R_{osc} is <u>stepped down</u> according to the ratio of the auto-transformer to the correct amount for a load resistance on the particular modulator tube used. Also the output voltage of the modulator is <u>stepped up</u> until its peak is equal to the DC voltage of the oscillator tube which will then accomplish 100% modulation.

Figure 10 shows transformer coupling. This has several advantages. The turns ratio of the transformer may be made correct to match the tubes properly and then if the peak voltage of the modulator tube is still not enough for 100% modulation the plus B voltage may be reduced until it is the same as the peak output voltage

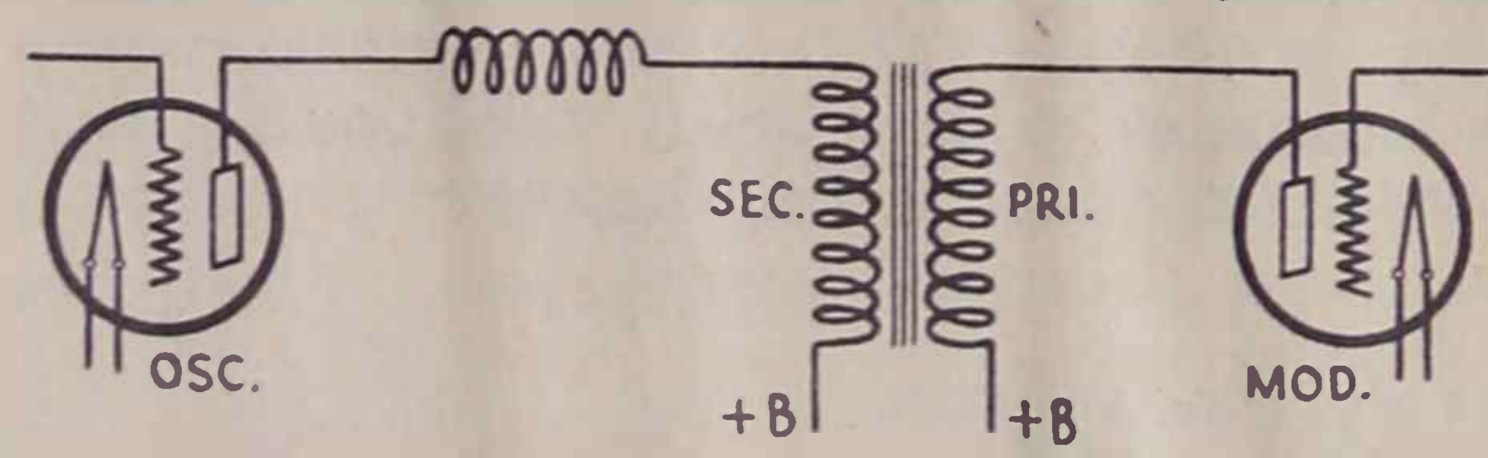

Figure 10

(appearing across the secondary) of the modulators. In addition, the windings of the transformer may be connected so that the direct currents of the two tubes cancel out the magnetizing flux in the core and much less iron can be used, thus giving smaller and lighter transformers. This is particularly advantageous in portable and mobile transmitters where weight is a premium.

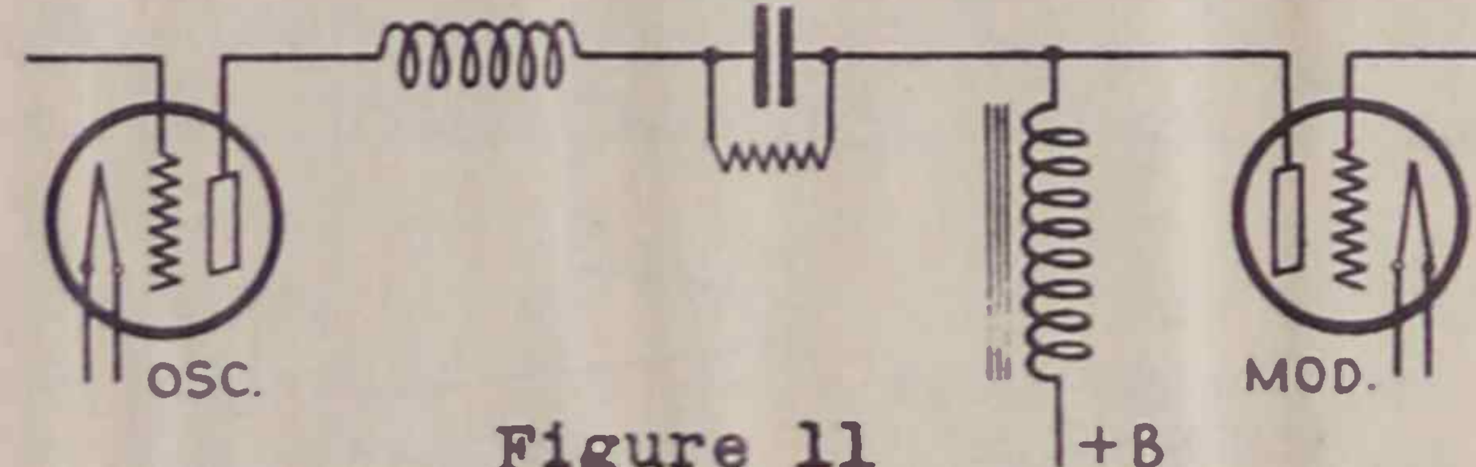

Figure 11

Figure 11 provides for 100% modulation by dropping the voltage applied to the oscillator, but allows no matching of resistances. In this case the proper tubes must be used. This circuit is a very common one, however.

In addition to the output voltage of the modulator tube being of sufficient value to modulate the oscillator 100% (that is, vary its voltage from 0 to 200%) the power output of the modulator tube must be enough to supply the additional input to the oscillator during modulation. Thus if the DC voltage on the oscillator tube is 400 and it draws 50 ma of plate current when loaded into an antenna the tube is offering a resistance of 8000 ohms as already e lai d. c letely modulate this the peak voltage fr the ator st be 4 ts also the wer output of the d- ator t be

$$\frac{E^2}{R} \text{ or } \frac{\left(\frac{E_b}{\ }\right)^2}{R} = \frac{\left(\frac{400}{\ }\right)^2}{8000} = \frac{\frac{160{,}000}{2}}{8000} = \frac{80{,}000}{8000} = 10 \text{ Watts}$$

The put power the oscillator uir to gene te the carrier is I_b= x . = watts. r ore the ator output st be 1/2 oscil tor input to p uce 1 d ation. It is interesting to note the audio power required for various degrees of dulation. e adjoini table i icates the A. F. wer required varies with m. A ently the A.F. output is always eq l to the oscillator in t r cessa to generate e carrier x m^2 2, e m is the ation fac r. Unfort tely t losses of the oscillator t e ve to be ulated, therefore the re efficient t oscillator is the less the waste in ive A.F. out t.

m	% of llator l r for Carrier Only
1.0	.5
.9	.
.8	.32
.7	.
.5	.125
.2	.02

Assume the carrier power of the station is 100 watts and the oscillator 60%. This makes the oscillator input 100/.6 or 166.66 watts, since efficiency $= \frac{\text{output}}{\text{input}} \times 100$.

For 100% modulation the modulator power output must therefore be 166.66 x .5 or 83.33 watts. If only 20% modulation was desired, the modulator output would need to be but 166.66 x .02 or 3.3332 watts. In the first case the modulator would have to be a bank of 8 or 9 UV 211 tubes or 4 UV 845 tubes or 1 UV 849 tube, the class A output of these tubes being respectively 10 watts, 21 watts, and 81 watts each. For the second case (20% modulation), a pair of UX 245 tubes, or 2 UX 210 tubes, or 1 UX 842 tube would fill the requirements. It is hoped that power considerations will not be taken too lightly by the student.

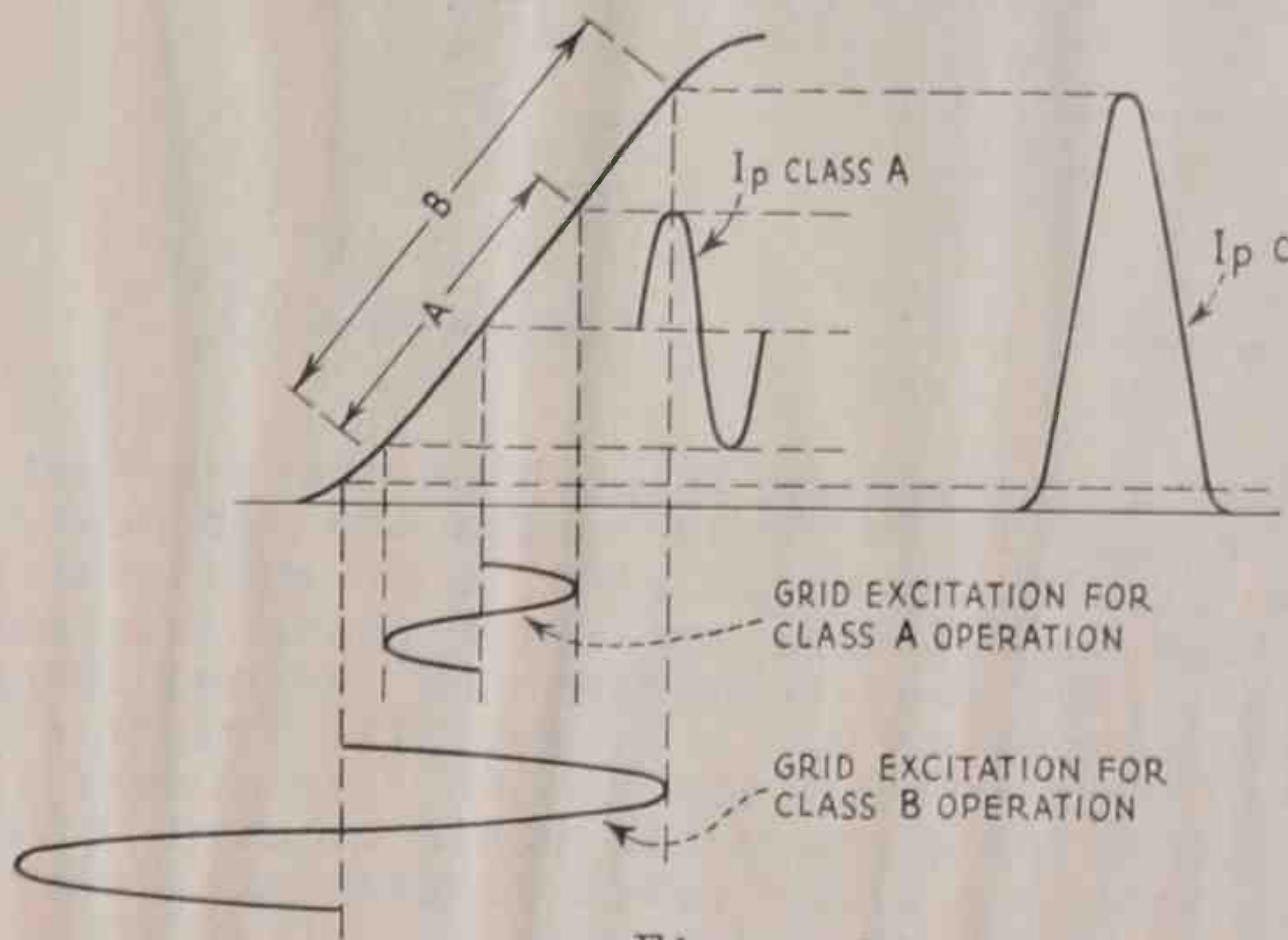

Figure 12

Modulated oscillators are no longer used for broadcasting, since carrier frequency depends to a slight extent on plate voltage and hence would be constantly changing during modulation and would give frequency modulation or "wobbulation" of the carrier. All that has been said of modulated oscillators however applies to plate modulated class C amplifiers, that is, power considerations, circuits, etc, need not be repeated. The class C R.F. amplifiers are merely driven or "excited" by the oscillator and have their plate voltage varied by the modulator tube or tubes.

CLASS B MODULATOR TUBES

In the Heising system just discussed the modulator tubes are operated class A. Four or five tubes in parallel are required to completely modulate a tube of the same type used as an R.F. amplifier (or oscillator). When tubes are operated class B however, the output is from 5 to 10 times the amount possible when the class A system is used, since under the class B operation the entire straight portion of the dynamic curve may be used from projected cut-off to the upper bend. The part of the curve utilized by class A and class B operation is shown relatively in Figure 12.

Two tubes are necessary in class B A.F. amplifiers in a "push-push" circuit, since the tubes are biased to projected cut-off only ½ of the A.F. cycle would be present in the output device if only one tube were used. Also, to take full advantage of the straight portion of the curve it is necessary to drive the grids positive which causes them to draw power and hence the driver stage must be capable of supplying this power, and since power is required for only a fraction of a cycle - depending on the bias used and the amplitude of the exciting voltage, the driver stage must have good regulation. All of which means that considerable care is required in designing transformers for class B use. Since the tubes operate with a much higher efficiency (usually about 50%) than class A tubes (usually 20 or 25%) a saving of power is also effected as well as in the number of tubes required. The circuit used for plate modulation of class C R.F. amplifier tubes by class B A.F. tubes is very much like the Heising transformer coupled circuit except for the transformers and tube layout.

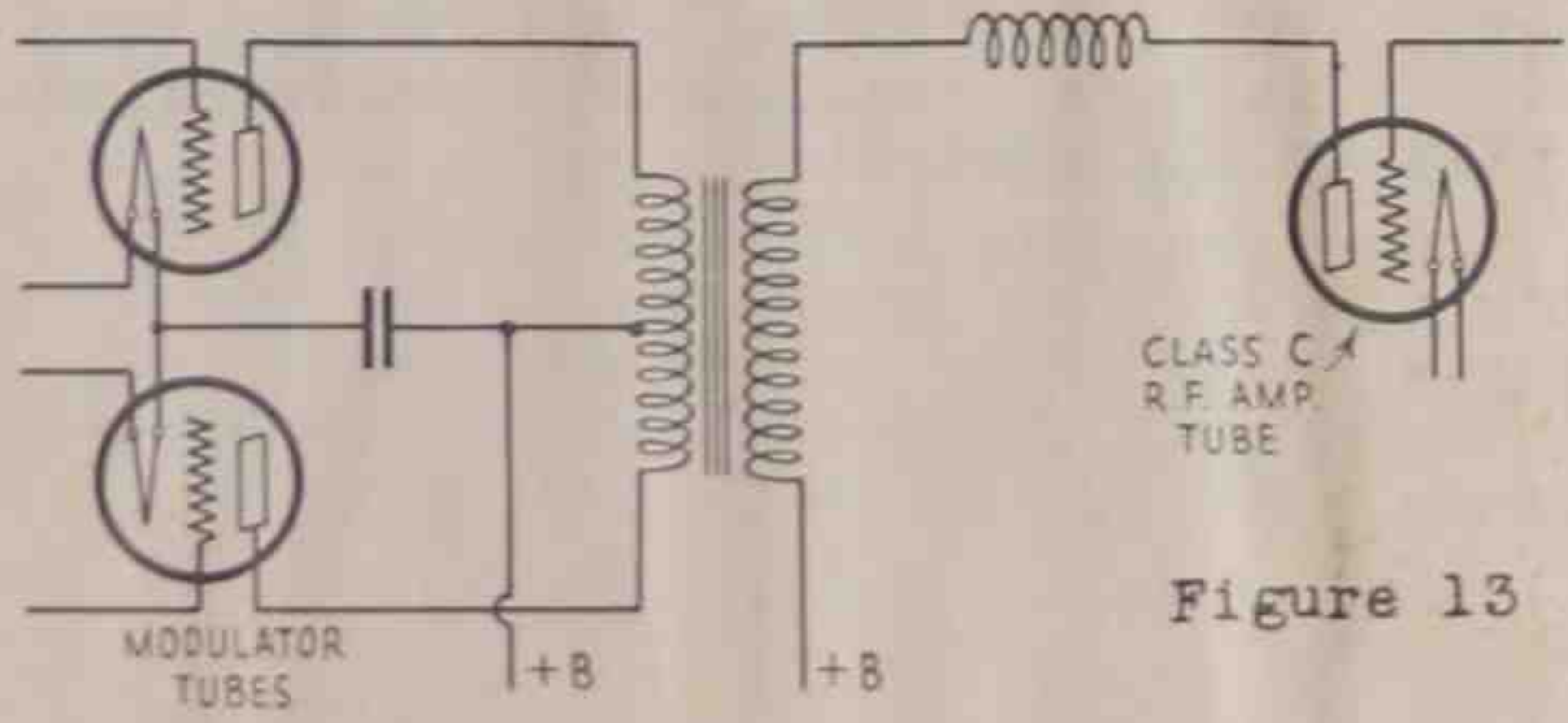

Figure 13

The explanation of class B modulators is perhaps the simplest of all to understand. A voltage is built up across the secondary winding of the output transformer which adds to or subtracts from the plus B supply voltage to the R.F. amplifier plate thus modulating the plate supply. The load resistance on the modulators is of course the DC resistance of the R.F. amplifier plate-filament circuit reflected back through the output transformer for proper matching. In high power systems the plate current of the R.F. amplifier is fed through a choke as in Figure 14 to keep from saturating the core of the transformer.

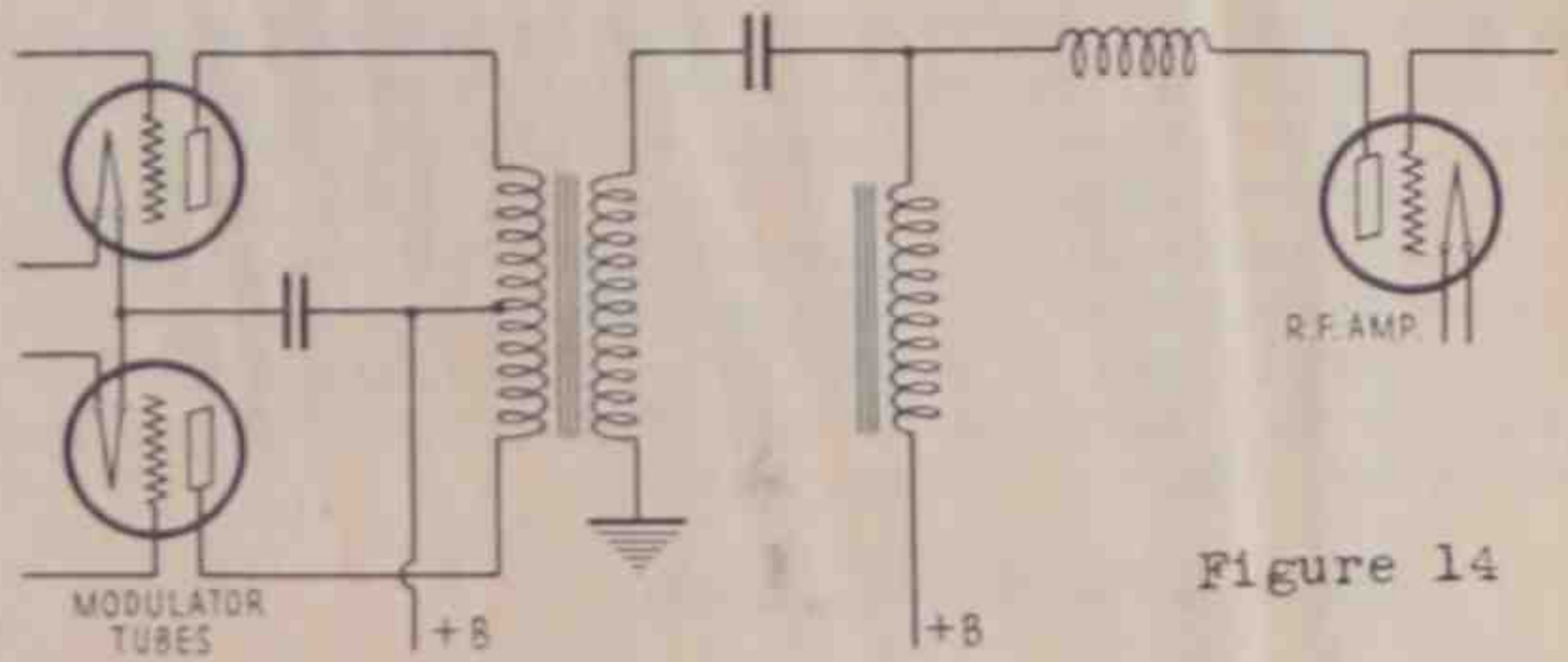

Figure 14

If the tubes are matched, the proper transformer ratio used and the driver stage (not shown) has sufficient power and good regulation, the only place distortion can occur is at the lower bend of the curve. This is not serious if the tubes are worked close to their maximum power rating because the curvature of the lower bend is not important compared with the total length of the straight portion of the curve.

GRID MODULATED R.F. AMPLIFIERS

One form of so called grid modulation is that employing a modulated wave as excitation to a linear or class B R.F. amplifier. The modulated wave is produced by plate modulating a low power stage whose output is then fed to the grid of the linear amplifier. Figure 15 shows how this works.

This system gives the same sort of antenna current variation as plate modulation, the only advantage being that low power A.F. equipment may be used, but the advantage is offset by the number and size of class B R.F. tubes required, since class B tubes are less efficient than class C. It was, however, used exclusively for the production of high power output, running into several thousand watts, since before the advent of class B A.F. amplification the

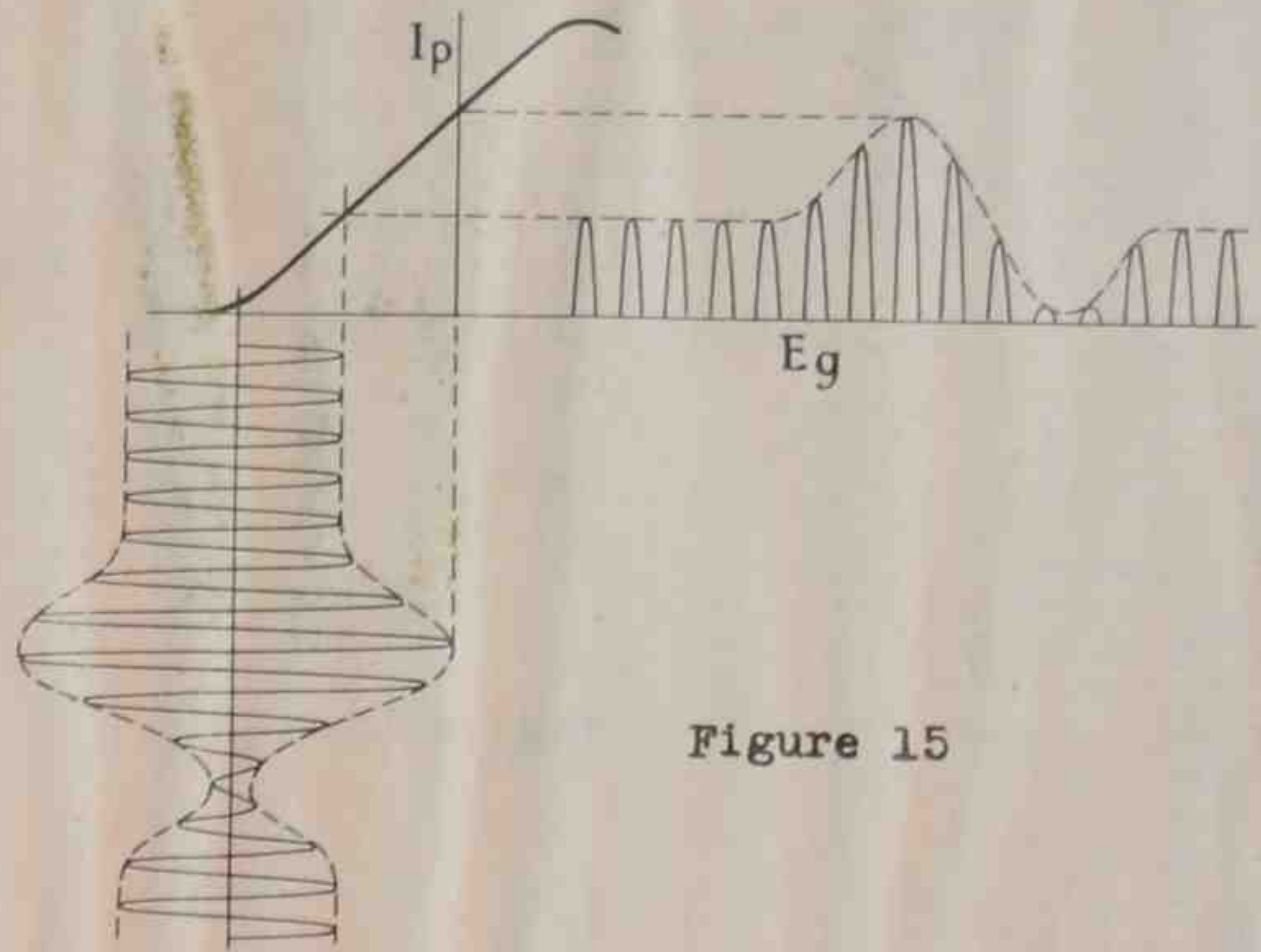

Figure 15

production of A.F. power at high levels by means of class A tubes was extremely expensive as the student will readily appreciate. High level modulation of the last R.F. stage in the transmitter is becoming more common now, however, since the possibilities and economies of class B A.F. amplification have been realized.

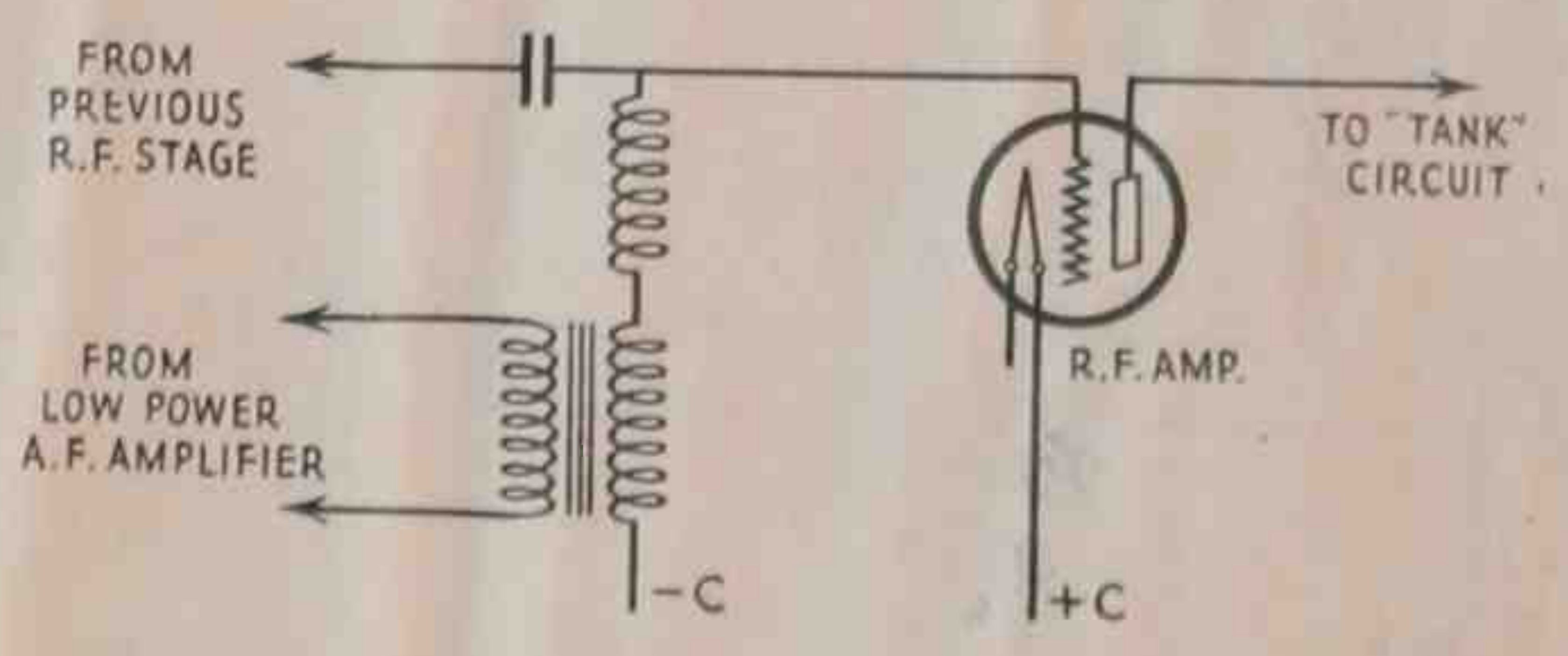

Figure 16

Another version of grid modulation that is extensively used is the type known as "grid bias" modulation. Figure 16 shows the schematic diagram.

It is quite evident from Figure 16 that any A.F. voltage built up across the secondary of the transformer will add or subtract to the bias on the R.F. tube at an audio rate and hence accomplish modulation as shown in Figure 17.

The tube is biased to approximately 1½ times the cut-off value and a constant R.F. grid voltage is applied. The bias being changed causes the tube to draw more or less plate current as in Figure 17. This method is a very good one inasmuch as practically no power is required from the modulator tube if the grid of the R.F. amplifier never goes positive and large transmitting tubes may be modulated by very low power A.F. tubes.

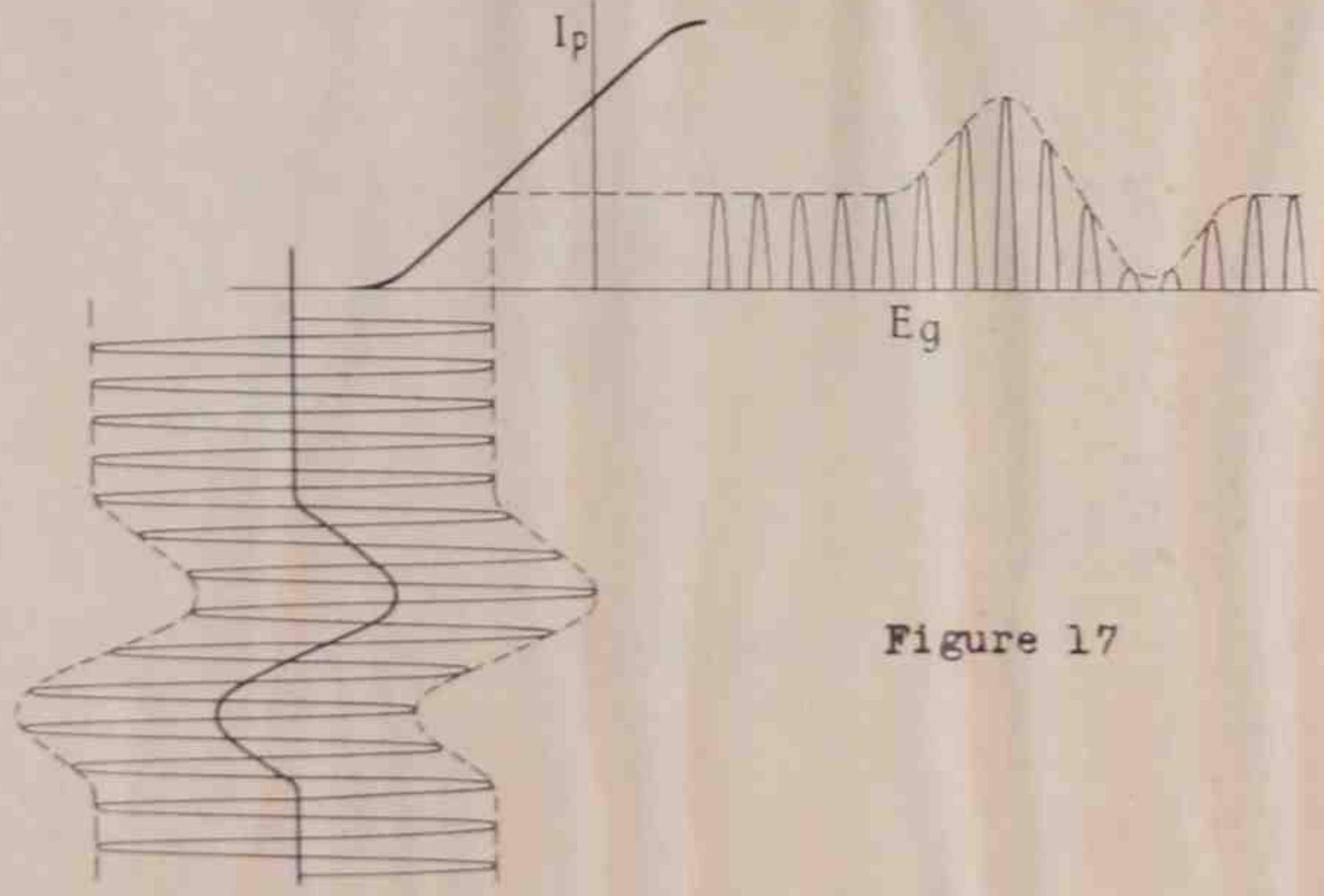

Figure 17

Another method of grid modulation is known as the Van der Bijl system. It has a limited use, being confined mostly to carrier current systems using wire lines.

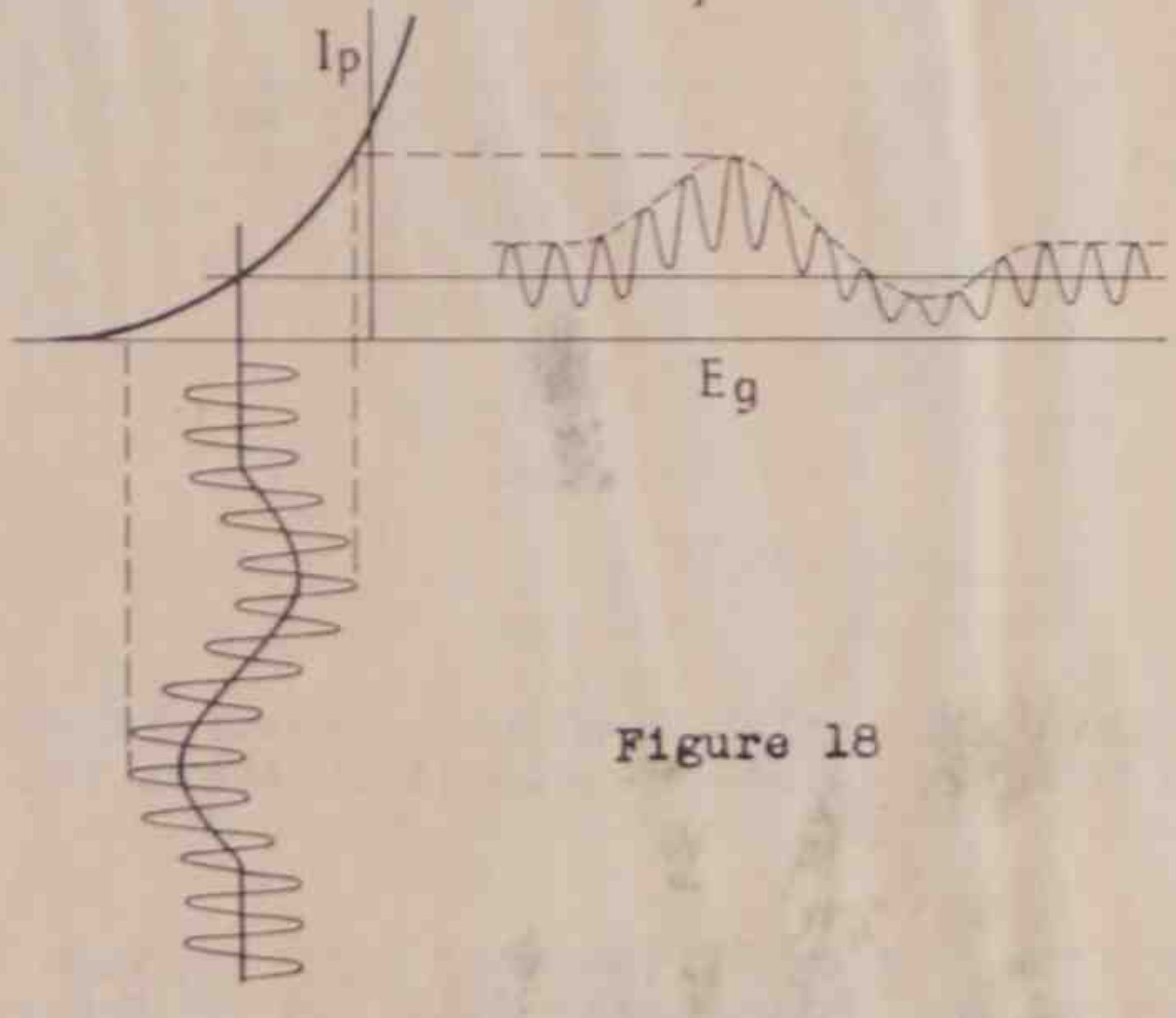

Figure 18

In the Van der Bijl system the tube is biased as in the class A service and a constant R.F. voltage is applied to the grid. The bias is then varied which, due to the curvature of the I_p-E_g curve, causes distortion of the plate current wave. Thus the plate current is changed at an A.F. rate and modulation occurs. (Figure 18).

MODULATION OF A TETRODE

The use of a screen-grid, four-element tube as an R.F. power amplifier in telephone transmitters has the advantage over triodes in that neutralization to prevent self oscillation in the amplifier stage is not necessary. The tetrode may be modulated in several ways as follows.

SCREEN-GRID MODULATION

Since the plate current of a four-element tube depends on screen voltage as well as other factors the screen may be modulated. A curve of screen voltage vs. tank or antenna current would appear as in Figure 19.

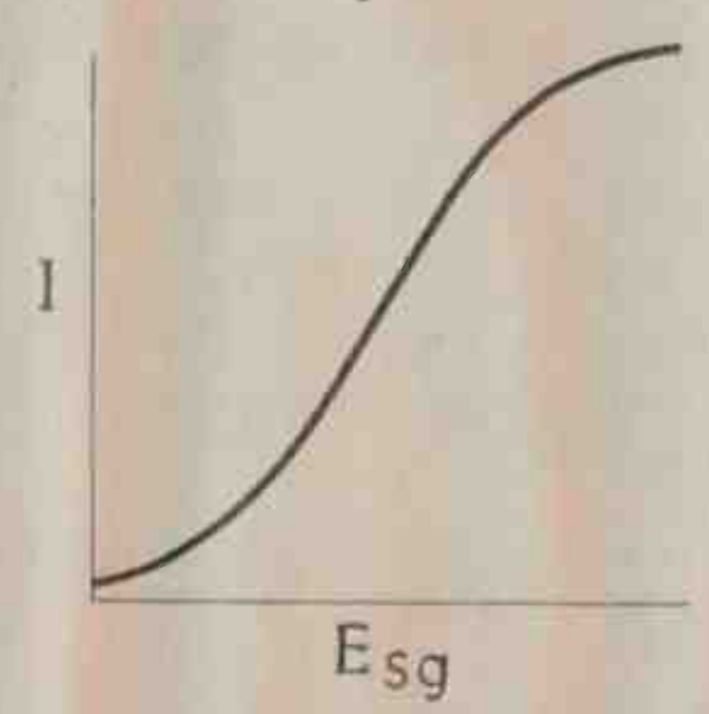

Figure 19

Obviously this curve is not linear except for a short portion at the center, hence screen modulation is not used if 100% modulation is desired. The method has several advantages however, particularly in low power and portable transmitters which do not require complete modulation and are of necessity as light in weight as possible. Several circuits are in use, some of which are shown below.

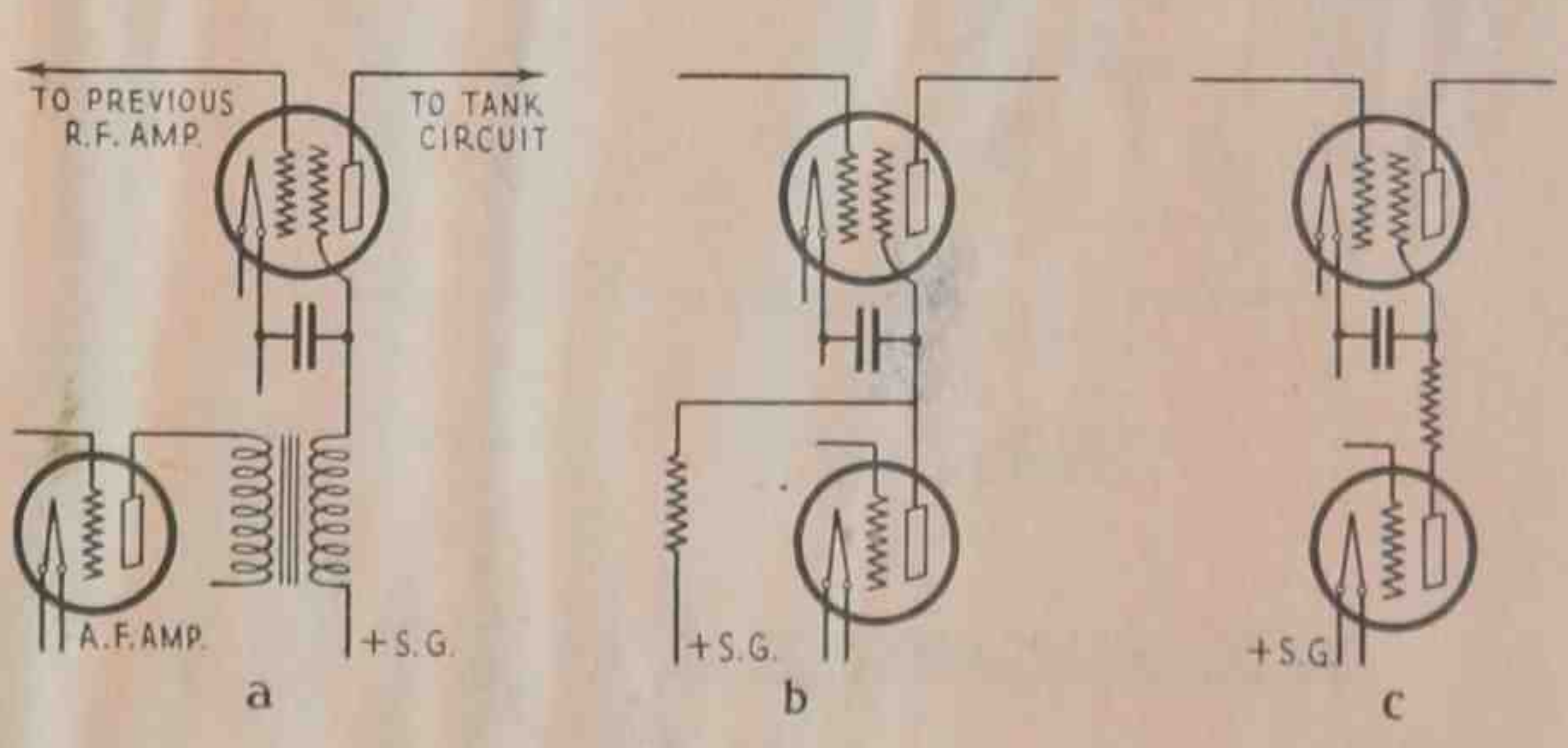

Figure 20

For screen modulation the R.F. amplifier must operate class B, hence the carrier output of the tube is only ¼ of the class C rating of the tube. For example, a UX 865 tube rated at 12.5 watts class C must only deliver a carrier output of 3 watts if the screen is to be modulated.

PLATE MODULATION OF A TETRODE

This may be accomplished by either a choke as in the Heising system or by class B modulator tubes as already discussed. The curve of tank, or antenna current vs. plate voltage with a constant screen voltage is shown in Figure 21.

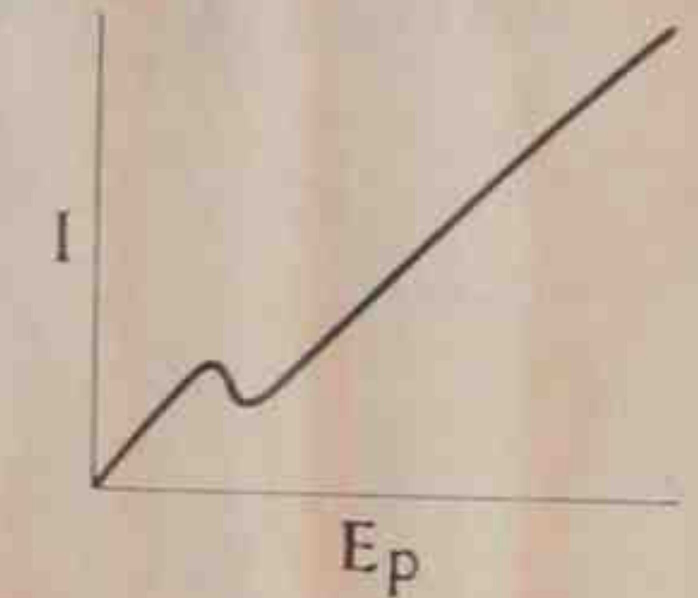

Figure 21

Obviously this is not capable of 100% modulation without distortion. The hump in the curve is caused by secondary emission of the screen when the plate voltage falls below the screen voltage. For degrees of modulation in the order of 90%, however, this method is satisfactory and has considerable usage.

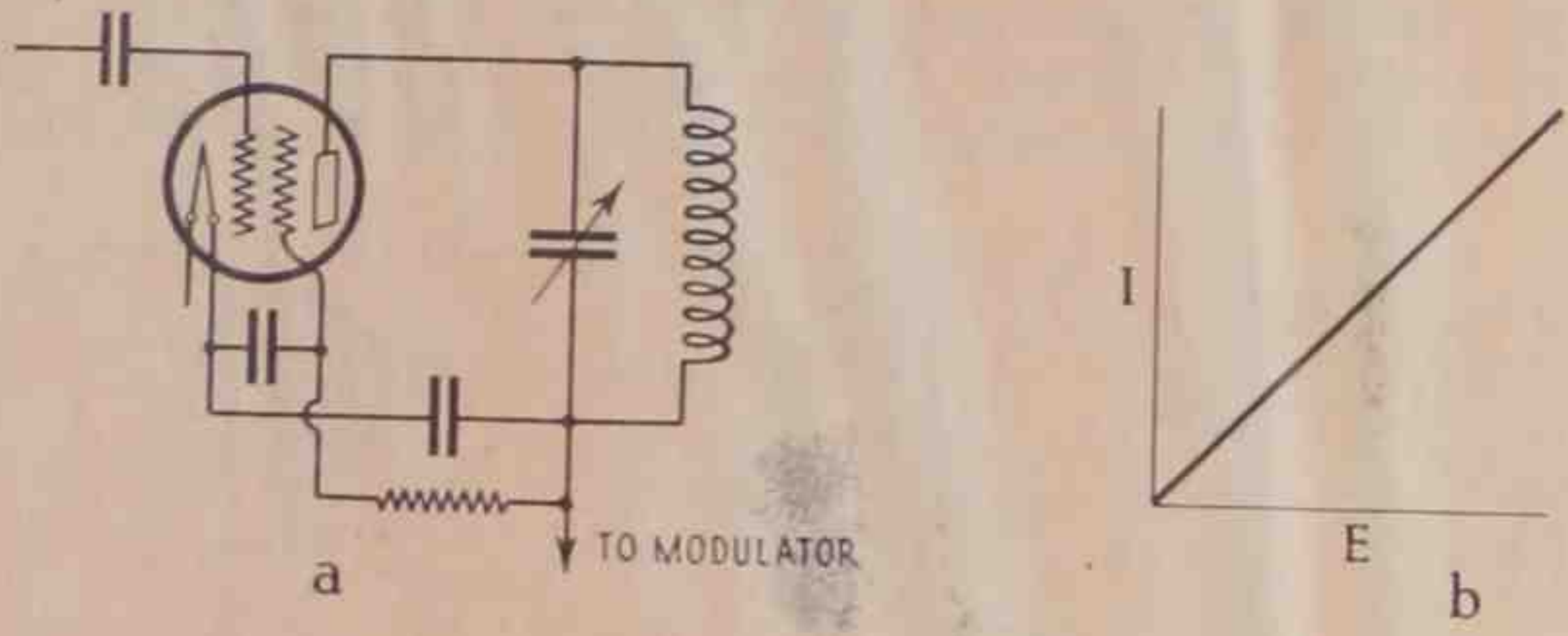

Figure 22

PLATE AND SCREEN MODULATION

If the circuit shown in Figure 22 is employed complete modulation may be secured with negligible distortion, since the screen voltage decreases proportionately with plate voltage and gives a curve of tank current vs. supply voltage that is essentially linear.

Grid modulation may be employed of course, but the most satisfactory way of modulating a tetrode is the latter one.

EXAMINATION QUESTIONS

1. Explain what is meant by a "carrier".

2. Draw a diagram showing 100% modulation.

3. (a)What are the "side-band" frequencies?
   (b)How much space in the radio spectrum would a 700 kc. carrier modulated by a 5000-cycle note occupy?

4. Assuming that the carrier power and modulation factor of a station could be adjusted to 1000 watts with m=.9 or 5000 watts with m=.4 which adjustment would produce the most side-band power?

5. What bands of frequencies are required for transmission of (a) voice (b) music (c) high quality music?

6. By what methods may amplitude modulation be accomplished?

7. What is meant by plate modulation?

8. Why are two tubes necessary for Class B A.F. amplification?

9. What is high level modulation?

10. Name a method of grid modulation.

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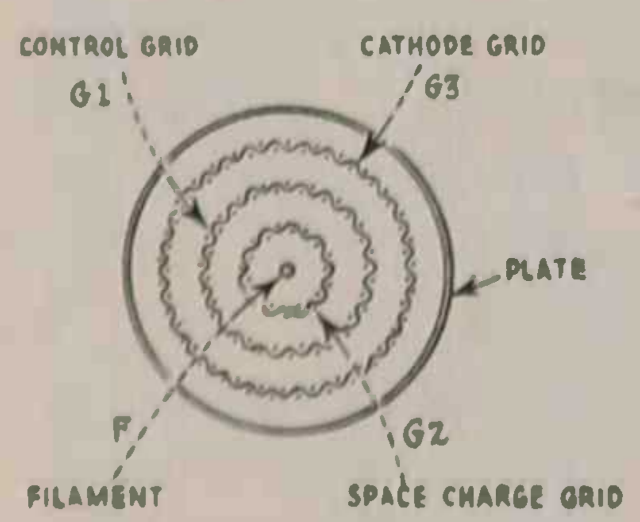
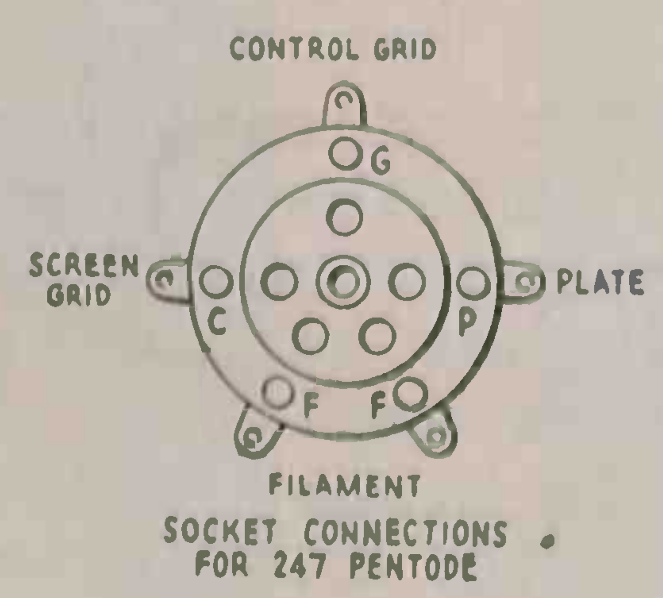
RECEIVING VACUUM TUBES

POWER OUTPUT PENTODE.....TYPE 247 FOR A-C SETS

Considerable interest exists at present in the pentode tube. The pentode, as its name implies, is a five-electrode tube. The outstanding characteristics of the tube are its high amplification factor, high internal resistance and high mutual conductance. These properties are obtained by the use of two electrodes or grids which are arranged in the tube as shown in Figure 1. In the illustration, the electrodes are identified as follows: F represents the filament; G1 is a conventional control grid; G2 is a grid or screen which is maintained at a high positive potential and serves to reduce the effects of "space charge" around the filament and to flatten out the plate current-plate voltage characteristics; and G3 is a grid or screen which is usually connected internally to the filament or cathode of the tube and is therefore maintained at essentially ground potential.

A very important function of grid G3 is to suppress or prevent the flow of electrons (liberated by secondary emission effects) from the plate P. The secondary emission is caused by the tremendous impact of electrons on the plate which liberates other electrons from the plate. These new secondary electrons would tend to move toward the screen grid because of its high positive potential were it not for the presence of the extra grid which is operated at the same potential as the filament and therefore does not exert an attraction for electrons. Hence, the secondary electrons return to the plate and together with the regular electrons that collect on the plate increase the flow of electrons in the plate circuit.





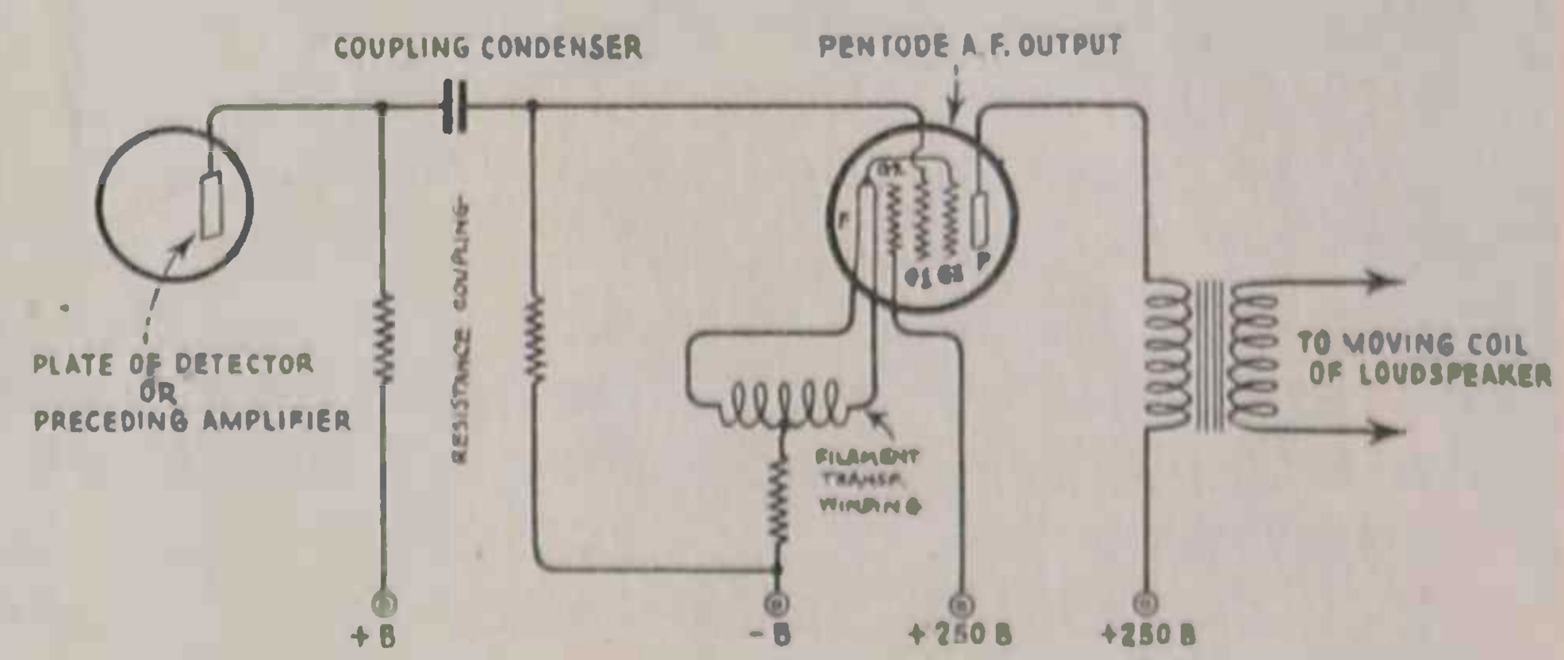


Figure 1 Figure 1-A Figure 2

A schematic connection for the pentode tube is shown in Figure 2. A pentode is thus essentially a power amplifier tube having high mutual conductance and high "power sensitivity," that is, relatively small input voltage is required to control rather high power in its plate circuit. This tube employs a coated filament designed primarily for a-c operation. The filament should be operated at its normal rated

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voltage of 2.5 volts at the normal design line voltage. The socket required by the pentode is of the standard UY type and should be mounted to hold the tube in a vertical position. Grid bias for the 247 may be obtained either from a fixed voltage source or by automatic self-biasing from a resistor in the cathode circuit.

POWER OUTPUT PENTODE - TYPE 247

Tentative Rating and Characteristics

Filament Voltage	2.5 volts
Filament Current	1.5 amperes
Plate Voltage, Recommended	250 volts
Screen Voltage, Recommended and Maximum	250 volts
Grid Voltage	-16.5 volts
Plate Current	32 milliamperes
Screen Current	7.5 milliamperes
Plate Resistance	38,000 ohms
Mutual Conductance	2,500 micromhos
Load Resistance, Approximate	7,000 ohms
Power Output	2.5 watts
Base and Socket	UY

The pentode has possible applications (with different designs) in both the audio-frequency and radio-frequency amplifier circuits of broadcast receivers. When used as a radio-frequency amplifier the tube has the form of a screen-grid tube in which an additional grid is placed between the filament (cathode) and usual control grid. This additional grid serves to reduce the effects of "space charge" around the filament (cathode) and results in a tube having higher mutual conductance than screen-grid tubes now available. The theoretical advantage sought in tubes of this kind in the r-f stage of a receiver is that, because of their greater amplification factor, the total number of tubes used might be reduced. However, present broadcast conditions and selectivity requirements are such that a reduction in the number of tuned r-f stages is not permissible and therefore, if one tube is used per stage, as other practical considerations require be done, the total number of radio-frequency tubes cannot be reduced. Also, if too much amplification per stage is attempted it will likely result in a circuit whose operation is critical and unstable. The new 247 pentode has been developed for use as an audio-frequency output or last stage amplifier tube in a-c receivers designed for it. Due to its higher undistorted output (U.P.O.) this tube takes the place of the 245 in the latest model sets.

PENTODE FOR BATTERY-OPERATED RECEIVERS - TYPE 233

The power amplifier pentode, type 233, has been developed for use in the power output stage of battery-operated receivers designed especially for it. The filament employed in this new tube is of the coated type and its low filament current drain makes this tube particularly applicable for use in combination with the 230 and 232 when one or both of these types are incorporated in sets where econo- of filament current is an important factor.

As in the case of other pentode tubes the large audio output of the 233 with relatively small input signal voltages on the grid is made possible by the addition of a "suppressor" grid between the screen and the plate.

POWER OUTPUT PENTODE - TYPE 233

Preliminary Ratings and Characteristics

Filament Voltage	2.0	volts
Filament Current	0.260	ampere
Plate Voltage	135	volts
Screen Voltage	135	volts
Grid Voltage	-13.5	volts
Plate Current	14	milliamperes
Screen Current	3	milliamperes
Plate Resistance	45,000	ohms
Mutual Conductance	1,400	micromhos
Amplification Factor	63	
Load Resistance	7,500	ohms
Undistorted Power Output	650	milliwatts
Base and Socket		UY

As we have already explained the suppressor is connected inside the tube to one end of the filament, and is effective in practically eliminating the secondary emission effects which limit the power output from four-electrode screen-grid type tubes.

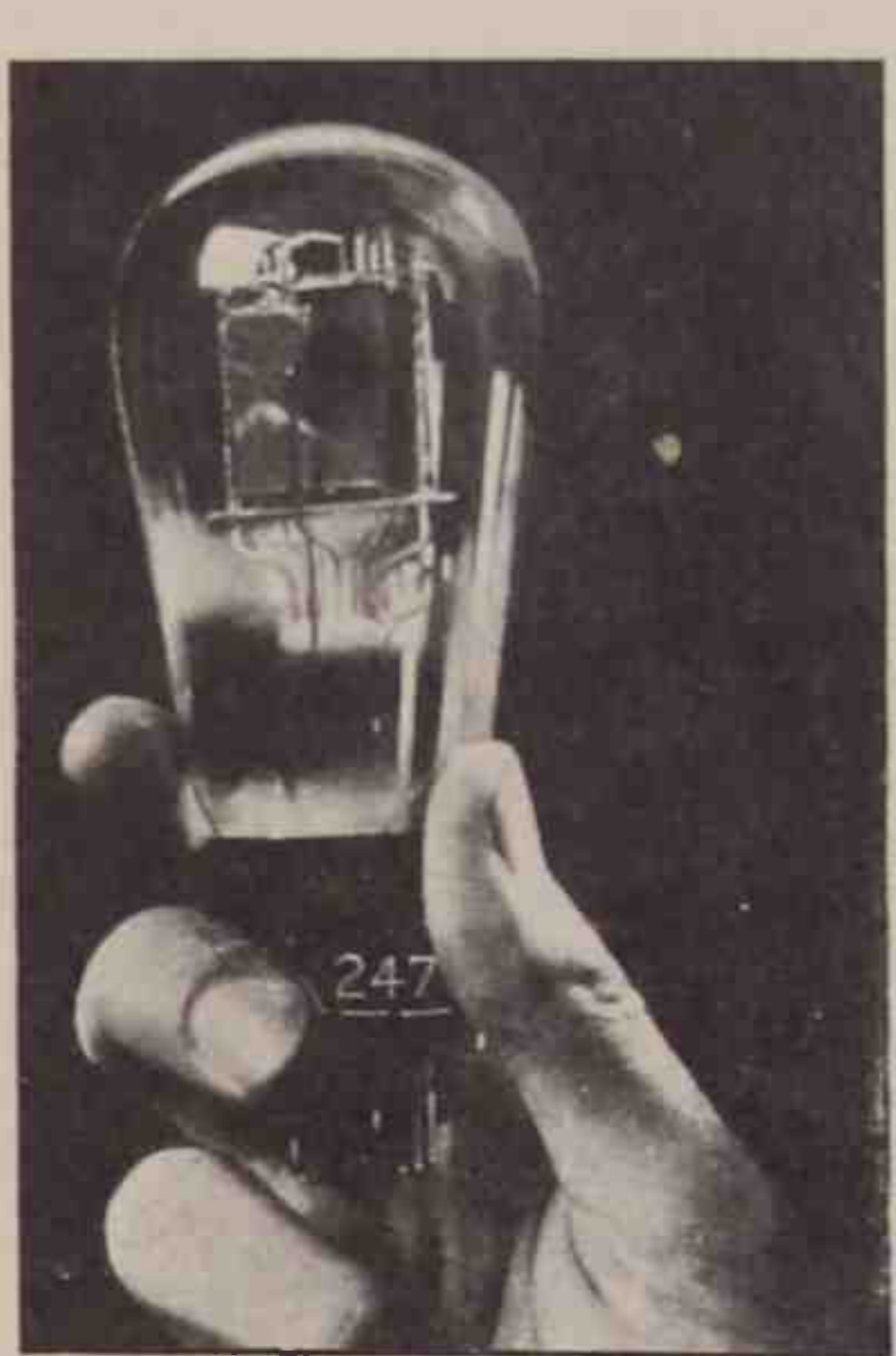

Figure 3

Figure 4

The tube illustrated in Figure 3 is the new 247 pentode which has been developed for use in the audio output stage of a-c receivers designed for it. The three tubes in the photograph in Figure 4 are the new series of indirectly heated cathode tubes designed especially for automobile receivers.

4

POWER AMPLIFIER TUBE - TYPE 171-A

The 171-A type vacuum tube is a power amplifier for supplying large undistorted power output to a loudspeaker. It is intended for use in the last stage of an audio-frequency amplifier. This tube is designed for use with the standard UX socket, which should be mounted so as to hold the tube in a vertical position. The socket should make firm contact on the filament prongs to minimize contact resistance. The socket connections are given in Figure 5.

The filament of the 171-A type may be operated from a storage battery or from the a-c line through a step-down transformer. In either case the voltage applied to the filament terminals should be the rated value of 5.0 volts. When operated at this voltage, the coated filament will glow at only a dull red color. If alternating current is used to operate the filament, the leads should be of twisted pair and should be kept away from other parts of the circuit where possible. It is recommended that the power be turned off before any tube is removed from the receiver so that excessive voltage will not be applied to the filaments, or heaters, of the remaining tubes.

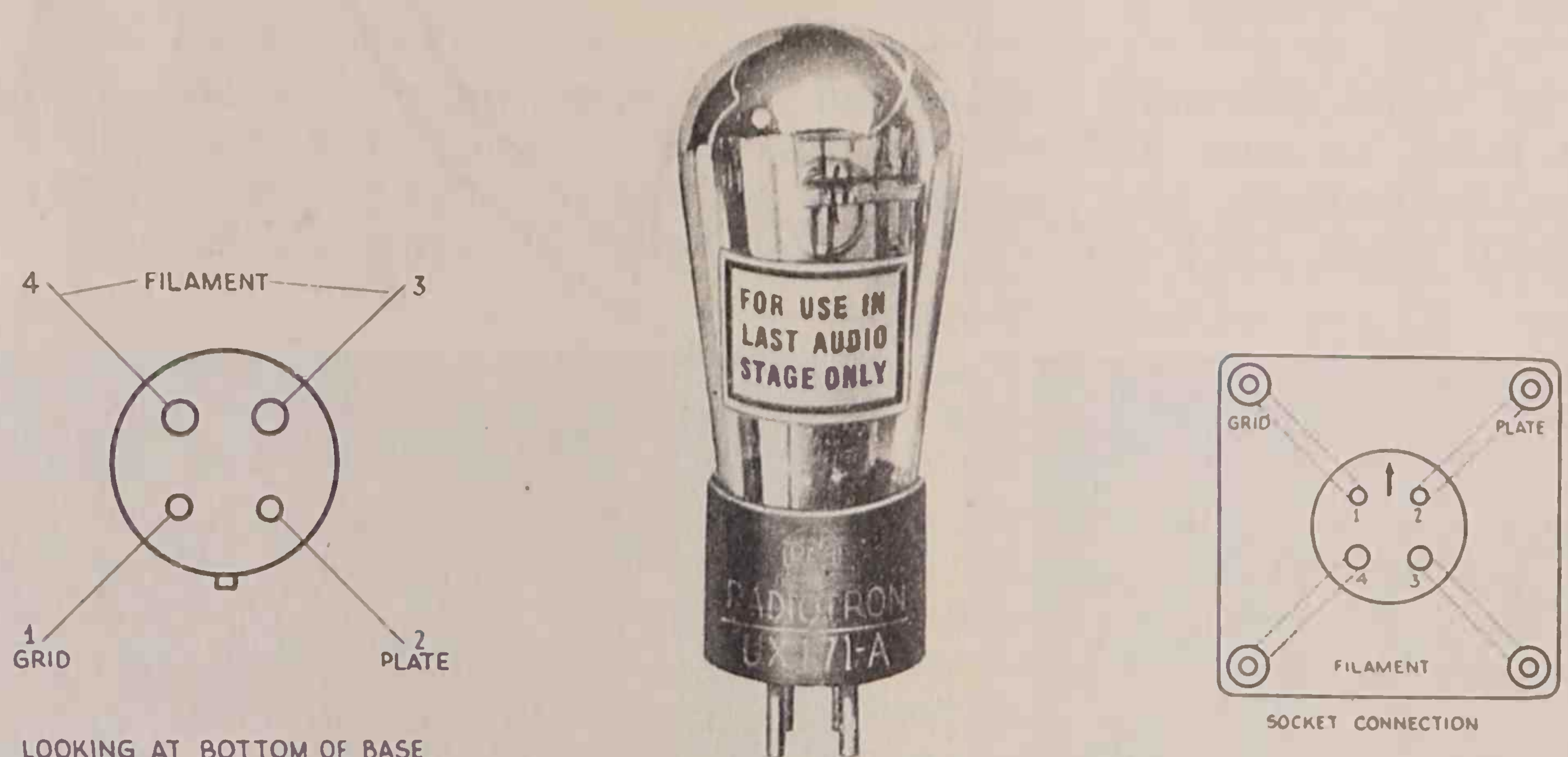

Figure 5

A-C LINE VOLTAGE. If the source of e.m.f. for operating the filament of the 171-A type is the a-c power line, precautions should be exercised to insure that the line voltage is the same as that for which the primary of the filament transformer is designed. To be sure that such is the case, the supply line voltage should be determined with a high grade a-c voltmeter having a range of 0 to 150 volts. If the line voltage measures in excess of that for which the transformer is designed, a series resistor should be inserted in the supply line to reduce the line voltage to the rated value of the transformer primary. Unless this is done, the excess input voltage will cause proportionately excessive voltage to be applied to the filament. Remember that any radio vacuum tube may be damaged or made inoperative by excessive operating voltage.

If the line voltage is consistently so much below that for which the primary of the transformer is designed as to make it impossible to ever obtain a filament voltage of 5.0 volts, it may be necessary to install a booster transformer between the a-c outlet and the transformer primary. Before such a transformer is installed, the a-c line fluctuations should be carefully measured. Many radio sets are equipped with a line voltage switch which permits adjustment of the power transformer primary to the line voltage. When this switch is properly adjusted, the series resistor or booster transformer mentioned above is seldom required.

CIRCUIT REQUIREMENTS. When the filament is operated from a d-c source, the grid and plate returns should be made to the negative filament terminal. When a-c is used on the filament, the plate and grid returns should be brought either to a mid-tapped resistor of from 20 to 40 ohms across the filament windings, or to the mid-tap of the filament winding itself.

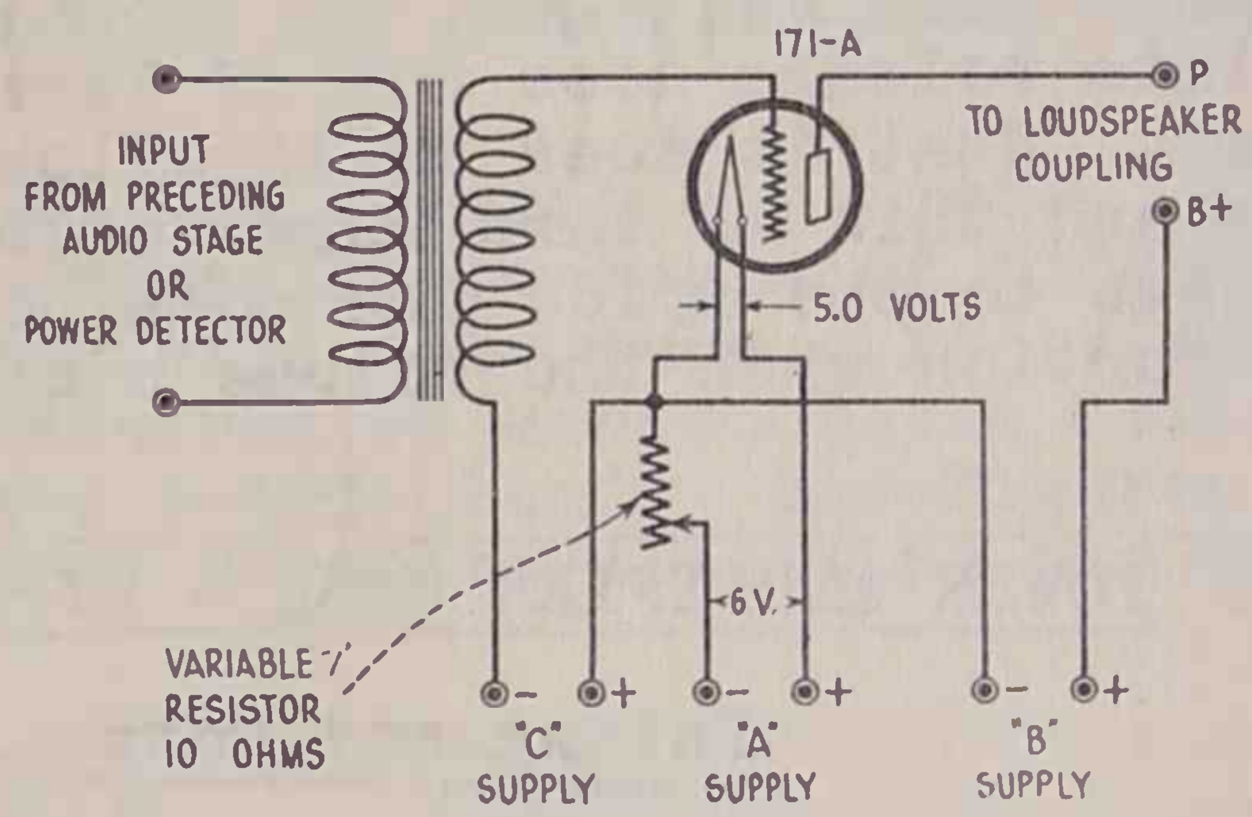

Figure 6

A negative grid bias, as shown in the table of "OPERATING VOLTAGES" on the following page, should always be used with this tube to prevent distortion and overloading. This bias may be obtained by means of a "C" battery or by means of the voltage drop through a resistor in the plate return lead, as shown in Figures 6 and 7 respectively. These diagrams show typical audio power amplifier circuits. The proper value of the resistor is 2150 ohms when 180 volts are used on the plate; 1700 ohms when 135 volts are used; and 1600 ohms when 90 volts are applied to the plate.

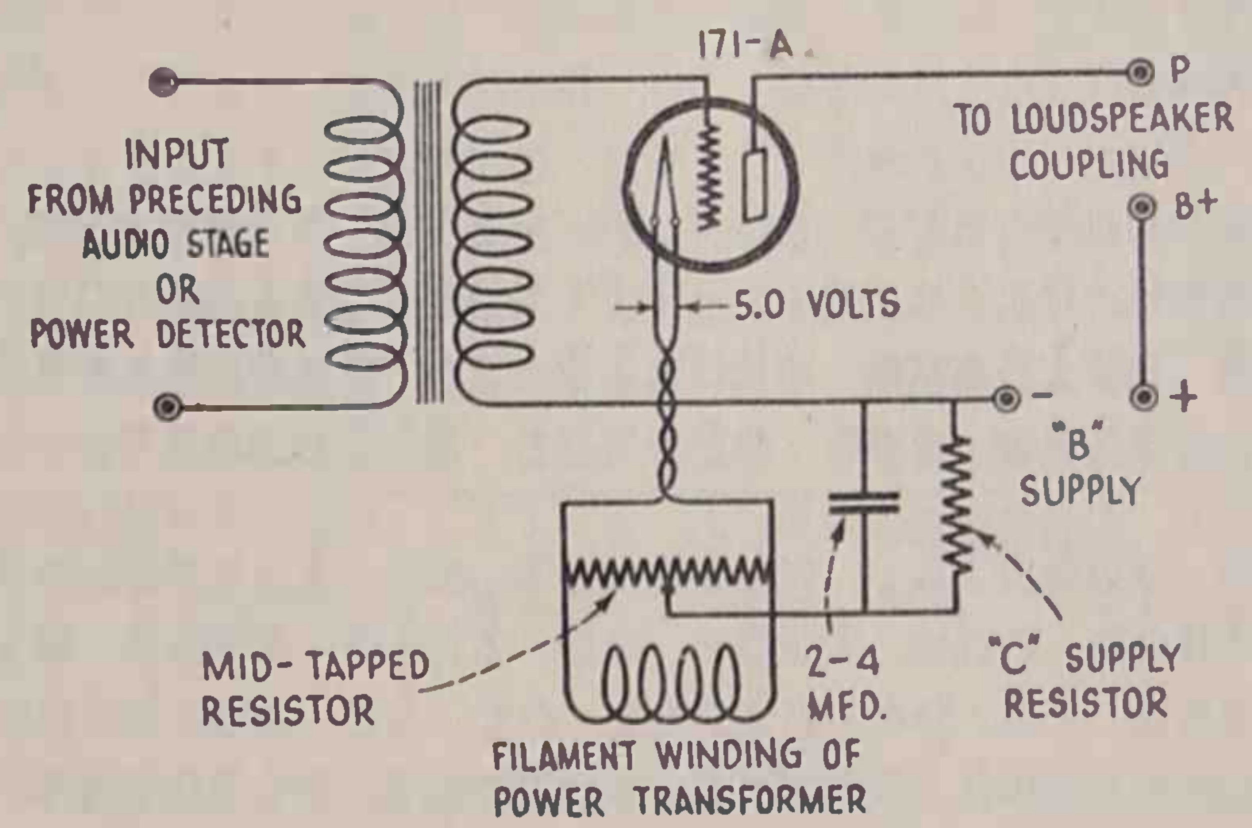

Figure 7

Either an output transformer or a choke coil and condenser should be used, as shown in Figure 8, to keep the high plate current of the 171-A from the windings of the loudspeaker driving unit.

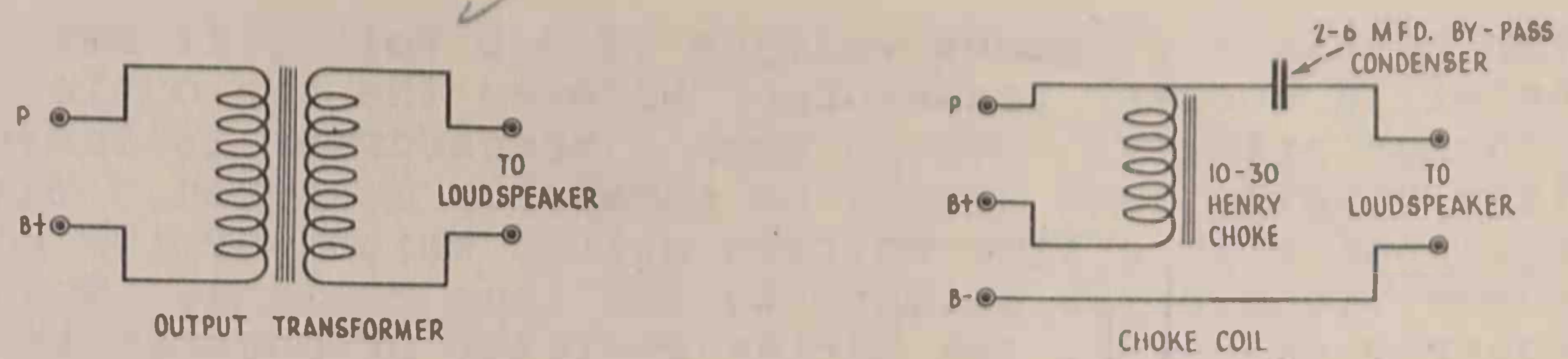

Figure 8

In regard to the operating voltages and characteristics of this tube it can be said that the value of 180 volts with its corresponding grid voltage need be used only in cases where there is a sufficient signal to secure the full grid swing and where the maximum power of the tube is desired. Where maximum output is not essential, the use of either of the lower values of plate voltage with their respective grid bias voltages, is recommended. It should be noted that high plate voltage does not of itself produce appreciably greater volume. What it does is to allow the use of a larger negative grid bias and this in turn permits the application of a larger signal voltage to the grid. The combined result gives higher volume without distortion when the volume control of the receiver is advanced.

POWER AMPLIFIER TUBE - TYPE 171-A

Rating and Data

Filament Voltage			5.0	volts a-c or d-c
Filament Current			.25	amperes
Plate Voltage	90	135	180	volts maximum
Grid Voltage (C-Bias)*	19	29.5	43	volts
Peak Grid Swing	16.5	27	40.5	volts
Plate Current	12	17.5	20	milliamperes
Plate Resistance	2250	1960	1850	ohms
Amplification Factor	3	3	3	
Mutual Conductance	1350	1520	1620	micromhos
Undistorted Power Output	125	370	700	milliwatts
Approximate Direct Inter-Electrode Capacitances				
Grid to Plate			8.2	mmf.
Grid to Filament			4.5	mmf.
Plate to Filament			2.5	mmf.

*Values of grid voltage are given with respect to the mid-point of the filament operated on a-c. If the filament is d-c operated, each given value of grid voltage should be decreased by 2.5 volts and be referred to the negative end of the filament.

If it is desired to obtain, without an increase in plate voltage, more power output than one tube of this type will deliver then two tubes may be operated in parallel or in push-pull. The parallel connection permits increased power output without any increase in the signal applied to the power stage, while the push-pull connection for maximum power output requires that the input signal to the power stage be doubled, but it provides more freedom from distortion.

7

POWER AMPLIFIER - TYPE 245

The 245 vacuum tube is a power amplifier for supplying large undistorted output to a loudspeaker. It is intended for use in the last stage of an audio-frequency amplifier, in a socket whose filament voltage is 2.5 volts. It should be borne in mind that a 245 tube is not interchangeable with a 171-A tube or any other power amplifier tube.

The socket connections for this tube are like the standard UY socket. It is important to locate a tube of this kind in a set to allow sufficient natural circulation to prevent overheating. The filament may be operated from a storage battery or from the a-c line through a step-down transformer. In either case the voltage to the filament terminals should be the rated value of 2.5 volts. Concerning low resistance connections in the filament circuit splices and about turning the power off before any tube is removed to prevent excessive voltage from being applied to the filaments or heaters of the remaining tubes, the same conditions hold for the 245 as for the 226.

CIRCUIT REQUIREMENTS. To prevent distortion and overloading, negative grid bias as shown in the table of "OPERATING VOLTAGES," should always be used with this tube. It is strongly recommended that this bias be obtained by means of the voltage drop through a resistor in the plate return lead. See Figures 9 and 10 for the general arrangement of circuits utilizing a-c or d-c filament voltage supply.

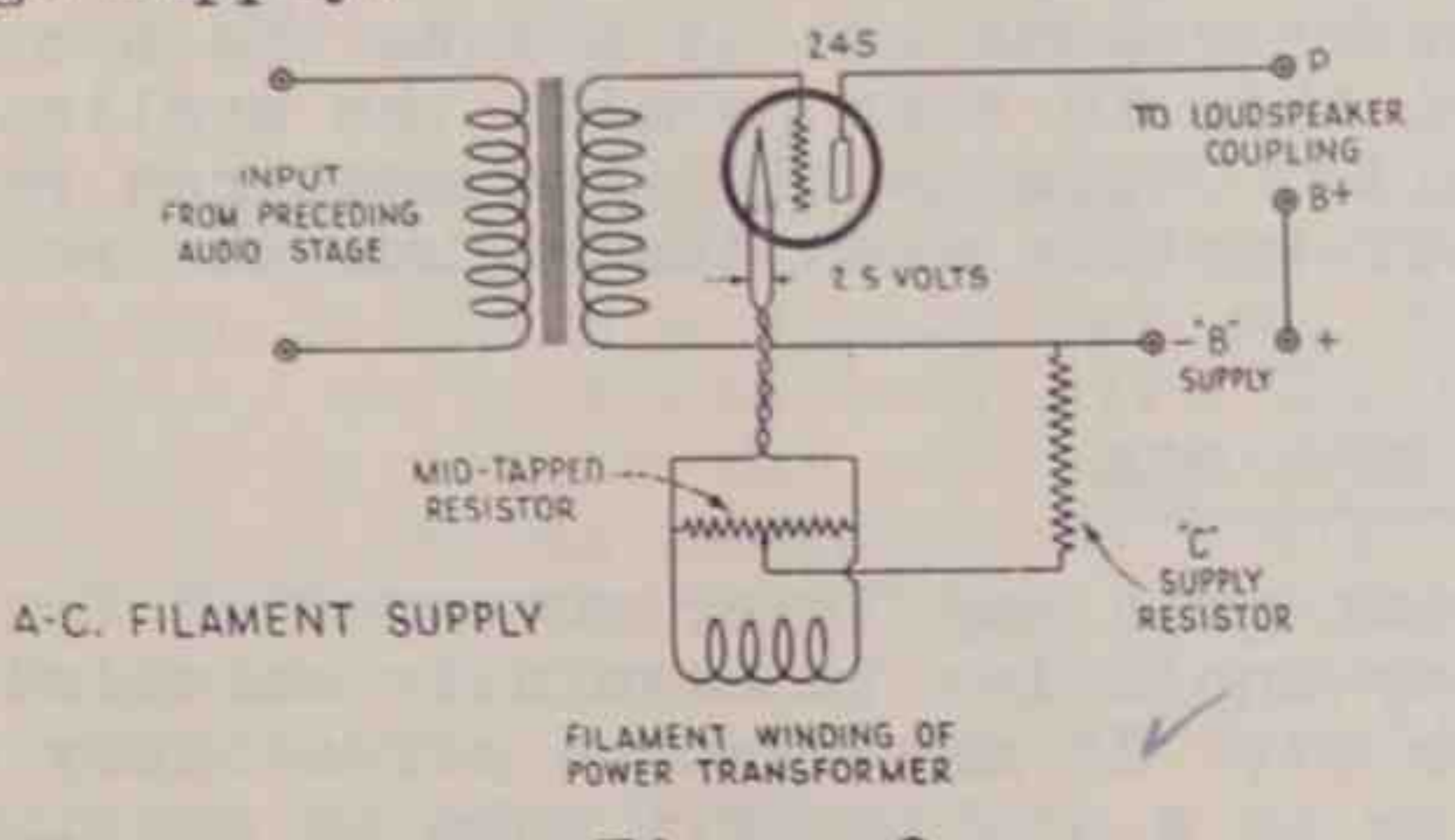

Figure 9

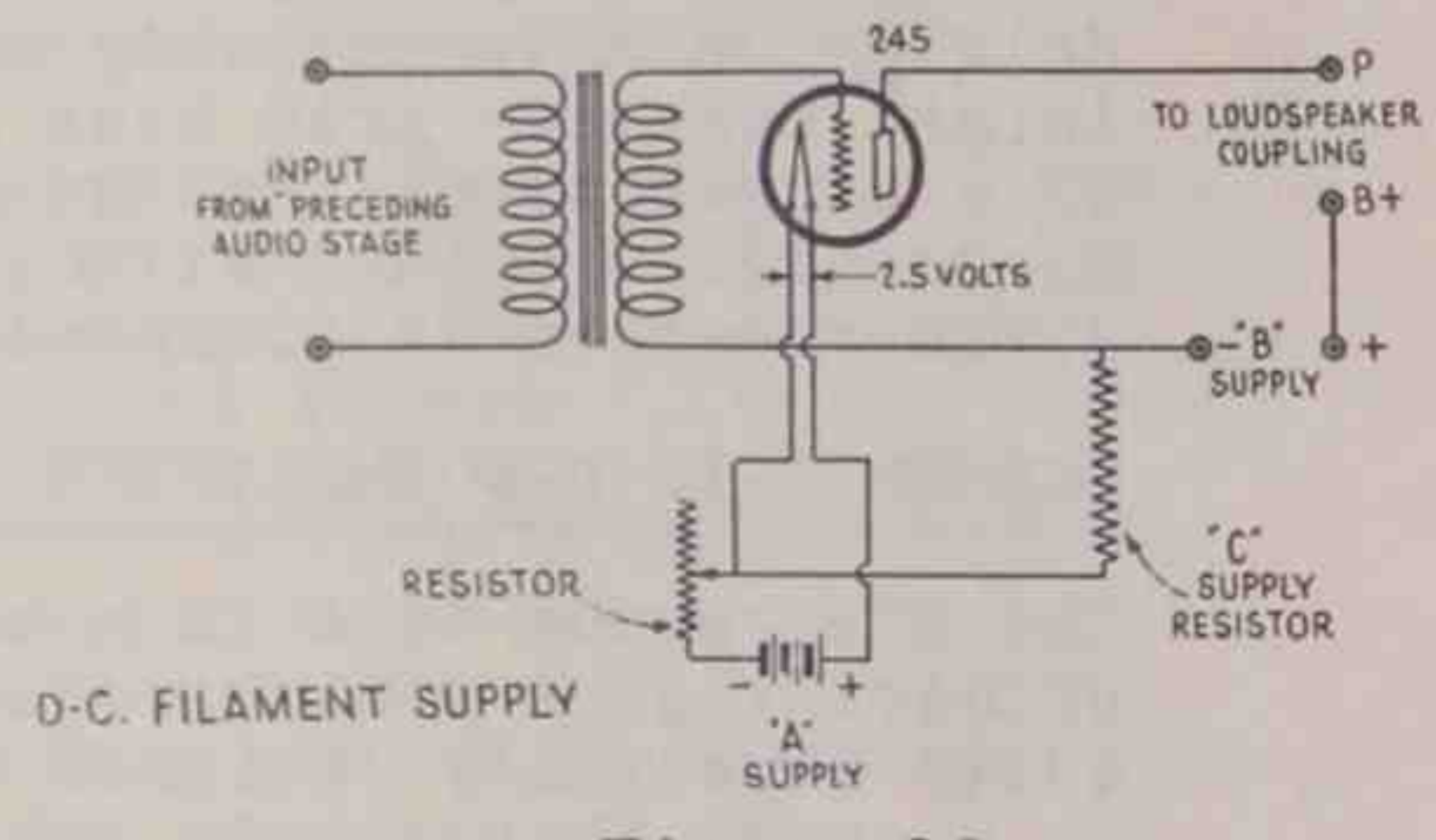

Figure 10

The proper value of a resistor in the plate return lead should be 1550 ohms when 250 volts are used on the plate, or 1350 ohms when 180 volts are used. This method of obtaining the bias must be used in any amplifier circuit where grid leaks are used. In such a circuit a grid leak having a resistance of greater than 1.0 megohm should not be used. When the filament is operated from a d-c source, the grid and plate returns should be made to the negative filament terminals. When a-c is used on the filament, the plate and grid returns should be brought to (1) a mid-tapped resistor of from 20 to 40 ohms across the filament windings, or (2) the mid-tap of the filament winding itself.

Either an output transformer or a choke coil and condenser should be used to keep the high plate current of the 245 from the windings of the loudspeaker driving unit. This was previously referred to in Figure 8.

POWER AMPLIFIER - TYPE 245

Rating and Data

Filament Voltage		2.5	volts a-c or d-c
Filament Current		1.5	amperes
Plate Voltage	180	250	volts (maximum)
Grid Voltage (C-Bias)	-33	-50	volts
Peak Grid Swing	33	50	volts
Plate Current	26	32	milliamperes
Plate Resistance	1950	1900	ohms
Amplification Constant	3.5	3.5	
Mutual Conductance	1800	1850	micromhos
Undistorted Power Output	780	1600	milliwatts

If it is desired to obtain more power output than one 245 tube will deliver then two 245 tubes may be operated in parallel or push-pull. The parallel connection permits increased power output without any increase in the signal applied to the power stage, while the push-pull connection for maximum power output requires that the input signal to the power stage be doubled, as previously explained.

The value of 250 volts with its negative grid bias of 50 volts need be used only in those cases where there is a sufficient signal to secure the full grid swing and where the maximum power output of a 245 tube is desired. Where maximum output is not essential, the lower value of 180 volts with a negative grid bias of 33 volts, is recommended. As stated before, high plate voltage does not of itself produce appreciably greater volume but it allows the use of a larger negative grid bias and this in turn permits the application of a larger signal to the grid. Consequently, the combined result gives higher volume without distortion when the volume control of a given receiver is advanced.

SCREEN GRID R-F AMPLIFIER - TYPE 222

The 222 vacuum tube is a screen-grid amplifier recommended for use primarily as a radio-frequency amplifier in carefully shielded circuits especially designed for it. It may also be effectively used as a space-charge grid tube or as a double-grid tube in special circuits. This tube is designed for use with the standard UX socket, the socket connections being given in Figure 11. The connection for the control grid is made to the metal cap at the top of the tube.

The voltage applied to the filament terminals of the 222 should not exceed the rated value of 3.3 volts. It may be supplied by either dry-cells so connected as to give 4.5 volts or by a storage battery of 6 volts, depe i upon whether 3.3 volt or 5.0 volt fil nt tubes e used in t other st es of the radio receivers.

en the 222 e is to be used in co ection with storage battery tubes, for e le bes ch as a 201-A, 112-A, and so on, then each 222 sho d ve a 15 o resistor connected in series with its negative fil nt lead with t resist tapped at 12 o . e resistor fil ent y then be connect directly in parallel with the 5 volt fil ts t other tubes and ope ted from the s common rheostat. is co ction is sho in Fi e 12.

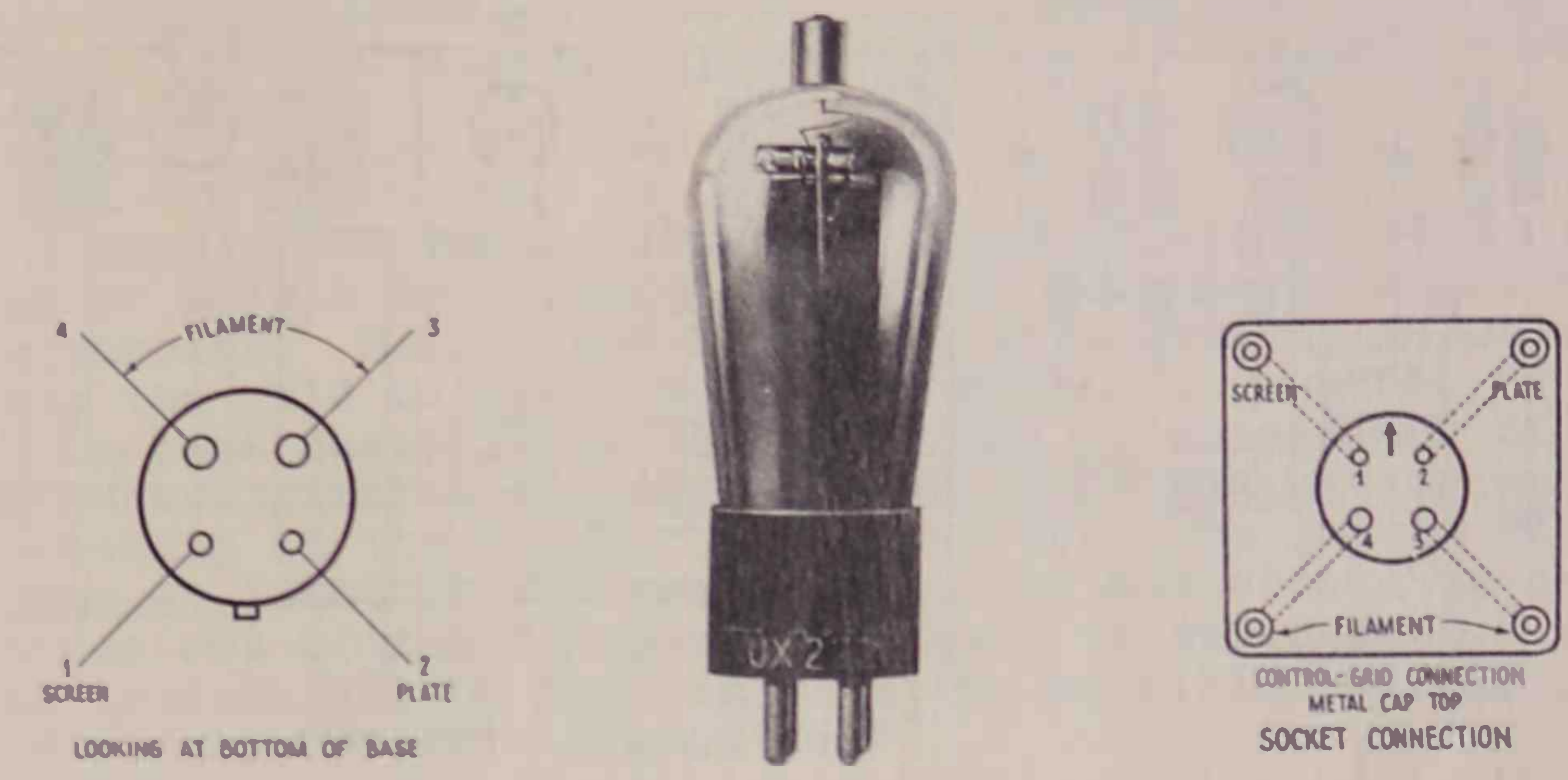

Figure 11

Or, if dry-cell tubes, such as a 199 and 120, are used the filament of the 222 may be connected directly in parallel with the filaments of the other tubes and operated from the same common rheostat. This arrangement is given in Figure 13. It is recommended that both the filament and plate voltage be disconnected before any tube is inserted in or removed from its socket as we suggested before.

HOW TO OBTAIN SCREEN VOLTAGE. The positive voltage for the screen should be obtained from a tap on the plate battery or from a tap so located on the B - supply device, such as a voltage divider for example, as to definitely give the required screen voltage. Never attempt to obtain the screen voltage by connecting the screen through a series resistor to a high plate voltage source, such as that of the power amplifier tube for instance. Such a series resistor connection will not in general be satisfactory for screen voltage supply because of the considerable variation in screen current of different tubes.

The screen voltage obtained from a definite voltage tap on the B - batte or the B - ply device y be de variable between 0 and 45 volts by the e of a potenti ter co ected as s n in Fig es 12 13 which t ical screen grid r-f plifier circuits. As the voltage appli to the sc en is reduced by adjus nt of the potenti ter, t l co uct ce of the 222 be is decreased with co equent r ti in vo . e potenti ter method, therefore, es a i ble volume control for e ceiver in ich it is used.

It sho d noted t t the potentio ter method of volume c - trol is ed wi a "B" battery so e of screen potential, precautions sho d be t en to p vide for opening the screen grid circuit co ection to the "B" battery when the r io set is t in use as indicated at X in Fi e 13. If this precauti is not observed, c - rent will c t to flow the potentio ter shorten the life of the batte .

10

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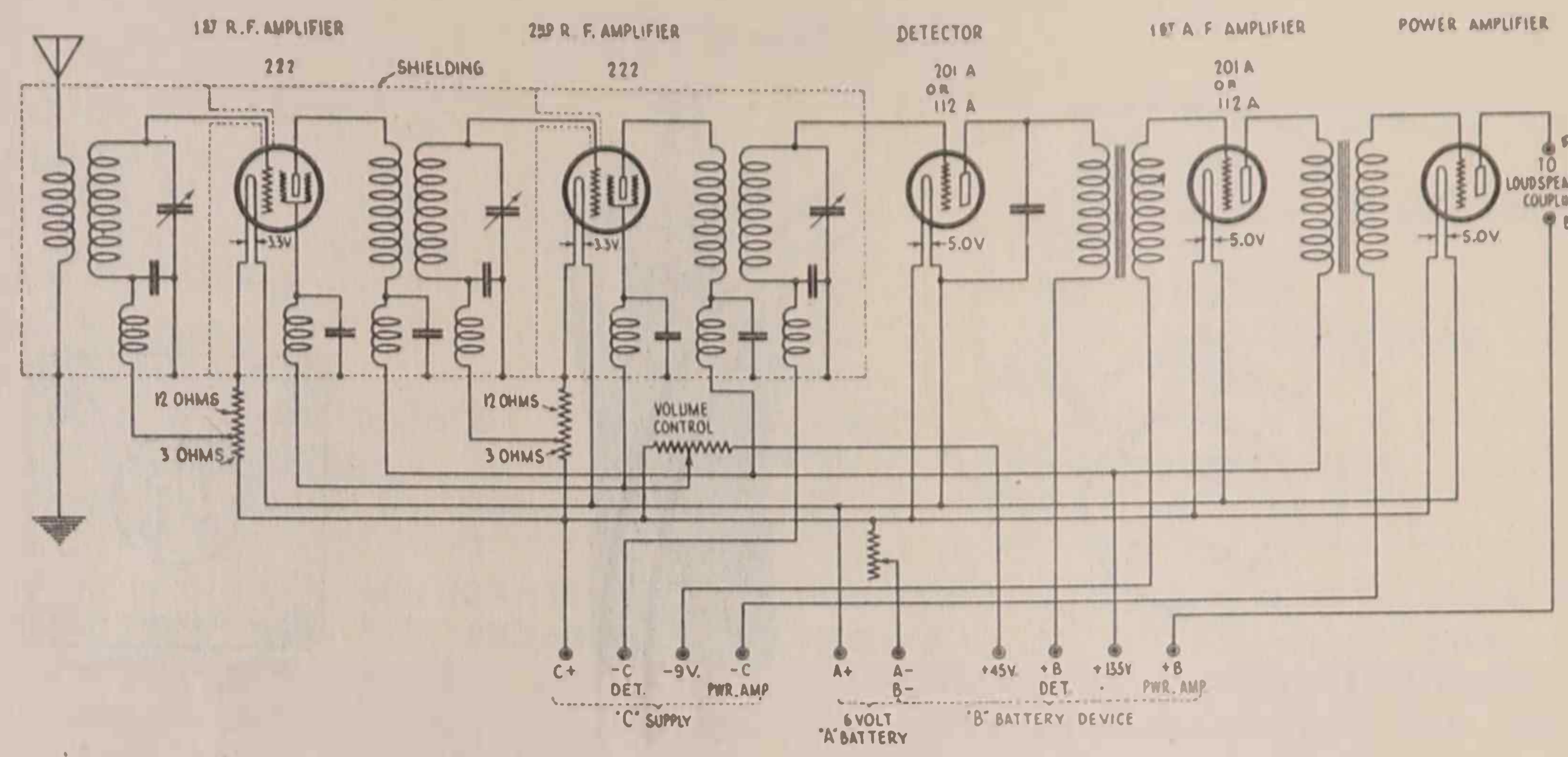

Figure 12

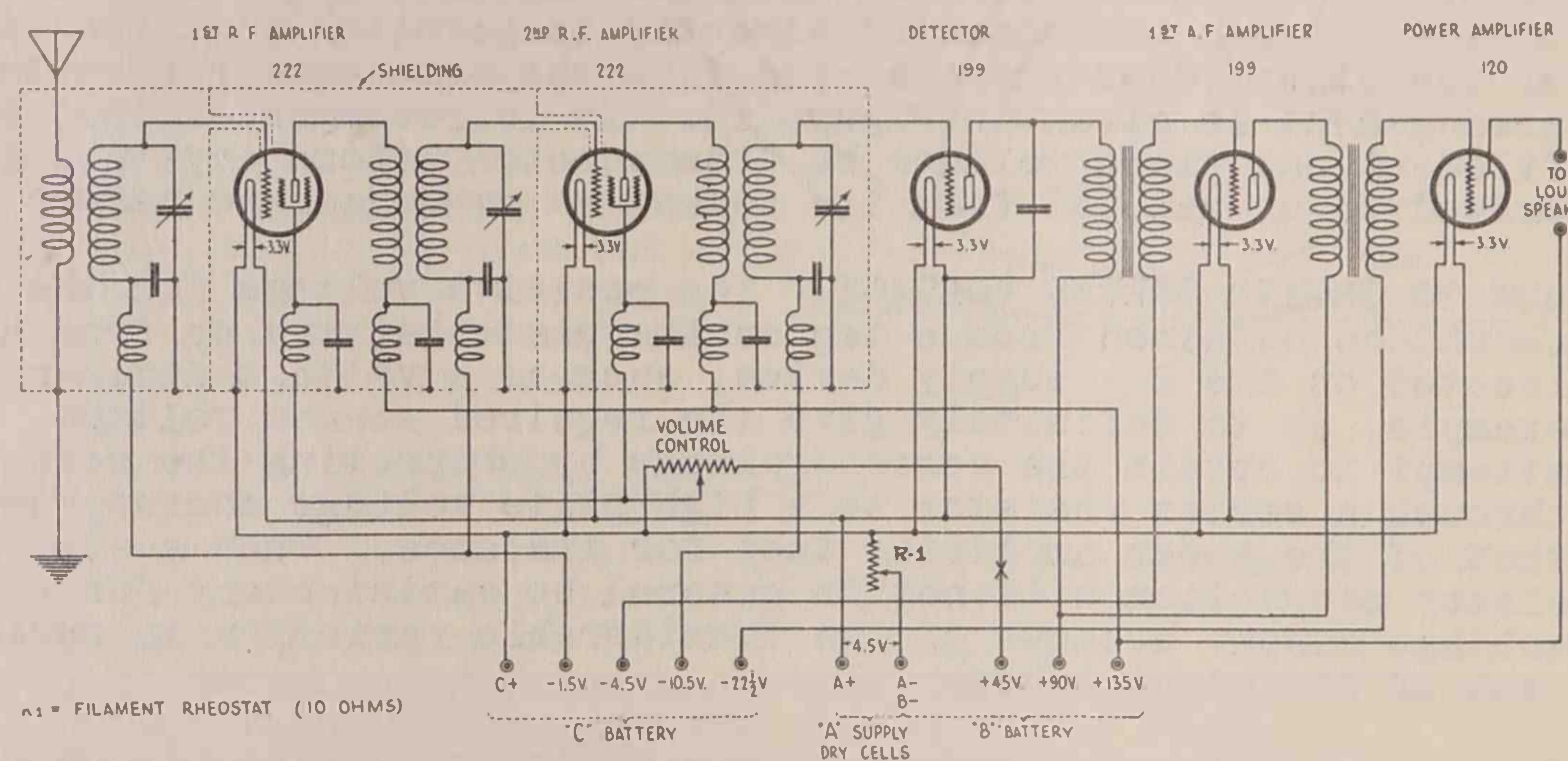

Figure 13

When the 222 type is used as a screen-grid radio-frequency amplifier, neutralization of the inter-electrode capacity between grid and plate to prevent feed-back through the tube is unnecessary because of the internal shielding by the screen. It is necessary, however, to take every precaution to avoid external coupling between the grid and plate circuit elements if stable operation of the 222 is to be obtained in circuits designed to give maximum gain per stage.

In multi-stage amplifier circuits, it is necessary to completely and effectively shield each stage, and to include within the stage

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shield all of the component parts of that stage. You can understand this arrangement by referring to Figures 12 and 13. Unless the coils and condensers of the various stages are shielded from each other, the amplification possibilities of the 222 cannot be fully realized.

If only a single 222 radio-frequency stage is used, it may not be necessary to shield this stage completely for reception of broadcast frequencies. Sufficient shielding will usually be obtained by placing the grid coil and condenser within a grounded metallic shield. In some cases it may be necessary to shield the 222 by a metallic jacket fitting closely over the tube and having an insulated opening at the top for the grid cap. The jacket should extend down at least to the base of the 222 and should be connected to either one of the filament terminals of the socket. The control grid lead should be kept as short as possible and should be spaced from other circuit elements.

The grid and plate circuit returns should be made to the negative filament terminal. The grid bias voltage of - 1.5 volts may be obtained from a "C" battery or from the drop in the 12 ohm portion of the tapped 15 ohm resistor which was previously mentioned. It should be noted that the tapped resistor method of obtaining the control-grid bias is usable only when the filament of the 222 is operated from a 6 volt "A" supply.

As a means of reducing coupling in the circuits external to the tube, the use of radio-frequency filters in all of the leads entering the stage shields as shown in Figures 12 and 13, is recommended. When filters are used the impedance of the circuit from screen to ground is kept as low as possible by the use of by-pass condensers.

In general, properly designed radio-frequency transformers are preferable to impedances for inter-stage coupling, and especially so in cases where a high impedance "B" supply device may cause oscillation below radio frequencies. If, however, impedance coupling is used between stages it is best to employ a blocking condenser having a capacitance of 0.00025 mfd. and a grid lead of from 2 to 5 megohms.

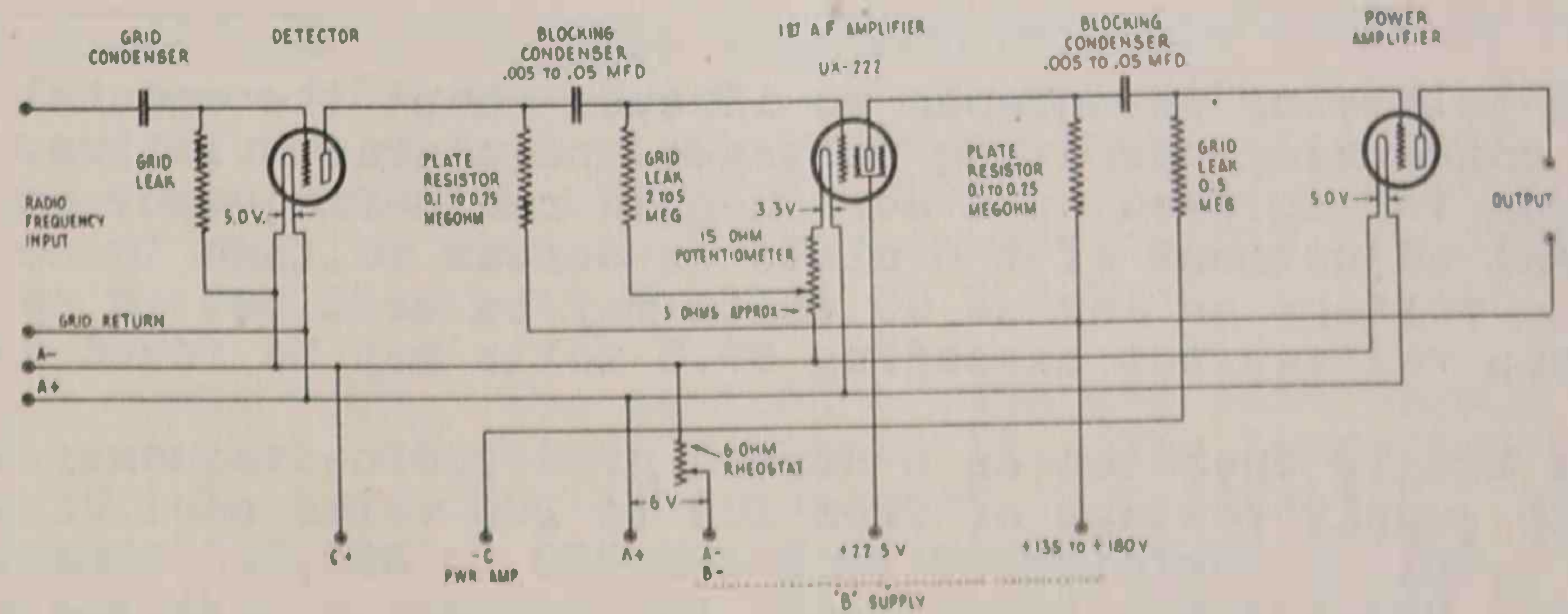


Figure 14

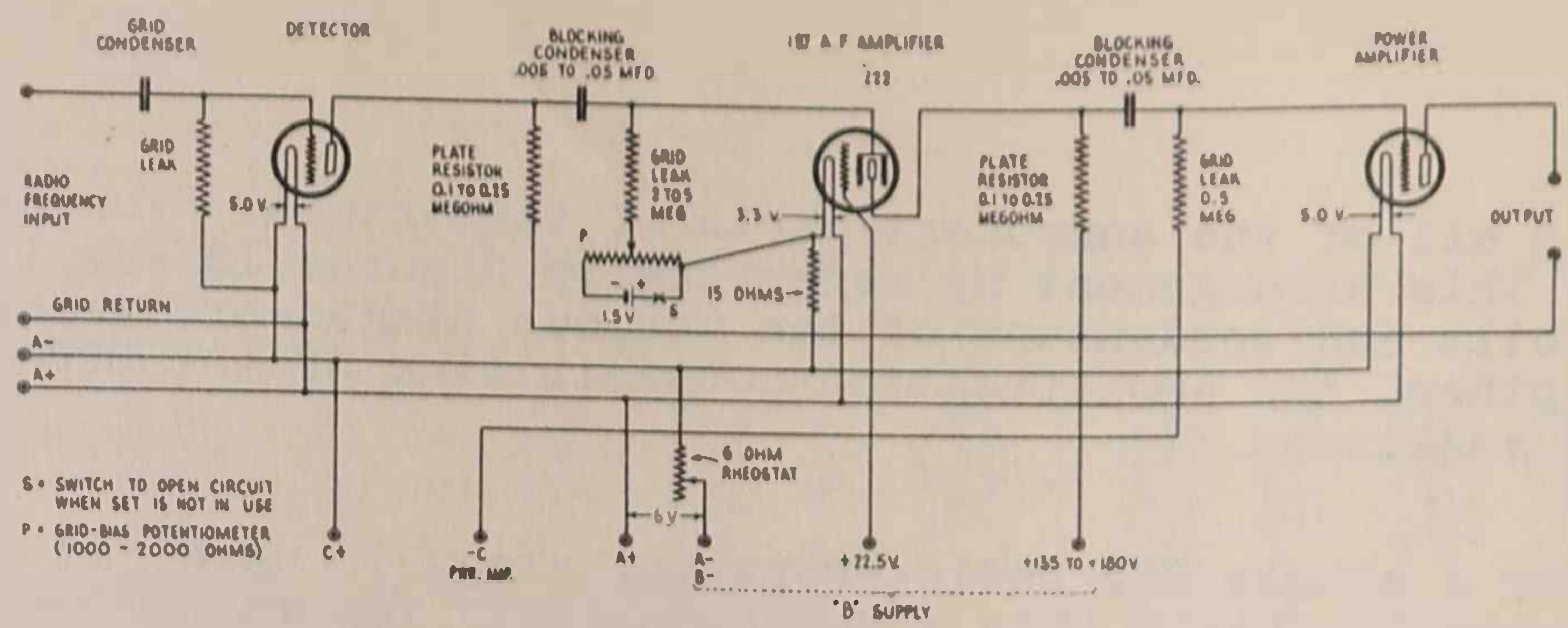


Figure 15

If the 222 type is to be operated as a screen-grid audio-frequency amplifier or as a space charge grid audio-frequency amplifier, resistance coupling should be used in its plate circuit. For either case, the value of the plate coupling resistor should be of the order of from 100,000 to 250,000 ohms. With the value of 250,000 ohms, a voltage amplification of 40 per stage should be obtained from either type of circuit. Suitable values of grid leaks and blocking condensers are shown in Figures 14 and 15. In Figure 14 you see a typical screen grid audio-amplifier circuit while Figure 15 gives a typical space charge grid audio-amplifier circuit.

SCREEN GRID R-F AMPLIFIER - TYPE 222

Rating and Data

Filament Voltage	3.3	volts
Filament Current	.132	ampere
Plate Voltage, Maximum and Recommended	135	volts
Grid Voltage (C-Bias)	-1.5	volts
Screen Voltage, Recommended	+45	volts
Plate Current	1.5	milliamperes
Screen Current	not over 1/3	of plate current
Plate Resistance	850,000	ohms
Amplification Factor	300	
Mutual Conductance	350	micromhos
Direct Inter-Electrode Capacitances		
Effective Grid-Plate	0.0025	mmf. maximum
Input	3.5	mmf. approx.
Output	12	mmf. approx.

In the following paragraphs we discuss about the special considerations concerning operating voltages and characteristics. When the 222 type is employed as a screen-grid radio-frequency amplifier, critical adjustment of the plate or screen voltage is not required. A plate voltage as low as 90 volts may be used but in special cases a screen voltage not exceeding 67.5 volts may be found desirable.

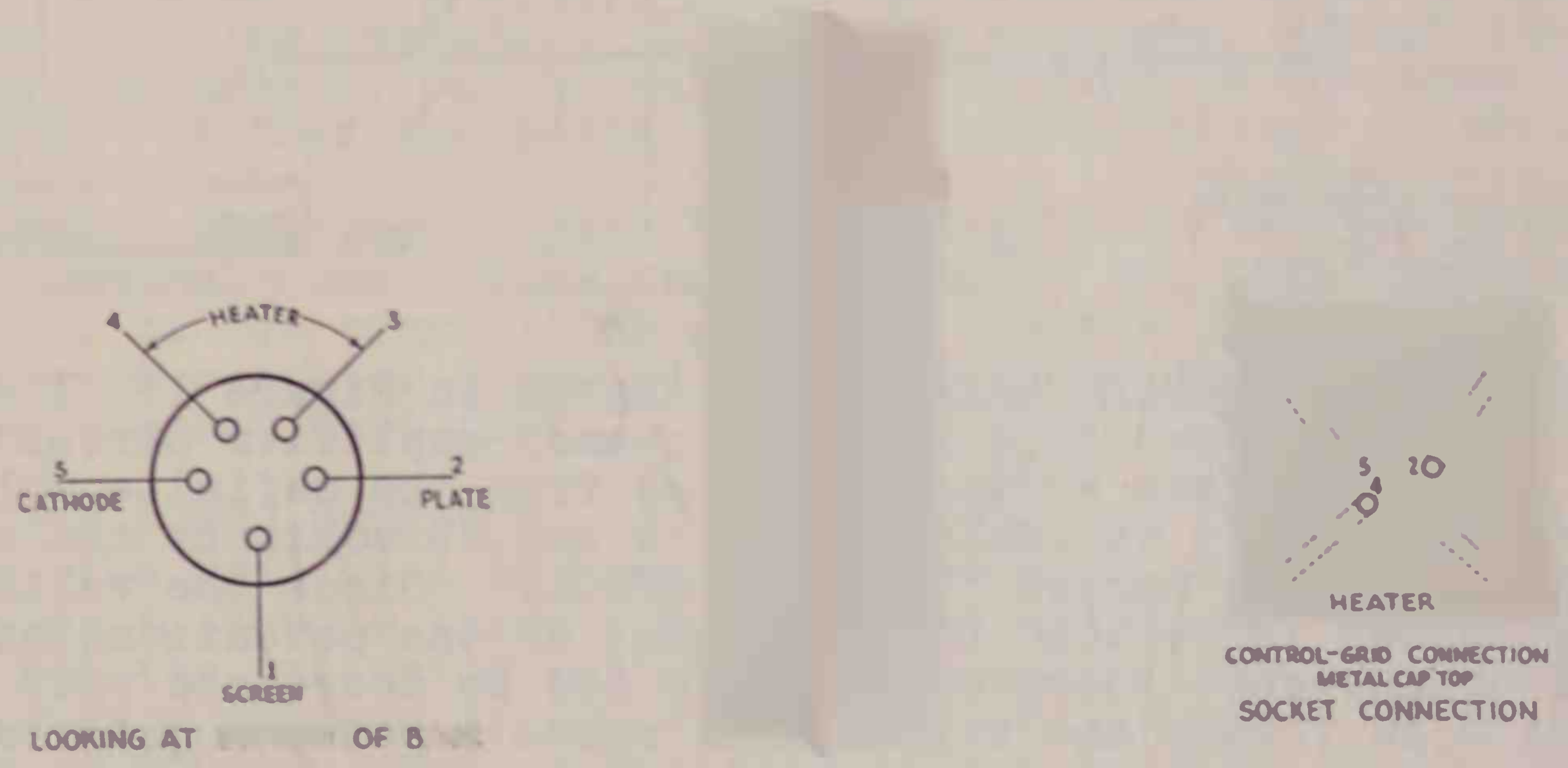
If the 222 is operated as a screen-grid audio-frequency amplifier, a plate supply voltage of from 135 to 180 volts applied through a plate coupling resistor of from 100,000 to 250,000 ohms is recommended. Under these conditions, the screen is operated preferably with + 22.5 volts, and the grid with from − .75 to − 1.5 volts. A higher value of screen voltage may be used but because of the greater voltage amplification obtained at the increased voltage, more critical circuit adjustment will be required.

When the 222 is connected as a space charge grid audio-frequency amplifier, the inner or control grid is operated at +22.5 volts to neutralize the electron space charge around the filament. The outer grid then becomes the control-grid and should be biased negatively by from 0 to - 1.5 volts depending upon the conditions of operation. For best results, the use of a variable control-grid bias potentiometer as shown in Figure 15, is recommended.

The screen-grid audio-frequency connection, in comparison with the space charge grid connection, will give somewhat lower maximum amplification but it wi permit of better audio-frequency fidelity.

S ..... -C - 2

224 vacuum tube is a sc - id lifier c taini a ter element ich its eration from t ti c t. It is rec nded for use pr ily as a radio- quency a lifi in c lly shielded cir its especially desi d for it t it also be effecti ed as a space charge d tube as a d ble id be in special cir ts as in the case of the 222 e which just discussed.



Fi e 16

e five-p base of the 2 e requires the st dard socket. As with l es of tubes the socket sho d e fi , r s - ce contact the s to ni ze contact resis ce. In Fi 16 we a et showing the so et co ectio for this tube d keep in d t t the co ection for the control id is de to the cap at e top of t tube.

CO TION. e heaters of the 224 e should be con- c n a le , as sh n in Fi 17. e transfo r winding s ply the aters sho d be des ed to intain 2.5 volts ss t heaters of t to n of 224 tubes used in the receiver. e to the hi ent d low voltage all co ectio in t heater cir it must be parti arly low resist ce and l ater circuit

14

leads hould be of high current carrying capacity with all splices well soldered. The heater leads to the different tubes should be as nearly of equal length as is found practicable to make them and all leads carrying alternating current should be of twisted pair.

THE CATHODE CONNECTION. Connection of the cathode to the heater should be made (1) preferably to the movable arm of a potentiometer connected across the heater winding of the power transformer, or (2) to a mid-tapped resistor across the heater winding, or (3) to the mid-point of the heater winding itself. In some circuits, biasing of the heater negative with respect to the cathode by not more than 9 volts may be helpful in reducing hum.

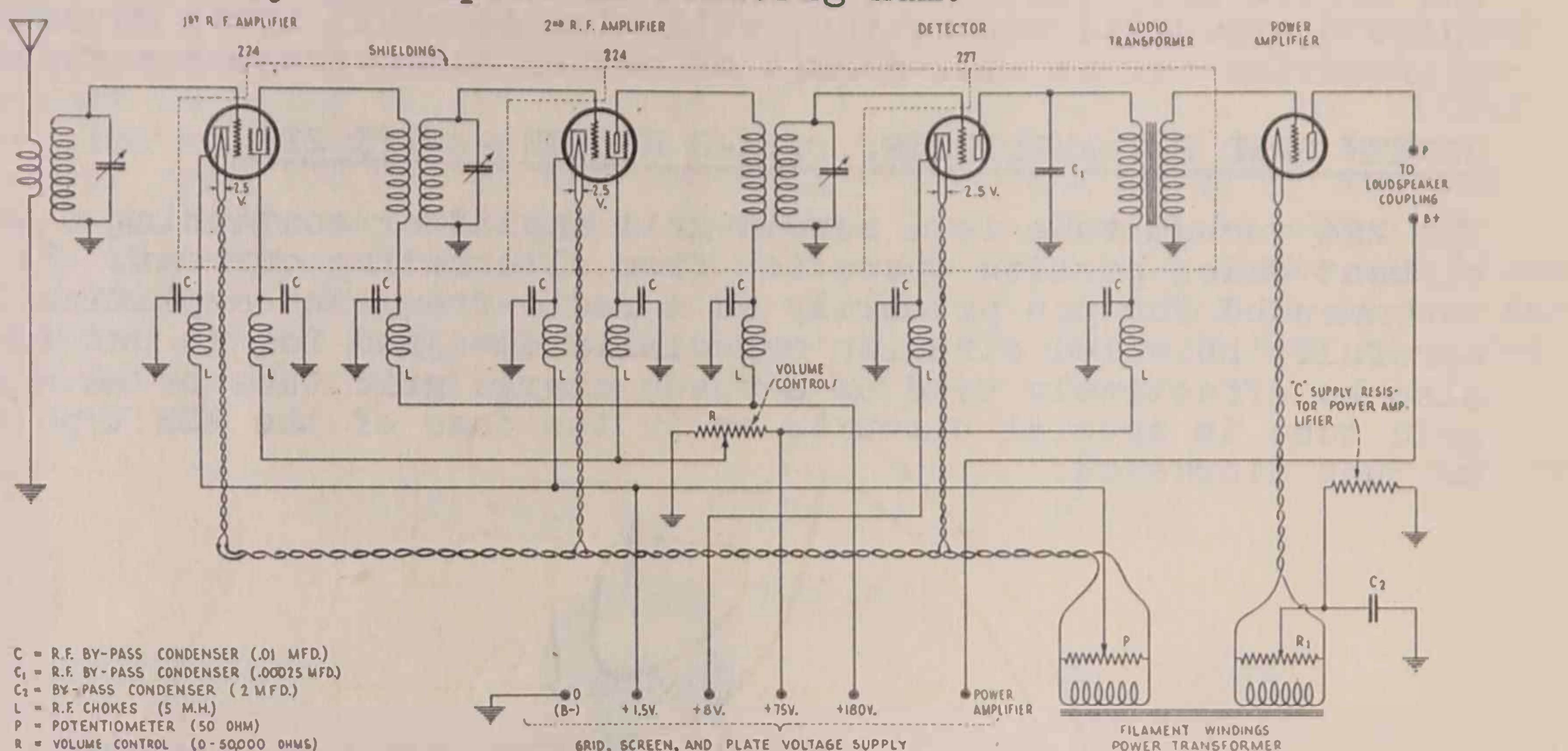


Figure 17

VOLTAGE FOR THE SCREEN GRID. The diagram in Figure 17 illustrates a typical a-c screen grid radio-frequency amplifier circuit. It shows how the screen voltage obtained from the definite voltage tap source may be made variable between 0 and 75 volts by the use of a potentiometer, R, marked "VOLUME CONTROL." Since the voltage applied to the screen is reduced by adjustment of the potentiometer, R, the mutual conductance therefore, of the 224 is decreased with consequent reduction in volume and this action makes a potentiometer a satisfactory volume control for the receiver.

A-C LINE VOLTAGE. The source of power for operating the heaters of the 224 tubes may be one of the secondary windings on the power transformer incorporated in the radio set, or it may be the secondary of a separate transformer. In either case, to obtain from the secondary a heater voltage of 2.5 volts, the transformer primary must be supplied with its rated voltage.

CIRCUIT REQUIREMENTS. When the 224 type is used as a screen-grid amplifier, neutralization of the inter-electrode capacity between grid and plate to prevent feed-back through the tube is unnecessary because of the internal shielding by the screen. It is necessary, however, to take every precaution to avoid external coupling between the grid and plate circuit elements if stable operation of the 224 is to be obtained in circuits designed to give maximum gain per stage.

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SCREEN GRID R-F AMPLIFIER.....A-C HEATER - TYPE 224

Rating and Data

Heater Voltage	2.5	volts a-c or d-c
Heater Current	1.75	amperes
Plate Voltage, Maximum and Recommended	180	volts
Grid Voltage (C-Bias)	-1.5	volts
Screen Voltage, Maximum	+75	volts
Plate Current	4	milliamperes
Screen Current	not over 1/3	of plate current
Plate Resistance	400,000	ohms
Amplification Factor	420	
Mutual Conductance	1050	micromhos
Direct Inter-Electrode Capacitances		
Grid-Plate 0.01 mmf. maximum; Input 5 mmf. approx.; Output 10 mmf. approx.		

In multi-stage amplifier circuits, it is necessary to completely and effectively shield each stage, and to include within the stage shield all of the component parts of that stage, as you will understand by referring to Figure 17. Unless the coils and condensers of the various stages are shielded from each other, the amplification possibilities of any screen grid tube cannot be realized.

If the 224 type is to be used as a screen-grid detector for either grid leak detection or grid bias detection, the latter being called power detection, resistance coupling should be used in its plate circuit. A value of from 200,000 to 500,000 ohms is best suited for the plate coupling resistor. All of the voltages, except the 1.5 volts for the heater, may be supplied from taps on the same "B" supply device. Neither the plate nor the screen voltage is critical.

The volume of the receiver may be effectively controlled by means of a potentiometer connected as shown in Figure 17, this arrangement being similar to the connections shown in Figures 12 and 13 or by a variable grid resistor inserted in the cathode circuit through which the plate current must flow.

<u>SCREEN GRID POWER DETECTOR.</u> If the 224 type is used as a screen-grid detector, the grid bias method of detection is recommended because of its ability to handle large input voltages without overloading. For this method the following suitable operating values are suggested: a plate supply voltage of 200 volts applied through a plate coupling resistor of 250,000 ohms, a positive screen voltage of 45 volts, and a negative grid bias (approximately 5 volts) so adjusted that a plate current of 0.1 milliampere is obtained with no a-c input signal. Fig. 18 shows the principle of connecting a screen-grid power detector.

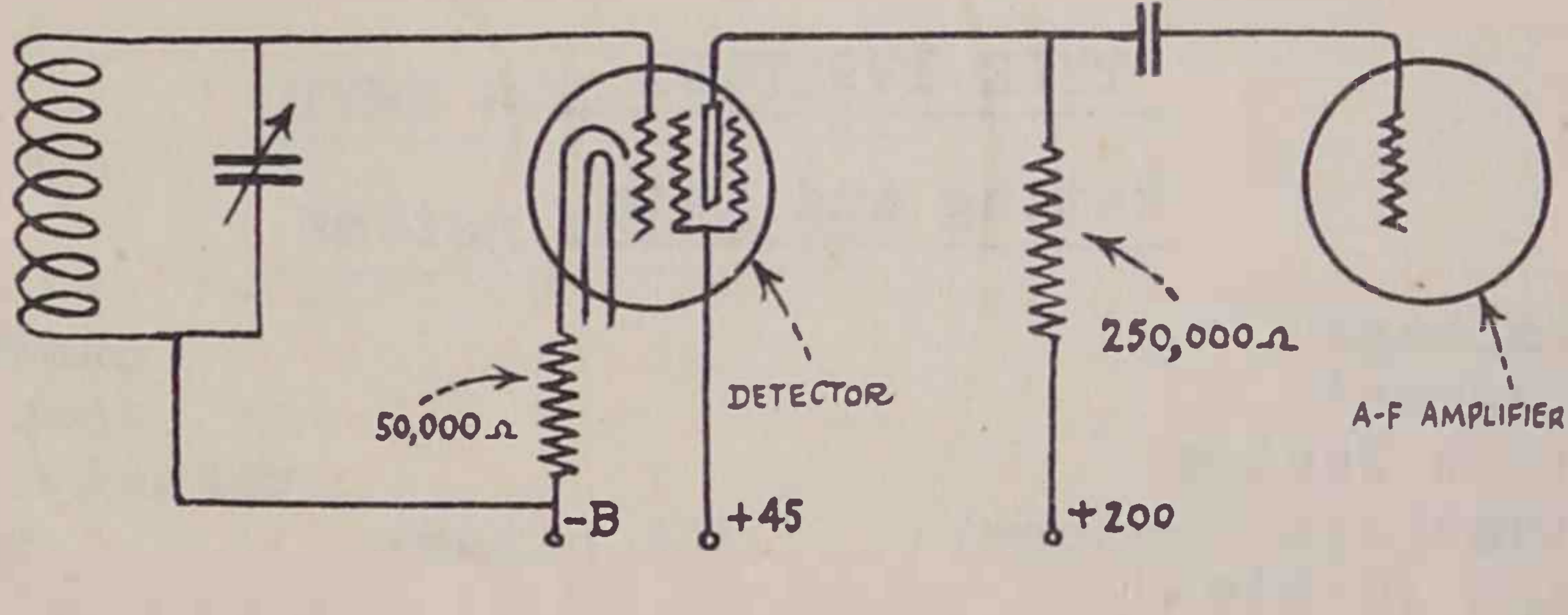

Figure 18

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TYPES WD 11 AND WD 12 FOR USE WITH DRY CELLS.

These tubes are among the earliest types of dry cell tube and were designed to be used with one or more #6 dry cells in parallel for filament supply. The -11 type tube has a special arrangement of prongs and so requires a special socket whereas the -12 type was designed to be used in a regular UX type socket. The electrical characteristics of both tubes are the same, hence, in either case the oxide coated filament consumes a quarter of an ampere at 1.1 volts and the plate may be operated with from 40 to 90 volts. Each type is a general purpose tube and can be used either as an r-f or a-f amplifier, or detector.

TYPES WD-11 AND WD-12

Rating and Data

Filament Voltage			1.1	volts
Filament Current			0.25	ampere
Plate Voltage	90	67	45	volts
Grid Voltage (C-Bias)	-4.5	-3	-.5 to 1.5	volts
Amplification Factor			6.6	

For use as a detector the grid return should be connected to the positive side of the filament and for this specific use a 2 megohm grid leak and .00025 mfd. condenser are recommended with 22½ to 45 volts on the plate.

TYPE 199 GENERAL PURPOSE BATTERY-TYPE TUBE.

These tubes are also general purpose battery-type tubes being designed to give more economical battery consumption than the -11 or -12 type. They may be used either as amplifiers or detectors, when used as a detector the grid circuit return should be connected to positive filament and a 3 megohm grid leak and .00025 grid condenser are recommended. Due to the low interelectrode capacity these tubes make good r-f amplifiers and, also, they can be used in the a-f stages to operate small speakers. Care should be taken to use the proper negative bias on the grid of the 199 whenever it is used as an amplifier.

TYPE 199 TUBE

Rating and Data

Filament Voltage	3.3	volts
Filament Current	.063	ampere
Amplification Factor	6.6	
Plate Voltage-	90	volts
Grid Voltage (C-Bias)	-4.5	volts

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The filament is of the thoriated tungsten type which may be reactivated if desired. Since the normal consumption is .06 ampere at 3.3 volts only three dry cells are necessary to supply the filament current.

TYPE 120 AUDIO OUTPUT AMPLIFIER.

This tube is a power amplifier designed to be used in the last stage of a receiver employing 199 type tubes. It operates with the same filament voltage as the 199 but takes twice as much current to heat the filament.

TYPE 120 AUDIO OUTPUT AMPLIFIER

Rating and Data

Filament Voltage	3.3	volts
Filament Current	0.132	ampere
Amplification Factor	3.3	
Plate Voltage (max.)	135	volts
Grid Voltage (C-Bias)	-22.5	volts

As the characteristic charts indicate, the 120 requires higher plate voltage and greater bias than the 199 and gives more power output without distortion.

TYPE 201-A STORAGE BATTERY TUBE.

For many years the 201-A tube has been the standard general purpose battery type tube. It was at one time the most popular type tube used in radio receivers where the space occupied by the batteries was not of great importance. Although the battery consumption is quite low for a 201-A filament yet a storage battery is recommended instead of dry cells. The plate current is greater than for the 199 and, therefore, higher capacity "B" batteries are recommended.

The filament is of the thoriated tungsten type rated at 5 volts and 0.25 ampere. The UV-type base with short prongs was first used with this tube but now the base has been changed to fit a standard UX socket.

TYPE 201-A TUBE

Rating and Data

Filament Voltage			5	volts
Filament Current			0.25	ampere
Amplification Factor			8	
Plate Voltage	(max.) 135	(recommended)	90	volts
Grid Voltage (C-Bias	-9		-4.5	volts

Detector operation is not critical and, as in the case of other types of tubes just discussed, a 2 megohm grid leak and 0.00025 mfd. condenser are recommended. The tube also makes a good r-f and a-f amplifier and, as mentioned before for other tubes, care should be taken to use the proper C-bias.

TYPE 240 USED WITH RESISTANCE COUPLING.

This tube is designed primarily to be used as a detector or audio-frequency amplifier where resistance coupling is desired. It is similar in appearance to the 201-A but the grid and plate construction differs to secure higher amplification and the plate impedance is also much higher than that of the 201-A.

TYPE 240 TUBE

Rating and Data

Filament Voltage	5	volts
Filament Current	.25	ampere
Amplification Factor	30	

240 USED AS AMPLIFIER

Plate Voltage	135	volts (recommended)	180	volts (max.)
Grid Voltage (C-Bias)	-1.5	volts	-3.0	volts
Plate Coupling Resistance	250,000	ohms	250,000	ohms

240 USED AS DETECTOR

(Grid Leak Detection)

Plate Voltage	135 to 180	volts
Plate Coupling Resistance	250,000	ohms
Grid Leak	2 - 5	megohms

(Grid Bias Detection)

Plate Voltage	135	volts	180	volts
Plate Coupling Resistance	250,000	ohms	250,000	ohms
Grid Voltage (C-Bias)	-3	volts	-4.5	volts

The above chart gives the various ratings for the 240 when used either as an amplifier, or a grid-leak or grid-bias detector. As just stated, this tube may be used for either grid leak or grid bias detection, the first giving higher sensitivity and the latter freedom from distortion on high signal input voltages. When used in a resistance coupled audio amplifier the 240 gives quite uniform amplification from 30 to 10,000 cycles.

TYPE 112-A AMPLIFIER.

This is an oxide coated storage battery tube, having a lower plate resistance than the 201-A. It may be used as a detector, r-f amplifier or a-f amplifier. For detector use it is recommended to use 45 volts on the plate, a 0.00025 mfd. grid condenser and a 2 to 3 megohm leak. Due to the difference in interelectrode capacity and plate resistance it may be difficult to control if used in a radio-frequency circuit but the low impedance, however, makes this tube most suitable for use in transformer coupled audio amplifiers. It also makes a good power amplifier having a greater output than the 201-A but less than the 171-A.

TYPE 112-A AMPLIFIER

Rating and Data

Filament Voltage			5	volts
Filament Current			.25	ampere
Amplification Factor			8.5	
Plate Voltage	135	volts (recommended)	180	volts (max.)
Grid Voltage	-9	volts	-13.5	volts

TYPE 250 POWER AMPLIFIER TUBE.

This tube is a heavy duty power amplifier intended for use in installations where more undistorted power output is required than for average home use. The 250 is larger in size than the 210 and requires greater bias for the same plate voltage. For this reason it cannot be used in a set formerly using a 210 unless the set is changed to increase the bias. When this is done it will give a greater power output than the 210. This tube has an oxide coated filament rated at 7.5 volts, 1.25 amperes and draws higher plate current and has lower impedance than the 210.

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Rating and ta

Fil nt Voltage				7.5	volts
Fil nt C t				1.25	pe s
plification Factor				3.8	
Plate Voltage	250	350	400	450	volts
Grid Volt (C-Bias)	-45	-63	-70	-	volts
Power Output (milli tts)	1000	2400	3400	4600	milliwatts

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TYPES 236, 237 and 238 DESIGNED FOR AUTOMOBILE RADIO RECEIVERS

This group of three tubes consists of a screen-grid tube, a general purpose tube and a power output pentode. All three are of the high vacuum type and employ coated cathodes indirectly heated. The cathodes, which are the same for all three types, have been carefully designed to insure uniform heating over as wide a range of heater voltages as possible in order that the tubes will perform satisfactorily under the normal voltage variation of automobile batteries during charge and discharge. This feature together with that of the general freedom from microphonic and battery circuit disturbances of the heater-cathode type, make these new tubes particularly suited for use in automobile receivers.

The 236 Screen-Grid tube is particularly recommended for operation as a radio-frequency amplifier in circuits especially designed for it. It may be employed also as a screen-grid detector.

The 237 general purpose tube is useful either as detector, amplifier or oscillator.

The 238 power amplifier pentode has been designed to give good output volume consistent with the relatively low voltage and limited capacity of the plate supply battery.

The 236 and 237 will also be found especially adaptable to the design of radio receivers for operation from the d-c power line. In such service the heaters of these two types may be connected in series to operate at 0.3 ampere. This is made possible by the uniform heating of the cathode over a wide voltage range to offset normal line voltage variation.

TYPE 236 FOR AUTOMOBILE SETS

This screen-grid tube may be used as either a radio-frequency amplifier, a detector or an intermediate-frequency amplifier in circuits especially designed for it. The 236 employs a coated cathode of the semi-quick-heater type designed for d-c operation only. Owi to the special cathode design, the heater volt e y r e between 5.5 a 8.5 volts during the charge d discharge cycles of the battery without appreciably affecting the perfo nce or serviceability of this tube. No resistor in the heater circuit is required for this t e operated from a 6-volt battery.

The socket required by the 236 is of the standard type d y be mounted to hold the tube in either a vertical or horizontal position. Socket connections are the s as for a -224.

Stable operation of the 236 in radio-frequency circuits desi ed to give xim gain per st e requires separation of the input and output circuit elements. In general, with lti-st e amplifier circuits, it is necessary to use co lete stage shielding enclosing all the components of each st . Unless this is done, the plification possibilities of the 236 will t be realized. e use of radio-frequency filters in all le s enteri the stage shields is advised to reduce

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coupling in external parts of the circuit. In regard to heater to cathode bias it should not exceed 45 volts.

Since the screen current of individual tubes is subject to variation, the use of a resistance in series with the plate voltage source for the screen voltage supply will result in poor regulation and uncertain operating screen voltages. It is recommended therefore, that the screen voltage be obtained from either a tap on the plate battery, or from a potentiometer or bleeder circuit which maintains the screen voltage approximately constant at the recommended value. If a bleeder circuit or potentiometer is used, its electrical design should be such as to provide adequate screen voltage regulation; otherwise, the effect will be essentially the same as that of a series resistor with resultant poor regulation. The volume of the receiver should be controlled preferably by varying the grid voltage. The control adjustment should be such as to impress not less than - 1.5 volts on the grid when recommended voltages are applied to the screen. The use of some device for reducing the signal input to the first radio-frequency tube will be necessary where strong local signals will cause high values of peak grid voltage.

TYPE 236 FOR AUTOMOBILE SETS

Rating and Data

Heater Voltage			6.3	volts d-c
Heater Current			0.3	ampere
Plate Voltage	90**	135	135*	volts
Screen Voltage	55**	67.5	75*	volts
Grid Voltage	-1.5**	-1.5	-1.5*	volts
Plate Current	1.8	3	3.5	milliamperes
Screen Current		not over 1/3	of plate	current
Plate Resistance	200,000	300,000	250,000	ohms
Amplification Factor	170	315	275	
Mutual Conductance	850	1050	1100	micromhos

The 236 may be employed as a screen-grid detector of either the grid-bias or grid-leak type. For both of these connections resistance coupling may be used with a plate coupling resistor. An equivalent reactor may be substituted for the plate resistor where greater output from low percentage modulated signals is desired. For most sensitive detection with resistance coupling, it will be necessary to reduce the screen voltage to from 20 to 45 volts. For plate detection the bias may be secured either from a fixed voltage source or by automatic biasing from a resistor in the cathode circuit.

TYPE 237 FOR AUTOMOBILE SETS

This three-electrode tube may be used in circuits of conventional design as either an amplifier, a detector or an oscillator. The tube employs a coated cathode of the semi-quick-heater type designed for d-c operation only. Owing to the special cathode design, the heater voltage may range between 5.5 and 8.5 volts during the charge and discharge cycles of the battery without appreciably affecting the performance of serviceability of this tube.

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TYPE 237 FOR AUTOMOBILE SETS

Rating and Data

Heater Voltage		6.3	volts d-c
Heater Current		0.3	ampere
Plate Voltage	90**	135*	volts
Grid Voltage	-6**	-9	volts
Plate Current	2.7	4.5	milliamperes
Plate Resistance	11,500	10,000	ohms
Amplification Factor	9	9	
Mutual Conductance	780	900	micromhos
Load Resistance***	14,000	12,500	ohms
Undistorted Power Output	30	75	milliwatts
Approximate Inter-Electrode Capacitances			
Grid to Plate	2.0 mmf.		
Grid to Cathode	3.3 mmf.		
Plate to Cathode	2.3 mmf.		
Base		small UY	
Socket		UY	

***Optimum load resistance for maximum undistorted power output as given.
*Recommended values for use in automobile receivers.
**Recommended values for use in receivers designed for 110 volt d-c operation.

In detector service, the 237 may be used either with grid lead and grid condenser or with grid bias. If grid leak detection is used, a condenser of 0.00025 mfd. and a grid leak of from 1 to 5 megohms will give excellent sensitivity. However, more stable operation and better quality will be obtained by using a low value of grid leak. For plate detection the bias may be secured either from a fixed voltage source or by automatic biasing from a resistor in the cathode circuit. The heater to cathode bias should not exceed 45 volts as in the case of type 236, and the socket connections are the same as for a UY-227.

TYPE 238 - POWER PENTODE FOR AUTOMOBILE SETS

The 238 is a screen-grid tube designed primarily for giving large audio power output for relatively small signal voltages impressed on the grid. This is made possible by the addition of a "suppressor" grid between the screen and the plate. The suppressor is connected inside the tube to the cathode and is therefore operated at the same potential as the cathode. When connected and operated in this manner, the suppressor is effective in practically eliminating the secondary emission effects which limit the power output from four-electrode screen-grid types.

Other considerations already mentioned in regard to the special types of automobile tubes are that the heater to cathode bias should not exceed 45 volts and the grid bias for the 238 may be obtained either from a fixed voltage source or by automatic self-biasing from a resistor in the cathode circuit. Also, this tube employs a coated cathode of the semi-quick-heater type designed for d-c operation only

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and owing to the special cathode design, the heater voltage may range between 5.5 and 8.5 volts during the charge and discharge cycles or the battery without appreciably affecting the performance or serviceability of this tube.

TYPE 238 - POWER PENTODE FOR AUTOMOBILE SETS

Rating and Data

Heater Voltage	6.3	volts
Heater Current	0.3	ampere
Plate Voltage, Recommended	135	volts
Screen Voltage, Recommended	135	volts
Grid Voltage	-13.5	volts
Plate Current	8	milliamperes
Screen Current	2.5	milliamperes
Plate Resistance	110,000	ohms
Amplification Factor	100	
Mutual Conductance	900	micromhos
Load Resistance	15,000	ohms
Undistorted Power Output	375	milliwatts
Base	small	UY
Socket		UY

THE 2-VOLT TYPE TUBES FOR BATTERY OPERATION

2-VOLT TUBE - DETECTOR AND AMPLIFIER - TYPE 230

The 230 is a new general purpose tube of the three electrode, high vacuum type. It employs a strong metallic filament coated with alkaline earth compounds. The filament has been designed to take as little power as possible consistent with satisfactory operating performance. This new tube, therefore, is particularly suited for use either as a detector or amplifier in radio receivers operating from dry-cells or from a storage battery where economy of filament current drain is important.

This 2 volt tube should be mounted in a vertical position and its socket and connections are the same as for the 199 tube. It should be mentioned that although the 230 is very free from microphonic disturbances, cushioning of its socket may be desirable.

The coated filament of the 230 should be operated at its rated value of 2.0 volts. This voltage may be supplied from dry-cells or from a single cell storage battery, but in either case an adjustable filament rheostat must be used together with a permanently installed indicating instrument to secure the proper filament voltage. This instrument should be either a voltmeter to indicate the terminal e.m.f. or a milliammeter to indicate the current drain. This requirement is applicable to all of the three types of 2 volt tubes, namely, the 230, 231 and 232 tubes. Bear in mind that fixed filament resistors will not give sufficient regulation to permit of satisfactory performance.

When this tube is used as a detector with a grid condenser and leak, the 230 tube should preferably be operated with a plate voltage of not more than 45 volts. The grid condenser and leak may be of usual sizes. However, as an amplifier, the 230 should always be used with a negative grid bias and for a plate voltage of 90 volts, it is best to use a grid bias of 4.5 volts.

2-VOLT TUBE - DETECTOR AND AMPLIFIER - TYPE 230

Rating and Data

Filament Voltage	2.0	volts
Filament Current	0.06	amperes
Plate Voltage (Maximum)	90	volts
Grid Voltage (C-Bias)	-4.5	volts
Plate Current	2.0	milliamperes
Plate Resistance	12,500	ohms
Amplification Factor	8.8	
Mutual Conductance	700	micromhos

Further, let us advise you that the 230 tube cannot be substituted for the 199 tube in radio sets designed for the latter, without circuit modifications. Suitable precautions must be taken to limit the filament voltage to 2.0 volts. In addition, the filament circuit must be altered to conform to the requirements of this new tube. If these tubes are used in tuned radio-frequency receivers not especially designed for them it may be necessary to readjust the neutralizing condensers or grid resistors before stable operation is obtained.

2-VOLT TUBE - POWER AMPLIFIER - TYPE 231

The 231 type tube is a new power amplifier tube of the three electrode, high vacuum type. It employs a strong metallic filament of the coated type which has been designed to take as little power as possible consistent with satisfactory operating performance. This new 231 tube, therefore, is particularly suited for use as the power output tube in radio receivers which operate with 230 or 232 type tubes. Both of the latter type may be used in the same receiver in conjunction with the 231, hence, all three types of the new 2 volt tubes may be employed in a single receiver.

2-VOLT TUBE - POWER AMPLIFIER - TYPE 231

Rating and Data

Filament Voltage	2.0	volts
Filament Current	0.130	ampere
Plate Voltage, Maximum and Recommended	135	volts
Grid Voltage (C-Bias)	-22.5	volts
Plate Current	8	milliamperes
Plate Resistance	4,000	ohms
Amplification Factor	3.5	
Mutual Conductance	875	micromhos
Undistorted Power Output	170	milliwatts

The 231 should be mounted in a vertical position and is to be used with a socket having connections the same as for the 199 or 120. It has been found that provision for cushioned sockets to prevent microphonic disturbances will not usually be necessary when this tube feeds directly into the loudspeaker.

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The recommended and maximum plate voltage for the 231 tube is 135 volts while the corresponding grid bias is - 22.5 volts. Under these operating conditions the plate current, which is 8 ma., is not high enough to require the use of a loudspeaker coupling device.

The 231 tube cannot be substituted for the 120 tube unless the filament circuit is altered to conform to the requirements of this new power output tube since the filament voltage must be limited to 2.0 volts.

2-VOLT TUBE - SCREEN GRID R-F AMPLIFIER - TYPE 232

The 232 type tube is a new screen grid tube recommended for use primarily as a radio-frequency amplifier. It employs a strong metallic filament of the coated type, which has been designed to take as little power as possible consistent with satisfactory operating performance. This new tube, therefore, is particularly useful in the radio-frequency stages of specially designed radio receivers operating from dry cells or from a storage battery where economy of filament current drain is important. The control grid is electrostatically shielded from the plate by means of an extra grid placed between plate and control grid and operated at a suitable positive potential. The resultant reduction in plate to control-grid capacity makes high voltage amplification per stage practical without external capacity neutralization circuits. This isolation of plate and grid results in a small change of plate current with a change of plate potential. The plate resistance, therefore, is high and averages about 800,000 ohms.

2-VOLT TUBE - SCREEN GRID R-F AMPLIFIER - TYPE 232

Rating and Data

Fil nt Volt e	2.0	volts
Fil ent C rent	0.06	pere
Plate Voltage, Max and Reco ended	135	volts
Grid Voltage (C-Bias)	-3	volts
Screen Voltage, im	67.5	volts
Plate C rent	1.5	milli peres
Screen C rent	not over 1/3	of plate current
Plate Resist ce	800,000	o
lification Factor	440	
Mutual Con ctance	550	micro os
Effective Grid-Plate Capacitances	0.02	. xim

e 232 tube should be mounted in a vertical position. e socket connections for the 232 are the same as for the 222 t e tube. Although the 232 is very free from microphonic dist bances, cushioning of its socket y be desirable.

The co ection for the control grid is de to the metal cap at the top of the glass envelope as is the ual procedure after placing screen-grid t tubes in their sockets.

e positive voltage for the screen should be obtained fr a tap on the plate battery and, therefore, never attempt to obtain the screen voltage by co ecting the screen thro h a series resistor to a high plate voltage source. Such a series resistor connection will not in general be satisfactory for screen voltage supply because of the uncertain drop produced by the considerable differences in screen currents of individual tubes.

Stable operation of the 232 tube in circuits designed to give maximum gain per stage requires separation of the input and output circuit elements. In general, it is necessary to use complete stage shielding including all the components of each stage. The use of filters in all leads entering the stage shields is advisable to reduce coupling in external parts of the circuit.

It is recommended that the operating voltage be applied to the 232 tube as follows: maximum plate voltage to be 135 volts with all corresponding negative grid bias of 3 volts, and a maximum positive screen voltage of 67.5 volts. You will find when using tubes of this type that neither plate nor screen voltage is critical. The control-grid bias for this tube when working on B-battery operated receivers should be obtained from a C-battery. The 232 tube cannot be substituted for the 222 tube in circuits designed for the latter, without circuit modifications, that is, the filament and grid circuits must be altered to conform to the requirements of this new screen-grid tube.

VARIABLE MU TUBE - TYPE 235

This most recent screen-grid tube has been developed primarily for use in radio-frequency and intermediate-frequency amplifier stages. It is effective in reducing cross-modulation, and modulation distortion over the entire range of received signals. Furthermore, its design is such as to permit easy control of a large range of signal voltages without the use of local-distant switches or antenna potentiometers. This feature makes the tube adaptable to automatic volume control design.

VARIABLE MU TUBE - TYPE 235

Tentative Rating and Normal Characteristics

Filament Voltage	2.5	volts
Filament Current	1.75	amperes
Plate Voltage, Recommended	180	volts
Screen Voltage, Recommended	75	volts
Grid Voltage	— 1.5	volts
Plate Current	9	milliamperes
Screen Current	not over 1/3	of plate current
Plate Resistance	200,000	ohms (approx.)
Mutual Conductance	1,100	micromhos
Approximate Inter-Electrode Capacitances		
Grid to Plate	.010	mmf. maximum
Input	5	mmf.
Output	10	mmf.
Base and Socket		UY

The 235 employs a cathode of the quick-heater type. Its heater should be operated at its normal rated voltage of 2.5 volts at the normal design line voltage. It is interesting to note that a recent survey of

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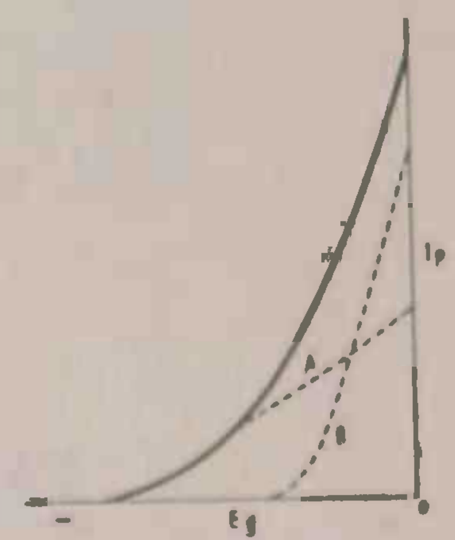
normal socket voltage conditions over the United States has established that 113 volts represents average operating conditions.

This tube has a very long characteristic curve that gradually drops off which indicates that very strong grid biases can be applied to the grid before the plate current reaches zero. In effect the signal voltage resulting from the oscillating current in the antenna system picks out the part of the characteristic curve of the tube it chooses to work upon, this being determined by the carrier voltage of this signal. A strong local signal may place a bias on the grid as low as 30 or more volts, whereas the desired signal which is much weaker in intensity may be working around a point which may be only a few volts or even tenths of volts negative. This tube's long characteristic curve is due to the special design of the tube elements which are made in different forms. For instance, the grid may be tilted, or the spacing between the wires may be greater at one part of the grid structure than at another, or the diameter may be nonuniform, that is, wide at one place and narrow at another and so on. Observe that curves A and B in Figure 19 illustrate the idea of how a variable mu tube combines the features of both a low-mu and high-mu tube which permits this tube to work over a wide range of input signal voltages. Curve A is the characteristic for a low-mu tube and curve B is the characteristic for a high-mu tube while the long curve drawn in solid line illustrates the combined characteristics. The various arrangements of tube structure cause a different, or variable mu-factor in operation for electrons emitted from the various elements of the cathode. When the grid bias is low, or near zero, the electron flow is such that current flows from all of these elements but as the grid bias becomes more negative the current from the elements havi   the higher mu-factors is cut off gradually at a certain rate.

The cathode should be connected directly to the center-point of the heater circuit. If this arrangement is not practical in some receiver designs, the heater may be made negative with respect to the cathode by a potential difference not exceeding 45 volts.



Fi   e 19

Since the screen current of individual tubes is subject to considerable variation, the use of resistance in series with a high voltage source for the screen voltage supply will result in poor regulation and certain operati screen voltages. It is reco nded, therefore, t t t screen voltage be obtained from a potenti ter fr a bleeder circuit which intains the screen voltage approxi tely constant at 75 volts. e electrical design of the potentio ter or bleeder should be such as to draw several ti s the xi m scre current; othe ise, the effect will be essentially the sa as t t of a series resistor with resultant poor regulation. Radio-frequency choke filters for screen voltage supply are preferred   to their l d-c resistance i i es satisfacto screen vo tage re lation.

Since t variati in plate c rent over the operati r e of this tube is ab t 9 milli eres, the xim c rent drain of several tubes y se a large ift in po r pack ou ut voltage. It is, therefore rec ended that the screen vol e e adjusted to a rage 75 vo ts between the two extre s of the vol co rol setti .

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Variation of the negative voltage applied to the grid will be found effective in changing the volume of the receiver. In order to utilize the full volume control range of this tube, an available grid bias voltage of approximately 75 volts will be required. This voltage should preferably be obtained from a potentiometer or bleeder circuit. If, however, the receiver is designed so that the required volume control can be obtained without exceeding 45 volts, the cathode resistor method of obtaining the grid bias control voltage is permissible.

The illustration below in Figure 20 shows a diagrammatic circuit for Super-Control R-F Amplifier RCA-235 and Power Amplifier Pentode RCA-247.

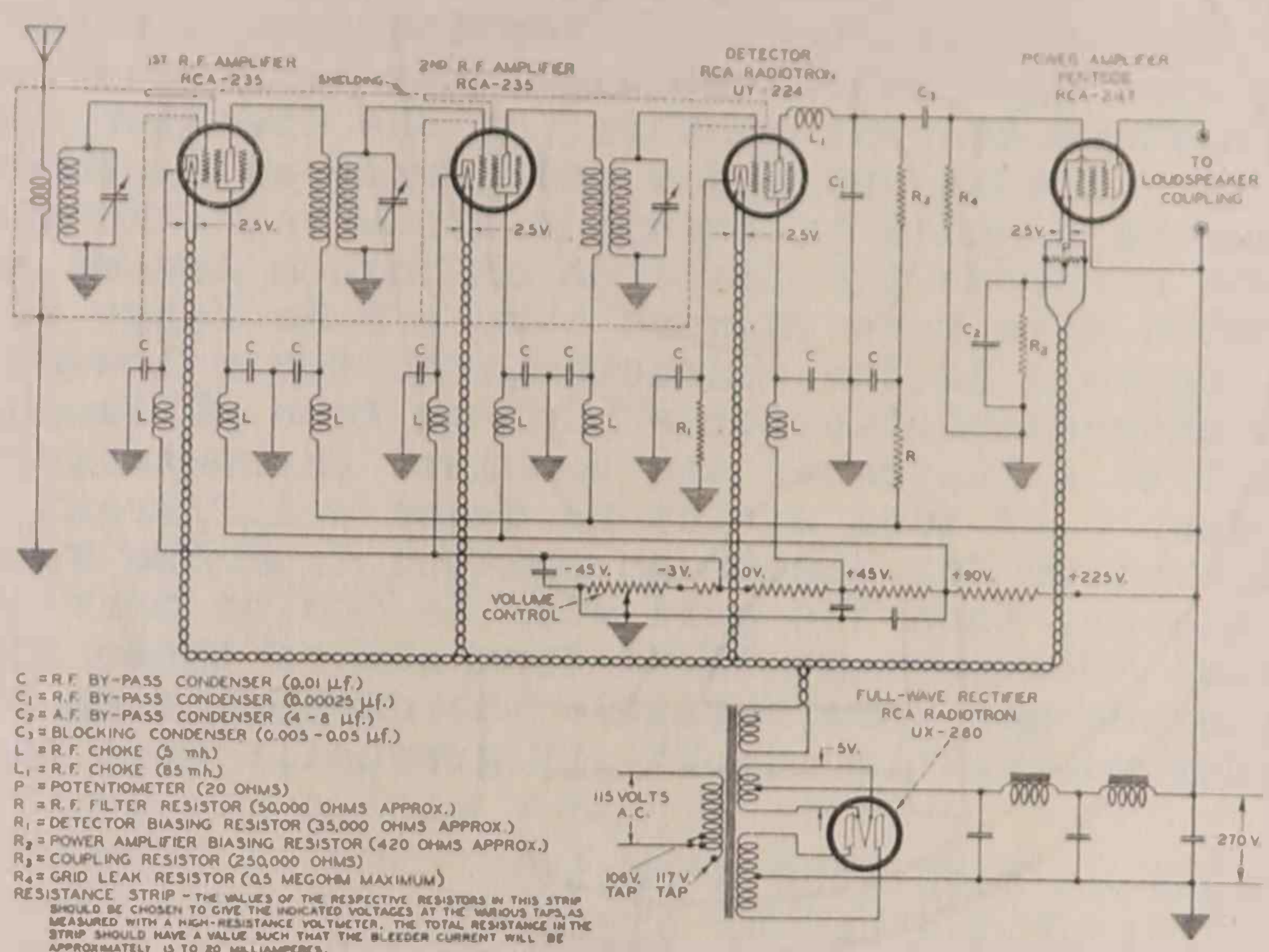


Figure 20

EXAMINATION QUESTIONS (V-13 #1.)

1. Explain the principle on which a pentode tube functions.
2. Calculate the "C" bias resistor for the 245 tube used in Figure 9 with 250 volts plate supply.
3. (a) Under what conditions would you use a 171-A tube with 90 volts applied to the plate and (b) with 180 volts applied?
4. How is screen grid voltage best obtained and how controlled?
5. What is the difference between space charge and screen grid connections?
6. Refer to Question 5. Which makes the better audio amplifier and why?
7. What advantage does the screen-grid type tube have over the 3-element tube as an r-f amplifier?
8. (a) Show by diagram how you would connect a loudspeaker to a 171-A tube, (b) to a 245 tube, and (c) Explain why for each case.
9. A 224 tube used as a detector has 200 volts applied to its plate thru a coupling resistor of 250,000 ohms. Assuming the plate current to be .1 milliampere what voltage is actually impressed on the tube?
10. Give the advantages of the type 235 tube over the type 224 tube.

AVERAGE CHARACTERISTICS CHART

DETECTORS AND AMPLIFIERS

GENERAL								DETECTION		
Type	Use	Base	Max. Overall Dimensions: Height	Max. Overall Dimensions: Diam.	Filament Supply	Filament Terminal Volts	Filament Current Amperes	Plate Supply Volts	Plate Current Milliamp.	Grid Return Lead To
WD-11	Detector or Amplifier	WD-11	4 1/8"	1 3/16"	D. C.	1.1	0.25	45	1.5	+F
WX-12	Detector or Amplifier	UX	4 11/16"	1 7/16"	D.C.	1.1	0.25	45	1.5	+F
UX-112-A	Detector or Amplifier	UX	4 11/16"	1 13/16"	D. C.	5.0	0.25	45	4.0	+F
UV-199	Detector or Amplifier	UV-199	3 1/2"	1 1/16"	D. C.	3.3	0.063	45	1.0	+F
UX-199	Detector or Amplifier	Small UX	4 1/8"	1 3/16"	D. C.	3.3	0.063	45	1.0	+F
UX-200-A	Detector	UX	4 11/16"	1 13/16"	D. C.	5.0	0.25	45	1.5	−F
UX-201-A	Detector or Amplifier	UX	4 11/16"	1 13/16"	D. C.	5.0	0.25	45	1.5	+F
UX-222	Radio Freq. Amplifier	UX	5 3/8"	1 13/16"	D. C.	3.3	0.132	—	—	—
UX-222	Audio Freq. Amplifier	UX	5 3/8"	1 13/16"	D. C.	3.3	0.132	—	—	—
UY-224	R. F. Amp. or Detector	UY	5 1/4"	1 13/16"	A. C. or D. C.	2.5	1.75	Refer to Technical Bulletin		Cath.
UY-224	Audio Freq. Amplifier	UY	5 1/4"	1 13/16"	A. C. or D. C.	2.5	1.75	—	—	—
UX-226	Amplifier	UX	4 11/16"	1 13/16"	A. C. or D. C.	1.5	1.05	—	—	—
UY-227	Detector or Amplifier	UY	4 11/16"	1 13/16"	A. C. or D. C.	2.5	1.75	45	3.5	Cath.
RCA-230	Detector or Amplifier	Small UX	4 1/4"	1 3/16"	D. C.	2.0	0.06	45	1.0	+F
RCA-232	Radio Freq. Amplifier	UX	5 1/4"	1 13/16"	D. C.	2.0	0.06	—	—	—
UX-240	Detector or Amplifier	UX	4 11/16"	1 13/16"	D. C.	5.0	0.25	135† 180†	0.3 0.4	+F

AMPLIFICATION										
Type	Plate Supply Volts	Grid Bias Voltage: D. C. on Fil.	Grid Bias Voltage: A. C. on Fil.	Plate Current Milliamp.	Screen Grid Volts	A. C. Plate Resistance Ohms	Mutual Conductance Micromhos	Voltage Amplification Factor	Ohms Load for Maximum Undistorted Output	Maximum Undistorted Output Milliwatts
WD-11	90 135	4.5 10.5	— —	2.5 3.0	— —	15500 15000	425 440	6.6 6.6	15500 18000	7 35
WX-12	90 135	4.5 10.5	— —	2.5 3.5	— —	15500 15000	425 440	6.6 6.6	15500 18000	7 35
UX-112-A	90 135	4.5 9.0	— —	5.2 6.2	— —	5600 5300	1500 1600	8.5 8.5	5600 8700	30 120
UV-199	90	4.5	—	2.5	—	15500	425	6.6	15500	7
UX-199	90	4.5	—	2.5	—	15500	425	6.6	15500	7
UX-200-A	Following UX-200-A Characteristics Apply Only for Detector Connection					30000	666	20	—	—
UX-201-A	90 135	4.5 9.0	— —	2.5 3.0	— —	11000 10000	725 800	8.0 8.0	11000 20000	15 55
UX-222 (Radio Freq.)	135 135	1.5 1.5	— —	1.5 3.3	45 67.5	850000 600000	350 480	300 290	— —	— —
UX-222 (Audio Freq.)	180†	1.5	—	0.3	22.5	2000000	175	350	—	—
UY-224 (R. F.)	180 180	1.5 3.0	1.5 3.0	4.0 4.0	75 90	400000 400000	1050 1000	420 400	— —	— —
UY-224 (Audio Freq.)	250‡	1.0	1.0	0.5	25	2000000	500	1000	—	—
UX-226	90 135 180	5.0 8.0 12.5	6.0 9.0 13.5	3.8 6.3 7.4	— — —	8600 7200 7000	955 1135 1170	8.2 8.2 8.2	9800 8800 10500	30 80 180
UY-227	90 135 180	6.0 9.0 13.5	6.0 9.0 13.5	2.7 4.5 5.0	— — —	11000 9000 9000	820 1000 1000	9.0 9.0 9.0	14000 13000 18700	30 80 165
RCA-230	90	4.5	—	2.0	—	12500	700	8.8	—	—
RCA-232	135	3.0	—	1.5	67.5	800000	550	440	—	—
UX-240	135‡ 180‡	1.5 3.0	— —	0.2 0.2	— —	150000 150000	200 200	30 30	— —	— —

*For Grid-Bias Detection, refer to Technical Bulletins.

†Applied through plate coupling resistor of 250000 ohms.

‡Applied through plate coupling resistor of 200000 ohms.

POWER AMPLIFIERS

Type	Use	Base	Height	Diam.	Filament Supply	Filament Terminal Volts	Filament Current Amperes	Plate Supply Volts (Detection)	Plate Current Milliamp. (Detection)	Grid Return Lead To
UX-112-A	Power Amplifier	UX	4 11/16"	1 13/16"	D. C. or A. C.	5.0	0.25	—	—	—
UX-120	Power Amplifier	Small UX	4 1/8"	1 3/16"	D. C.	3.3	0.132	—	—	—
UX-171-A	Power Amplifier	UX	4 11/16"	1 13/16"	A. C. or D. C.	5.0	0.25	—	—	—
UX-210	Power Amplifier	UX	5 5/8"	2 3/16"	A. C. or D. C.	7.5	1.25	—	—	—
RCA-231	Power Amplifier	Small UX	4 1/4"	1 3/16"	D. C.	2.0	0.130	—	—	—
UX-245	Power Amplifier	UX	5 5/8"	2 3/16"	A. C. or D. C.	2.5	1.5	—	—	—
UX-250	Power Amplifier	UX	6 1/4"	2 11/16"	A. C. or D. C.	7.5	1.25	—	—	—

Type	Plate Supply Volts	Grid Bias D. C. on Fil.	Grid Bias A. C. on Fil.	Plate Current Milliamp.	Screen Grid Volts	A. C. Plate Resistance Ohms	Mutual Conductance Micromhos	Voltage Amplification Factor	Ohms Load for Maximum Undistorted Output	Maximum Undistorted Output Milliwatts
UX-112-A	135 180	9.0 13.5	11.5 15.0	6.2 7.6	— —	5300 5000	1600 1700	8.5 8.5	8700 10800	120 260
UX-120	135	22.5	—	6.5	—	6300	525	3.3	6500	110
UX-171-A	90 135 180	16.5 27.0 40.5	19.0 29.5 43.0	12.0 17.5 20.0	— — —	2250 1960 1810	1330 1520 1620	3.0 3.0 3.0	3200 3500 5350	125 370 700
UX-210	250 350 425	18.0 27.0 35.0	22.0 31.0 39.0	10.0 16.0 18.0	— — —	6000 5150 5000	1330 1550 1600	8.0 8.0 8.0	13000 11000 10000	400 900 1600
RCA-231	135	22.5	—	8.0	—	4000	875	3.5	—	170
UX-245	180 250	33.0 48.5	34.5 50.0	25.0 34.0	— —	1900 1750	1850 2000	3.5 3.5	3500 3900	780 1600
UX-250	250 350 400 450	41.0 59.0 66.0 80.0	45.0 63.0 70.0 84.0	28.0 45.0 55.0 55.0	— — — —	2100 1900 1800 1800	1800 2000 2100 2100	3.8 3.8 3.8 3.8	4300 4100 3670 4350	1000 2300 3400 4600

RECTIFIERS

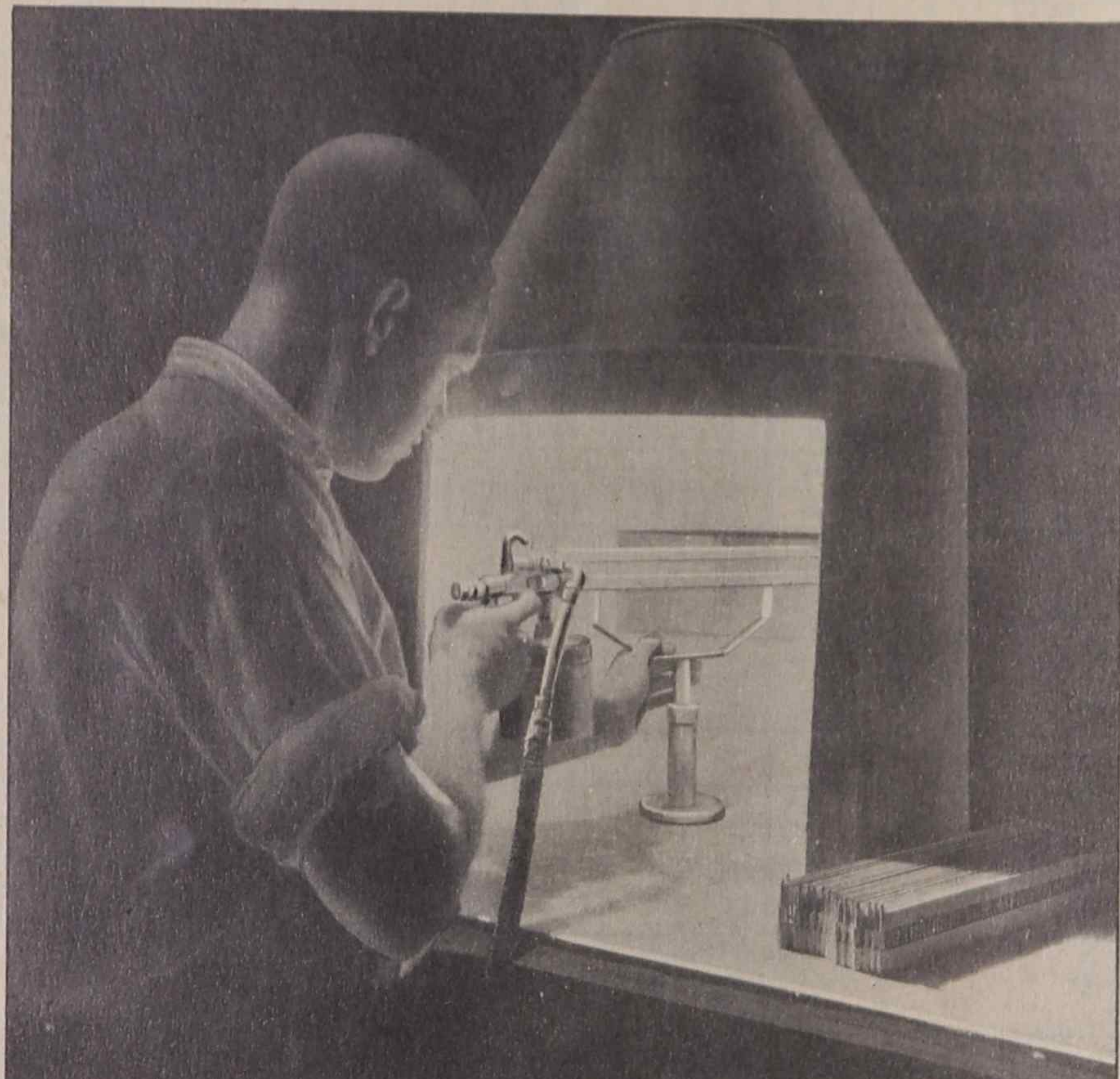
Type	Use	Base	Height	Diam.	Filament Supply	Filament Terminal Volts	Filament Current Amperes		
UX-280	Full-Wave Rectifier	UX	5 5/8"	2 3/16"	A. C.	5.0	2.0	1 { A. C. Voltage per Plate (Volts RMS) ... 350; D. C. Output Current (Maximum MA.) ... 125 2 { A. C. Voltage per Plate (Maximum Volts RMS.) ... 400; D. C. Output Current (Maximum MA.) ... 110	For D. C. Output Voltage delivered to filter of typical rectifier circuits, refer to Technical Bulletin.
UX-281	Half-Wave Rectifier	UX	6 1/4"	2 7/16"	A. C.	7.5	1.25	A. C. Plate Voltage (Maximum Volts RMS.) ... 700 D. C. Output Current (Maximum MA.) ... 85	For D. C. Output Voltage delivered to filter of typical rectifier circuits, refer to Technical Bulletin.

SPECIAL PURPOSE

Type	Use	Base	Height	Diam.		
UX-874	Voltage Regulator	UX	5 5/8"	2 3/16"	Designed to keep output voltage of B-Eliminators constant when different values of "B" current are supplied.	Operating Voltage ... 90 Volts D. C. Starting Voltage ... 125 Volts D. C. Operating Current ... 10-50 Milliamperes
UV-876	Current Regulator (Ballast Tube)	Mogul	8"	2 1/16"	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage.	Operating Current ... 1.7 Amperes Voltage Range ... 40-60 Volts
UV-886	Current Regulator (Ballast Tube)	Mogul	8"	2 1/16"	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage.	Operating Current ... 2.05 Amperes Voltage Range ... 40-60 Volts

FOR AMATEUR AND EXPERIMENTAL TRANSMITTING USE

Type	Use	Base	Maximum Overall Dimensions: Height	Maximum Overall Dimensions: Width	Filament Terminal Volts	Filament Current Amperes	Voltage Amp. Factor	Normal Plate Volts	Approx. Grid Bias Volts	Approx. Screen Volts	Maximum Plate Current Amperes	Maximum Plate Dissipation Watts	Normal Power Output Watts
UX-852	Oscillator or R. F. Amplifier	UX	8 3/4"	6 1/8"	10.0	3.25	12	2000	250	—	0.10	100	75
UX-865	Oscillator or R. F. Amplifier	UX	6 1/4"	2 3/16"	7.5	2.0	150	500	75	125	0.06	15	7.5
UX-866	Half-Wave Rectifier	UX	6 3/8"	2 7/16"	2.5	5.0	Maximum Peak Inverse Voltage ... 5000 Volts Maximum Peak Plate Current ... 0.6 Ampere Approximate Tube Voltage Drop ... 15 Volts						



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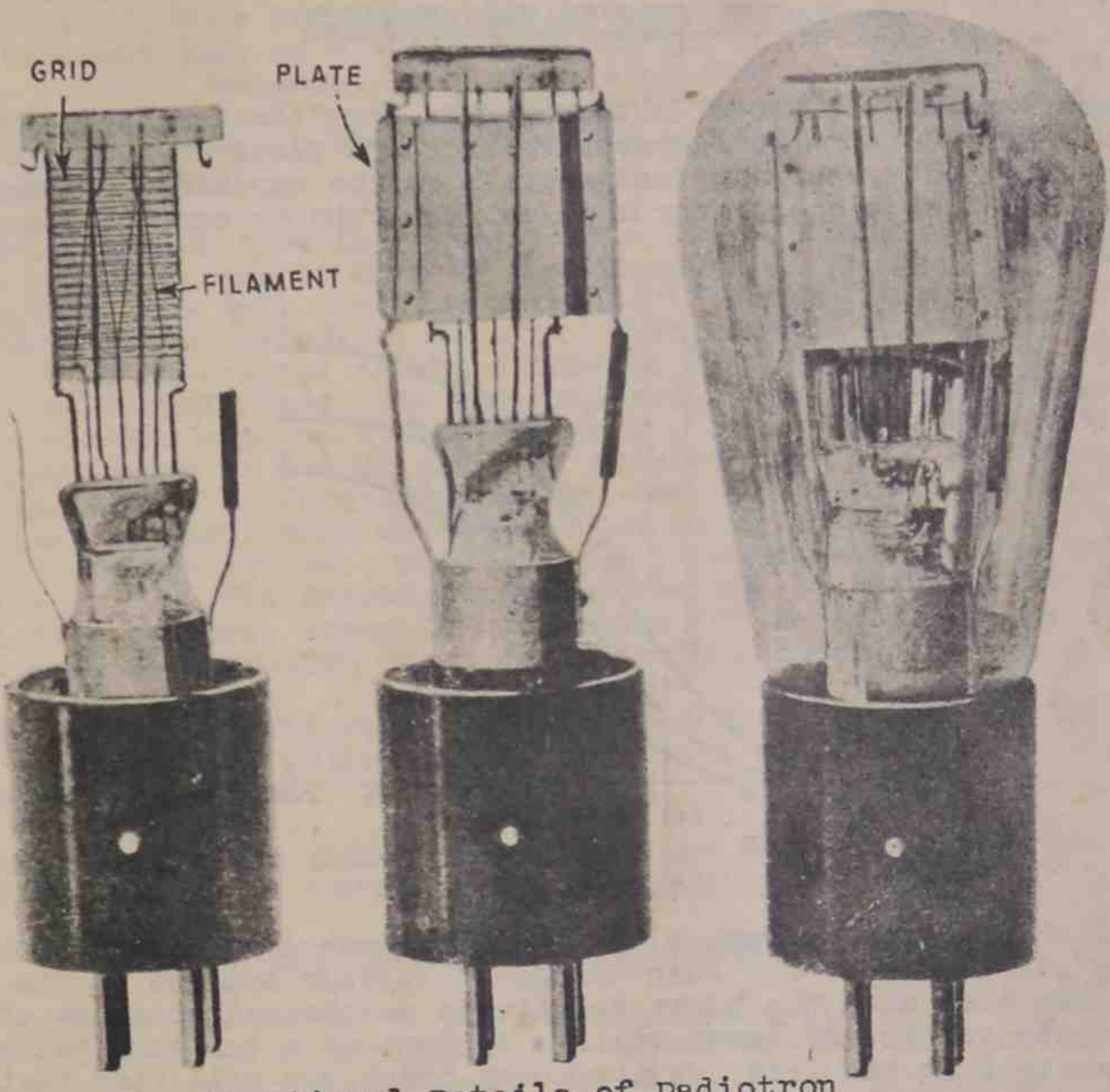

Constructional Details of Radiotron
RCA-210

VACUUM TUBE CHARACTERISTICS

Vol.13 #2

Dewey Classification R130

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VACUUM TUBE CHARACTERISTICS

The characteristic curves of a vacuum tube show the relation between the plate current and the filament voltage and plate current and the applied grid voltages. The fundamentals may be explained by their use which enables the operator to adjust the tube for certain required functioning.

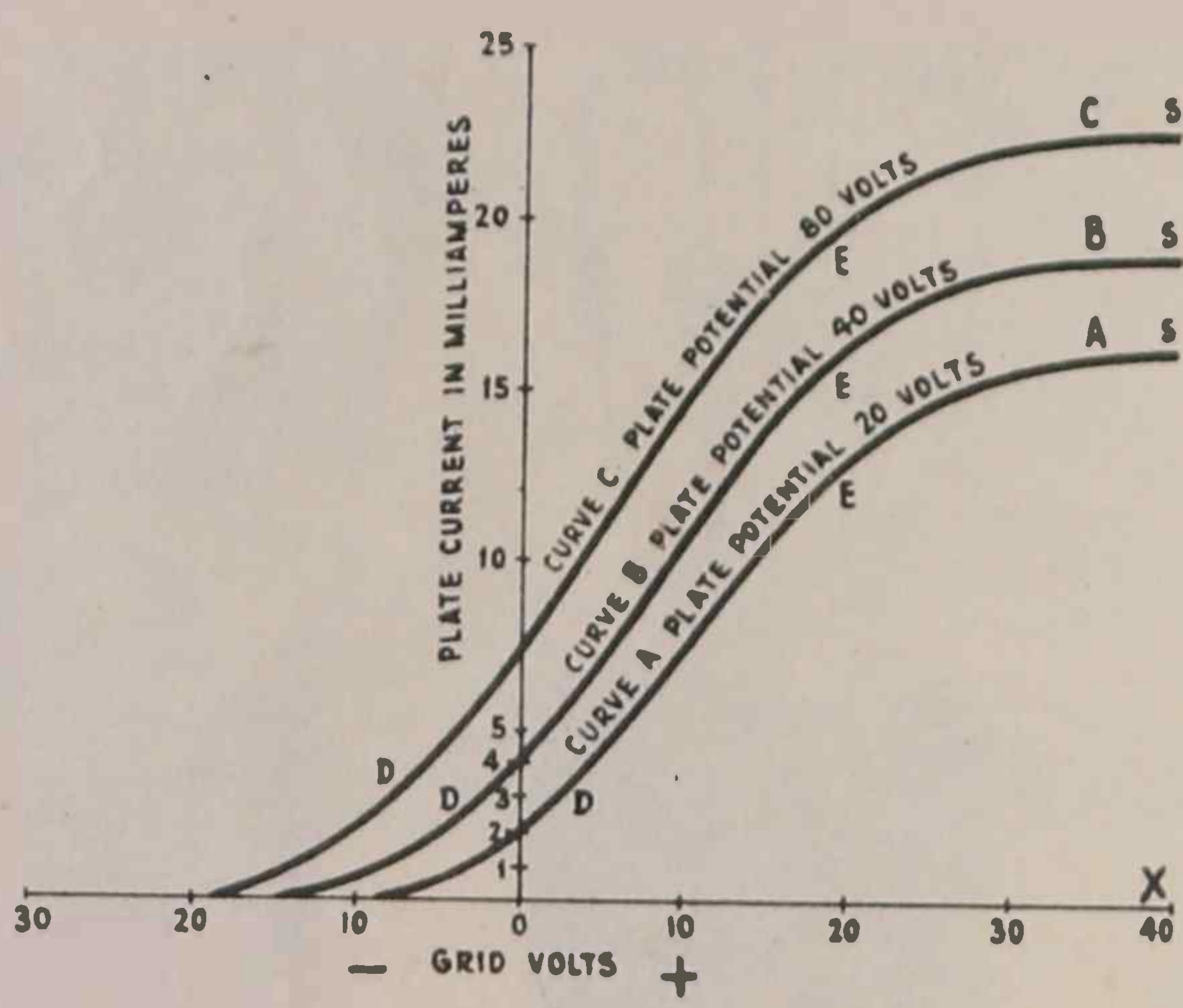

Figure 1

Figure 1 shows three curves, A, B, and C. Curve A represents the changing plate current for each change in voltage applied to the grid of the tube when the plate voltage is maintained constant at twenty volts and the filament voltage is kept at a constant value. Follow curve A to the left; at its lower point you will find that the plate current reaches zero. This happens because the grid is given a negative potential as shown by the grid voltage which is marked along the X axis. When the grid is strongly negative the electrons from the filament are prevented from passing to the plate and, in consequence of this fact, no plate current flow results. The grid, being negative, stops the electron flow to the plate. When, however, the potential applied to the grid becomes less negative more electrons are allowed to pass to the plate. When the grid becomes positive and is increased in positive value the plate current will correspondingly increase. This increasing value of plate current is shown by the straight portion of curve A between points D and E.

If the grid voltage is continuously increased in positive value there will be a point reached where the plate current will cease to increase. This is termed the point of saturation. By the term, "point of saturation", we mean that, provided the filament voltage and plate voltage are kept at a constant value, any further increase in positive potential value on the grid will not increase the plate current flow. This is indicated by the flattening of the curve at point S and is called the point of saturation. When the positive potential of the grid is further increased the current flowing in the circuit may start to decrease. This is caused by the fact that the grid has become so highly positive that it robs the plate of electrons which otherwise would have passed to the plate.

GRID CURRENT

When the grid is made positive it is obvious from the law, "unlike charges attract", that the grid will attract the electrons to itself from the filament just as a positively charged plate will attract electrons. Since a movement or flow of electrons constitutes a flow of current it is evident that, with the grid positive, there will be a flow of electrons or current in the grid and through any circuit connected to the grid.

A large grid current flow is not desirable in the radio circuit and means are taken to keep it down to a minimum value which will be explained later. The only function intended of the grid is to control the current flow in the plate circuit. When current flows in the grid it must be subtracted from the current that would normally flow in the plate circuit since both the grid and plate current originate from the electrons emitted by the filament. It is seen, then, that a positive grid tends to rob the plate of electrons and sets up a current in the grid circuit performing no useful work and reduces the plate current flow. A small grid current is put to useful purpose, as explained in detector action. Grid current is practically prevented by maintaining the grid negative through the use of what is termed a grid biasing battery, commonly called the "C" battery, and placing it in the grid circuit with its negative pole connected to the grid.

Curves "B" and "C" of Figure 1 differ only from curve "A" in that curve "B" indicates 40 volts used on the plate while in curve "C" eighty volts was applied.

In all three curves the same filament voltage was maintained, the general form of all the curves being practically the same.

THE VACUUM TUBE AMPLIFIER

Before taking up the action of the vacuum tube employed as a detector we will consider it as an amplifier for the reason that its fundamental actions are more easily understood. We will, for this purpose, use a vacuum tube circuit with supplementary curves to describe the action as we proceed.

Figure 2 represents a circuit which we will use to describe the principle of the tube as an amplifier. It was explained that when a positive voltage is placed on the grid the resulting flow of plate current will also assume a certain increased value. When, however, the grid voltage is changed the plate current will also make a corresponding change, the exact amount depending upon the characteristics of the tube. The tube acting as an amplifier should operate on the straight portion of the characteristic curve or the part of curve A, of Figure 1, between D and E.

Now let us return to Figure 2. When an incoming Radio wave is impressed on coil L1 through induction by coil L the wave will alternate and the oscillations composing this wave will be regular oscillations, that is, each oscillation will alternately vary from a positive to a negative value. When the wave is made up of continuous oscillations the positive value may be considered practically equal to the negative value. In the damped wave, however, each half oscillation will be somewhat less than the preceding half oscillation. We will consider the wave to be a continuous one. When it is impressed upon coil L1 it will introduce in the grid circuit of the tube an alternating voltage. This will cause the grid to become positive one instant and negative the following instant. When positive, an increased plate current flows and, when negative, the plate current will decrease. This action is shown by the curve Figure 3.

By carefully studying this curve it will be seen that, because the grid voltage varies equally, the increases of current in the plate circuit are followed by decreases of equal magnitude.

In Figure 3 the zero voltage line is shown intersecting the characteristic curve at its mid-point A. When an alternating voltage B C G F K, and so on to Z, which is representing the incoming wave, is impressed on the grid, the tube will operate over that portion

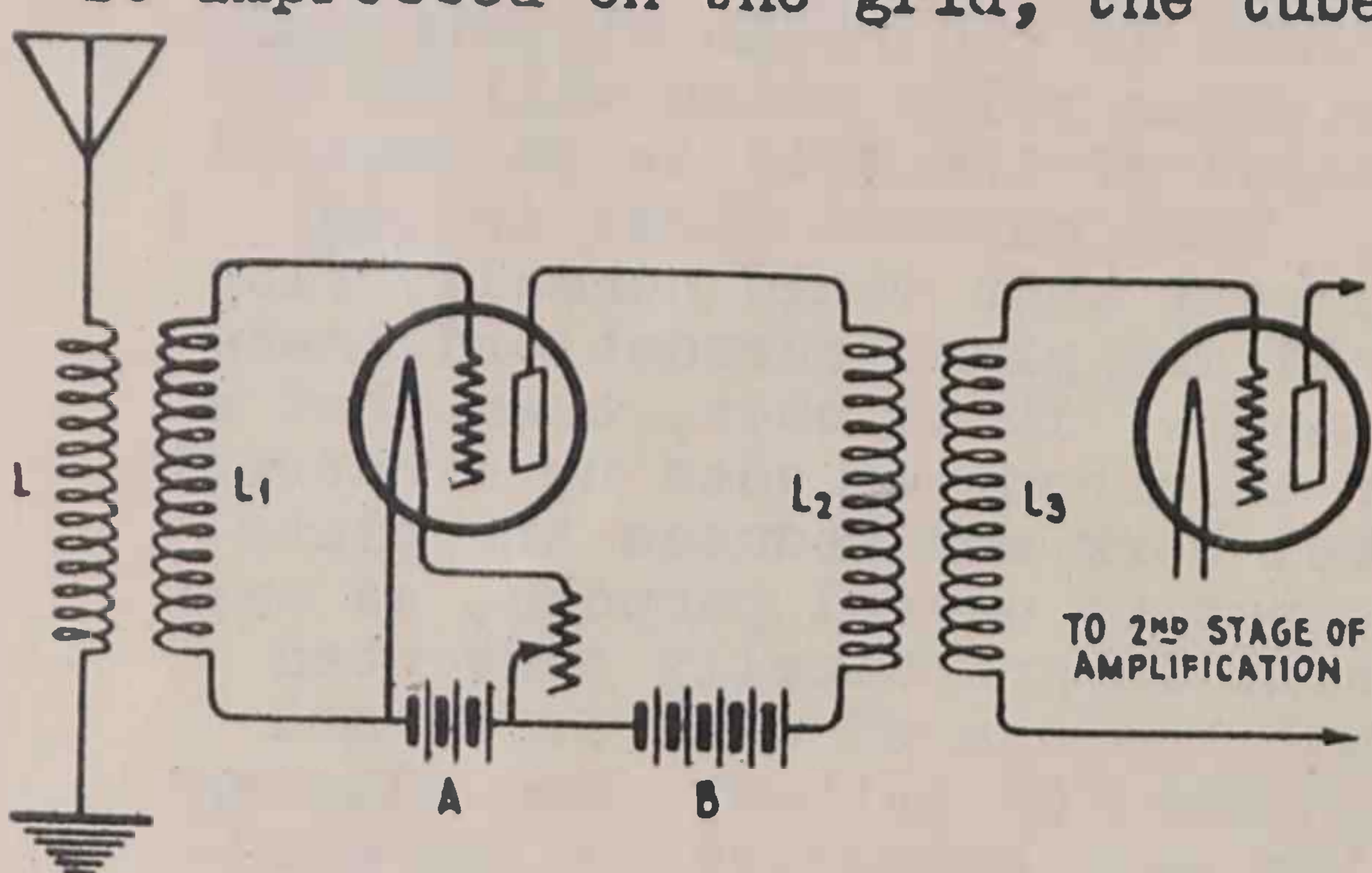

Figure 2

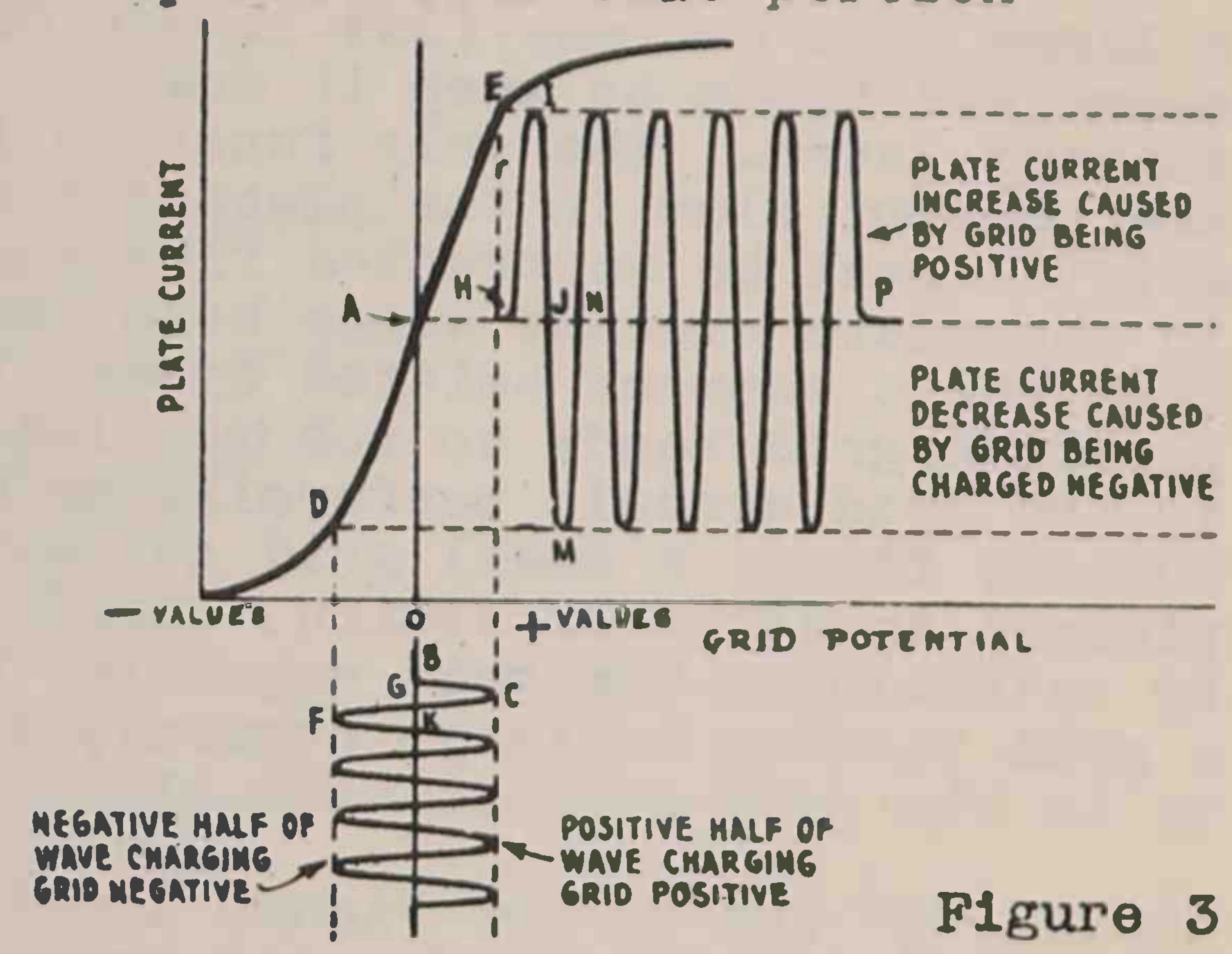

Figure 3

of the characteristic curve between the points D and E. This, you will observe, is on the straight portion of the curve, and the distance DA will be equal to AE.

B C G, which is the positive half of the incoming signal wave will therefore produce a plate current variation shown by the letters H I J, while the negative half of the signal wave G F K will produce a plate current variation J M N which will be equal, but opposite to H I J. These variations of plate current produce a plate current of a pulsating nature as shown between points H and P, the form of which will be exactly similar to the form of the incoming signal wave, B C G F K. The amplitude, however, will be different in that the variations of plate current will have a much greater amplitude than that of the incoming signal which was impressed on the grid.

The fundamental idea of amplification is that, for a given variation in grid voltage, there will be a greater variation in the plate current, than would take place if the plate voltage were varied by the same amount as the grid voltage. The plate variations, although greater in amplitude than the grid variations, will be exactly similar in form.

For a given grid voltage the plate current has a given strength while operating on the straight portion of the curve. If the characteristic of the tube, however, is such that the curve will have a steep slope at the operating point, as shown by the curve of Figure 4, then the variation of the plate current would be quite large for a given variation of the grid voltage.

The magnitude of amplification will depend in part upon the characteristics of the particular tube to be used and also upon the voltage charge applied to the grid. The applied grid voltage can be controlled by the operator of the receiver, but the amplifying factor of the tube, that is, the amplification constant is entirely dependent upon the design of the tube itself.

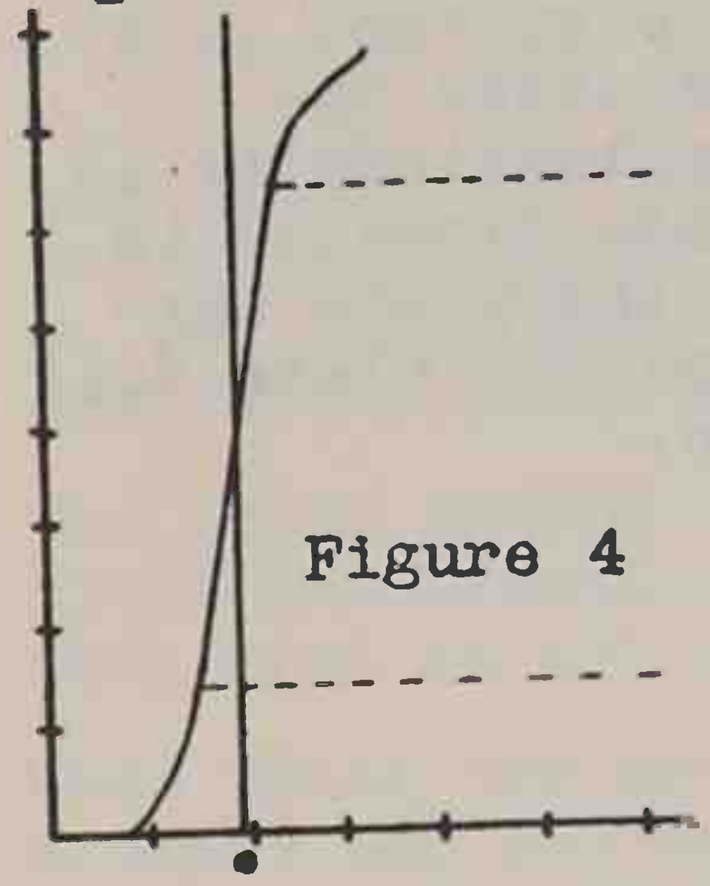

Figure 4

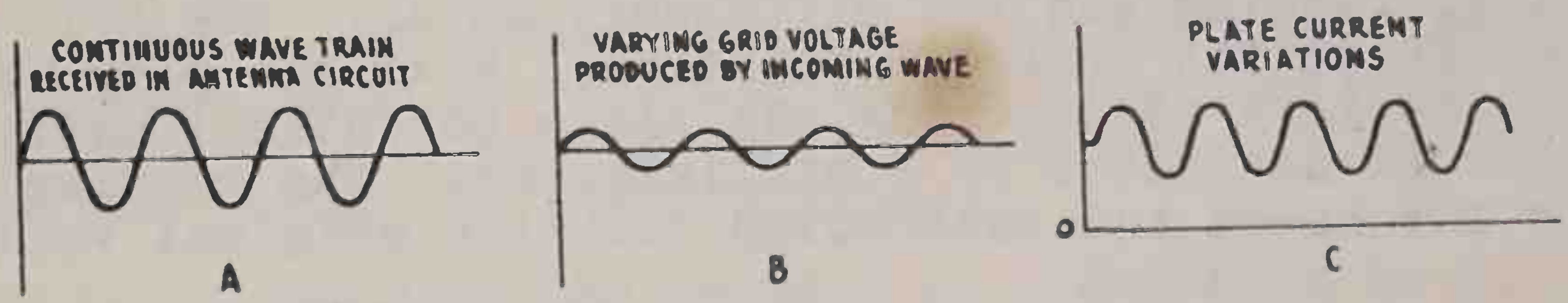

Figure 5

The amplification constant, or Mu, of a vacuum tube is defined mathematically as:

$$Mu = \frac{dI_p \times dE_p}{dI_p \times dE_g}$$

where

Mu=Amplification constant, or the ratio of the effectiveness of the grid voltage in causing plate current changes as compared to the effectiveness of the plate voltage.

dI_p=Change in plate current.

dE_p=Change in plate voltage that will produce a given plate current change.

dE_g=Change in grid voltage that will produce the same plate current change, which is read—Mu equals the difference in plate current, times the plate voltage change which produced it; divided by the difference in plate current, times the grid voltage change which caused it.

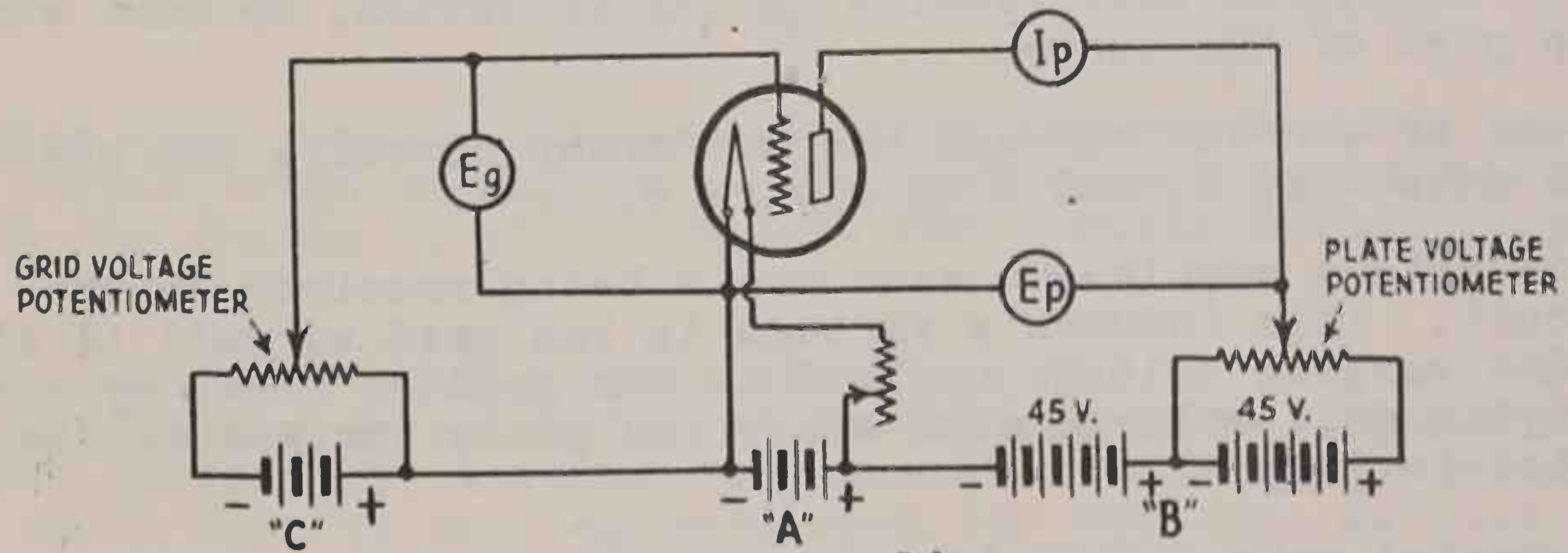

Figure 6A

This constant, or characteristic of a vacuum tube can readily be determined by the simple circuit arrangement shown in Figure 6A.

It is operated in the following manner: The grid and plate voltage potentiometers are set so that the grid and plate voltage readings are those voltages which we wish to know the amplification constant of the tube. The readings of the plate milliammeter and the grid and plate volt meters are noted and listed as:

	I_p	E_p	E_g
Normal value	.006	80+	3-
Changed	.004	68+	5-
Difference	2	12	2

The negative grid voltage is increased to produce small arbitrary change in plate current, let us say, from 6 to 4 milliamperes. This is done by moving the grid potentiometer to the left. When the plate current is 4 milliamperes the reading on the grid volt meter is listed under the original E_g reading and the difference noted. The grid potentiometer is now returned to its original position. Next the plate potentiometer is moved to the left (decreasing the plate potential) until the plate current again is decreased by 2 milliamperes. The reading on the plate volt meter is now noted and subtracted from the original value.

We now have $dI_p = .002$, $dE_p = 12$, $dE_g = 2$

Substituting these values in the formulae

$$Mu = \frac{dI_p x dE_p}{dI_p x dE_g}$$

$$Mu = \frac{.002x12}{.002x2} = \frac{12}{2} = \frac{6}{1}$$

Amplification factor, or Mu=6

In reference to the varying plate current it is desirable to make clear at this time that, although the plate current varies constantly and regularly, it cannot be called an alternating current because it does not have negative values. It has only successively large and small positive values.

Suppose we use the tube as an amplifier with a plate potential of twenty volts. Inspection of curve A of Figure 1 will bring out the fact that, with the grid normally at zero potential, the plate current variation will not be as large as in the previous case of Figure 3 due to the smaller slope of the curve at point D. It must be remembered that, for best results in amplification, we must work on the steep part of the curve.

The variations of current through the different circuits can now be shown by the graphs A, B, and C in Figure 5.

Graph A represents a continuous wave train being received in the antenna circuit. This induces a voltage in the grid circuit L1 of Figure 2. The varying voltage applied to the grid is shown by graph B. This varying grid voltage will cause the plate current to vary as represented in graph C.

In graph C special note should be taken of the variation of the plate current for it shows the current starting at some fixed positive value and varying from greater to lesser positive values. This varying plate current, on passing through the primary winding L2 of the transformer in Figure 2, induces in the secondary L3 an alternating E.M.F. which is impressed between the grid and the filament of the second tube.

The plate current through L2 of the first tube is greater than the grid voltage induced in L1 of the same tube. By using the transformer to transfer energy from L2 to L3 the voltage impressed on the second tube will then be much greater than that on the first tube. The character of the variations, however, will remain the same as those of the first tube.

THE TUBE DETECTOR

The purpose of the vacuum tube as a detector is to rectify the radio frequency currents collected by the receiving aerial.

The vacuum tube may be used in two ways to obtain rectification (detection). One of these methods is to connect the tube in the circuit, and adjust the grid, plate, and filament voltages to the extent that the normal operation will occur at the bend of the characteristic curve of the tube, and it is thus utilized to obtain detection. This is called the plate current method of rectification.

The other method in which the tube may be used as a detector is to include in the grid circuit of the detector a grid leak and grid condenser. When used in this way detection is obtained by grid current rectification.

When using the method first stated the tube rectifies because the increases and decreases of plate current are made unequal when changes in the grid voltage are applied when operating at the bend of the characteristic curve.

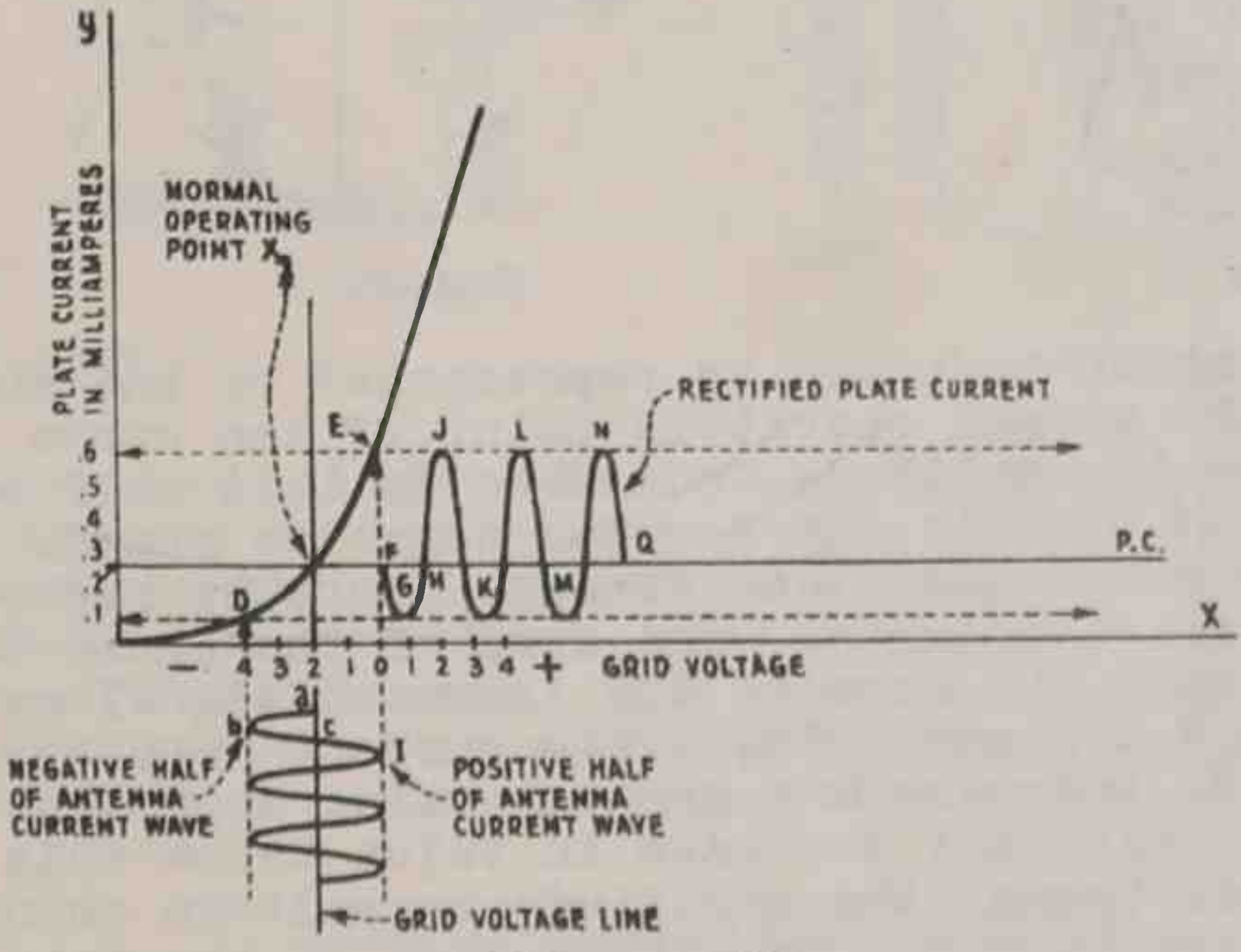

Figure 6B

In Figure 6B we have a grid voltage plate current curve which is similar to the curves shown in Figure 1. This curve has been explained and it shows the change in plate current for a given change in grid voltage.

We will now assume that the grid is biased at two volts negative. The normal plate current is indicated by the horizontal line P.C. which we have arbitrarily assumed to represent .2 milliamperes. A continuous radio wave is now impinged upon the antenna, setting up therein an alternating E.M.F. which in turn causes an alternating E.M.F. to be impressed upon the grid of the tube through suitable coupling devices. This incoming signal wave is clearly shown in Figure 6 along the grid voltage line.

The incoming signal wave will have a certain voltage which is alternating first positive and then negative and it will add to or subtract from the voltage already on the grid. When no signal wave is being received the grid voltage is normally 2 volts negative shown by the grid voltage line which intersects the characteristic curve at "X_1". At this point of intersection a horizontal line, P.C., is drawn parallel to the "X" axis indicating the normal plate current flow with the grid at 2 volts negative. The incoming signal wave is now impressed upon the grid and, as shown, is of equal amplitude on both sides of the grid voltage line. The maximum amplitude of this wave is shown to the left of the grid voltage line of negative two volts and it will decrease the negative charge already on the grid to 4 volts negative. Following the dotted line from the maximum point of the amplitude it will intersect the curve at "D", and the horizontal dotted line drawn parallel to the X axis shows the value of the plate current flowing when the grid is at 4 volts negative potential. The grid voltage was made more negative, as just stated, by the negative voltage of the incoming wave being added to the negative charge already on the grid.

The negative amplitude of the wave now begins to decrease and, on reaching the grid voltage line, the grid will be restored to its normal condition, having a charge of 2 volts negative. This will

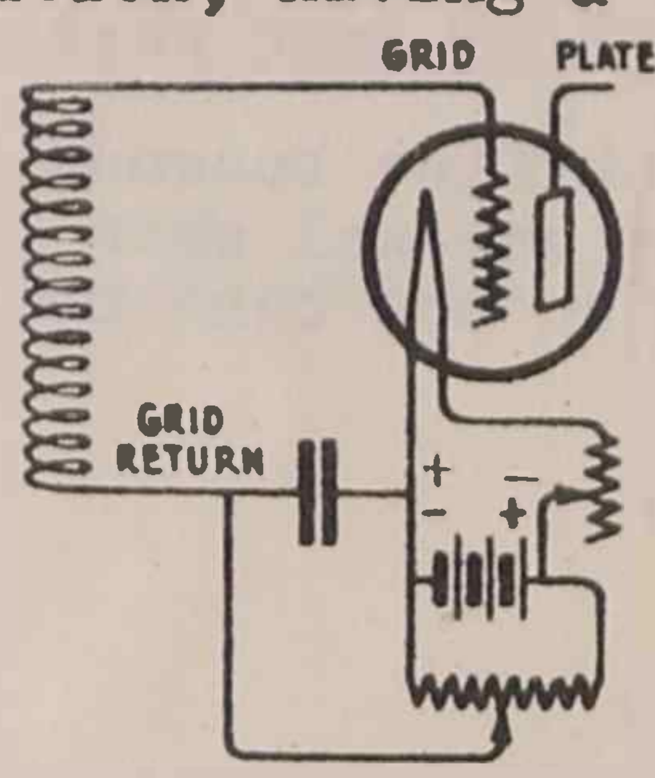

Figure 7

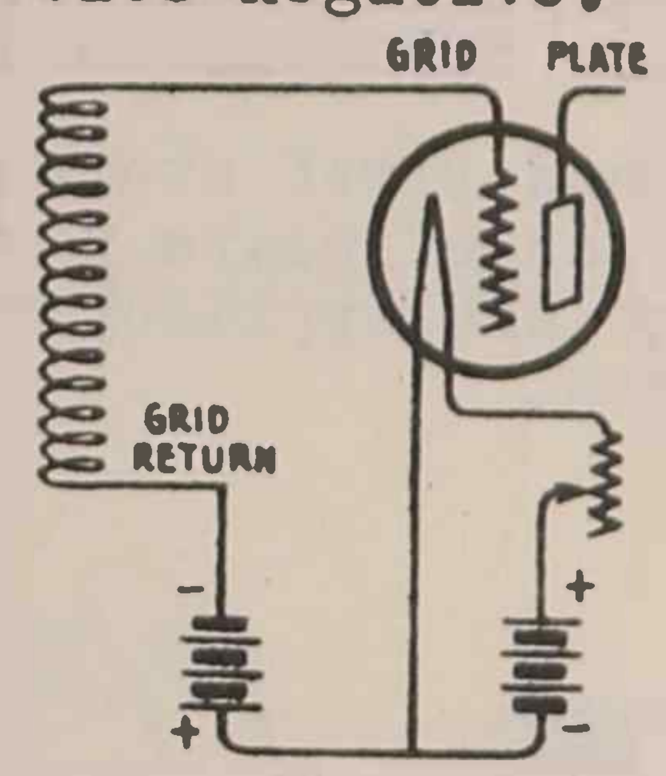

Figure 8

cause the plate current to increase as represented by the curve between points D to the normal operating point of the curve "X_1". The wave now increases in amplitude from C to I; this half of the wave, being positive, it offsets the 2 volts negative charge reducing it to zero with a resulting plate current increase represented by "E" on the characteristic curve. The form of the plate current curve will follow exactly the form of the incoming signal waves, which is shown by F G H J K etc. The plate current impulses, as shown by letters J L N, increase to a greater value above the normal plate current line PC than they decrease in value below this line, as shown by G K M, even though the amplitude or voltage changes of the incoming signal wave is equal on either side of the grid voltage line. Because the changes of the grid voltage produce this result, this method of rectification is given the name "plate current rectification". Rectification results when the operating point of the curve occurs near the lower bend or knee of the characteristic curve.

If the grid voltage line was made to intersect the characteristic curve higher up where the curve is nearly a straight line the increases and decreases of plate current above and below the normal plate current line would be nearly equal and amplification instead of rectification would be obtained.

BIASING METHODS

Biasing the grid may be accomplished by employing a potentiometer connected across the filament lighting battery as shown in Figure 7. The center, or movable arm of the potentiometer, is connected to the grid return and the ends of the potentiometer winding is connected to the positive and negative sides of the filament battery.

When the potentiometer arm is moved to the left it will place a positive bias on the grid and moving it to the right makes the grid negative. With this system a close adjustment can be secured which affords an opportunity for the operator to shift the operating point. at will until the best point of detection is found.

Another method of placing a bias on the grid is to use a biasing battery, called the "C" battery. The detector circuit in Figure 8 shows how the "C" battery is connected to bias the grid. This method does not allow as fine an adjustment as the potentiometer because the operator can only vary the grid voltage by the number of taps brought out on the "C" battery and, in general, the taps are in one and one half volt steps.

Although the biasing methods just described may be used, they have been replaced in practically all radio broadcast receivers by connecting the grid return directly to either the positive or negative side of the filament, depending upon the type of tube used, that is, whether a highly evacuated or hard tube, or a gas filled or soft tube.

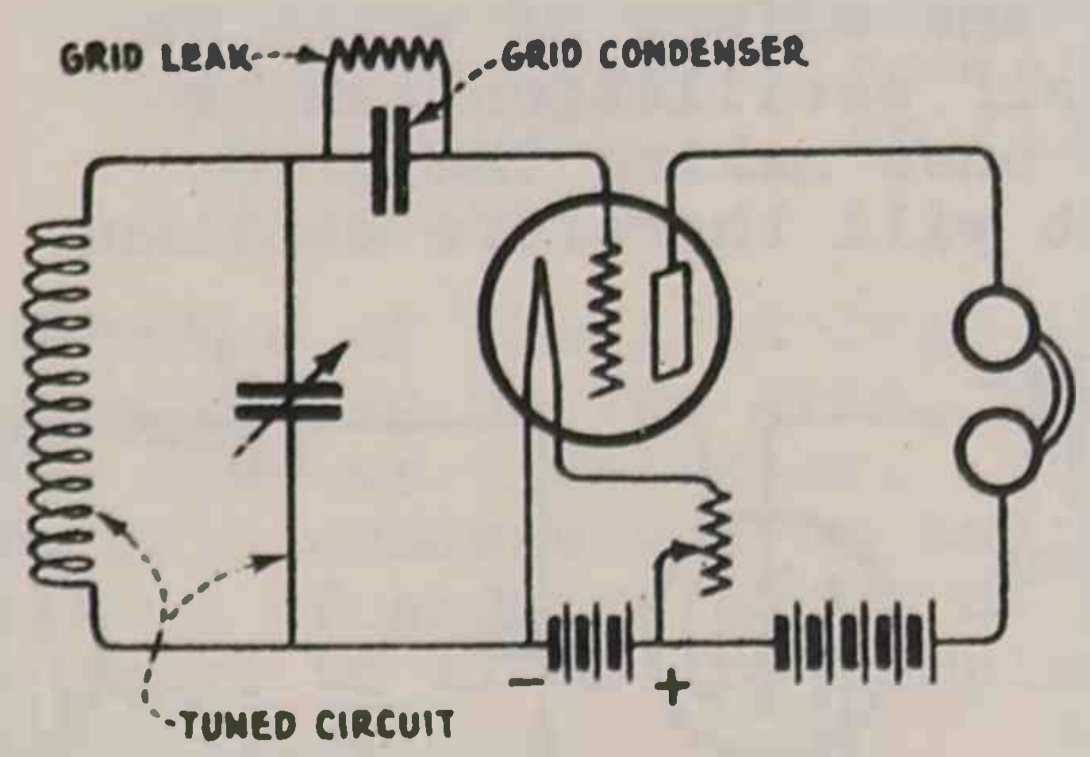

Figure 9

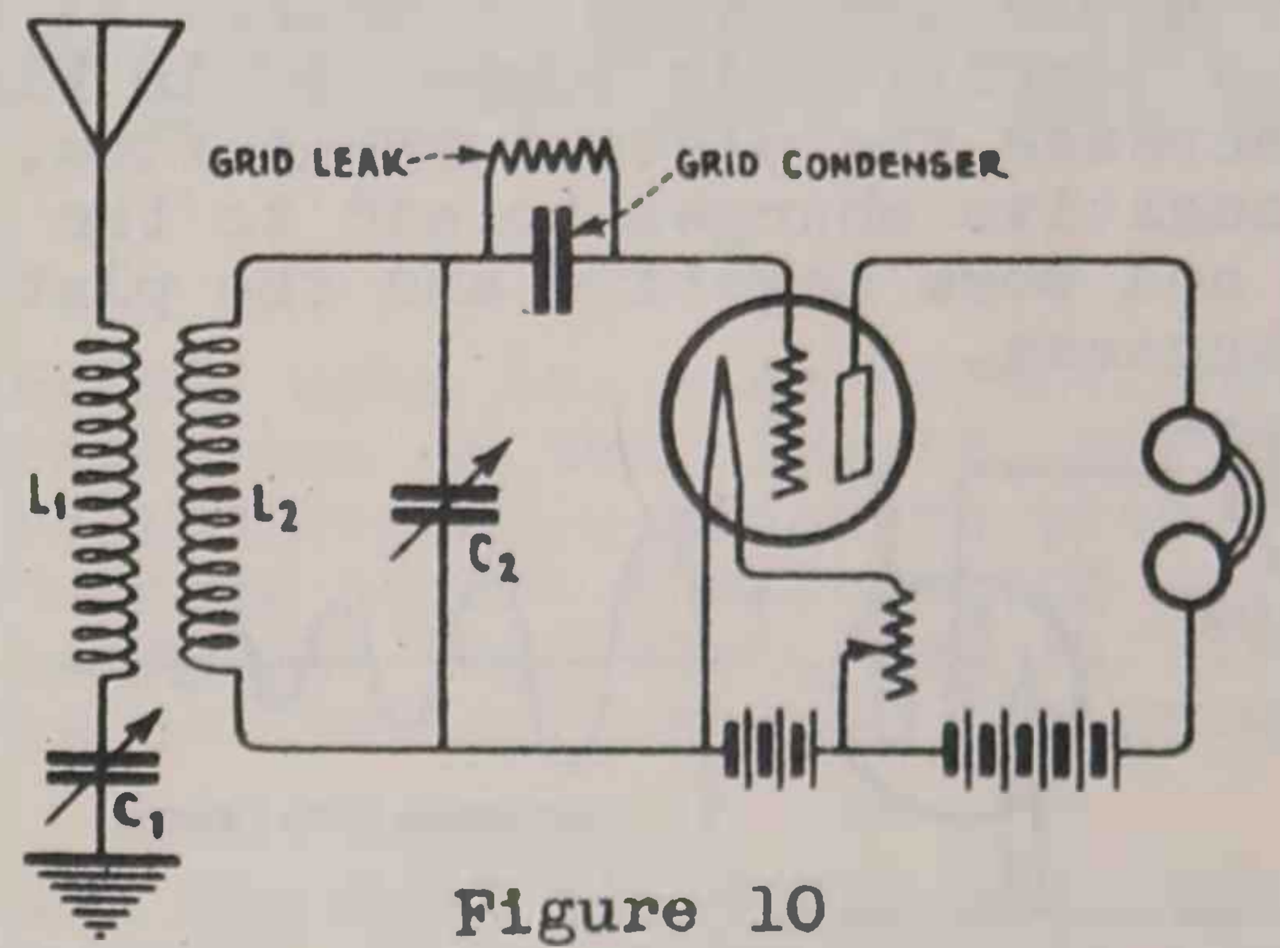

Figure 10

It is desirable when a hard tube is used as a detector to connect the grid return directly to the positive side of the filament. When using a soft tube such as the old UV-200 as a detector or the new UX-200-A, it is then considered best to connect the grid return directly to the negative side of the filament. The grid is maintained positive when connected to the positive side of the filament circuit and negative when connected to the negative side of the filament.

GRID CURRENT RECTIFICATION

When a grid condenser and grid leak are connected in the circuit of a vacuum tube detector, as shown in Figures 9 and 10, grid current rectification takes place. The only change in this circuit from the detector circuit utilizing the plate current rectification method is the omission of the grid, or "C" battery, and the insertion of a grid condenser in the grid lead. When no signal wave is being received the plate potential supplied by the "B" battery will be of a constant value with a steady current flow in the plate circuit. Practically no current will flow in the grid circuit because the grid is insulated from the filament by the small grid condenser.

Now assuming that the condenser insulates the circuit perfectly then, with this condition, the potential of the grid (only when first set in operation) will be that corresponding to a zero current in the grid circuit.

We will now assume that the antenna is energized by a damped wave. The wave will be picked up by the antenna and will pass through the inductance coil L_1 and condenser C_1 to ground and induce an E.M.F. in L_2 C_2 circuit as shown in Figure 10. Current will now flow through the grid condenser to the grid placing thereon an alternating positive and negative charge.

Refer to Figure 11A showing simply that part of Figure 10 which includes condenser C_2 , the grid condenser, and the tube elements. During the positive half cycle of the incoming oscillations, shown in Figure 11B, the grid becomes positive and the conductivity of the tube is increased, that is, electrons are assisted to the plate by the positive grid and more current flows in the plate circuit. The grid naturally will retain some of these electrons. The negative half cycle of the incoming wave passes through the same circuits making the grid negative this time as shown in Figure 12. Since the grid is negative it repels a great many of the electrons emitted by the filament and the tube becomes less conductive, and current flow in the plate circuit is reduced.

Duri the ne ative half cycles grid does not lose the electrons it acc ate d positive half cycles and, therefore, at every cycle the negative charge is built up gradually on the grid. Such a condition is s ested in Fig e 13, the effect of ch is to decrease the plate c rent flow. Each half oscillation causes the negative charges to add to the previous ones ki the grid more d more negative and the plate current ll therefore continue to decrease.

Fi e 11A

Fi e 11B

Fi e 12

Fi e 13

It is desirable to have the grid circuit pe nently retain the negative charge it has ac ulated d i the successive cycles the first incomi wave train sho by c ve A, Fi e 14. After the d ped oscillations have died out, s means must be provid for the acc ated charge to move away from the id and t s restore the grid to its original condition of zero grid voltage bef the next wave train arrives.

In the earlier types of tubes considerable gas was present in the tube due to the fact that a high evacuation of the tube could not be successfully accomplished. This gas formed a high resistance path over which the acc ulated grid charge could pass to the fil nt, thus automatically restoring the grid to its condition of z id voltage before the incoming wave train was im essed upon it

Wi modern va p ps the tubes are more highly e usted and bec s necessary to provide a circuit w ch will allow the id ac ation to escape. This is accomplished by placing a hi resist ce in parallel with the id condenser. This hi resistanc is called a id leak. Fi e 10 shows how it is connected aroun t grid c enser.

Let us rev the foregoi statements now in o er to better e st t part the grid leak plays.

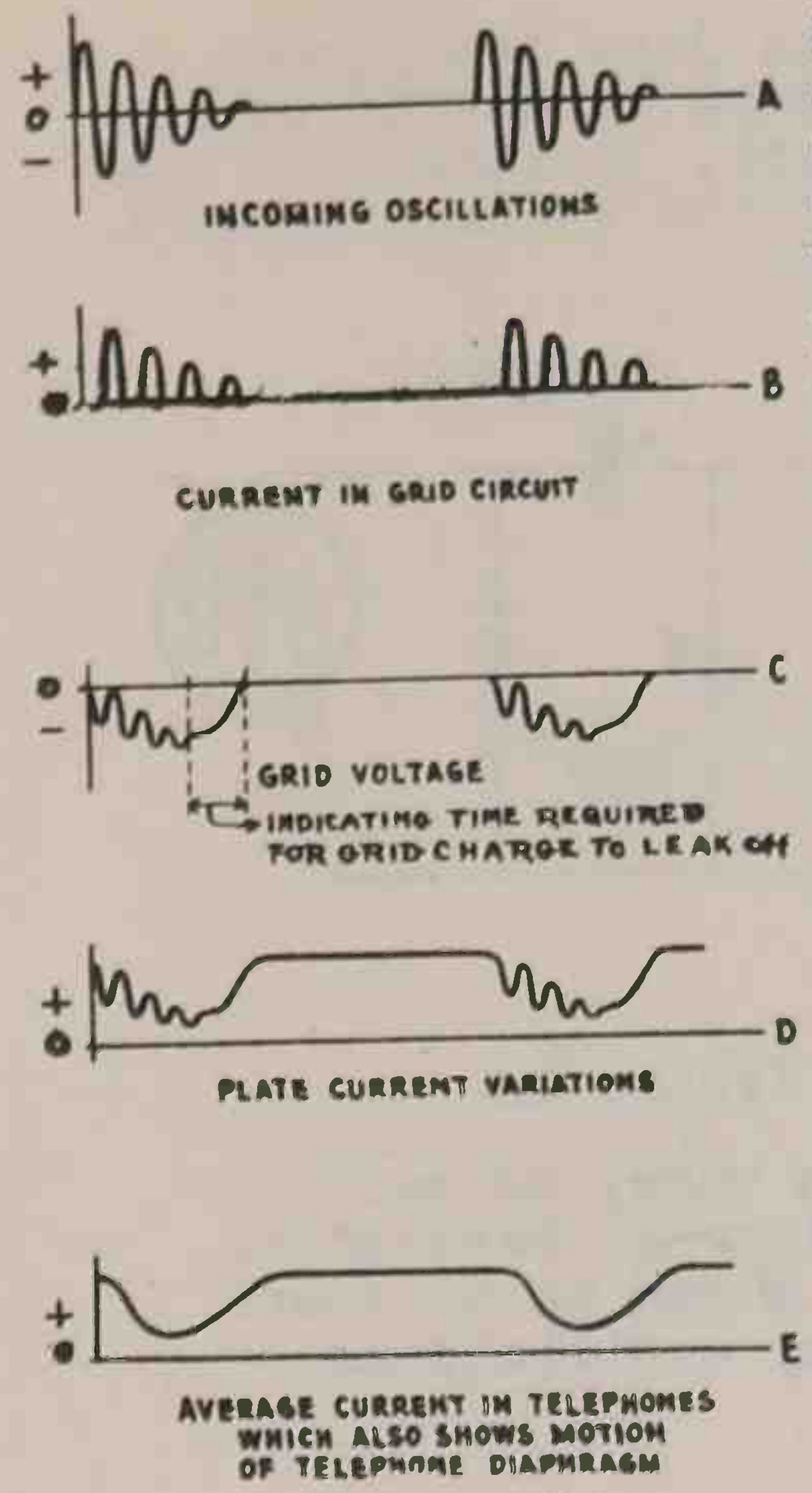

Figure 14

In Figure 13 the incoming wave train, acting alternately positive and negative on the grid of the tube, has caused a large accumulation of negative charges on the grid which continues all through the series of oscillations comprising one wave train of the signal. Electrons cannot escape to the filament through the vacuum for we are considering our tube to be highly exhausted, or a hard tube, with little or no gas present. Electrons cannot flow through the grid condenser back to the filament because a condenser will not pass direct current, and the electrons are potentially direct current. They can, however, leak away and return to the filament through the high resistance grid leak we have placed in parallel with the grid condenser. The resistance of this leak varies from a million to five million ohms and higher values and offers considerable opposition to the movement of the accumulated grid charge. Because of this high resistance all during the increasing voltages of one wave train of the incoming signal the grid becomes more and more negative. The negative charge accumulates faster than the high resistance grid leak will allow it to pass off to filament.

The value of the grid leak in ohms depends upon the size of the charge accumulating on the grid, the characteristics of the circuit, and the tube used as a detector. It should be sufficiently great to prevent the grid condenser from totally discharging before the incoming oscillations of any one group of signals have been completed, and sufficiently small to allow the completed charge to leak off between the groups of oscillations.

When the value of the leak is too small the grid condenser will not charge fully thus decreasing the efficiency of the tube and, if too large in value, it will amount to the same as no grid leak at all. For example, in a circuit having no leak and receiving a large charge the charge may jump to the filament through surface leakage across the grid condenser, or it may take place across the insulation of the tube socket. This will produce a PUTT PUTT PUTT sound in the telephones, occuring periodically as each charge accumulates and discharges. This may happen, as stated above, if the grid leak resistance is too high or if no grid leak is used.

The grid leak may be connected in either of two ways as shown in Figure 10 and Figure 15. A study of these two circuits will show that, by either connection, the results obtained will be somewhat similar, in that a path is provided for electrons to flow to the filament.

In Figure 10, the charge flows through L_2 to the filament, while in Figure 15 it flows directly to the filament without passing through inductance L_2. This method of rectification (grid current) is a much better one to use than plate current rectification since rectification (detection) can be obtained at any point of the characteristic curve of the tube, and is the method used at the present time in practically all broadcast receiving circuits.

Figure 14 illustrates the variations in the circuits just described. Curve A, as stated is a representation of the incoming groups of oscillations. Curve B represents the grid circuit current. C indicates the grid voltage, D the plate current variations, and E the average current through the telephone receivers. Curve C is of particular interest in this series of curves because it shows the grid voltage oscillating at radio frequency, becoming more and more negative until the groups of oscillations cease and the grid charge leaks off to filament through the grid leak. The grid then assumes its normal voltage and a new group of oscillations is impressed on the circuit. Curve D shows the radio frequency oscillations in the plate circuit current. They oscillate at radio frequencies and follow the grid voltage variations, but the average plate current makes only one large variation for each group of oscillations impressed on the grid. The telephones do not respond, as you know, to radio frequencies, but will respond to the average plate current variations. This average variation which affects the phones is shown at E, there being one large variation for each group of incoming oscillations.

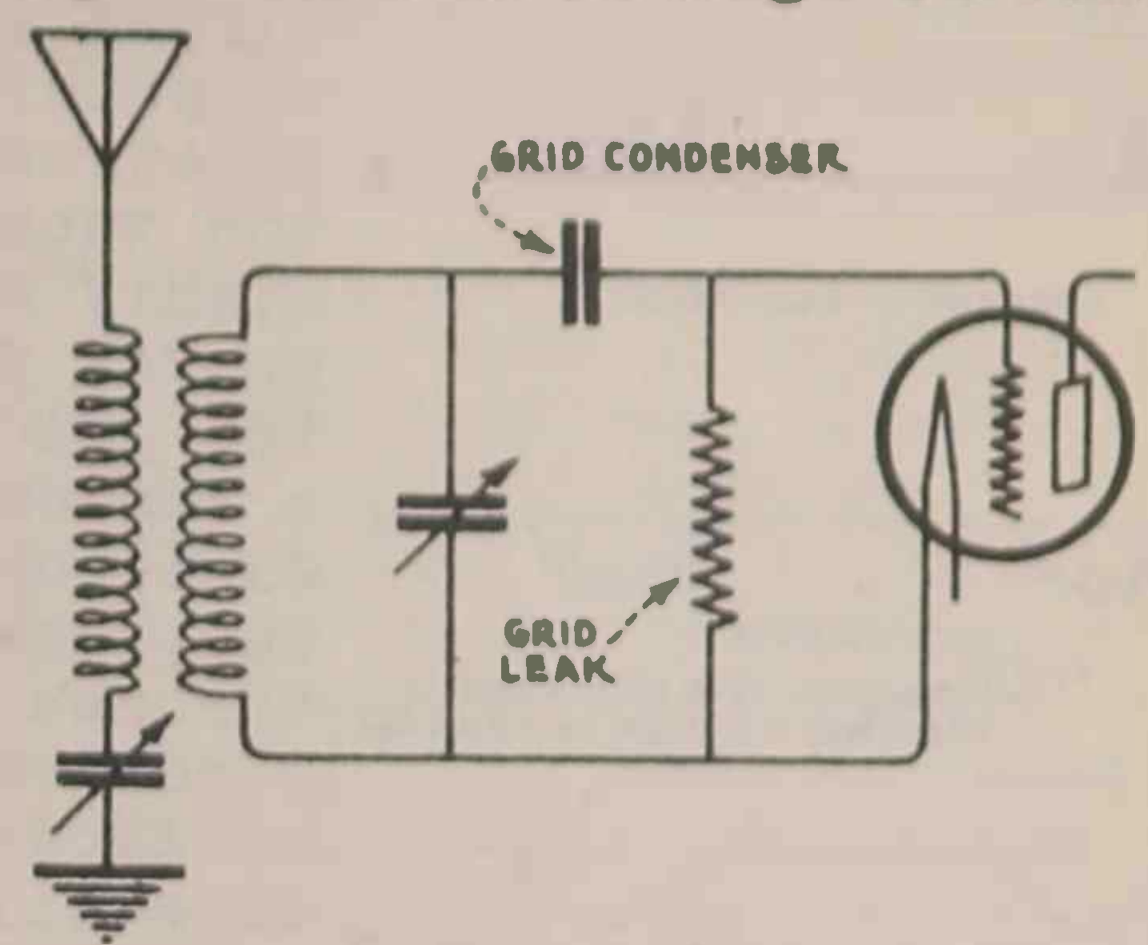

Figure 15

EXAMINATION QUESTIONS

1. What is the characteristic curve of the vacuum tube intended to show?
2. What is meant by the "saturation point"?
3. Is it desirable to have a large grid current flow?
4. How is the grid current flow prevented?
5. What is the fundamental idea of amplification in the vacuum tube?
6. What is the purpose of the vacuum tube as a detector?
7. State two ways of placing a bias on the grid of a vacuum tube.
8. What difference exists between the detector circuit employing grid current rectification and the detector circuit employing plate current rectification?
9. How is the grid condenser connected in the circuit?
10. Show by diagram two ways of placing a grid leak and condenser in the detector circuit.

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VACUUM TUBE THEORY

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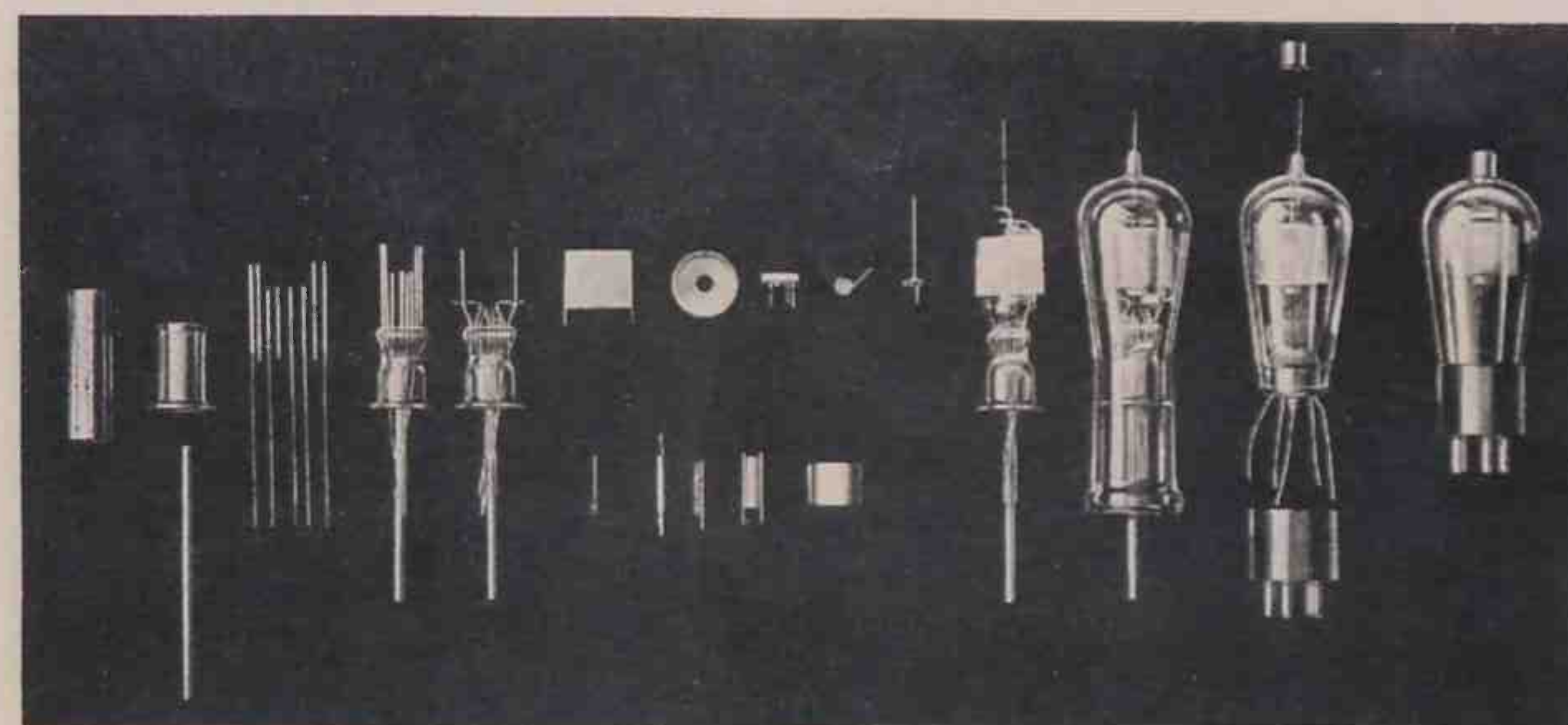

Parts Assembly of the '24-A Type Tube

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VACUUM TUBE THEORY

We now come to the study of the Vacuum Tube, a device which is the very heart of the radio receiver. The student will, at this point, have to give his undivided attention to that which follows and proceed with an open mind and active imagination. In order to understand the action of the vacuum tube we should review the action of the electron in a vacuum. To imagine an electron is one thing, but to follow the actions of electrons is quite another. The study of the electron theory as applied to the vacuum tube is comparatively easy if the student will concentrate, otherwise it is a difficult study and only results in a state of confusion. It is intensely interesting and, when understood, gives a clear idea of the relation between radio circuits and vacuum tubes.

The vacuum tube is not confined to radio alone; it is used in any number of other scientific fields, especially those in which high frequency rays are involved.

Let us consider for the time being that in the vacuum tube we have a device which will not only rectify an alternating current but will also reproduce, in amplified form, the most feeble variations of E.M.F. applied to it regardless of the frequency.

The tube may be employed as a rectifier of alternating currents of any frequency. The term rectifier is sometimes used to indicate the detector action.

It is termed a radio frequency amplifier when it is used to amplify the high frequency currents induced in the antenna by the incoming signal wave.

Further, the tube is used to amplify the output currents of the detector and when so used it is known as an audio frequency amplifier.

When used as a generator of high frequency undamped oscillations in an oscillatory circuit it is called an oscillator.

Before these various functions can be explained it is necessary to have a knowledge of the characteristics of the vacuum tube and to what extent these characteristics can be controlled. Until recent years no satisfactory explanation was offered concerning many phases of electrical phenomena known to science. As the application of electricity developed, however, there was a great amount of data secured which enabled scientists to formulate some of the laws governing the flow of electricity. For example, the relation between electromotive force, current, and resistance was explained by Dr. Ohm and put into the form of a law, the law being known universally as Ohm's Law.

Discoveries were also made regarding the generation of electrical pressure by chemical action between certain liquids and metals. This led to the development of the battery, and then came the evolution of the dynamo. No satisfactory explanation was offered at the time concerning the electrical phenomena of these discoveries yet they were of great practical value in determining from the results obtained, experimentally, many of the present laws of electricity. It also became necessary to settle upon certain arbitrary standard units by which electrical force and energy could be measured and computed, these being known as Universal Electrical Units which were explained in a previous lesson.

It was also found necessary to assume a certain direction in which electricity flowed through a conductor. Scientists decided to call the copper or carbon plate of a primary cell the positive terminal, and the zinc plate the negative terminal, and considered that electricity flowed in an external circuit from the positive electrode to the negative electrode. It must be understood that this direction given to the current flow was entirely an arbitrary one and was agreed upon only as a matter of convenience in understanding certain phenomena.

For many years the atom was regarded as the smallest unit into which matter could be divided and still retain its chemical and physical properties and the phenomenon was then explained by the atomic theory. In recent years many scientists have accepted the general belief that the atom is itself subdivided into many thousands of particles termed electrons and that these electrons carry with them a charge of electricity. It has been found that under certain conditions these electrons or particles of negative electricity can be de to move. Their movement is from a negative to a positive electrode and when in motion they constitute a current flow. T s new t ory is kno as the "Electron theory of tter".

N E

Thermionic current is the name given to electricity which is t result of electrons t own off or emitted from hot bodies. A discovery made by Thomas A. Edison in 1884, known as "T Edison Effect", gave rise to an investigation of the ionic c rents which leads up to the vacu tube of today. Edison, in his work with the electric l p, fou that after a l p d been in use so ti a dark coati for d on the inside of the lamp, becomi in some instances nearly black with lo continual use. He became interested in this effect a further research bro ht out the fact that when a tal plate was placed inside the lamp and connected to one side of a sensitive galvanometer a the other te inal of the galvano ter then connected to the positive te inal of t battery s plyi c rent to the filament of the lamp, the galvanometer would show a deflection when the filament of the la was heated.

T effect at the time seemed to i icate t t an electric c rent flowed from the positive side of the filament thro h the galvano ter to the plate inside the l , t o h the vacu of the lamp, returni to the filament. Edison also discovered that, when the galvan eter terminal was removed from the positive side of the filament and connected to the negative side, practically no deflection of the galvanometer followed. After the discovery of this phenomenon experiments were carried out by several scientists. J. A Fleming, after considerable experimenting and research on the Edison effect, came to the conclusion that NEGATIVE electricity passed from the filament of the lamp to the plate when the plate was relatively cold with respect to the filament and the plate was charged to a positive potential.

Conclusions of the experiments of J.J. Thompson led to the belief that what is now called the electron existed and that negative electricity consisted of masses of these electrons which were forced away from the filament of an electric lamp when the filament was brought to incandescence. In other words the filament itself consisted of these infinitely small particles called electrons. It has now been generally accepted that it is by means of the electron that electricity is carried through a conductor or through a vacuum.

There are always large numbers of electrons in an atom and normally this quantity amounts to a given number just sufficient to neutralize the effect of the positive nucleus. Generally but one electron can be detached from an atom even though it may have a great many associate electrons. Under normal conditions the atom possesses no electrical charge because a perfect state of neutralization exists between the positive charge and the electrons. When, however, one of the free electrons is forced away by some cause or other this perfect balance is destroyed and the atom predominates in positive charge because it is now deficient in its complement of electrons.

ELECTRON EMISSION

The emission of electrons is dependent upon the temperature of the filament, the size (area) of the filament, the nature of the substance employed as the filament, and the medium in which the filament is heated. The number of electrons emitted will be proportional to the area of the filament. For example, if you have two filament lengths, one twice as long as the other, by heating one filament to a given temperature a certain electron emission occurs. With the same heat applied to the filament of twice the length, double the emission occurs. This happens however only when the same heat is applied to both filaments.

The temperature of the filament is very important in that, with each increase of filament heat, there will be an increase in electron emission. This increase in electron emission increases as the temperature increases until the maximum emission takes place which is just below the melting point of the filament. Heating the filament to excessive temperature is of no advantage as you will later learn.

The composition of the filament, that is, the material employed in its manufacture, will have a bearing upon the electron emission. Some metals, when heated, do not emit as many electrons as others. Carbon, for example will emit a certain quantity of electrons but not nearly in as large quantities as tungsten. Tungsten is materially helped in electronic emission when another metal called thorium is combined with it. It is the Thoriated Tungsten filament that is used in many types of tubes because at low temperatures it has a very high rate of electron emission.

There is still another factor which has a great influence on electron emission and that is the medium in which the emission occurs. In the first place it must be in a vacuum, or at least a partial one. It is quite impossible to obtain a complete vacuum and small traces of gas left in the tube will decrease the electron emission. Most of the gases in the tube, with few exceptions, are inert gases. The presence of gas in the vacuum presents a resistance to the emission of electrons unless ionization takes place. (This particular subject will be taken up later in more detail).

The most important factor in the rate of emission is the temperature of the filament for, upon the rate of emission alone in a certain tube, will depend the number of electrons emitted. It must be understood at this point that the term "Emission" refers only to the emerging of the electrons from the filament and not to the passage of the electron through the vacuum.

Suppose now we attempt to visualize that which takes place in the filament when it is heated. As heat is applied the whole atomic structure is set into a violent agitation and the free electrons about the atoms of the filament are set into rapid vibration. With each increase of heat this vibration increases and the electrons finally gain a velocity in their movements great enough to carry them beyond the positive force of the atom which normally holds them within the filament. As this velocity is attained they emerge from the filament in clouds much as does steam from a pan of boili water. This hap ns only after they ve acquired a speed which is able to project t m beyond the influence of the at   to which they lo .

Once beyond the attractive force of t   parent atom they are subject to collisions which are contin lly occ i   as they move about in the filament. Their velocity, on leavi   the filament, varies according to the retardi   effect these collisions have had upon the electron in its attempt to escape. Once outside t   filament they again have difficulty d   to t   gas molecules which   y be present within the vacu ,   with which they contin lly collide   til their energy is exhausted whereupon they are drawn back to the fil ent.

SP   C   GE

The electron constitutes a negative charge of electricity a , on emerg-i   from the fil   nt, leaves t   filament positive   respect to the projected electron. The te ency, therefore is for the electron to   attracted back to t   fila   . Any gas n the vacu   also presents a resistance to be overcome by t   electron. T re is also another re-pelli   effect which must be ov c e. This is the repelli   effect of electrons which are movi   at a eater distance from the filament than the newly emitted electrons.

As stated before, t   electrons fill the space about the heated fila- nt much as ste   fills the space over a p   of boili   water. The electrons, in their countless th sands,   y be considered as actual particles of negative electricity, a   they constitute in reality an actual negative charge   the space they fill. It is this co ition t t is called "T   Space Charge".

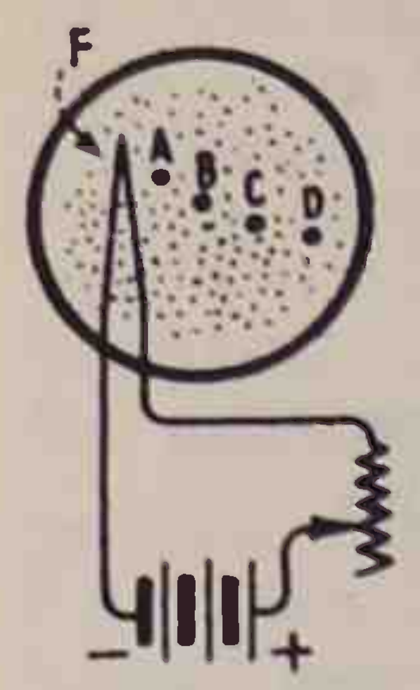


Figure 1

Let us now consider the effect this space charge has upon electrons leaving the filament and, for example, we will consider a single electron. In Figure 1 the filament·is shown emitting electrons which are represented by the black dots. The electron A, which is represented by the enlarged dot, is shown a short distance from the filament F and we will assume its velocity carries it to the point shown, first, by overcoming the tendency of the filament to draw it back, second, its velocity carries it against whatever resistance is offered by any gas present and, third, it is carried against the repelling force exercised against it by the electrons which are moving about ahead of it.

At the point shown at "A" the velocity of the electron is spent and it has no further energy to carry it ahead. It is then easily influenced by the repelling action of the electrons beyond it,- also by the attractive force of the filament and it finally returns and is absorbed by the filament.

We will consider Electron "B" as having gained a greater velocity on leaving the filament. It reaches point B before it is drawn back to the filament.

Electron "C" has left the filament at a still greater velocity than either A or B and has reached the point C as shown. This electron has reached a point in the space charge where there is a greater number of electrons behind it than ahead of it and, since like charges repel, electron "C" is actually assisted on its course further away from the filament to point D.

The foregoing will serve to acquaint you with at least a working knowledge of the forces acting upon the electron, this being important because it accounts for certain phenomena which will be encountered later on in our detailed study of the tube.

THE PLATE

In addition to creating a supply of electrons in the vacuum tube it is necessary that we also create some attraction which will cause these electrons to move from their point of origin. This is accomplished by sealing a second element called the plate in the vacuum space. This is shown in Figure 2. It is to be noted that the plate has a connecting lead brought out for a purpose which we will soon explain. For the time being we shall consider the plate as shown in Figure 2 to be sealed in the tube but not connected in any way.

Electrons being emitted will accumulate on the plate and charge it to a negative potential, the negative charge will increase until the plate repels any further electrons moving in its vicinity. Let us now give the plate a positive charge by connecting it to the positive side of a battery, called the "B" battery, as shown in Figure 3. Since this makes the plate positive its natural tendency, in order to restore the state of balance, is to attract any negative charge possible. This it does by drawing to it the electrons being emitted by the filament.

When the plate is connected in the circuit as shown in Figure 3, and is given a positive charge, electro-static lines of force immediately are set up between the plate and terminate at the filament. It is along these lines of force that a positive charge of electricity, as formerly understood, would travel. The electron being a negative charge would move along the same lines of force but from filament to plate which simple means, when expressed differently, that the positive plate will attract to it the negative electrons (unlike charges attract). The attractive force the plate has for the electrons will depend upon the potential of the plate relative to that of the filament

The original tube, known as the Fleming Valve, consisted of only two elements, the filament and plate, as shown in Figure 3.

CHARACTERISTICS OF THE FLEMING VALVE

The phenomenon of a vacuum tube can best be understood by making a preliminary study of the Fleming Valve.

Figure 2

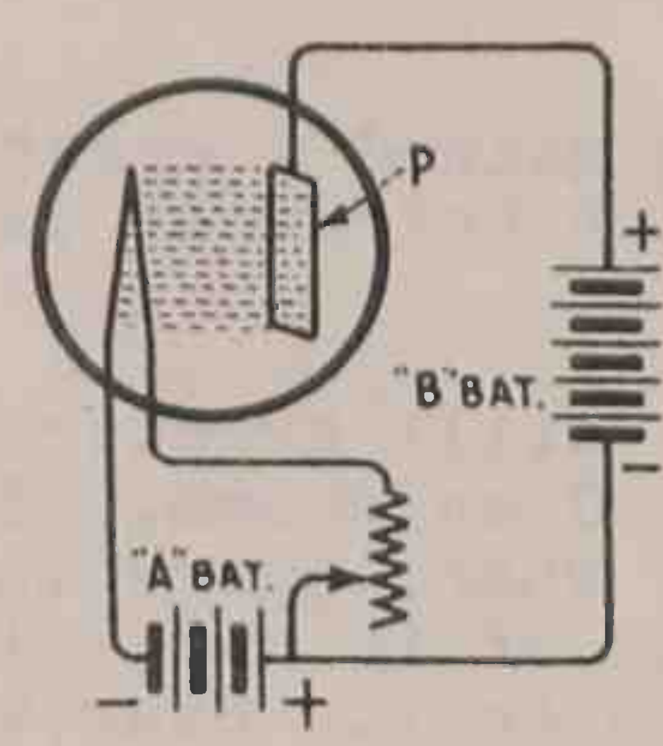


Figure 3

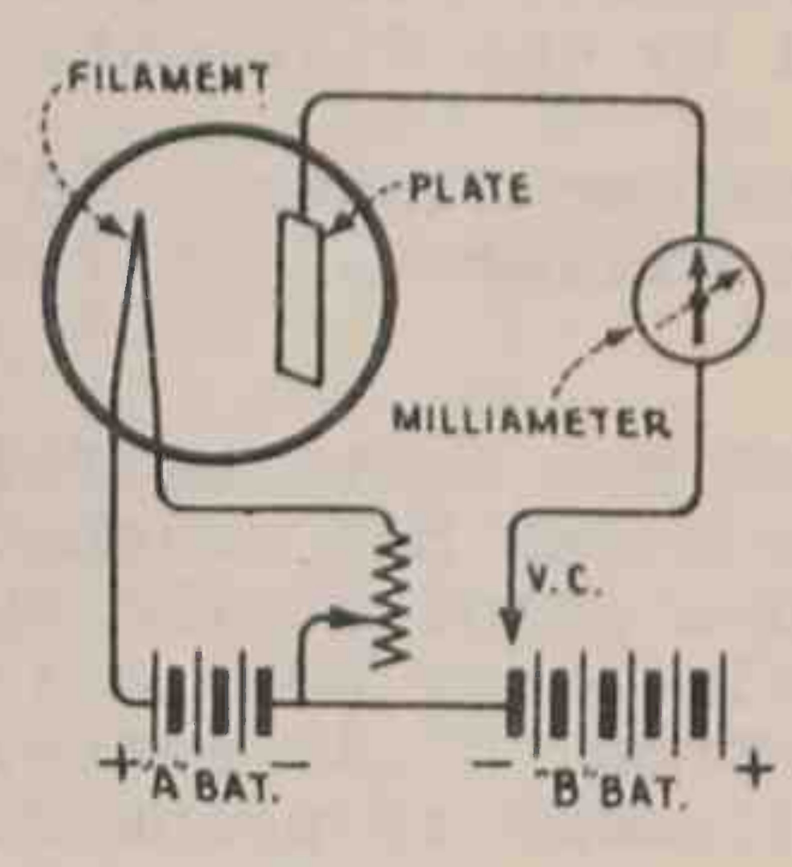


Figure 4

The circuit consists of a source of current, known as the "A" battery to heat the filament. The E.M.F. applied to the filament is made variable. A source of E.M.F., known as the "B" battery, is used to charge the plate and this should also be variable. Such a circuit is shown in Figure 4.

If the plate has a very small positive potential placed on it as shown in Figure 5 a very weak current will flow through the plate circuit, P, M, A, F, because, under these conditions, only a limited number of electrons will reach the plate and the greater majority of them are drawn back into the filament.

It is to be noted here that the plate will have a potential about equal to the filament. Let us, however, connect a battery in the plate circuit as shown in Figure 5A, giving the plate a high positive potential with respect to the filament. Under these conditions nearly all the electrons emitted from the filament will be attracted to the plate resulting in a flow of a comparitively large plate current, as indicated by the milliameter reading. If the B battery is connected as shown in Figure 4 thus placing a negative potential on the plate, the meter will show no deflection because the emitted electrons are negative and they will be repelled by the negative plate. This clearly indicates that electricity cannot flow from the plate to the filament due to the fact that no electrons are passing in the direction of the filament.

As we stated before the rate of emission will depend upon the material of which the filament is made, the size of the filament, and the temperature at which the filament is heated. In the vacuum tube the temperature of the filament is a variable factor. We cannot change the position nor size of any of the elements within the tube, but we can change the filament temperature by a variation of the current passed through it. For a given filament current there will be a corresponding temperature and this temperature will remain constant, providing the current is not varied. At a certain temperature a definite number of electrons will be emitted.

If the circuit as shown in Figure 6 is set up with the filament switch F S open filament current will not flow and no electrons are emitted· hence no plate current will flow, which is indicated by zero reading of the milliameter, M.A. When switch FS is closed current will flow through the filament from battery A. Electrons will then be emitted and as the current increases through the filament its temperature will be increased with a corresponding increase of electron emission.

If the rheostat is set at a point where less than normal filament current flows through the filament and the plate voltage is varied from

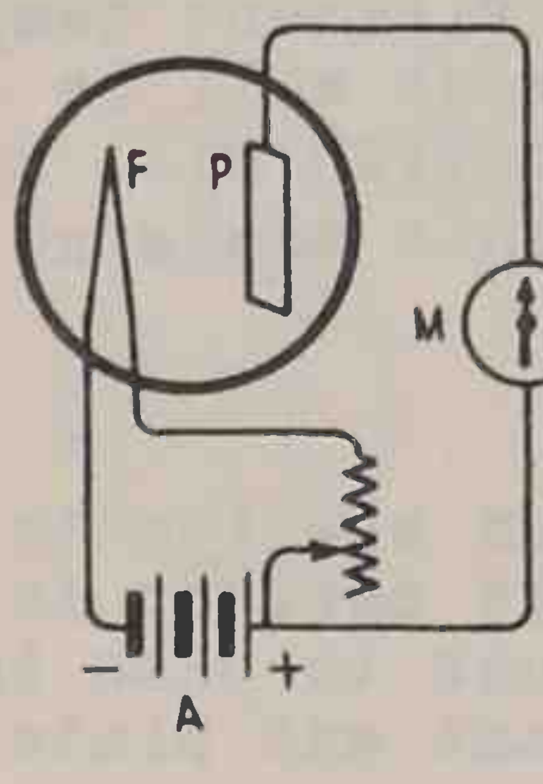


Figure 5

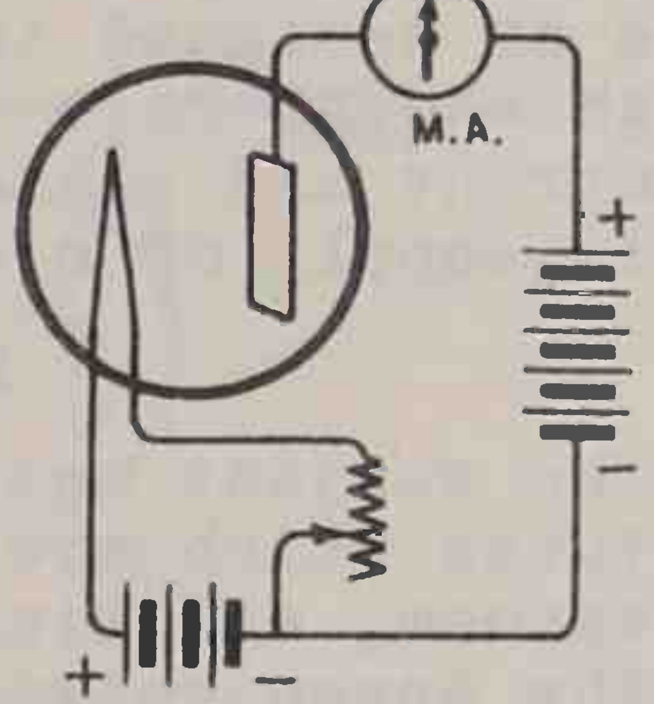


Figure 5A

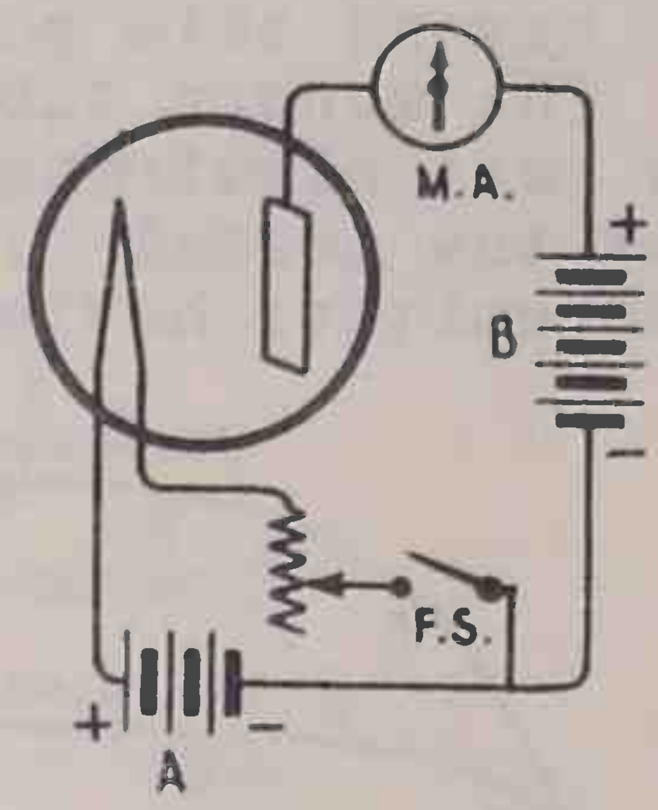


Figure 6

zero upward by changing the taps on the "B" battery a curve as shown in Figure 7, A,B,C,D, is obtained. This shows that plate current increases as the plate voltage is increased. An examination of this curve shows that as the plate voltage is increased at first there is a rapid increase in plate current (A). After a certain value of plate voltage is applied there is no appreciable increase produced in plate current by increasing the plate voltage. This is shown by the horizontal portion D of the curve. If the filament current is now increased and the plate voltage again is varied from zero upward the change in plate current takes place along the curve AEFG. Here the plate current coincides with the lower filament current along part A, but continues to increase above the bend B obtained with the lower filament current. After a certain plate voltage is applied the plate current again fails to increase for further increase in plate potential. This is indicated by the horizontal portion G which however is higher than D, obtained with the lower filament current. If other similar curves are drawn, each corresponding to a definite filament current, the same characteristics would be noted in each, namely a part where the plate current increases as the plate voltage increases and a part were the plate current is constant even though the plate voltage increases.

From these curves it is evident that with a definite filament current there is a definite plate current that cannot be exceeded. Moreover these curves show that as the filament current increases the maximum value of plate current also increases. This shows that a condition exists in the tube itself which limits the amount of current that can be obtained from the filament. Furthermore it seems certain that this limiting factor depends on the filament temperature which in turn depends on the filament current. Thus we can say that the maximum plate current obtainable depends on the filament. But for each filament temperature there is a definite maximum value of plate current.

A further study shows that the proportion of electrons attracted to the plate depends on the magnitude of the plate potential. When the filament temperature is kept constant and the plate voltage gradually increased the number of electrons attracted to the plate, and therefore the current in the plate circuit, will gradually increase as shown at (A) and (B) of Figure 8. This will continue until a condition is reached where all the electrons are drawn over to the plate as shown at (C). A further increase of plate potential will not result in any increase of plate current. This maximum plate current, beyond which there is no increase for increased plate voltage is known as the saturation current of the tube. For each filament temperature there is a different value of saturation current. Saturation for any definite temperature of the filament occurs when the plate attracts the electrons at the same rate as they are being emitted by the filament. In order to increase the plate current beyond this point it is necessary to increase the filament temperature. The modern tube must be so designed that its filament will be able to emit electrons at a high enough rate so that saturation will not occur at the normal filament current and plate voltage. This means an electron emitter having an ample supply of electrons.

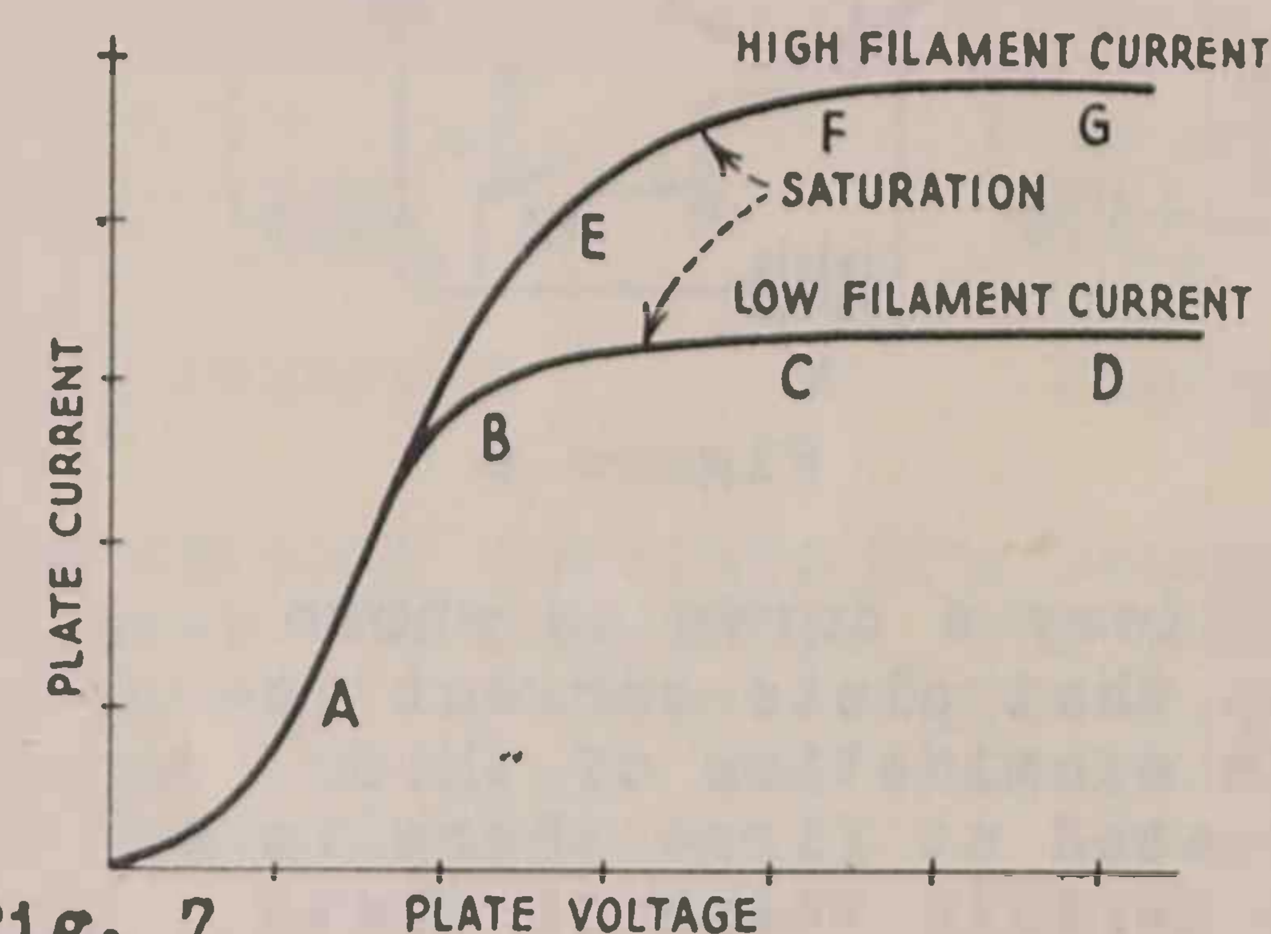


Fig. 7
Characteristic Curves of a Two-Electrode Tube at Two Different Filament Temperatures

GAS EFFECTS

The subject matter just given applies to tubes which are theoretically perfect in vacuum, allowing the electrons to pass in the space between the filament and plate without interference.

When, however, small traces of gas are left in the tube the electron current, which flows when a positive potential is applied to the plate, is increased over that obtained under the same conditions with tubes highly evacuated. The increase in electron current takes place, however, on the condition that ionization takes place.

IONIZATION

Ionization is the effect produced when electrons, on their path from the filament to the plate, collide with the molecules of gas in the tube. The molecule of gas is disrupted by the collision and it frees detachable electrons which then flow with the main body of electrons originating at the filament.

As the "B" voltage is increased the attraction of the plate for the electrons is increased. This, of course, affects the speed of the electrons and when they strike the gas molecules with greater speed the number of electrons freed from the molecules of gas will be increased. It is the liberated electrons from the gas molecules joining the main stream of electrons that increases the plate current.

When the electrons being emitted from the filament have attained a speed great enough they break up the gas molecule into free electrons leaving the gas molecule positively charged. In other words the gas molecule has been ionized and is now what is termed a positive ion. When this takes place in a vacuum tube to any great extent it is made evident by a blue glow which fills the space about the plate because at this point the greatest velocity of the electron occurs. The positive ions thus formed cannot flow to the plate because the plate is positively charged, and like charges repel, and the ions will then move toward the filament. Upon striking the filament they break loose more electrons, which again increases the quantity of electrons available to bombard the plate.

Ionization, therefore, is the splitting or breaking up of gas molecules into free electrons which are always negative and positive charged ions. The freed electrons forming with the main stream of electrons, and the ions shaking more electrons free from the filament which at once start on their journey to the plate, produces increased current in the plate circuit.

THE THREE-ELEMENT VACUUM TUBE

The three-electrode tube differs from the two-element tube only in the introduction of a third element, called the grid.

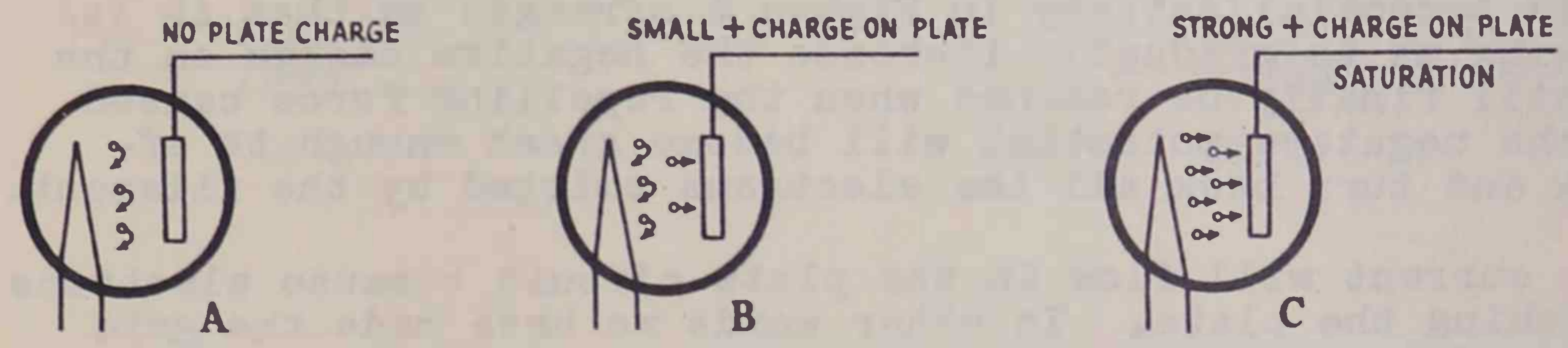


Fig. 8—Action of Electrons in a Two-Element Tube

The introduction of the grid brought about a change in radio that has had a far reaching effect. In fact it was the most important contribution made in the advancement of radio communication since the Fleming Valve was perfected. It greatly increased the sensitiveness of all receiving apparatus used in radio and is directly responsible for all the uses of the modern vacuum tube in transmitting and receiving apparatus.

The grid is capable of controlling the electrons which fill the space between the filament and plate. It exercises a directive power over the cloud of electrons which are racing with tremendous speeds toward the plate. The grid allows certain quantities of the electrons to proceed to the plate or it may prevent them in some cases from striking the plate at all.

By making the grid alternately positive and negative the quantity of electrons flowing from the hot filament to the plate can be increased or decreased. It can thus control large powers of plate current. The amazing feature here is that very small power applied to the grid will exercise this control. How this is accomplished will now be considered

THE USE OF THE GRID

The theory of the two-electrode tube, relative to the electron flow, the space charge, etc., will now be applied while explaining the effects produced by the introduction of the third element, the grid.

The grid is placed in the tube to control the electron flow from filament to plate. For this reason it is often compared to the trigger action of a gun, or the valve control over water, steam lines etc. In the grid, however, we utilize electricity to effect this control. You will remember in our study of the two-electrode tube that the space between the filament and plate was filled with minute negative charges, the electrons. You also know that like charges of electricity will repel and unlike charges will attract.

Now let us refer to the three-electrode tube shown in Figure 9. The grid will then be right in the middle of the cloud of electrons constituting the space charge. If we now connect the negative terminal of a third battery "C" to the grid as shown in Figure 9 we place a negative charge on the grid which will assist the negative space charge.

Since the space charge is already negative an additional negative charge on the grid will repel the greater number of electrons which otherwise would have traveled directly to the plate. As soon as this happens the plate is robbed of electrons and a drop in plate current results. If we have the grid potential battery in Figure 9 arranged so that it is variable, allowing us to gradually increase the negative charge on the grid, a point will finally be reached when the repelling force caused by increasing the negative potential will become great enough to effectually block and turn back all the electrons emitted by the filament.

In this case no current will flow in the plate circuit because electrons are not now reaching the plate. In other words we have made the grid equal in negative force to the positive attraction of the plate and neutralization is the result.

Now let us reverse the battery "C" so the positive terminal is connected to the grid as shown in Figure 10. This will give the grid a positive charge and, since unlike charges attract, the grid will have the effect of attracting the electrons and also conteracting, to a certain extent, the negative space charge. The plate current will be increased because the grid, being made positive, has now added an attractive positive force to that of the plate and consequently assists the plate in attracting electrons to it. By this added positive force in the electron paths the electrons gain a much greater velocity and pass between the fine grid wires striking the plate in greater quantities.

Some of the electrons strike the grid and cause a current to flow therein. This current is usually small and later on methods will be introduced to keep it at a minimum because large grid current is undesirable. If this grid battery C is made variable as in the case of Figure 9, and then gradually changed so that an increasing positive charge is placed on the grid, more and more electrons will be assisted to the plate, but there will be a point reached where further increasing the positive potential of the grid will not draw more electrons from the filament. When the saturation point has been reached further increasing the grid potential will not increase the plate current.

When we consider the repelling effect the space charge has on electrons being emitted it is easily understood how the electron flow is effected when we introduce any element that will either increase or decrease this action of the space charge. The grid has the power to exercise this control as you have observed.

The radio wave is alternating current, rapidly changing from positive to negative. This current is led directly to the grid in the radio receiver and changes the grid rapidly from positive to negative thereby controlling the flow of electrons which, in turn, determine the plate current flow. The plate current flowing through the telephone receivers is made to change in this way. The tube action in the receiving set will bring this explanation out in more detail.

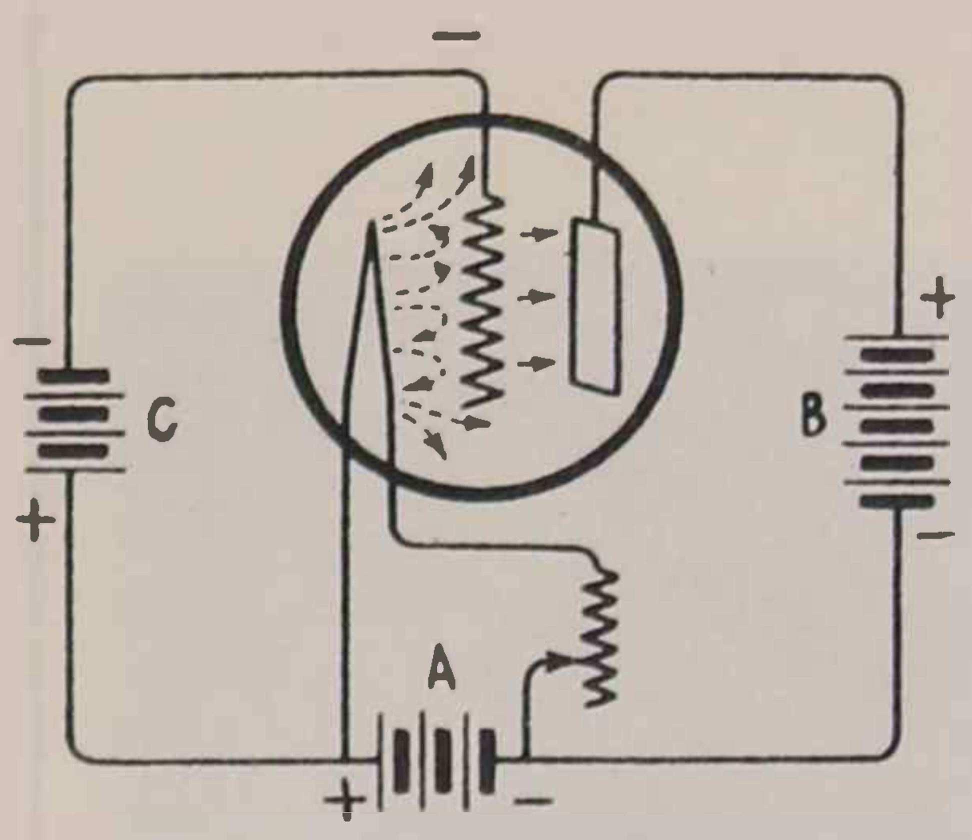


Figure 9

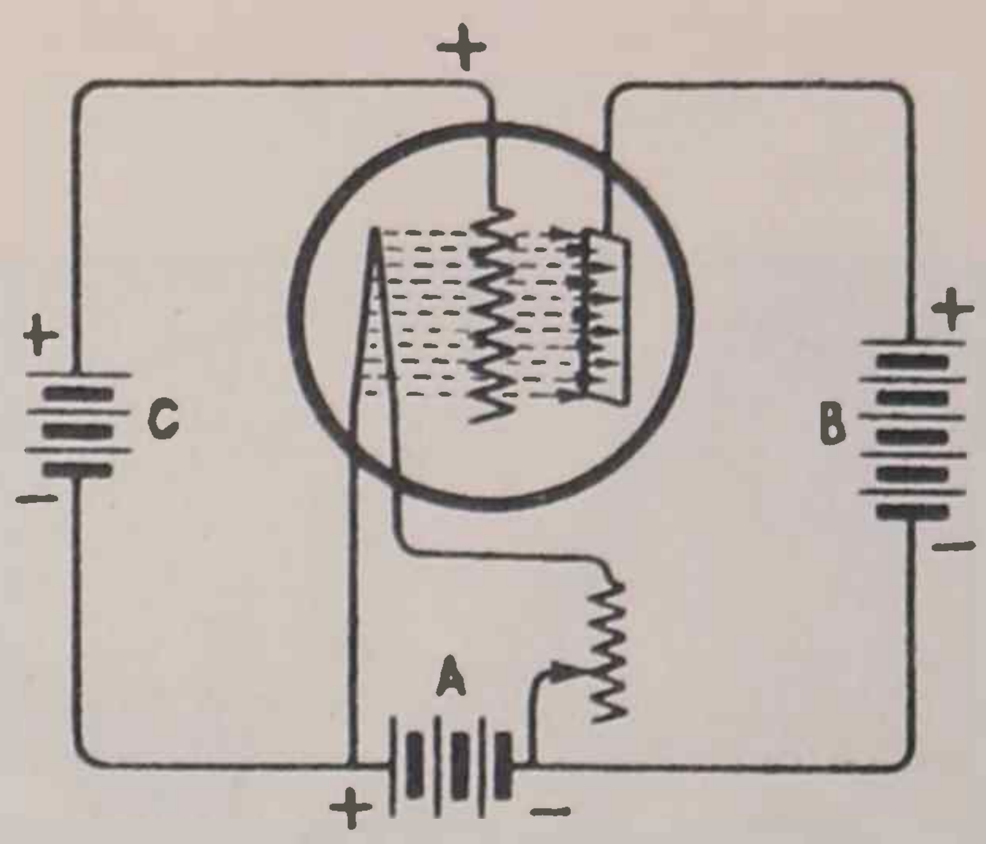


Figure 10

EXAMINATION QUESTIONS

1. What are Thermionic Currents?

2. Of what importance was the discovery of the "Edison Effect"?

3. Does the atom normally possess an electrical charge?

4. Upon what does electron emission depend?

5. Tell what you know about "space charge".

6. (a) In a vacuum tube what is the function of the plate?
   (b) The filament?

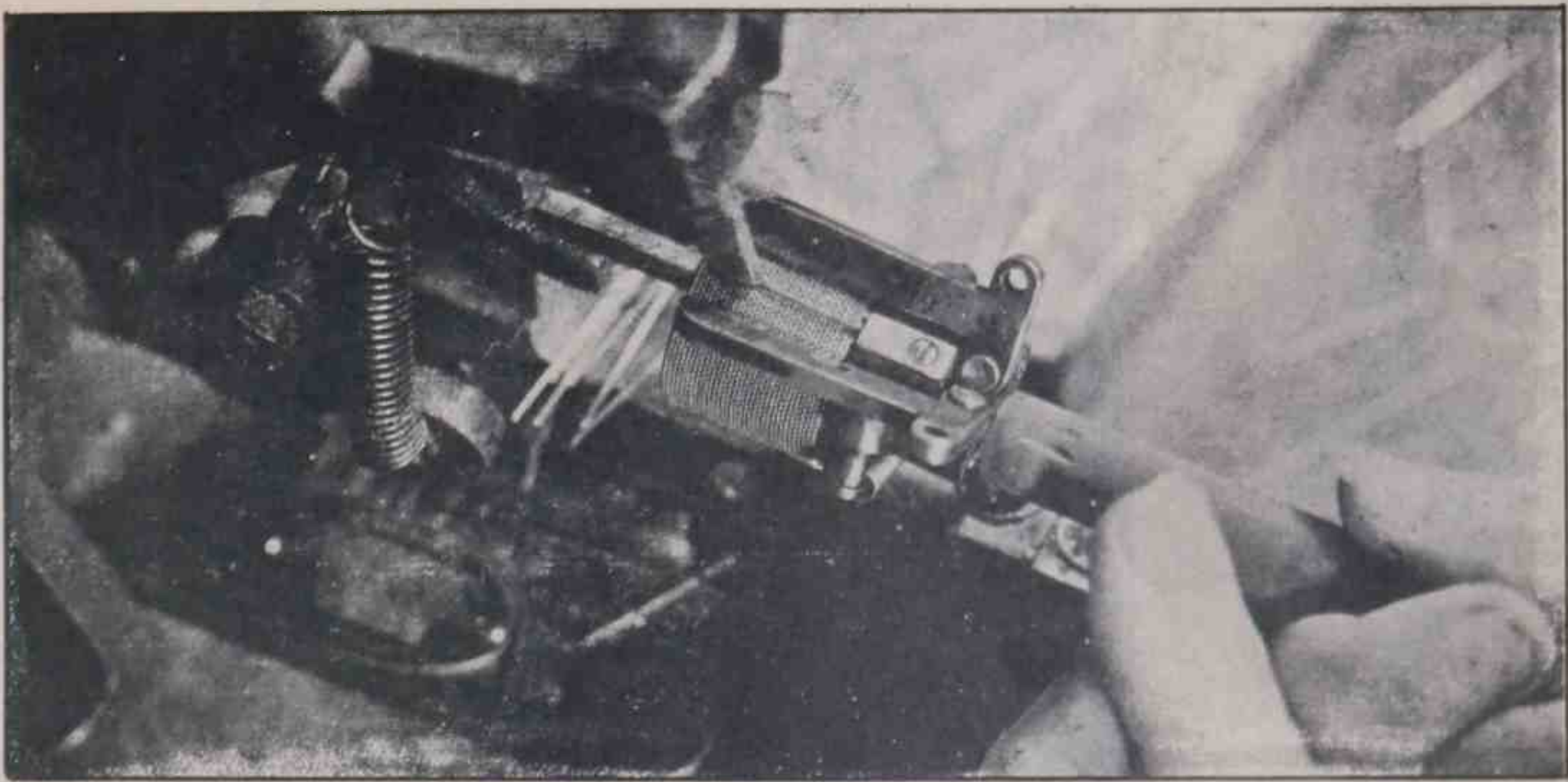
7. What is the effect of ionization?

8. How does the three-element tube differ from the Fleming Valve?

9. Of what importance is the grid element?

10. When the heat applied to the filament is increased is there an increase in the electron emission?

DATA SHEET



Method of Welding the Screen Grid

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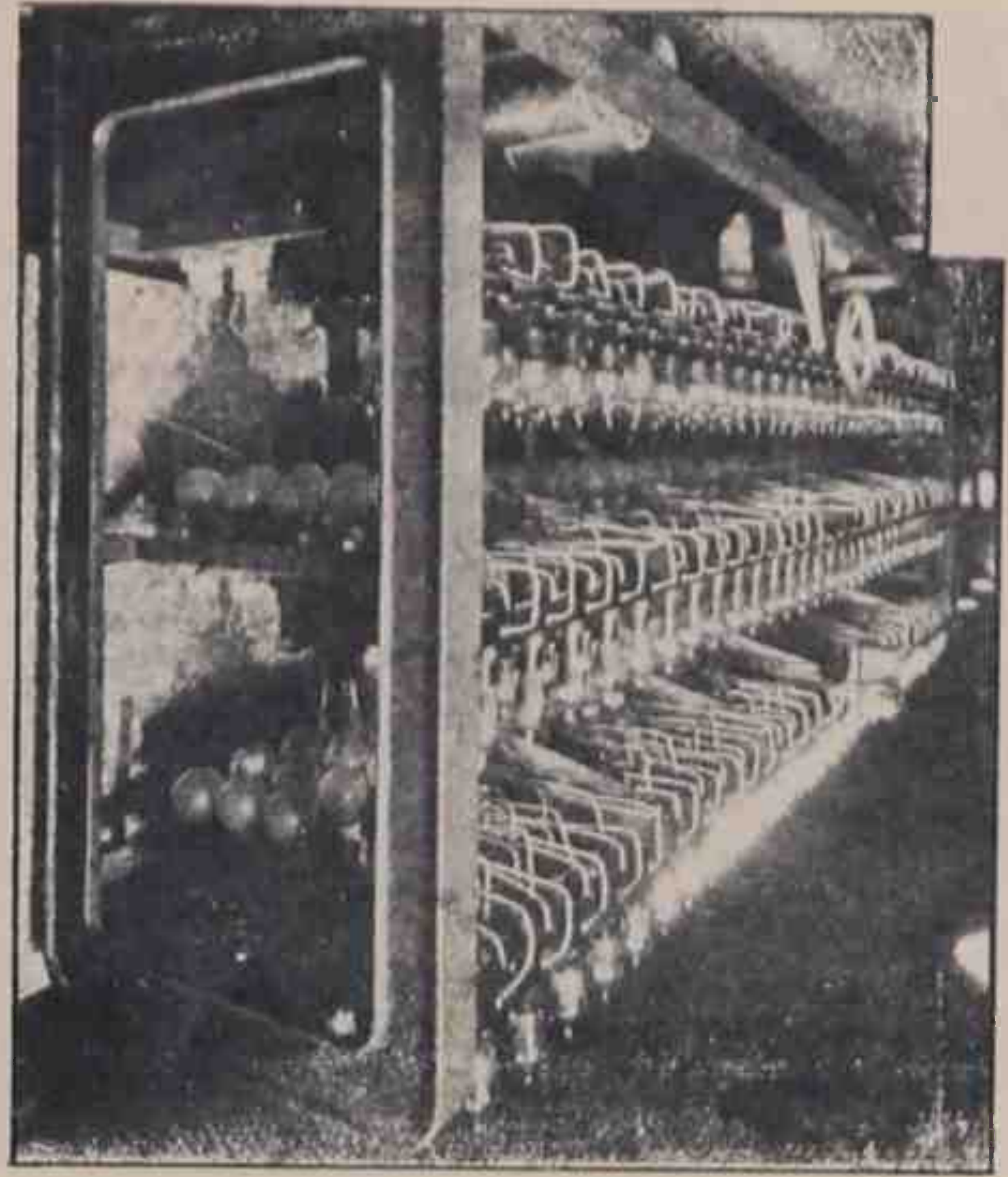

Radiotrons in the
Seasoning and Degassifying
Process

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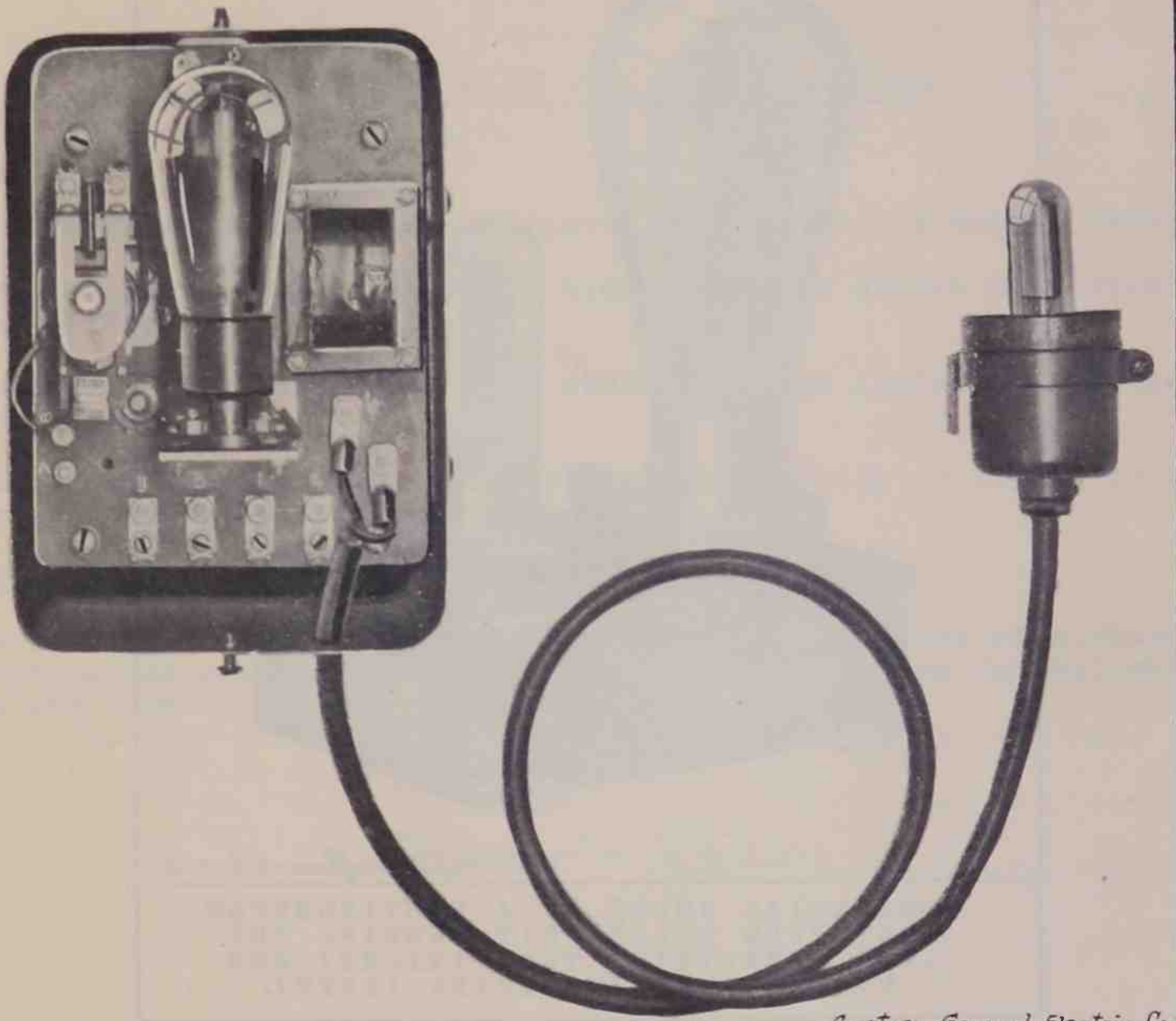

Courtesy General Electric Co.

A PHOTOELECTRIC RELAY UNIT SHOWING THE "ELECTRIC EYE" OR PHOTOTUBE AT RIGHT AND AMPLIFIER AND RELAY AT LEFT.

Theory and Uses of Photoelectric Tubes

Dewey Classification 535.3

VOL. 13, No. 5

Courtesy Westinghouse E. & M. Co.

COMMERCIAL MODEL OF A WESTINGHOUSE PHOTOTUBE RELAY UNIT SHOWING THE LIGHT SENSITIVE TUBE (RIGHT) AND VACUUM TUBE AMPLIFIER (LEFT).

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THEORY AND USES OF PHOTOELECTRIC TUBES

DEFINITION

In its broadest sense photoelectricity covers two phenomena, namely,

(1) The release of radiant energy when electrons strike particles of matter.

(2) The release of electrons when radiant energy falls on particles of matter.

It concerns, therefore, a transfer from electricity to light, or a transfer from light to electricity.

TYPES OF PHOTOELECTRIC PHENOMENA

Under the first type is the ordinary arc lamp, in which an electric current causes gases to become incandescent, producing radiant energy in the form of visible light waves.

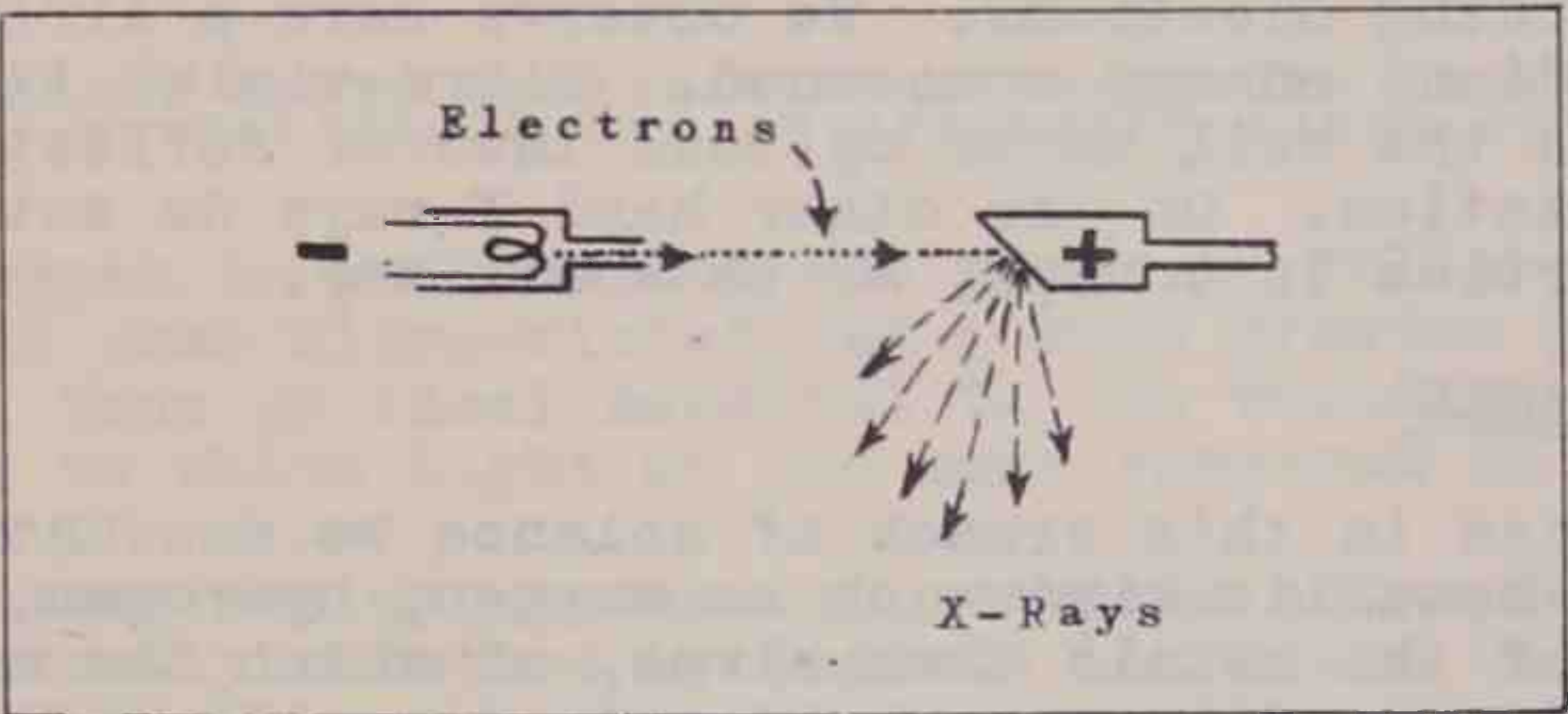


Fig. 1 - PRINCIPLE OF COOLIDGE X-RAY TUBE.

Also under the first type we note the Coolidge X-ray tube, which is simply illustrated in Fig. 1. Here we have a flow of electrons from a filament, the electrons being condensed by a sheath into a fine cathode ray. These electrons attain a tremendous velocity due to the attractive force of the high positive charge on the anode, which is called the "target" for the electron stream. The energy of the electrons in motion is communicated to the molecules of tungsten at the target surface, and these convert the energy into a form of radiation which we call X-rays.

The reverse effect is the emission of electrons from molecules of matter when radiant energy falls on them. This effect was originally discovered by Hallwachs. He found that if a body is negatively charged it will lose that charge when subjected to ultra-violet light. On the other hand, if the body is positively charged it will not be affected by the ultra-violet light. If a negatively charged body loses its charge under the influence of light it follows from the electron theory that we should be able to collect those charges under certain conditions by placing near it a positively charged body. This compares with the ordinary vacuum tube used for radio purposes, in which a positively charged plate is used to collect the electrons given off by the incandescent cathode. In Fig. 2 is shown the energy paths concerned with the Hallwachs effect.

Theoretically at least we could accomplish a double transfer, as shown in Fig. 3. Here we have radiant energy in the form of ultra-violet light directed onto a negatively charged metallic body in a vacuum and which gives up electrons; these would be attracted to the

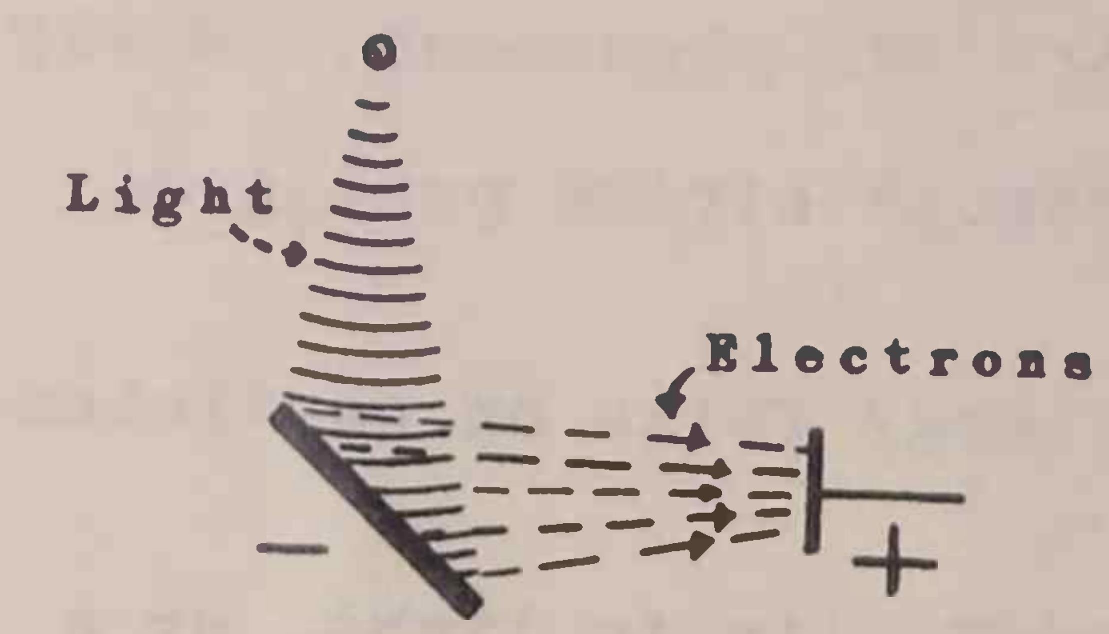


Fig. 2 - PRINCIPLE OF THE HALLWACHS EFFECT.

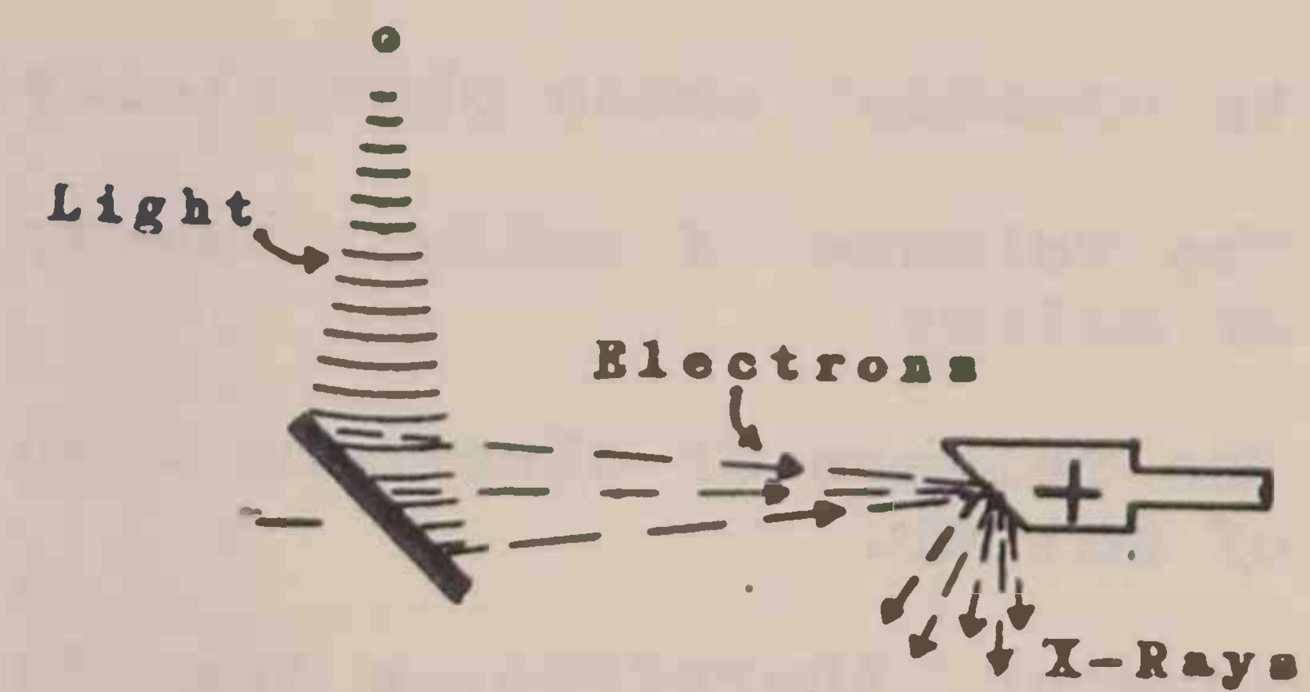


Fig. 3 - THEORETICAL IDEA OF A DOUBLE TRANSFER OF ENERGY.

anode or target. If a sufficient number of electrons could be emitted from the cathode in a given time (not practically possible) X-rays might be radiated from the target due to the energy wrapped up in the bombarding electrons. We observe here a difference in the two forms of radiant energy concerned. Ultra-violet light, while invisible, obeys the well-known optical laws of reflection, refraction and polarization. On the other h d X-rays do not. They do have some properties in common, as we shall see.

Z

In v ious devices in this br ch of science enco ter gases, t only of the non-metallic kind such as o gen, h rogen, heli , etc. but also those of the metals the elves, of which the st frequently used is the v or of r , which is no lly a fluid. You e f li with the latter in the wide spread use of mercu vapor la s, d you find it also rc y vapor rectifiers.

s lec es containi two or more at be dissociated into positive and so times negative ions by putting the gas in the line of action of y one of the t ee paths sho in Fig. 3. In like fashion the single-atom lecules which e electrically neutral e u ly de over into positive ions.

Ultra-violet li t c ionize rc y vapor by causing t release of one or re elect om the rcury atom.

Electrons in motion at a sufficient speed may "knock off" other electrons from a gas molecule in their path, leaving positively charged atoms or ions, and sometimes negative ions, depending on the molecular construction.

Furthermore, X-rays also have the ionizing power.

SENSITIVITY TO LIGHT. In a foregoing paragraph we mentioned that Hallwachs, in his experiment, used ultra-violet light. There were natural limitations to this early device on account of the nature of the light. It is easy to see that in a practical way it is much

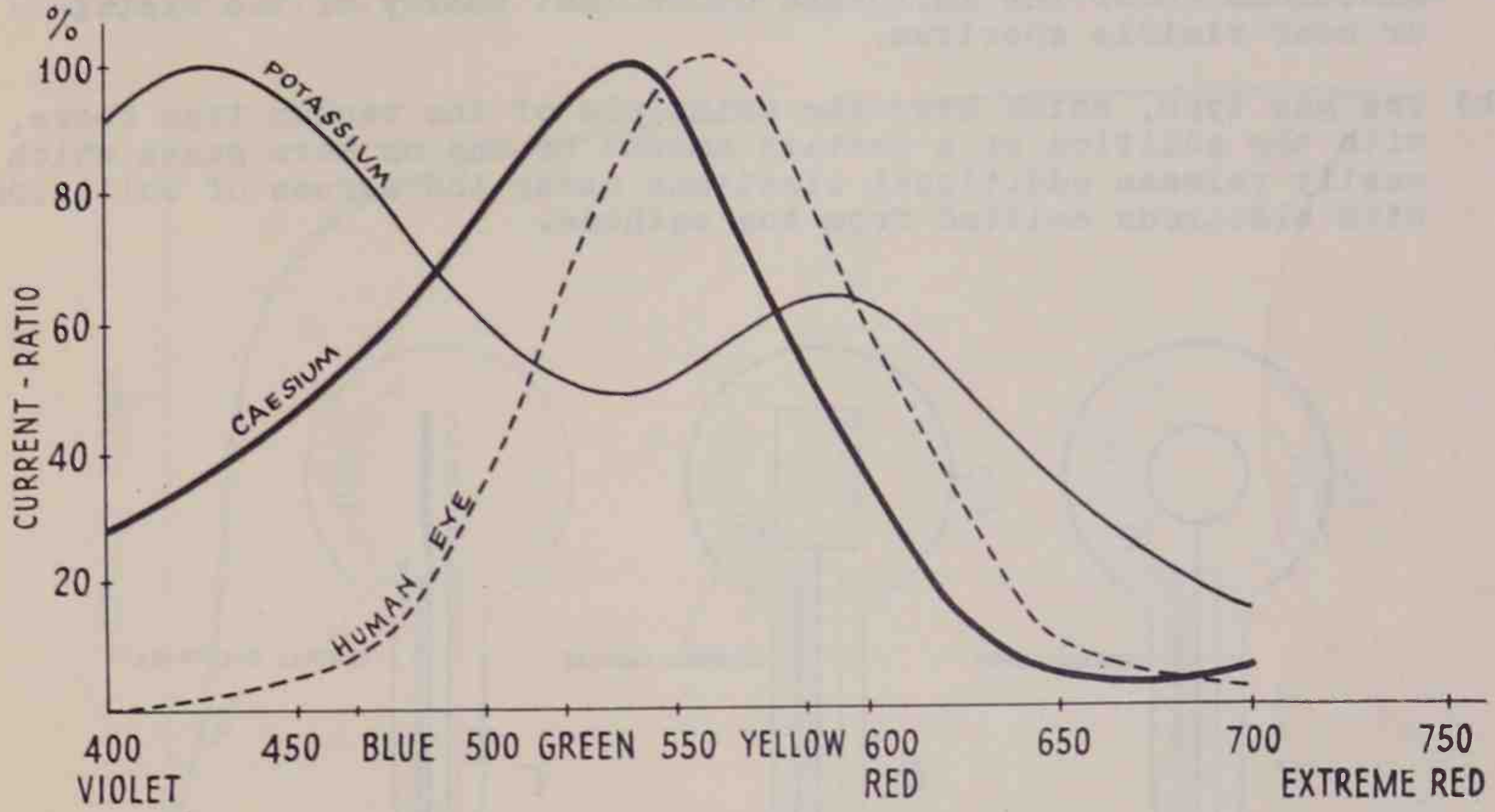


Fig. 4 - CHART SHOWS COMPARATIVE SENSITIVITY OF POTASSIUM, CAESIUM, AND THE HUMAN EYE AT DIFFERENT LIGHT FREQUENCIES.

easier and cheaper to produce and see white or yellow light — which usually contain some ultra-violet, but a much greater percentage of other colors. Thus an ideal material to use would be one that is more sensitive to white light or the same spectrum as the eye.

The discovery that sodium, potassium, caesium and a few other elements were instantly affected by visible light led to intensive development work which brought the photoelectric cell up to its present stage. Although these cells are quite highly developed yet they are not as uniform in performance as the radio tube. Photoelectric cells and radio tubes in general appearance resemble each other and both are classified as "electron discharge devices" although it must be remembered that in the case of the photocell the emission is caused by light while in the thermionic (radio) tube the emission is due to incandescence of the filament or cathode.

An examination of the chart in Fig. 4, which shows the sensitivity of various materials at different light frequencies, indicates that caesium compares favorably with that of the eye. Caesium, however, when used alone is not as sensitive as potassium or copper oxide but it has been found that by coating the caesium on silver oxide its sensitivity is greatly increased and furthermore its frequency characteristic is kept approximately the same as that of the eye.

PRINCIPLES USED IN THE PHOTO-EMISSIVE CELLS

Based on the principles used we have two types of photo-emissive cells or phototubes:

(a) The vacuum type, which consists of a highly evacuated vessel enclosing a positive electrode and a negative electrode, the latter consisting of a surface of such material that it will emit electrons under the influence of radiant energy of the visible or near visible spectrum.

(b) The gas type, which uses the principle of the vacuum type above, with the addition of a certain amount of one or more gases which easily release additional electrons under the forces of collision with electrons emitted from the cathode.

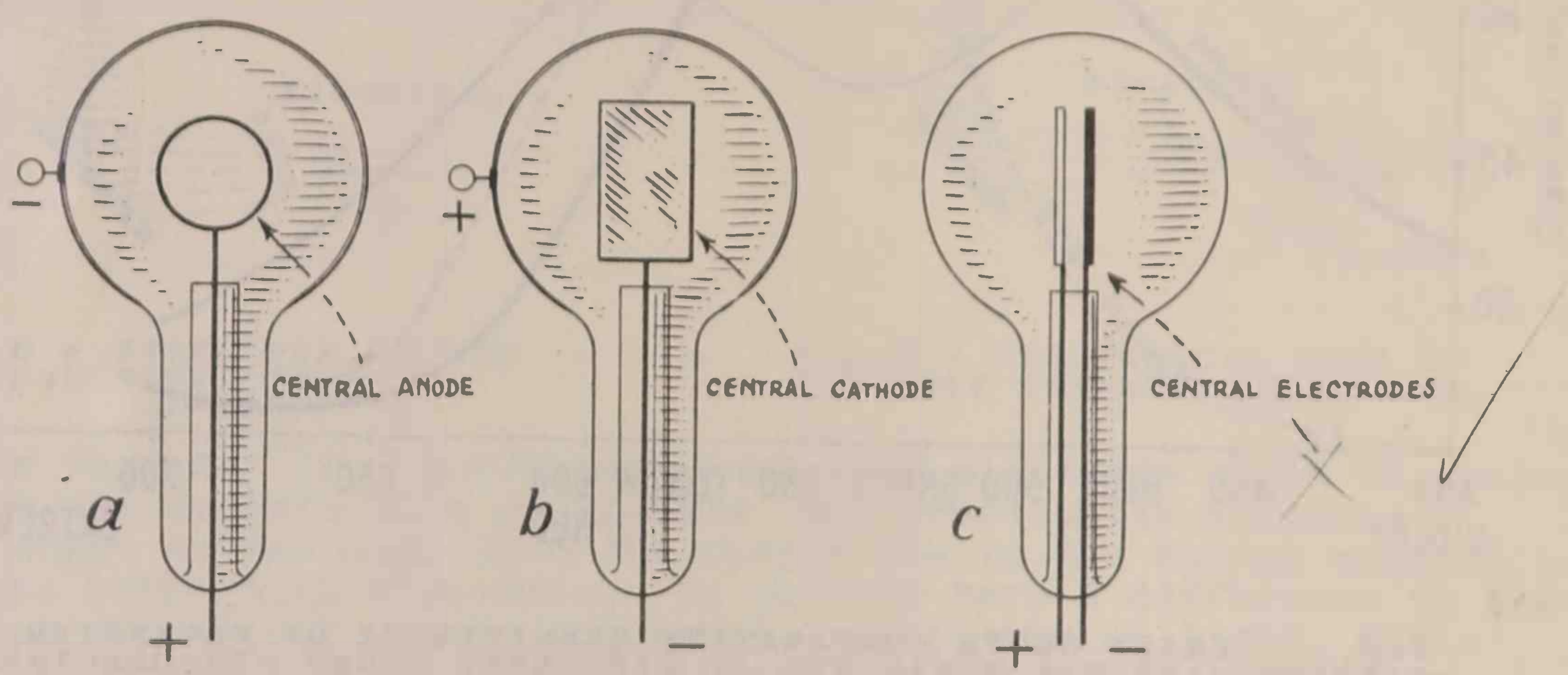


Fig.5 - PHOTOTUBES ARE CLASSIFIED HERE ACCORDING TO ARRANGEMENT OF THEIR ELECTRODES.

STRUCTURAL FORMS

The three most common forms of phototubes now in use are (a) the central anode, (b) the central cathode, and (c) the central electrodes. In the central anode type the inner surface of the tube is coated with the light sensitive alkali while a rod, used for the anode, is located inside and near the center of the tube. In the central cathode type the inner surface of the tube is coated with a metallic substance and a plate, coated with light sensitive material, is located in the center of the tube. In either case the coating on the inside wall of the tube is connected electrically to a terminal which is brought outside the tube. The third type mentioned or the central electrode tube is now the tube most generally used in so d-on-film movies. It consists of a centrally located rod (anode) with a s i-cylindrical plate (li t s sitized cathode) p tially rrounding it. . 5 sho the n al arr t of the elect des.

VACUUM CELL. When the electrodes of a photocell function in a high vacuum it gives them a much different characteristic than when they work in a gas filled medium. When the cathode of a vacuum type cell is subjected to light a certain number of electrons are released and if a high positive potential is applied to the anode all of these electrons will be attracted to and flow toward the anode. On the other hand, if the anode voltage is comparatively low all of the liberated electrons will not be attracted to the anode, but many will continue to remain on the cathode. This characteristic showing the variation in current (electron flow) for a given fixed light intensity, with changes in anode potential is shown in Fig. 6. When the voltage is sufficient to remove all the electrons released by the light, a further increase of voltage should not produce an increase in electron flow. When this condition is reached the current has

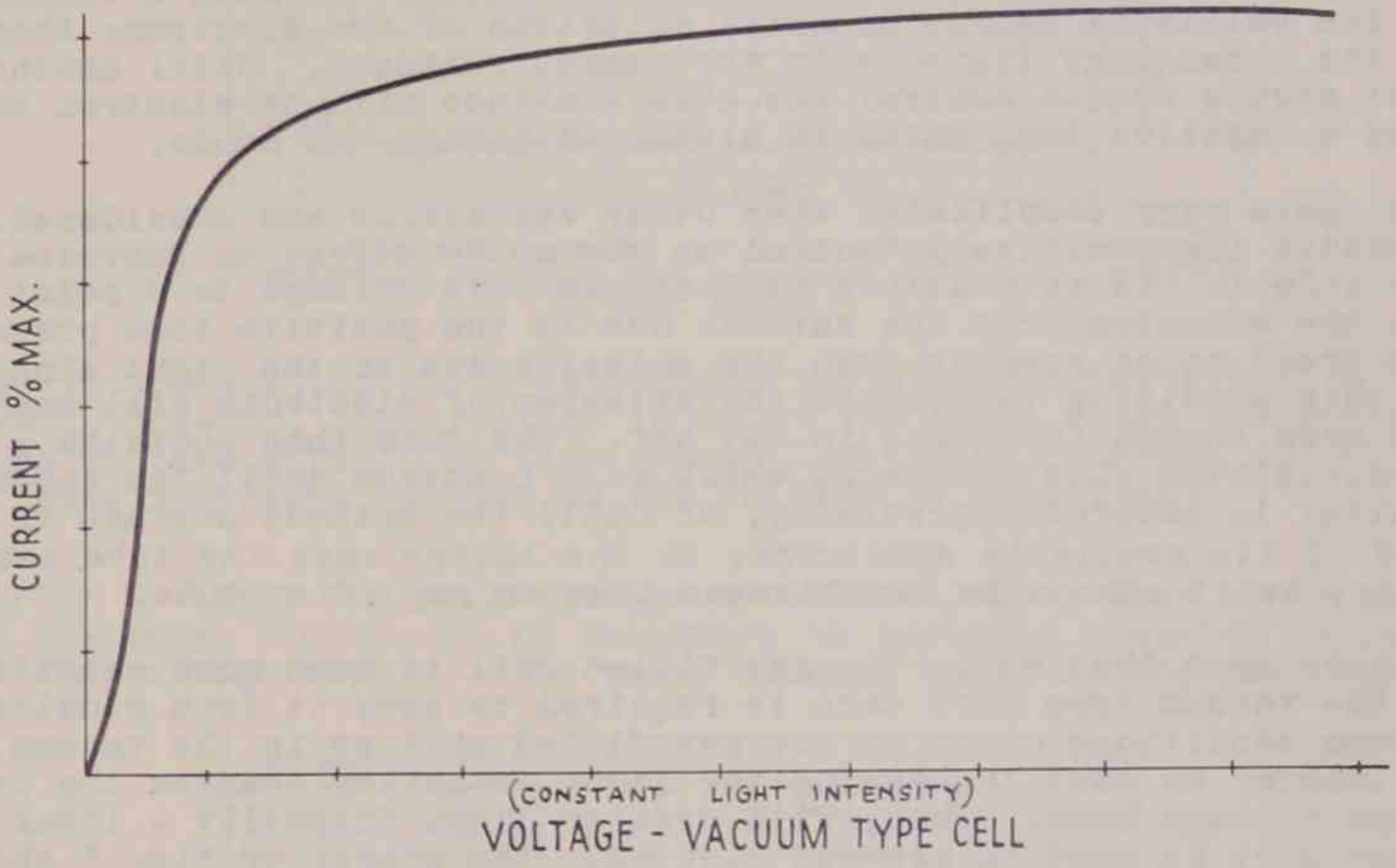


Fig.6 - CHART SHOWS RELATION BETWEEN CURRENT FLOW AND VOLTAGE CHANGES IN A VACUUM TYPE CELL WITH CONSTANT LIGHT INTENSITY.

reached the saturation value. Of course, if the light intensity is changed the voltage-current curve will be different and the saturation current will increase as the light intensity is increased. Due to imperfect vacuum and rough surfaces on the cathode holding back some electrons there will always be some slight increase in current for an increase in voltage, but this increase becomes so slight that it need not be considered.

EFFECT OF GAS ON CELLS. The action of gas filled cells is much more difficult to understand than the explanation just given for the action of the vacuum type cell. In the first place only gases which do not react chemically with photoelectric material can be used.

Argon, neon and helium answer these qualifications. The normal electron stream in motion will have scattered through it gas molecules which are electrically neutral, and therefore not attracted to either the anode or the cathode. The random motion of the gas molecules through the space of the tube will have no special direction. When an electron collides with a molecule the elastic properties of each may cause them to merely bounce off, their directions and velocities being changed but slightly. If the electron velocity is sufficiently great, however, it may give up some of its energy to the task of freeing another electron from the ties that bound it into the structure of a gas atom. The additional electron joins the stream of electrons originating at the cathode, and more electrons reach the anode than were caused by the light falling on the cathode. The gas atom which was robbed of an electron is no longer neutral, having become a positive ion. This ion is repelled from the anode, and attracted to the cathode, whose charge is of the opposite polarity. During its motion in that direction, it may join another electron and become neutral; or it may approach and reach the cathode at such a velocity that the collision causes an extra agitation of the electrons there, with the consequent increase in the number released. Still another effect occurs when a neutral gas atom combines with an electron to become a negative ion, which is attracted toward the anode.

It all gets very complicated when other variations are considered. Increasing the positive potential on the anode serves to increase the whole effect. It is possible to increase this voltage to a point where the emission from the cathode due to the positive ions present, is as great as or greater than the emission due to the light alone. When this condition is reached the emission of electrons will continue even though the light is cut off. The tube then contains a self-sustaining glow discharge which will continue until the anode potential is lowered appreciably, or until the cathode surface is robbed of its available electrons. In the latter case the tube becomes useless, as it cannot be reactivated like an amplifier tube.

It can be seen that while the gas filled cell is much more sensitive than the vacuum type more care is required to keep it from glowing. The same conditions exist in the gas filled cell as in the vacuum cell insofar as that increasing the light intensity changes the best maximum voltage used. Thus, with greater light intensity a lower voltage must be used to prevent glowing. The graphs of Fig. 7 show this. (The "lumen" is the unit of "luminous flux," which may be defined as the radiant power evaluated according to its visibility). The current sensitivities are graphed for three types of cells made by the Westinghouse E. & M. Co.

Type VA is a vacuum cell having a color-response approximating that of the human eye. Type VB is also a vacuum cell, but having about fifteen times the sensitivity of Type VA, but resembles the latter in that it gives constant output for steady light flux, over a wide range of cell voltages. The gas filled Type GB cell gives increased output up to a limit of about 90 volts. The graph at the right of Fig. 7 shows that the unwanted glow discharge occurs at a voltage which depends on the light flux.

Fig. 8 gives the response per unit energy of the three cells mentioned, with a comparison with the human eye. It will be noted that the GB cell has about five times the response of the VB cell, at the voltages used in taking the data, but that the color response of the two cells is identical.

Referring again to Fig. 7 we see the reason for the greater sensitivity of the gas filled cell. At about 30 volts on the horizontal scale, the VB cell has reached the saturation point for the steady

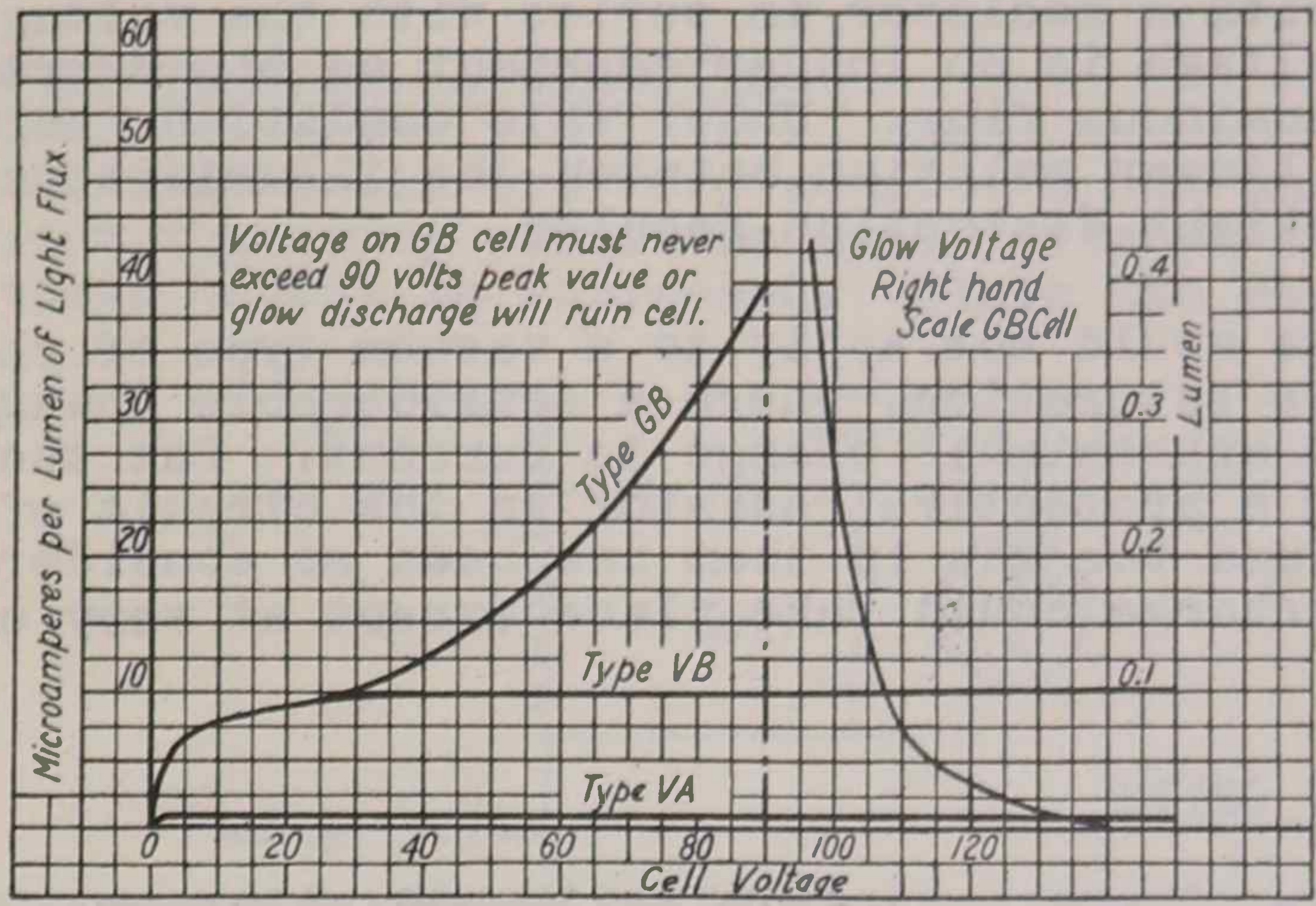


Fig. 7 - TYPICAL CURVES OF AVERAGE CELL OUT-PUT AS A FUNCTION OF APPLIED VOLTAGE AT A LIGHT FLUX OF ONE LUMEN.

light flux condition which determines the electron emission. In the GB cell, however, this voltage is about the point where ionization begins to take effect for that steady light flux, and the current per lumen increases rapidly as the voltage is increased.

In order to limit the cell voltage to a value below that at which glow discharge starts, it is customary to insert a resistor in series with the voltage supply. Its value is such that, as the cell cur-

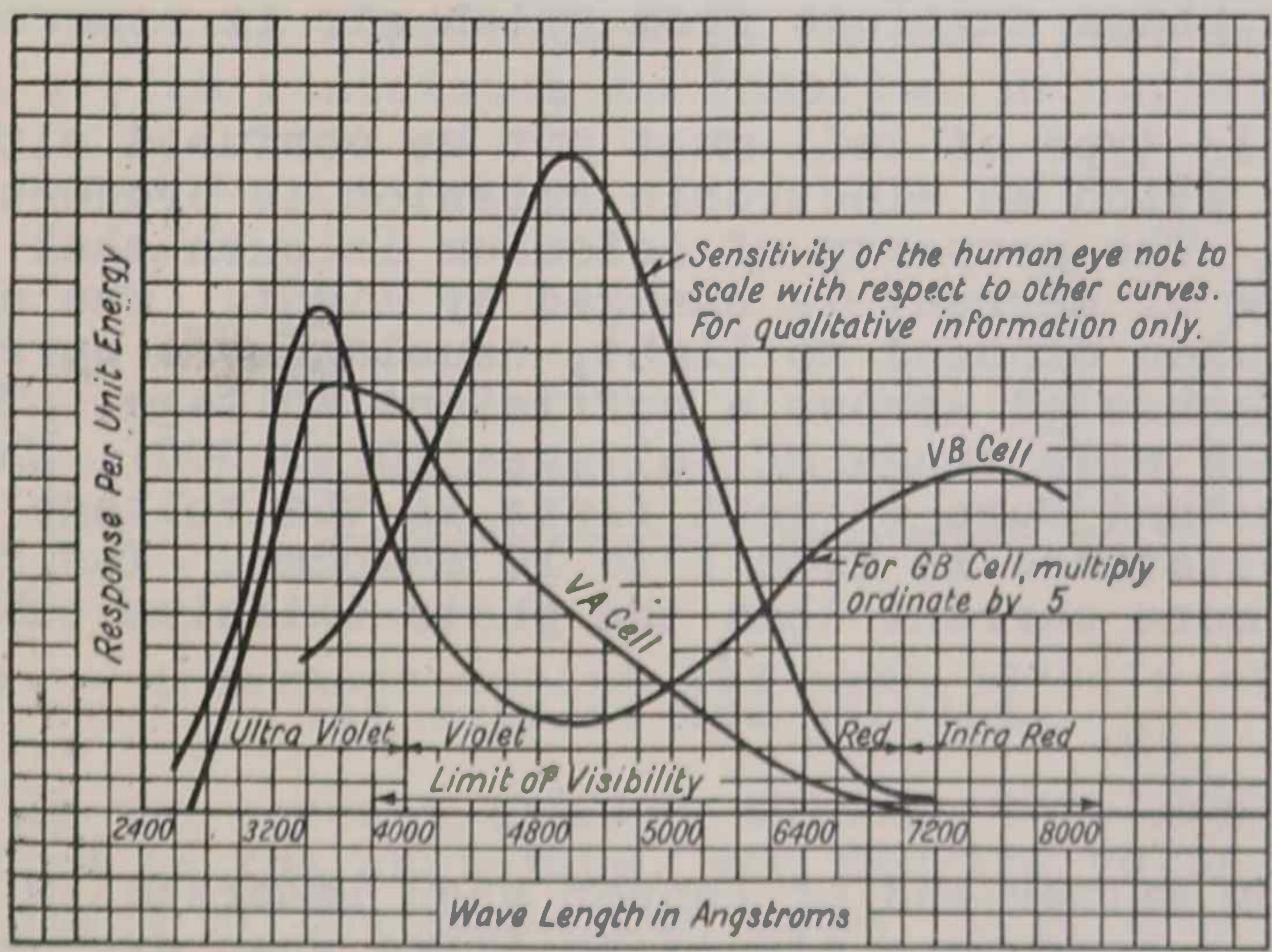


Fig. 8 - COLOR SENSITIVITY OF AVERAGE CELLS OF WESTINGHOUSE TYPES VA, VB AND GB.

rent increases too rapidly near the glow discharge point, the voltage drop across the series resistor will lower the voltage across the cell electrodes. This, of course, reduces the tendency toward a glow discharge. It has a certain disadvantage, in that the average voltage across the electrodes will depend upon the average illumination. What we would like to have is the use of a steady voltage on the electrodes, with the current varying directly as the luminous flux changes. With a resistor in series with the voltage supply, the electrode voltage is no longer constant as the current varies with change in luminous flux. Under this condition there is no longer a nearly linear relation between the illumination and the current, and a slight distortion results.

This disadvantage would not apply to a vacuum type of phototube which is operated above saturation, where a considerable change in electrode voltage makes no appreciable change in current. But then, there is no use in having a protective resistor in the circuit of vacuum phototubes, because the gas in them has been so considerably reduced that no glow discharge could take place except at very extraordinary voltages.

PHOTO-CONDUCTIVE CELLS

The earliest form of photoelectric cell used selenium, but up to very recent times the inherent sluggishness of response limited its usefulness to very few applications. A modern development which is manufactured by the Burgess Battery Company under the name "Radiovisor Bridge" makes use of a unique contact surface and the selenium is carefully treated by a special process. This overcomes much of the slow action of the selenium, and it is claimed to be responsive to variations in light up to a frequency of 10,000 cycles per second. The cell or bridge as it is called consists of two gold electrodes fused into glass. Each electrode is in the shape of a comb, and they are placed with their teeth interlocking, but not touching. The molten selenium is poured over these electrodes in a thin layer and then given a heat treatment to convert it into the chemical form in which it is most sensitive to light. The electrode assembly is then placed in a glass envelope from which air is removed.

The action of this type of cell must not be confused with the photo-emissive cell in which an electronic emission is proportionately caused by light. The property of selenium is such that its resistance to the flow of current is changed by light. The cell resistance decreases when exposed to light, causing more current to flow if the cell is connected across a sufficient voltage. The bridge may be used over a wide range of voltages(10 to 500), the principal difference being that more current flows as the voltage is increased. When dark the resistance is from 1 to 10 megohms. The "bridge" passes appreciably more current than the photo-emissive tubes previously described.

PHOTO-VOLTAIC CELLS

Several oxides of silver and of copper when immersed in solutions of sodium hydroxide become more electropositive when exposed to light. When an electrode having a crystalline cupric oxide surface is associated with an inert electrode of lead, the additional electrochemical potential caused by light makes itself evident as an internal electromotive force which is available for causing current to flow through some external circuit connected across the two electrodes.

The voltage developed in this cell is proportional to the luminous flux to which it is exposed. No external battery is required, which differentiates it from the photo-emissive and the photo-conductive types of cell.

APPLICATION OF PHOTOTUBES IN CIRCUITS

Potassium and caesium cells are very sensitive, but pass such small amount of current that they cannot be used for most commercial purposes unless their output is increased. Since the resistance from

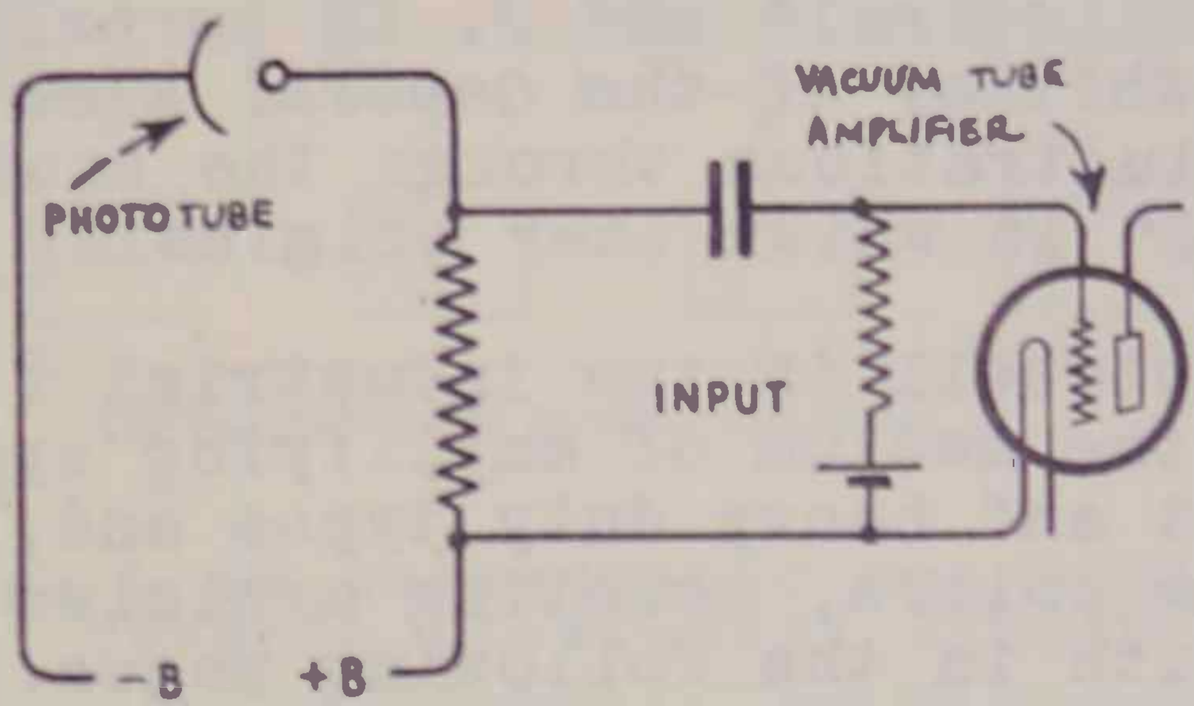


Fig. 9 - ONE METHOD OF COUPLING A PHOTOTUBE TO AN AMPLIFIER TUBE CIRCUIT.

anode to cathode is quite high they are known as high impedance cells. This brings about two requirements. If they are to be used for the production of alternating current of a wide range of frequencies, such as in Sound Pictures and Television, the input impedance of the following amplifier must match that of the phototube. As with any other high impedance circuit, it must be adequately protected by shielding from responding to stray electrostatic d electromagnetic fields ich uld o se t duce r dom voltages in the si l. se d pe as noise in So d Pic es, d as flecks of light d shadow in t pict e-effect produced at a re te Television receiver.

One method of coupli a photo be to a lifier tube is sho in Fig. 9, whe a high sis ce is inserted in series with the volt-

Fig. 10 - AUTOTRANSFORMERS ARE USED HERE TO STEP-DOWN AND STEP-UP THE VOLTAGE.

e supp . As ent c es this resistor due to li t variations on the photo be, the va ing voltage-drop is - p ied to the input of the lifier tube. is syst es it visab e t t t f rst lifier tube be p ced close to the ph be, not y for noise prevention, but also to prevent the ca ac y of a lo ca e acti as a t at hi frequencies.

u es e ev t , d convenience of const ction im- b t e c rcuit of Fig. 10, usi autotr sformer close to the phototube to step down the voltage. At the desired location of the first amplifier tube a similar autotransformer steps up the voltage which is applied to the grid of the tube. You will note that this satisfies our requirements because (1) the load on the phototube is a high impedance, (2) the input to the amplifier tube is a high impedance, and (3) the connecting circuit has a low impedance not subject to capacity or magnetic effects to any appreciable degree.

<u>INDUSTRIAL USES OF PHOTOTUBES.</u> The articles entitled "Illumination Control" and "Smoke Density" which follow were written by Messrs. W. R. G. Baker, A. S. FitzGerald and J. I. Cornell of the RCA Victor Company and Mr. C. F. Whitney of the General Electric Company, and are given here with illustrations through the courtesy of the publishers of "ELECTRONICS" in which they originally appeared.

Applications of the photocell in the industrial field are for the control of power through the medium of amplifying systems, thyratrons and relays of the light and heavy duty types and, for indicating smoke density, matching colors, counting articles and so on. These topics will be dealt with in the following pages. Thus many devices that were formerly controlled by hand or by clock-work are now controlled by the photocell. For generations light has been considered

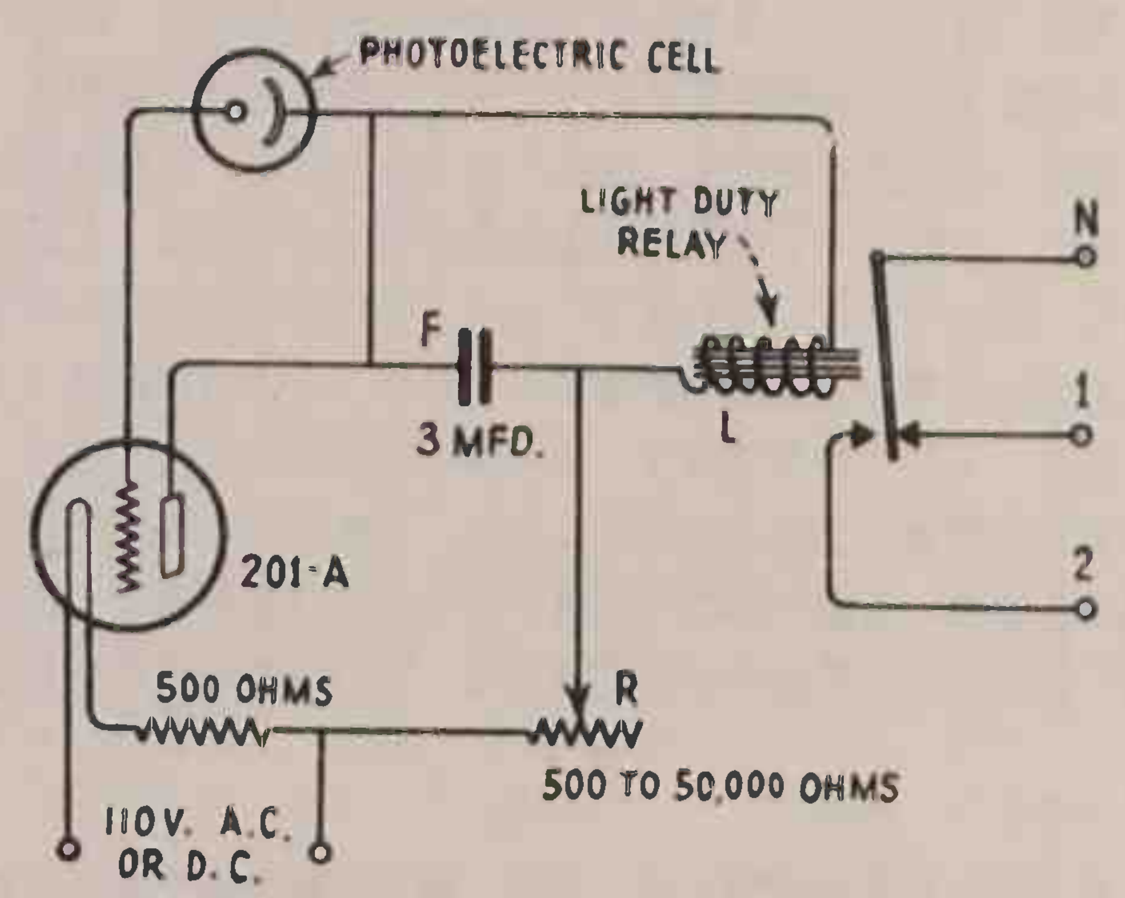


Fig. 11 - A RELAY CIRCUIT WITH PHOTOTUBE AND VACUUM TUBE AMPLIFIER.

only as "something to read by"; of late, however, engineers have begun to realize that beams of light can be put to work. The medium through which light serves for these uses is the surface of an electrode in the phototube which emits electrons under the stimulation of visible or invisible light, as previously explained. These electrons can be used to operate relays and thereby control power of any amount.

A photoelectric cell has the advantage over other devices of being able to operate in periods of unusual darkness during daylight hours which may be caused by a storm for example. Ordinarily during storms apparatus controlled by clock-work would not function. When photocells are used for the switching of incandescent lights used for lighting or for beacons, they are placed in a "window" which faces towards the north so that the direct rays of the sun will not damage the cell. Relays working in conjunction with the light sensitive device make contact when the light shining in the window is less than a certain amount. A typical light-duty relay circuit with photocell and vacuum tube amplifier is shown in Figure 11.

The general scheme for combining several light-duty relays to control many different circuits operated from one light sensitive cell is illustrated in Figure 12. Each relay operates at its own critical current and controls its own heavy duty relay and circuit, although the whole is energized by the same photoelectric cell.

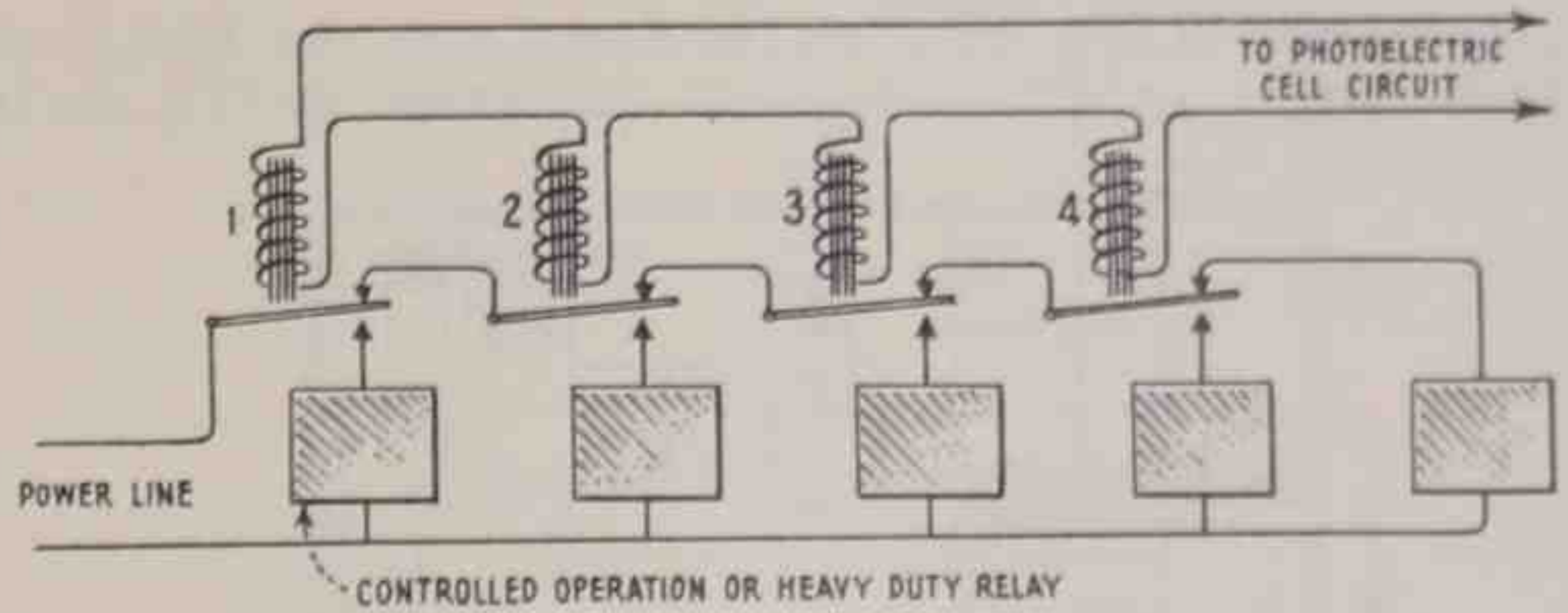


Fig. 12 - AN ARRANGEMENT FOR COMBINING SEVERAL LIGHT-DUTY RELAYS.

A magnetic counting device operated by a photocell is used in many factories at the present time to count the number of articles, such as packages, which pass through a conveyer at a certain point. Any object that is large enough to interrupt a beam of light will operate a photocell, and as a photocell is practically instantaneous in operation, almost any speed may be obtained.

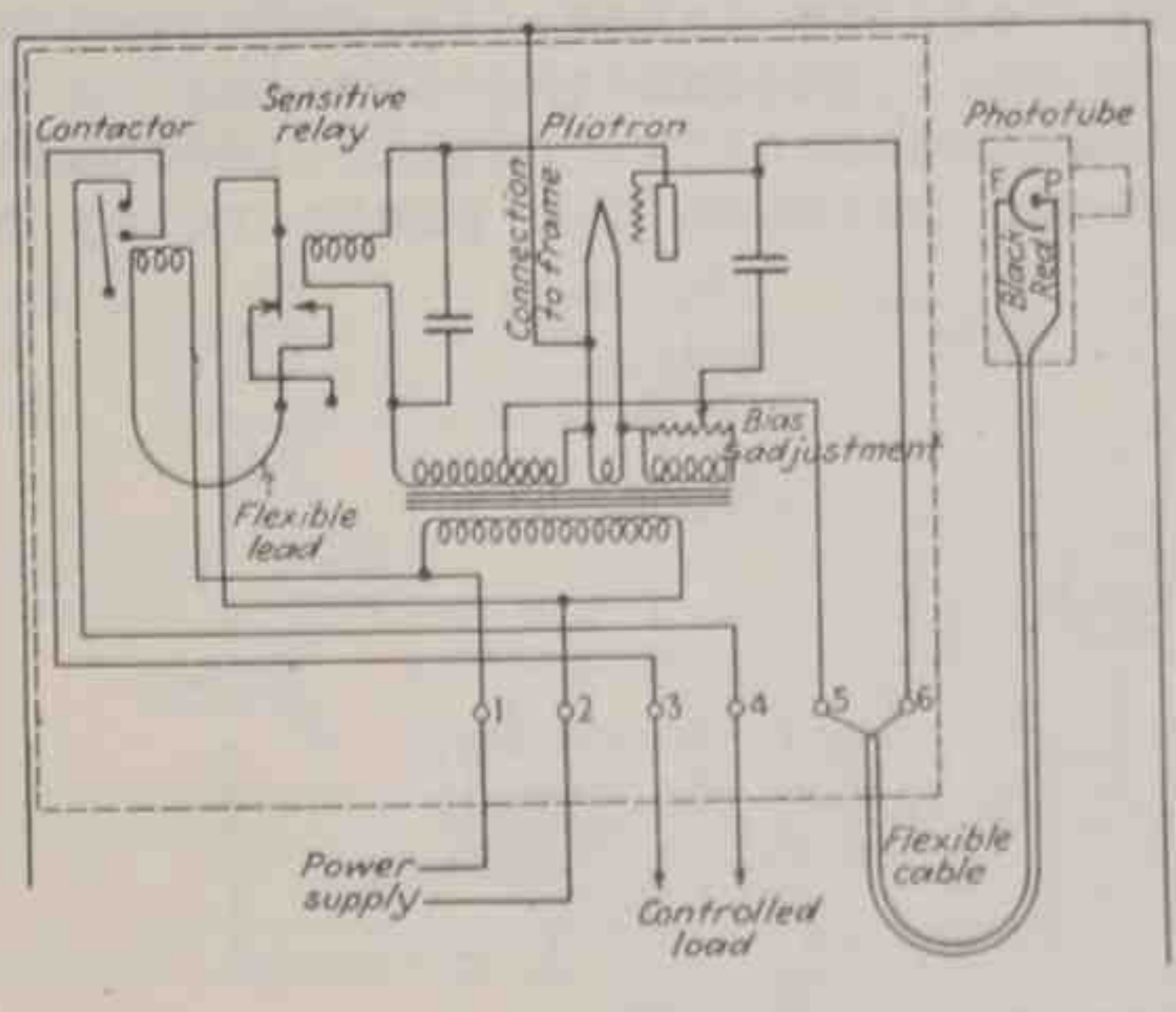


Fig. 13 - CIRCUIT CONNECTIONS OF A LIGHT-OPERATED RELAY.

ILLUMINATION CONTROL. For example, the circuit shown in Figure 13 combines a phototube and triode to form a light-operated relay. The pliotron grid is "biased" negatively by means of a potentiometer across the winding of a transformer and serves to keep the plate current at a low value insufficient to energize a small relay in the plate circuit. A phototube also connects to the grid and a winding of the transformer in such a manner that when light strikes the phototube the grid is made less negative increasing the plate current so that the plate relay is energized. Thus the relay is energized when light strikes the phototube and de-energized when the light is cut off. A contactor capable of controlling usual circuits is operated by the plate relay contacts. By means of normally closed and normally open contacts on the plate relay the contactor may be either energized or de-energized when the light strikes the phototube. The photograph of a commercial unit of this type, illustrated on the front cover, shows the phototube connected to an amplifier and relay unit by means of a flexible cable, thus allowing the phototube to be

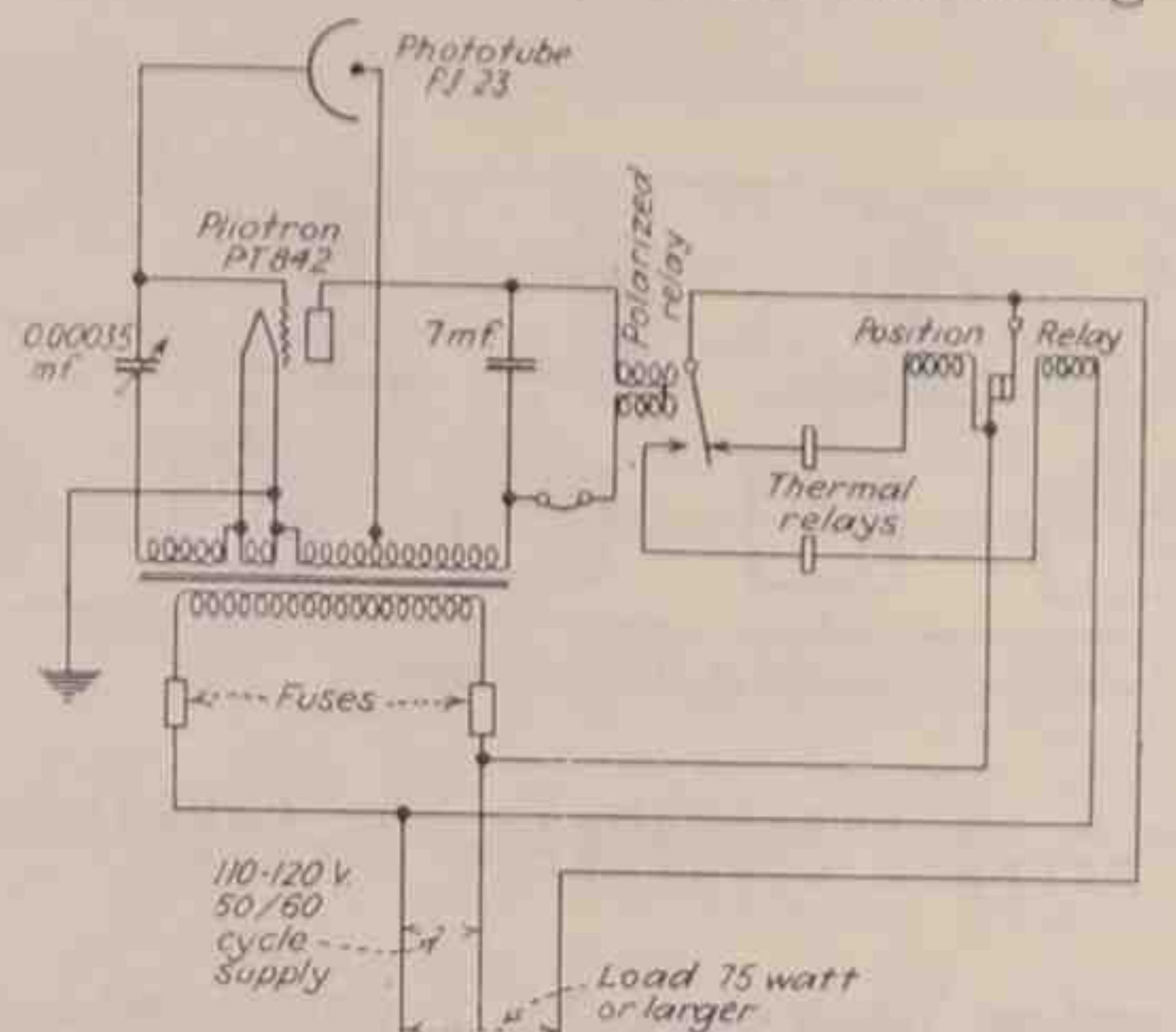


Fig. 14 - THIS CIRCUIT IS ESPECIALLY ADAPTED FOR CONTROL OF ARTIFICIAL ILLUMINATION IN ACCORDANCE WITH DAYLIGHT.

mounted in a variety of positions as required by the application. A modification of the circuit in Figure 13 is shown in Figure 14. Here a phototube and triode are similarly combined, but with special features. The negative bias of the triode is adjusted by means of a variable capacitor which facilitates the setting of the device for operation at a given light intensity. Small thermally operated time-delay relays are interposed between the plate relay and the position

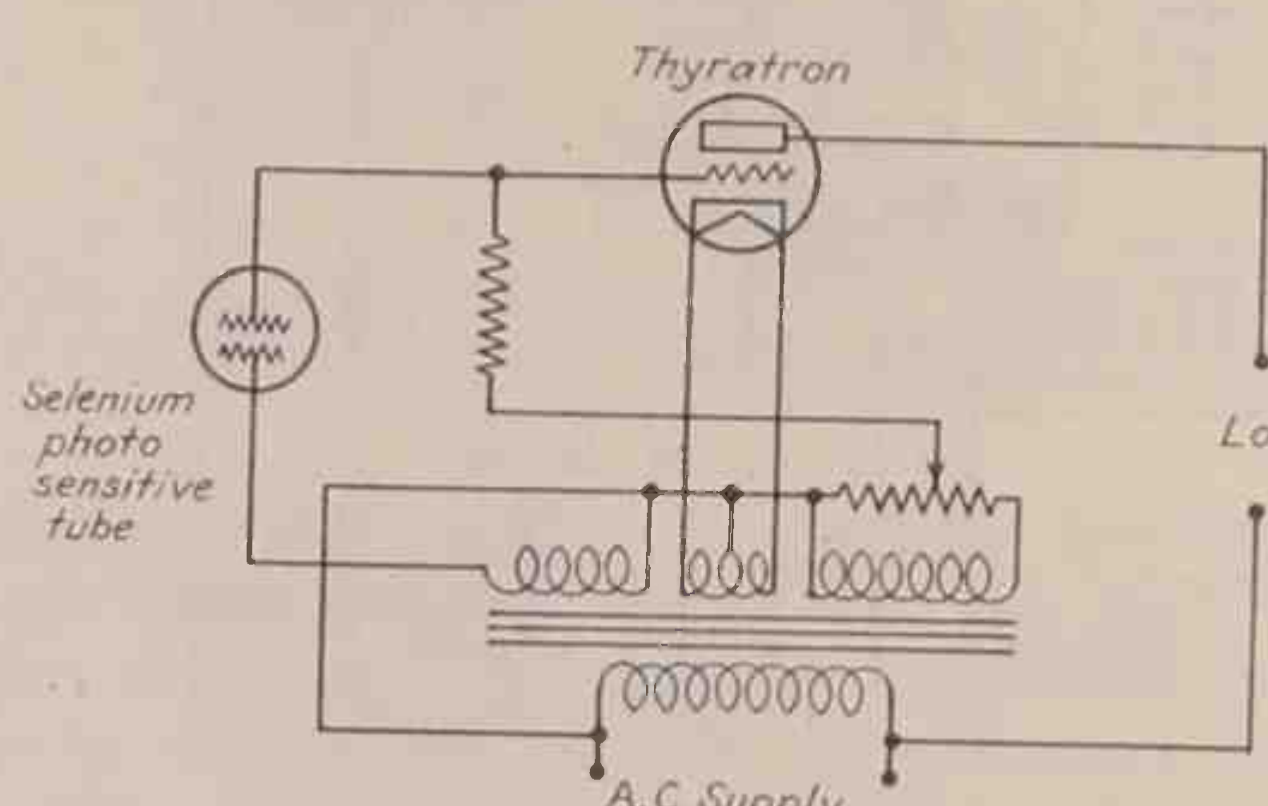


Fig. 15 - A MECHANICAL RELAY IS NOT REQUIRED IN THIS ILLUMINATION CONTROL CIRCUIT.

relay making it necessary for a given change of light to be maintained for several seconds before the position relay is operated. This circuit is particularly adapted for the control of artificial illumination in accordance with daylight. It has been used for street light and sign control. Such apparatus will automatically turn lights "on" and "off."

The circuit in Figure 15 combines a thyratron and a selenium photosensitive tube. It provides for illumination control by means of an "on" and "off" relay which is sensitive to light and capable of controlling a large contactor or load directly without the use of a sensitive mechanical relay. When no light falls on the selenium tube the thyratron has positive bias, but when the selenium tube is exposed to sufficient light, this bias is overcome and the thyratron ceases to pass current.

The practicability of the photoelectric cell for regulating traffic lights is being given serious consideration. The Westinghouse Elec-

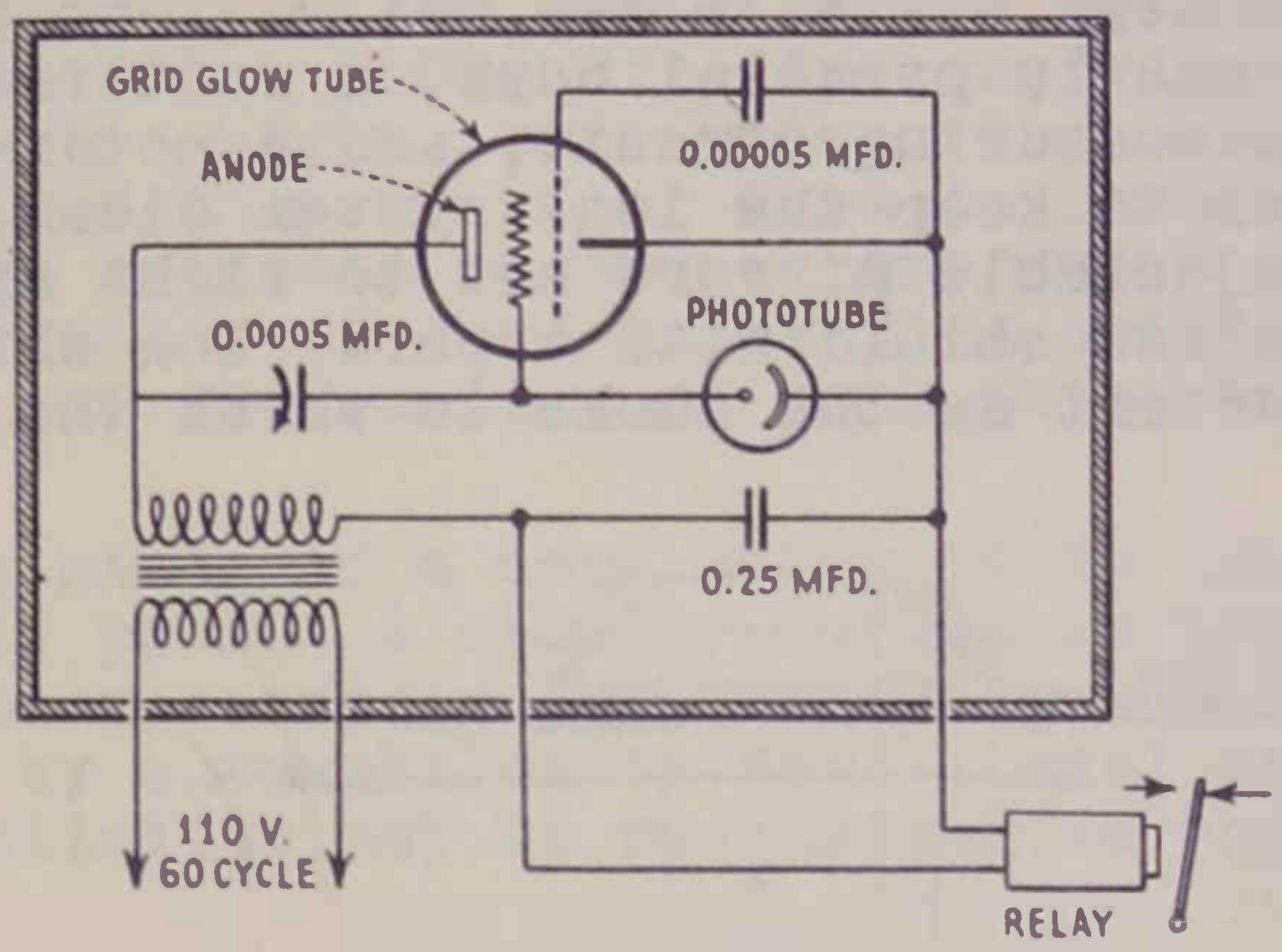


Fig. 16 - PHOTOTUBE SECTION OF A DEVICE WHICH CONTROLS TRAFFIC LIGHTS.

tric and Manufacturing Company has installed traffic lights operated by neon tubes on certain street corners for this purpose. It has long been felt that the stopping of traffic at regular time intervals

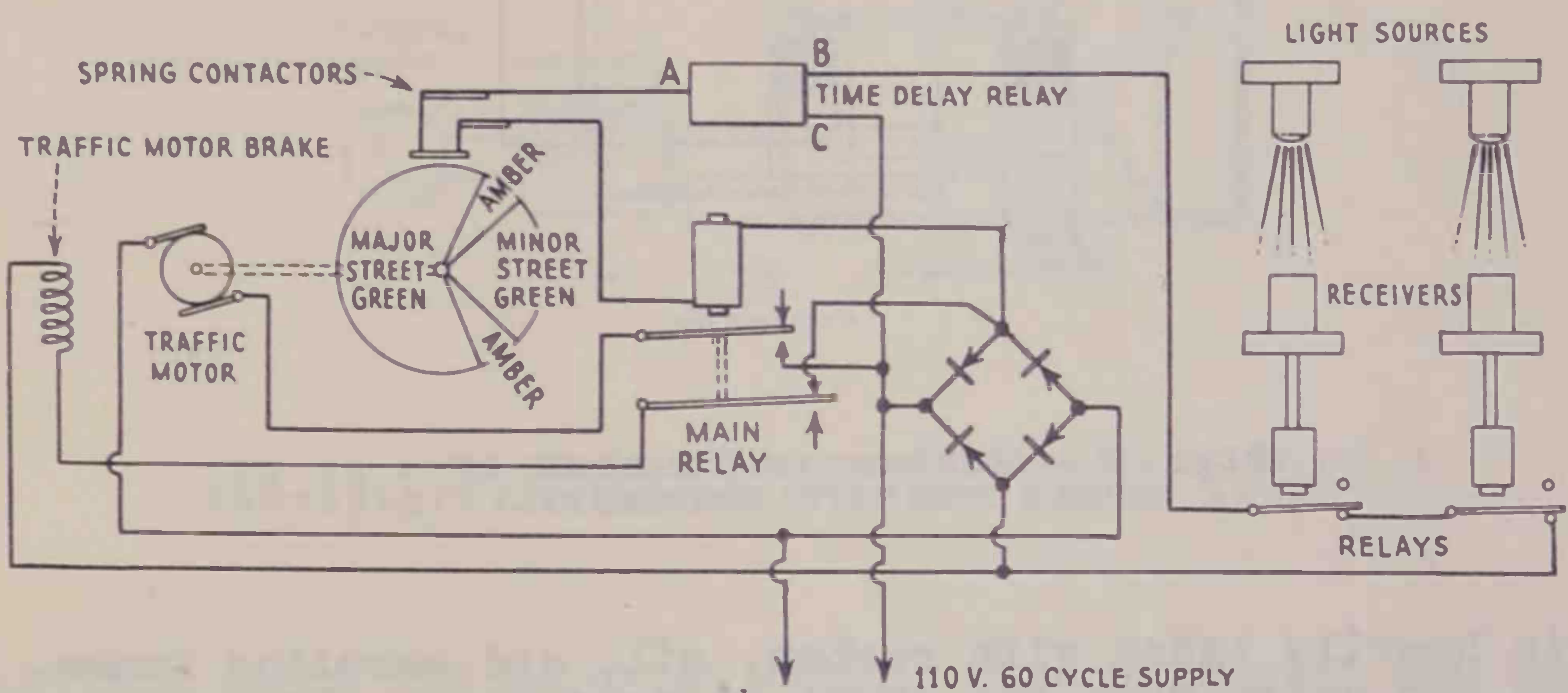


Fig. 17 - THE LIGHT AND RELAY MECHANISM OF A DEVICE USED FOR CONTROLLING TRAFFIC LIGHTS.

on main highways is wasteful of time as very often there are no cars waiting on the intersecting minor street to cross when the main thoroughfare light turns red. The ideal method would be to have a green light on the main thoro hfare at all times giving the right of way to the nor street only when it is needed.

e general gement of the phototube circuit and light and relay mechanism are sho respectively in Fi es 16 d 17. e function depends primarily upon the interruption of a beam of light by an automobile or any vehicle which comes between the photocell and the light source. In order not to stop traffic on the main highway when cars make a right turn from the highway to the minor street a time delay relay is used which makes it necessary for a car to stop in front of the light beam for a few seconds before the traffic light will change color.

SMOKE DENSITY. Figure 18 shows a schematic diagram of a smoke density recorder which has been built in two units. One box contains a source of light giving a nearly parallel beam, a rectifier-filter system, a photoelectric tube measuring circuit, and a motor-rotated glass dust shield with a wiper to keep the lens system clean. A second box contains a pair of adjustable mirrors set to right angles together with another rotating glass shield with wiper. The shields with cleaning mechanism are important as the smoke to which the whole apparatus is

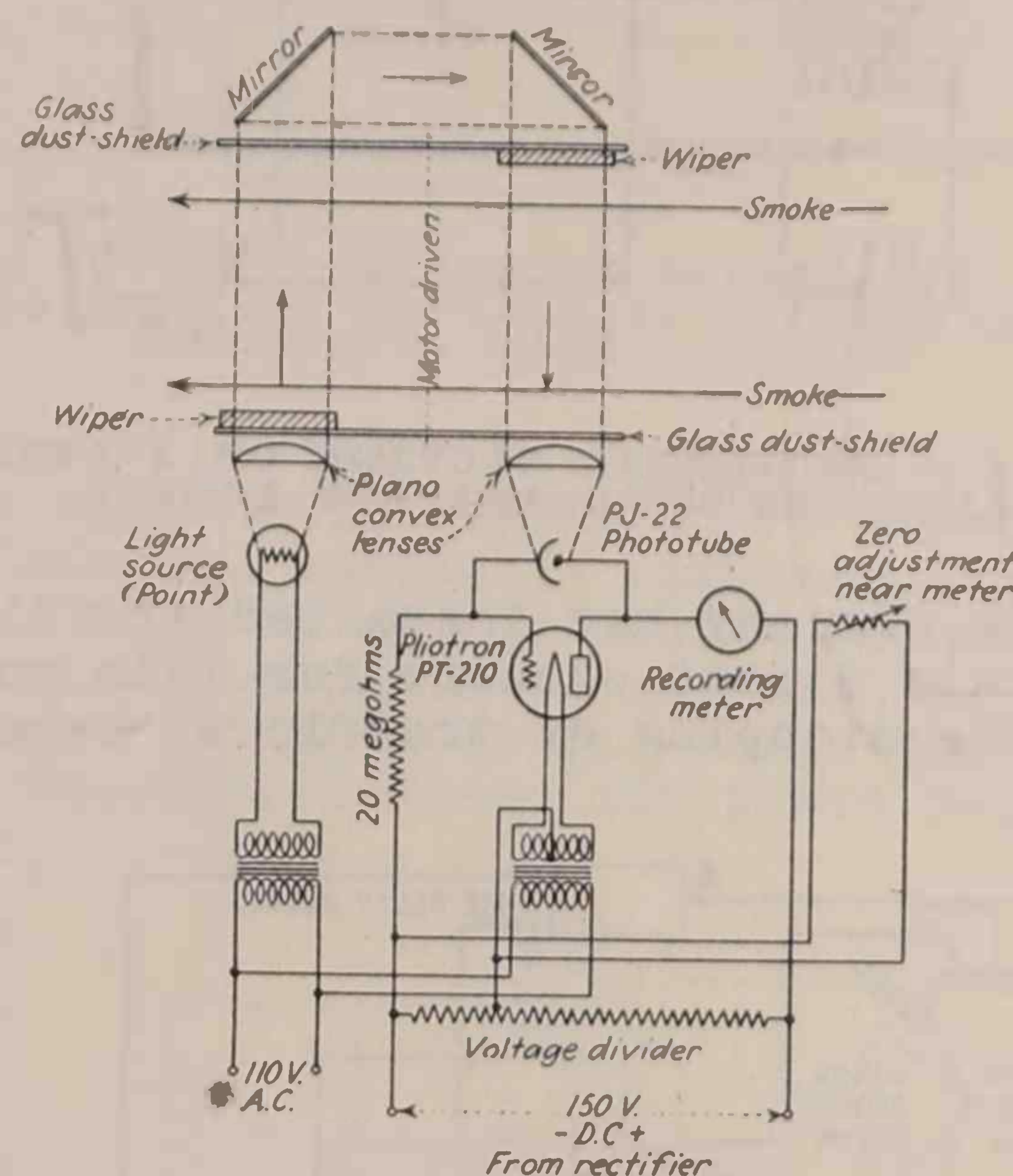


Fig. 18 - SCHEMATIC DIAGRAM OF A SMOKE DENSITY RECORDER.

exposed is heavily laden with carbon, oil, and gasoline fumes. In some cases the units were set about 80 feet apart giving a total beam length of 160 feet.

The system operates as follows: With no smoke interposed between the lens system and mirror system, a fixed amount of light reaches the photoelectric tube which keeps the grid positive with respect to the cathode allowing the plate current to assume a high value. When smoke is carried by the forced draft through the light beam the light is diffused depending upon the density of the smoke. The decreased light on the phototube causes the potential of the grid to become re negative d thus cause a decrease in plate curr t. is c - rent is brou t to the in supe iso control room d a graph is made on a recording milliammeter. A device also made by the Westinghouse Electric and Manufacturing Company for indicating the density of smoke makes use of a combination photocell and amplifier.

The unit is placed in a metal box and is mounted at the end of a small pipe, the end of which opens into one side of a chimney. On the other side of the chimney a lamp is placed so that its rays are directed toward the photocell at the end of the pipe. Thus the rays from the lamp first traverse the smoke in the chimney, then the small pipe, and finally reach the photocell where any change in the smoky medium through which the light rays pass will be recorded and amplified. The output of the amplifier tube is connected to a recorder upon which is kept an accurate record of the smoke density over a period of time. The color of flue gases in a chimney is indicative, to a certain extent, of the quality of combustion in the furnace.

When a chimney emits gases of a dark color it is usually an indication that the fire is poor. A similar device is used in the Holland Automobile Tunnel which connects New York City and Jersey City. The gas fumes given off by automobiles in this tunnel are measured so that the proper ventilation may be maintained to prevent injury to health.

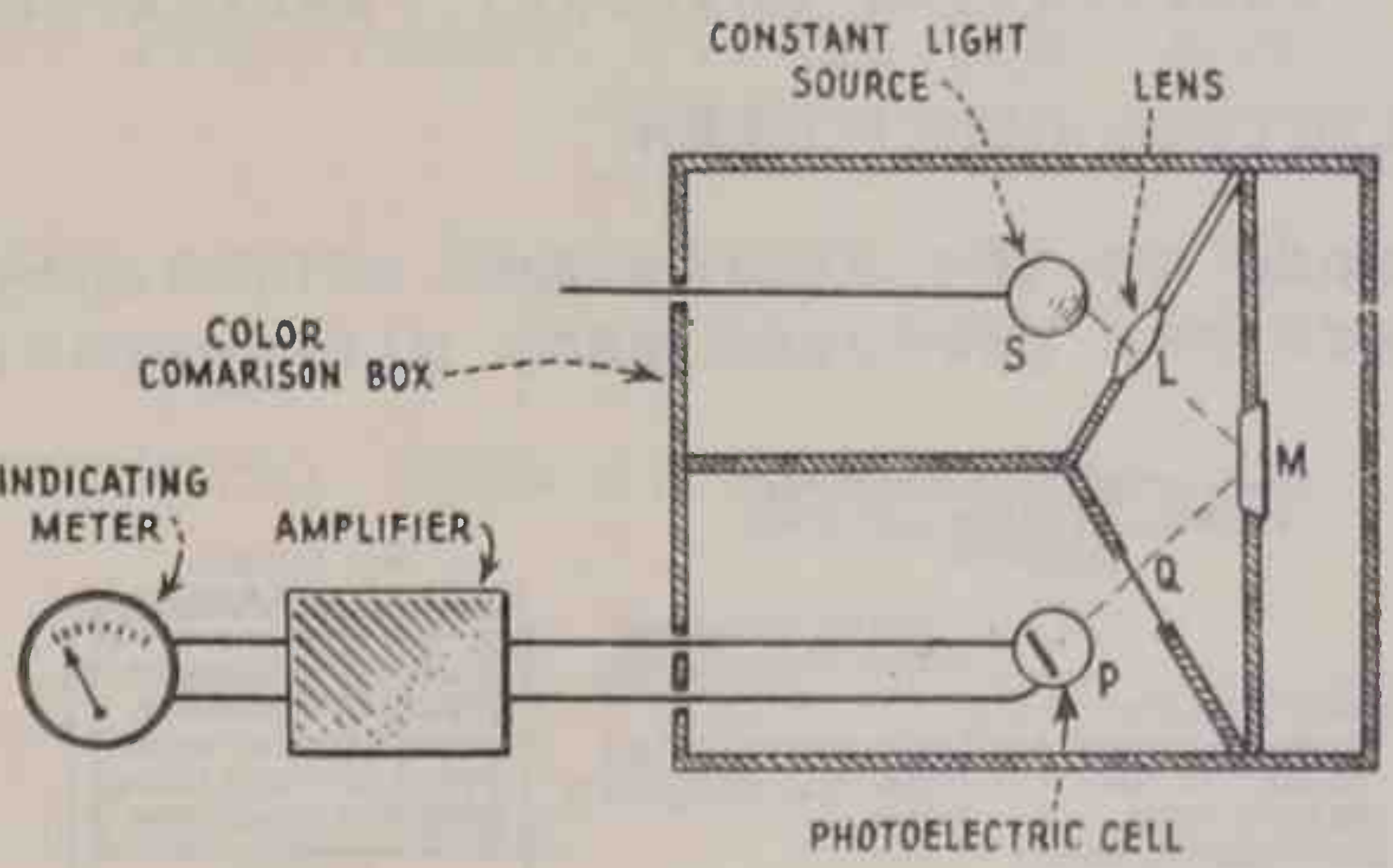


Fig.19 - ILLUSTRATING THE GENERAL PLAN OF A PHOTOELECTRIC COMPARATOR FOR COLOR MATCHING.

PHOTOELECTRIC CELLS FOR MATCHING COLOR. The photocell may be used in various practical ways for the measurement of different qualities and intensities of light much more accurately than can be accomplished by the eye. This is particularly useful for matching colors.

Figure 19 shows in general how a phototube P, is connected through an amplifier to a meter to indicate any change in color at M. The meter is placed in the plate circuit of the amplifier to provide the indication. A constant source of light S is caused to pass through a lens L and is reflected from any material M whose color is to be compared with that of the standard color glass at Q. If the color of the substance at M is identical with that of the glass at Q no variation will be recorded by the photocell P, and therefore there will be no fluctuation of the indicating meter. The entire unit is made of a light proof material. Color filters may be used to match colors at various points in the spectrum. If, however, the color glass Q is omitted there will be an indication on the meter as the photocell responds to the particular color frequency to which it is sensitive.

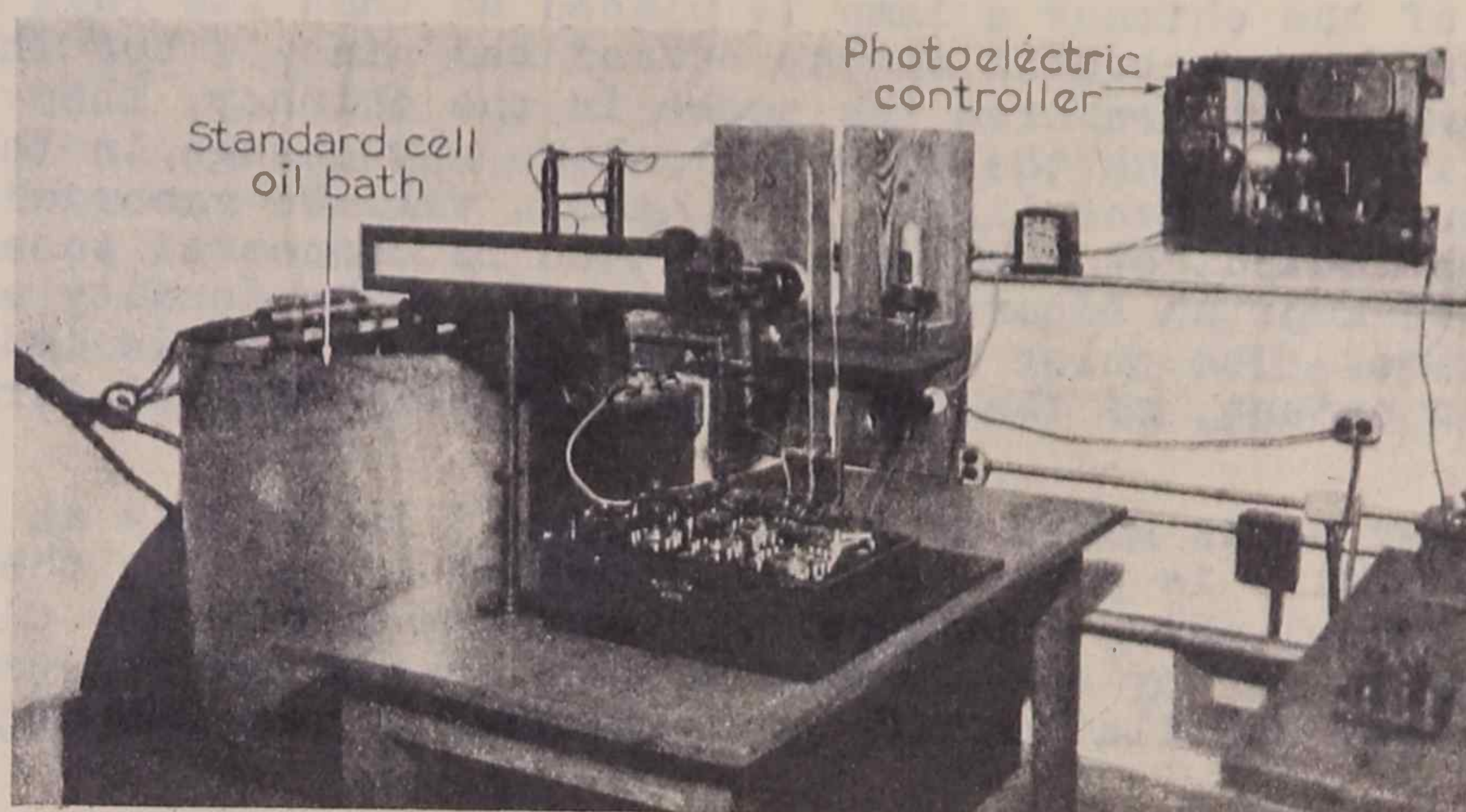


Fig. 20- VIEW OF INSTALLATION USED FOR MAINTAINING CONSTANT TEMPERATURE.

A PRECISION PHOTOELECTRIC CONTROLLER

The rapid strides made in the design and efficiency of electron tubes in the last few years has produced many ultra-sensitive instruments

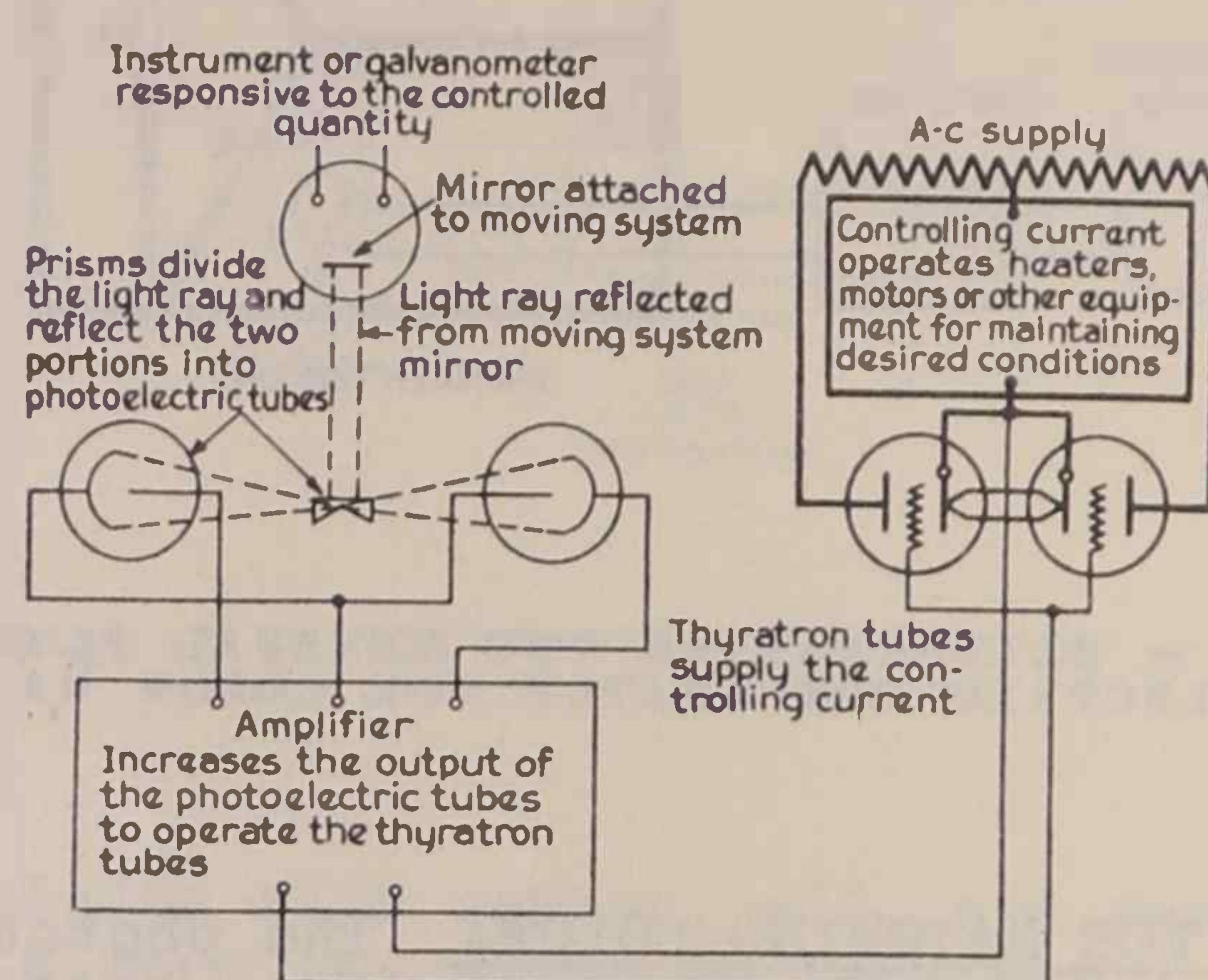


Fig. 21 - DIAGRAM OF CONNECTIONS FOR PHOTOELECTRIC CONTROLLER.

used in the measurement of both electrical and non-electrical quantities. One example is the photoelectric controller, shown in Figure 20, developed by the General Electric Co. for maintaining the standard cell oil bath at constant temperature: the oil bath is in the tank at the left. The schematic diagram of the controller is shown in Figure 21. In brief the equipment operates as follows: The basic instrument is connected across the balance points of a Wheatstone bridge consisting of copper and manganin resistance immersed in the oil bath. The bridge is adjusted to balance at 25° C. and will become unbalanced at other temperatures because of the difference in the temperature coefficient of opposite resistance arms. The illumination on the phototubes will become unbalanced when an unbalance in the bridge deflects the basic instrument. The unbalancing of the illumination on the phototubes sets up a potential which is amplified and applied to the grids of the thyratrons which in turn regulate the value of the heating current passing through resistors placed in the oil bath. The heating effect of the control current is continuously balanced against the cooling effect of water which circulates in the oil bath.

EXAMINATION QUESTIONS

1. What is the principal advantage of the caesium type phototube over the selenium cell?

2. What is the principal disadvantage of any phototube compared to the selenium cell?

3. What is the chief requirement of the load connected to a phototube?

4. What effect on the above is caused by a small capacity in shunt to the load?

5. Describe the structural form of phototubes most used in sound pictures.

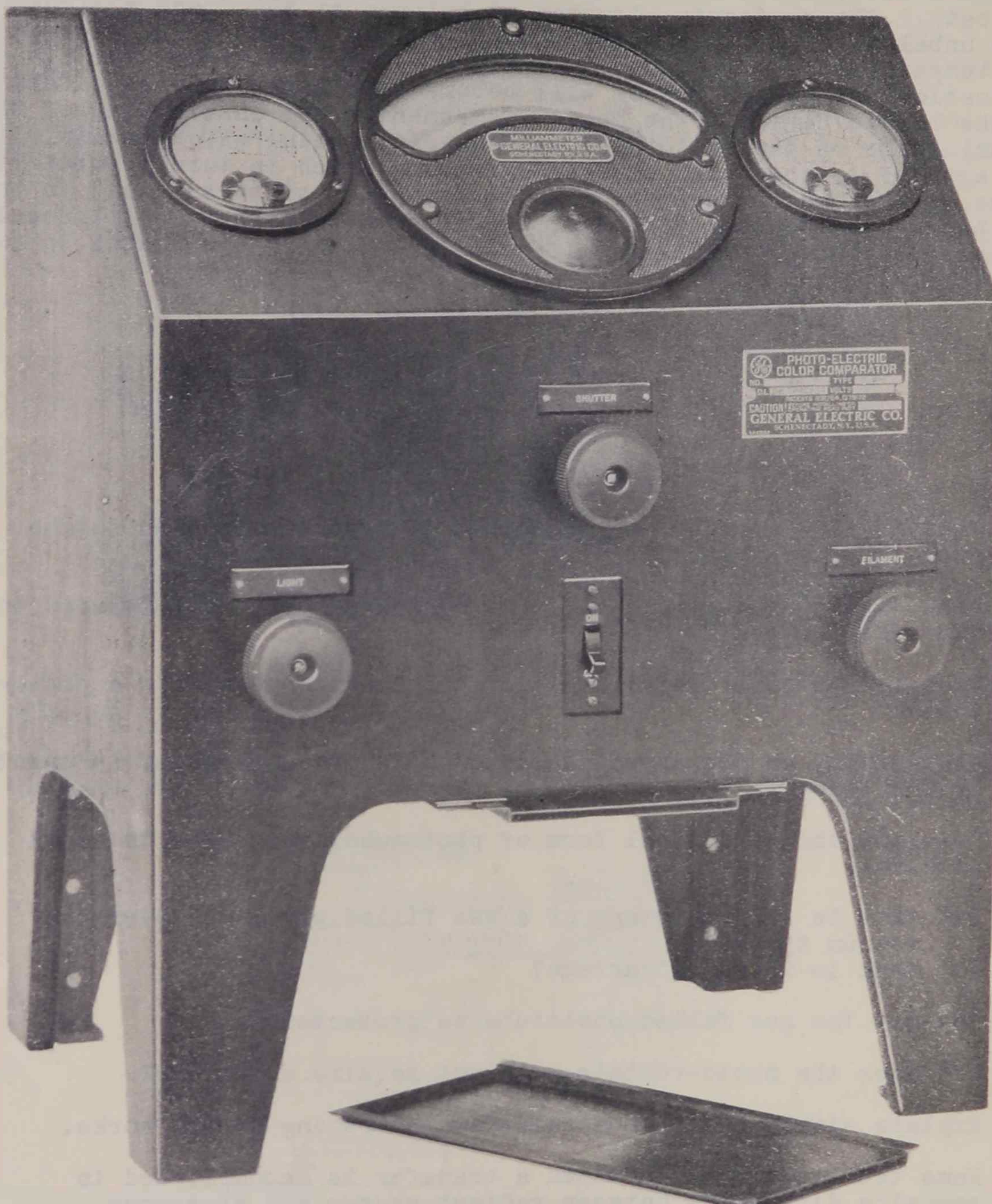
6. (a) What is the advantage of a gas filled phototube over the vacuum type?
   (b) What is the disadvantage?

7. How may the gas filled phototube be protected?

8. Why does the photo-voltaic cell not require a battery?

9. Explain simply how a smoke density indicating device works.

10. Name two inventions in which a transfer is accomplished in opposite directions between radiant energy and electrons.



Courtesy General Electric Co.

A PHOTOELECTRIC TUBE OPERATES IN THIS COLOR COMPARATOR USED TO MATCH THE ROAST OF COFFEE BEANS.

RCA INSTITUTES INC.

3212

PRINTED IN U.S.A.

VOL. 13, No. 5

RCA

INSTITUTES INC

America's Oldest Radio School

CATALOG No. 3302

R. C. A. INSTITUTES, INC.

RESIDENT SCHOOLS

New York School, 75 Varick Street
W. F. AUFENANGER, *Superintendent*

Chicago School, 1154 Merchandise Mart
GEORGE I. MARTIN, *Superintendent*

HOME STUDY DIVISION

75 Varick Street, New York, N. Y.

R. C. A. INSTITUTES, INC.—Home Office—75 Varick Street, New York, N. Y.

R·C·A·INSTITUTES·INC·
AMERICA'S OLDEST RADIO SCHOOL
HOME OFFICE 75 VARICK STREET
NEW YORK

FFICE OF THE
RESIDENT

Dear Sir:

In presenting you this copy of its catalogue, R.C.A. INSTITUTES extends its well wishes for your future.

During the twenty-four years of our existence as a radio training school we have watched the progress of many men, like yourself, with an interest in radio. Many of them have studied in this school. In the earlier years they came because it was the only radio school; more recently, in most cases, because of our connection with the radio industry, which carries with it a source of knowledge of late radio developments and an assurance of the best and most modern equipment.

We have seen these men apply themselves with earnestness and ambition. As time went on, we have seen them leave with their diplomas, their training completed. It is a matter of pride with R.C.A. INSTITUTES how many of them have sent their friends or their employees to the school they attended. That, in itself, tells a story of our training facilities. It bespeaks, moreover, the confidence of the well trained man in the future of radio.

It is to men like its former students that R.C.A. INSTITUTES addresses its present catalogue. We hope you are of this type - ambitious and confident of the ultimate future of the radio industry. Confidence in the progressive development of radio in its various branches is a real help in acquiring knowledge of its technique and practice. It is incumbent upon us to uphold the prime purpose of R.C.A. INSTITUTES - providing thoroughly trained personnel to carry on the work of the industry, of which R.C.A. INSTITUTES has long been recognized as an important integral part. We promise no easy jump to success and are not seeking students who expect one. The students we are looking for are those who recognize the difficulties success in any line entails and the large part proper preparation plays in it. We make no promises as to employment.

We invite you to visit us and inspect our instruction facilities without obligation. Should you decide to enroll, we shall be glad to welcome you as a student. If it is inconvenient for you to attend our day or evening classes, there is an excellent flexible system for home study, several new features of which are described in the Home Study section of this catalogue.

Cordially yours,

C. J. Pannill

President

RCA Institutes Inc. A Radio Corporation of America Subsidiary

S. O. 759979 5M 2-16-33

ORIGINAL

Application for Enrollment in

R. C. A. INSTITUTES RESIDENT SCHOOL

at { ☐ New York, N. Y., 75 Varick Street
☐ Chicago, Ill., 1154 Merchandise Mart.

Applicant should answer all questions on the original and duplicate (both sides), and send to address checked above.

I hereby apply for enrollment in the Resident School course checked ☒ below. If this application is accepted in writing by the R. C. A. Institutes, Inc., the duplicate will be detached and returned to me, and this application, together with the terms and conditions printed in Catalog No. 3302 shall constitute an agreement between the undersigned and the R. C. A. Institutes, Inc. If not accepted, the **$10.00** advance payment, I enclose herewith will be returned.

I understand that **I AM NOT OBLIGATED IN ANY WAY WHATSOEVER, TO COMPLETE THE COURSE, NOR TO PAY FOR IT IN FULL,** and that class instruction will be furnished only in proportion to payments I may make; in consideration whereof the R. C. A. Institutes, Inc., reserves the right to alter or discontinue any course or to terminate this agreement upon sixty (60) days' notice without liability of any kind.

COURSES	DAY		EVENING	
	Weekly Tuition	Class Starting	Weekly Tuition	Class Starting
GENERAL COURSE Nos. 1, 2, 3 and 4	$10		$6	
RADIO BROADCASTING Studio, Transmitters and Code	$10		$6	
SOUND Commercial and Home Talkies, and Fundamentals of Television	$10		$6	
COMMERCIAL OPERATING Marine and Aviation Radio, Aerology	$8		$5	
RADIO SERVICE Broadcast Receivers, Home Talkies, Television	$7		$4	
COMBINATION, OR OTHER COURSE:				

All prior agreements or understandings, whether written or oral, between the R. C. A. Institutes, Inc., and the applicant are hereby terminated.

Dated.......................................19........ ....
(Signature of Applicant)

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Application for Enrollment in

R. C. A. INSTITUTES RESIDENT SCHOOL

at { ☐ New York, N. Y., 75 Varick Street
☐ Chicago, Ill., 1154 Merchandise Mart.

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I hereby apply for enrollment in the Resident School course checked ☒ reverse side. If this application is accepted in writing by the R. C. A. Institutes, Inc., the duplicate will be detached and returned to me, and this application, together with the terms and conditions printed in Catalog No. 3302 shall constitute an agreement between the undersigned and the R. C. A. Institutes, Inc. If not accepted, the **$10.00** advance payment, I enclose herewith will be returned.

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All prior agreements or understandings, whether written or oral, between the R. C. A. Institutes, Inc., and the applicant are hereby terminated.

DO NOT USE THIS SPACE

....
(Signature of Applicant)

Dated.......................................19........

Resident School Courses

THE Resident School courses offered by the R.C.A. Institutes cover practically every branch of radio. There are elementary courses for the beginner as well as more difficult work for the advanced student. Instruction in Radio Broadcasting, Radio Operating, Aviation Radio, Radio Service work, Advanced Radio Service, Sound Motion Pictures and Public Address work are now being offered.

THE RADIO BROADCASTING COURSE offers complete training in every detail of broadcasting from the studio to the transmitter. It is the most complete course on the subject ever offered, and was made possible only by the co-operation of some of the broadcasting stations, two of the largest operating groups and the foremost manufacturers of broadcasting equipment. This course prepares for a radiotelephone operator's license examination.

THE RADIO OPERATING COURSE prepares a student for a Second or Third Class Radiotelegraph Operator's License Examination. Complete training in code, technical equipment, as well as necessary radio laws are part of this course. The Radio Operating Course is given in both Resident Schools. The instruction given in the Aviation Radio part of this course covers every detail of aviation radio equipment for both ground and plane use. Instruction is also given in aerology and avigation for the radioman.

THE RADIO SERVICE COURSE offers complete training in servicing of radio receivers and other home entertainment equipment and is designed to train a man so that he may go out into the field as a radio serviceman. This course is given in all Resident Schools.

THE ADVANCED RADIO SERVICE COURSE provides an intensive training in advanced radio service, factory testing methods as well as testing methods and equipment employed in some of the larger service laboratories. This course provides the necessary training to fit a man to take charge of a large service organization.

THE SOUND COURSE offers complete training in the installation and maintenance of Sound equipment in theatres and other places where such equipment might be installed. The installation and maintenance of public address systems is also covered. This course is given in the New York and Chicago Resident Schools.

LOCATION OF RESIDENT SCHOOLS

EACH school of the R.C.A. Institutes is conveniently located with regard to transit facilities. Comfortable living rooms are obtainable in nice locations at the usual low big-city rates. Many students choose to live in the smaller near-by cities and towns. In New York members of the staff of the Institutes commute from New Jersey, Connecticut, Long Island and places north of the city, the year around.

The New York school is conveniently reached from any section of Manhattan, Bronx, Brooklyn, Queens or points in New Jersey.

The Canal Street station of the Seventh Avenue subway is within a few feet of the entrances to the building. The Grand Street station of the Sixth Avenue elevated railroad, and the Desbrosses Street express station of the Ninth Avenue line, are within three short blocks. Crosstown surface cars pass the building. A station of the new Eighth Avenue subway is a short block away. The entrance to the vehicular tunnel to New Jersey is across Holland Plaza, while the exit is on the opposite side of Canal Street.

In Chicago the school is on the eleventh floor, northwest section, of the famous Merchandise Mart at 222 North Bank Drive, close to and overlooking the junction of the Chicago rivers. The Merchandise Mart station of the elevated railroad is entered direct from the building. This line connects with all electric lines to Northern Illinois. Surface cars pass the door and it is but a minute's walk to the center of the loop district. The building is noted for the unusual amount of sunlight flooding all floors and for its modern "air conditioning" system.

PERTINENT INFORMATION ABOUT RESIDENT SCHOOL COURSES

DAY classes are in session morning and afternoon, except Saturdays and holidays. Evening classes are in session on scheduled days, Saturdays and holidays excepted.

Classes are conducted throughout the entire year. The R.C.A. Institutes does not suspend classes for summer vacation. Dates on which new classes convene will be found in the Class Schedule obtainable upon request from nearest school.

R.C.A. Institutes reserves the right to reject any applicant and to expel any student who does not maintain the proper interest in his studies. R.C.A. Institutes also reserves the right to change, without notice, tuition fees, instruction outlines or class schedules.

Tuition fees, or any portion of fees paid, will in no case be returned. The advance payment, however, will be refunded if the application is not accepted or the enrollment is not completed.

General Course

GENERAL COURSES No. 1 and No. 2 are especially arranged for students who desire to cover the entire field of radio, and to prepare themselves for handling problems of practical radio engineering in any associated fields that may result from new developments yet to come.

As the name implies, the General Course includes all subjects given individually in the four basic courses described in detail in the following pages of this catalog. The student thus obtains a thorough general knowledge and wider perspective of the radio industry as a whole. In addition, he receives practical and complete training in each of the basic specialized branches of the art. He is, therefore, not limited to one particular field of endeavor, but is in a position to choose intelligently the field which he wishes to follow as a career. He also possesses the diversified training necessary to take immediate advantage of opportunities in related fields as they arise.

Students taking General Course No. 1 are required to have one and one-half years of high school algebra.

The order in which studies in the four basic courses are covered by students taking General Course No. 1 is as follows:

1.—Sound Course
2.—Broadcast Course
3.—Radio Service Course
4.—Operating Course

This is, however, only possible if the student has one and one-half years of high school algebra or more.

Fifty-two weeks are required to complete the day course and one hundred eleven weeks for the evening course. The tuition fee is $160.00 which includes all text books. A $10.00 advance payment must accompany the enrollment application; $20 is payable when classes begin, and the balance may be paid at the rate of $10.00 per week for the day class and $6.00 per week for the evening class.

General Course No. 2 covers the same work as No. 1, but is designed for those persons lacking the necessary academic training for entrance in No. 1.

A typical set-up in the field illustrating sound-recording methods

The order in which studies in the four basic courses are covered by students taking General Course No. 2 is as follows:

1.—Commercial Operating Course
2.—Radio Service Course
3.—Broadcast Course
4.—Sound Course

The reason for the change in sequence being that the student is given the necessary academic training which he lacks during the first half of the Commercial Operating Course. This, of course, lengthens the number of classroom hours.

This course requires sixty-five weeks for completion in the day class and one hundred thirty-seven weeks in the evening. The tuition fee is $510.00 and may be paid on the same terms as General Course No. 1.

Class schedules may be obtained by writing to the nearest school. Since these classes are limited in size, an early registration is suggested to avoid the disappointment of finding all the classes filled.

RESIDENT SCHOOL

RADIO *Broadcasting*

TO EXCEL in performance is the paramount desire among the various broadcasting stations and systems. Utmost efforts are exercised to retain public interest and approval. As a result the directors of radio broadcasting have long been striving to raise their program presentations to the highest plane. At the same time experts are busy with problems of modulation, monitoring and transmission. All proposals promising improvement are investigated. And in the general progress of raising the art to the highest standard, the personnel, as well, is included.

It is recognized, and logically so, that if standards of broadcasting are to be elevated and maintained at the highest level, there must be provision for educating and actual training of the personnel. With the advent of Television and other innovations in the offing, there should be a need for trained men to operate broadcasting station apparatus.

This training must be along approved lines and it must have the actual indorsement of those experienced in the art so as to assure incorporation of their ideals.

Instruction courses formulated from the angle of only one or two individual stations, without considering the larger broadcasting systems or the art as a whole, are likely to confuse the student and retard progress in the broadcasting field.

With these predominating thoughts, executives, engineers and technicians of NBC (National Broadcasting Company), CBS (Columbia Broadcasting System), WOR (The Bamberger Broadcasting Service), WGY (General Electric Company), KDKA (Westinghouse Electric and Manufacturing Co.) and other stations throughout the country, have assisted in the compilation of the R.C.A. Institutes Radio Broadcasting Course. In addition the manufacturers of equipment used in broadcasting, including RCA Victor Co., Inc., and Western Electric Company, have cooperated with information on the use of their apparatus.

The value of the R.C.A. Institutes Course in Radio Broadcasting can well be appreciated from the standpoint of its authentic compilation, and extension to apply to current developments. To travel along with the developments in the art requires direct contact with laboratory design of apparatus and advanced practice in its use in the field. R.C.A. Institutes is in a position to maintain this contact, and revises its courses to include instruction about new developments as rapidly as they occur.

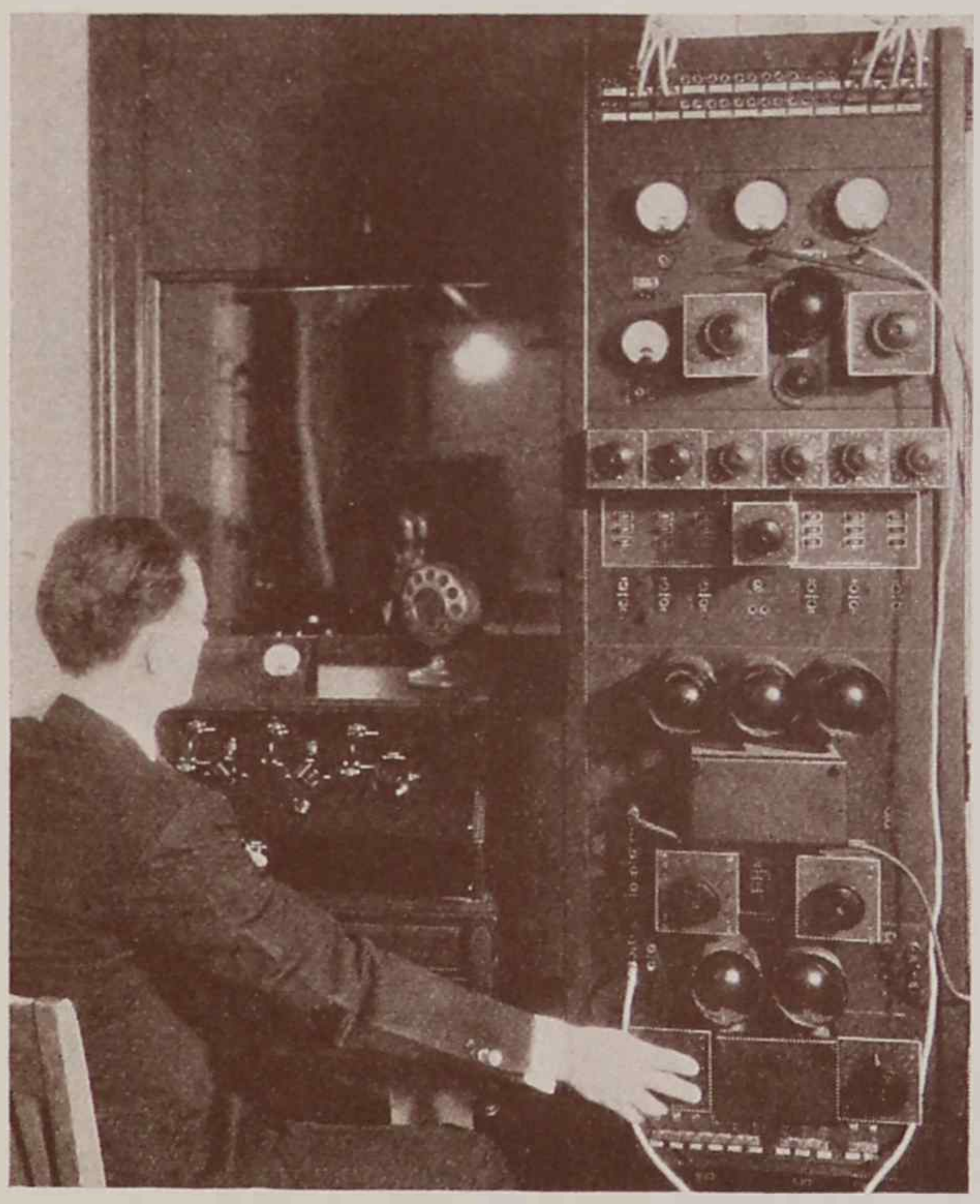
This Radio Broadcasting Course was originally compiled solely for instruction of the employed personnel of the various broadcasting companies. It, therefore, reflects the ideals of the established broadcasting organizations.

It was immediately realized, however, that limitation of enrollment for the course to present broadcasting stations' personnel would not take care of the future. It was believed that as time goes on the need for trained men would increase. For this reason it was decided to accept applications for the course from young men showing aptitude for broadcasting work who submit acceptable qualifications.

Now a word about the outline of the R.C.A. Institutes Course in Broadcasting. We believe this is by far the most comprehensive course in Radio Broadcasting ever attempted by any school. Extensive training is given in the operation, maintenance and repair of broadcasting studio control room equipment as well as broadcasting transmitters.

Since this course prepares a student for a position with any broadcasting system, it is essential that the student have a training in code, the reason for this being that a great deal of the interdepartmental communications are carried on by telegraph. The student in this course is, therefore, required to attain a speed of at least fifteen (15) words per minute for graduation.

This training in code is of special importance when a man becomes a member of the field group or remote crew. Very often his only method of communication back to the studios is by means of telegraph. The use of short wave transmitters is becoming of great importance in remote pickups, and a knowledge of code in the operation of these units is highly desirable.

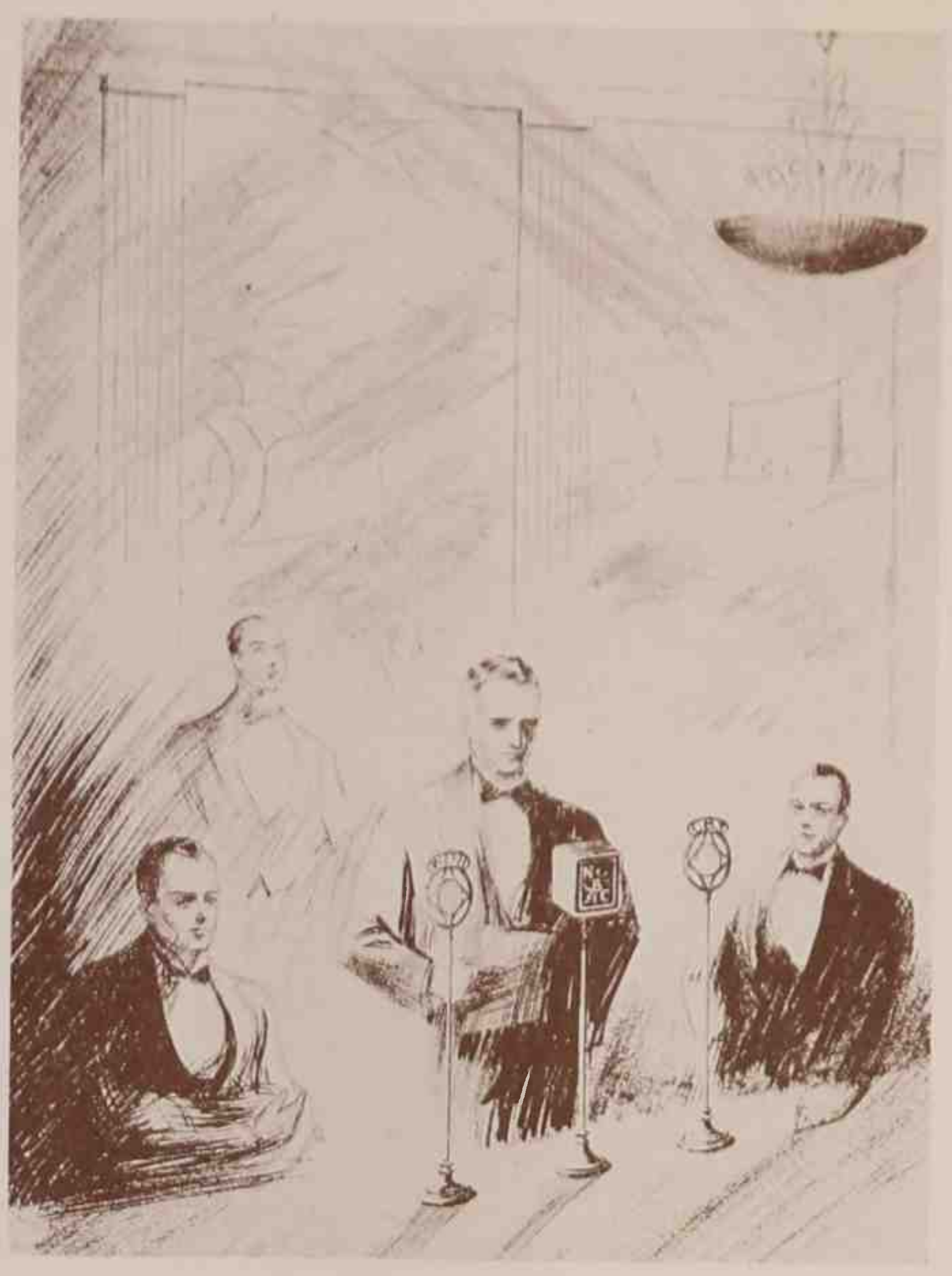


Students are given instruction in the maintenance and operation of broadcasting equipment

TECHNICAL SUBJECTS

THE following subjects are covered in the technical section of the course: Electron theory, Ohm's law, power and energy, primary and storage cells, magnetism, electromagnetic induction, DC motors, DC generators, DC meters, AC theory, AC circuits, transformers, AC motors, the decibel, impedance matching, filters, attenuators and volume controls, vacuum tubes, amplifier theory, photoelectric cells, physics of sound, acoustics, broadcast studios, microphones and microphone placement, mixer panels, audio amplifiers, volume indicators, monitor equipment, relays and control circuits, characteristics of telephone lines, necessity of impedance matching, audio oscillators, making frequency runs, equalizer and line equalization, pads, filters and networks, remote pick-ups, studio and control room power supply, electrical transcription equipment and disc recording, handling chain programs, control room design for multiple studio, standard commercial control equipment, transmitter power supply, motors, generators and control equipment, high voltage rectifiers, filter equipment, quartz crystal, crystal oscillators and temperature control units, buffer amplifiers, intermediate power amplifiers, modulation systems, modulator tubes and characteristics, modulated power amplifiers, linear power amplifiers, standard broadcasting transmitters and their operation, short wave broadcasting transmitters, television transmitters, antenna coupling systems, antennas, harmonic elimination, RF measurements, oscillographs and oscilloscopes, water supply and cooling systems, synchronizing methods, station management, Federal Radio Commission regulations, International Radio Convention and Radio Acts of the United States.

Persons desiring to take this course should have had at least two years of academic or scientific high school work or its equivalent. Some musical training is desirable, but not absolutely necessary.



Proper installation of microphones requires technical training—students are given this training in the Radio Broadcasting Course

A student is given information and theory instruction in the proper maintenance and operation of standard broadcasting equipment as it exists today. He is given actual practice in control room work and the monitoring of programs by being required to act as control operator in the studio. Inspection trips are arranged for the students to visit the studios of the National Broadcasting Company, Columbia Broadcasting System and other stations, as well as to view some of the larger broadcasting transmitters in actual operation. The student is also made familiar with some of the problems that arise in dealing with artists, program arrangement and other things which would be of considerable importance were he to become manager of a broadcasting station.

The school is equipped with a broadcasting studio, control room, and standard broadcasting control equipment. The instructors have had years of experience in teaching students the practical phase of Radio Broadcasting. This method of instruction combined with the actual operation, adjustment and assembling of transmitting and monitoring apparatus provides the student with the theory and technique of present-day Radio Broadcasting Stations.

LENGTH OF COURSE

ABOUT 7 months in the day classes, and 14 months in the evening classes are required for the completion of the Radio Broadcasting Course.

TUITION FEE

THE tuition fee is $310, payable $10 per week for day classes, or $6 per week for evening classes. Ten per cent discount will be allowed when the full tuition fee is paid in advance. An advance payment of $10 is required at the time of enrollment, and $20 of the tuition fee is payable when the class begins.

Broadcasting activities hold a fascination from every angle. The technical man who sets a microphone on top of a tall building or at a point of vantage for the broadcasting of an exciting event, finds satisfaction in an accomplishment that results in perfect operation, and he shares the thrills of the listening public.

RESIDENT SCHOOL

Sound Course

INCLUDING HOME TALKIES AND FUNDAMENTALS OF TELEVISION

[FOR EXTENSION COURSE SEE PAGE 12]

THE day of the talking movie is here and many trained men have been employed in this new field of opportunity. Educational institutions are beginning to utilize sound equipment on a broad scale. Grade schools, high schools, colleges and private schools greatly outnumber theatres, and this phase of development has been barely touched.

The Sound Course not only teaches the student how to install and service modern sound apparatus, but it also covers the principles of sound and light subjects. Knowledge of these subjects will enable the student to take advantage of the opportunities in Acoustical Correction Engineering, Public Address Systems, Television and allied fields.

This course has been prepared with the idea in mind that the student is a beginner, hence no previous training in electricity or radio is required.

During the first part of the course the student is given a thorough training in the elements of electricity, principles of amplifiers, characteristics of vacuum tubes and photo-electric cells.

This preliminary work enables the student to readily assimilate the instruction given in the second part of the course where theory and practice go hand in hand in studying practical laboratory work on all standard types of sound motion picture and public address equipment.

Persons desiring to take this course should have had two years of academic or scientific high school work or its equivalent.

Students learn by working on standard apparatus

LABORATORY EQUIPMENT

THE laboratory equipment consists of an acoustically treated auditorium completely equipped with modern sound screen and sound projectors as well as various types of RCA Photophone and Western Electric sound equipment; Portable sound equipment, Recording Amplifiers, Microphones, and Sound-on-Disc Recording equipment.

LENGTH OF COURSE

SIX months in the day classes and forty weeks in the evening classes are required for the completion of the Sound Course.

Applicants for the Sound Course may interview one of the Institutes' instructors before enrolling. An appointment for interview is not necessary. The Institute's offices are open daily and evenings except Saturdays, Sundays and Holidays.

Class schedules may be obtained by writing to the nearest school, and individuals contemplating enrollment should register early as the classes are limited in size.

This course provides a most excellent background for those wishing to specialize in television.

Due to the increased use of photo-electric equipment in industrial work a special section of the course is devoted to this subject, taking up such applications as elevator control, door openers, counting, matching, assorting, etc.

SUBJECTS COVERED

ACOUSTICS—Acoustics of Theatres and Sound Stages, Methods of Measuring and Calculating Reverberation Time, Correction of Acoustical Defects.

PHYSICS OF LIGHT—General Theory of Light, Optics—including Principles of Lenses, Prisms, and Reflectors; Principles of Photography—including Color Photography.

MOTION PICTURES—General Theory; Motion Picture Cameras and Motion Picture Projectors, including a study of commercial forms and component parts.

ARC LAMP MECHANISMS—General Theory, Study of Low Intensity Reflector Type, High-low Intensity, and High Intensity Lamps; Methods of Feeding Carbons; Arc Lamp Supply.

RECORDING OF SOUND—General Considerations—Frequency, Amplitude, and Surface Noise Limitations; Disc Recording—Recording Mechanisms, Record Materials, Record Processing, Wide Range Recording; Film Recording, Variable Area, Variable Density Light Gate, Variable Density Glow Lamp; Noiseless Recording as applied to each of above systems, High Fidelity Photophone Recording; Typical Recording Layouts—Sound Stages, Microphone Technique, Sound-Recording Channel, Preliminary or Booster Amplifier, Volume Control Panel, Main Amplifier, Bridging Amplifiers, Portable Equipment Newsreel, Motor Systems—Synchronous Motor System, Interlocking Motor System, Non-interlocking System.

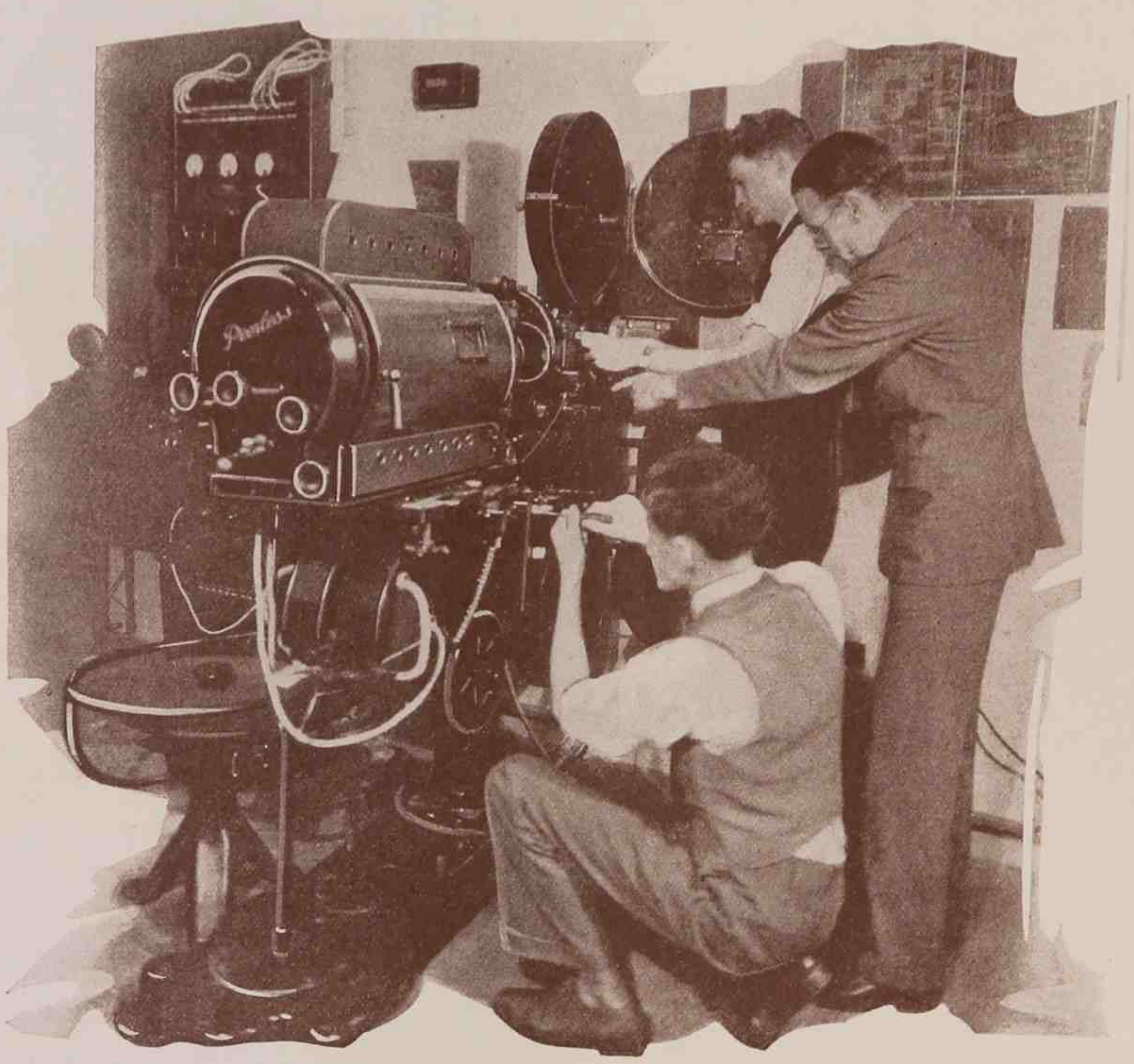
REPRODUCTION OF SOUND—Theory of Photo-electric cell, Photo-electric cell coupling Devices, Optical Systems, Exciter Lamps, Methods of obtaining Constant Film Speed, Study of Various Sound Heads, General Study of Reproducing Equipment.

THEATRE LAYOUT AND INSTALLATION—General Theatre Construction, Architecture, Stage and Booth Layout; Electrical Specifications and Construction; General Method of Installation of Equipment.

LOUDSPEAKERS AND PICKUPS—Theory of Pick-ups; Study of Various Types; Frequency and Mechanical Impedance Characteristics; Theory of Loudspeakers, Motor Units, Diaphragms, Horns; Features of Design of Motor Units, Diaphragms, and Horns; Frequency Characteristics; Installation and Orientation of Loudspeakers; Methods of Coupling Loudspeakers to Amplifier; Auto Transformer Coupling and Impedance Matching.

SERVICING OF MOTION PICTURE REPRODUCING EQUIPMENT—Sound Head Adjustments; Servicing and Testing of Amplifiers; Analysis of Various Sound Motion Picture Equipment, including 16 mm.; Frequency Output Characteristics.

PUBLIC ADDRESS AND PROGRAM DISTRIBUTION SYSTEMS—Choice of Proper Size Equipment for Installation; Microphone Stations; Mixer Control Panels; Amplifiers; Loudspeaker Banks; Industrial Applications of Photo-electric Cells.



Receiving instruction on adjustment and operation of Sound Motion Picture Apparatus

TUITION FEE

THE tuition fee for the Sound Course is $226, payable $10 per week for day classes, or $6 per week for evening classes. Ten per cent discount will be allowed when the full tuition fee is paid in advance. An advance payment of $10 is required at the time of enrollment, and $20 of the tuition fee is payable when the class begins.

RESIDENT SCHOOL

Radio Service —

[FOR EXTENSION COURSE SEE PAGE 15]

THIS course is one designed to train men in the theory of operation, maintenance and repair of Broadcasting Receivers, their associated accessories and equipment. It is a course for anyone interested in radio receiving apparatus including those who are already engaged in the radio industry. Radio dealers, distributors and men in service shops will find it especially helpful. Advertisers and salesmen will be better equipped and more successful in their own chosen lines of endeavor in this branch of the radio industry with the training this course provides.

No previous knowledge of radio, electricity, or mechanics is required for registration in this course.

The laboratory is also equipped with standard and modern types of test equipment, which includes set analyzers, meters, broadcast and intermediate frequency test oscillators, tube checkers—both counter and laboratory types—beat frequency oscillators, ohmmeter and capacity meters, etc. These are all available for student instruction and use.

The Institutes does not, however, supply students with small tools, and each student must supply himself with the necessary screw drivers, pliers, etc., which are necessary for service work.

Note—All students are held responsible for the return in good condition of all testing equipment requisitioned to them for laboratory work during the course.

The student receives instruction in the proper use of set analyzers

Thorough training is given in the theory and practice of radio receiving circuits, from the fundamental principles to actual practical testing, trouble shooting, repair and shop work. This course trains the student to qualify as a radio serviceman.

LABORATORY EQUIPMENT

THE R.C.A. Institutes' Receiver Service Laboratory is one of the most completely equipped laboratories of its kind in the country. The equipment consists of a large number of modern battery, A.C. and D.C. operated broadcast receivers, short wave receivers, police alarm receivers, automobile receivers, all products of well-known standard manufacturers, together with numerous types of reproducing and recording devices and record changers. All of this apparatus is used for the sole purpose of instructing students in maintenance, trouble shooting, testing and repair.

SUBJECTS TAUGHT

FUNDAMENTALS of electricity; batteries and battery chargers; magnetism and electromagnetism; alternating current; transformers; sound, electrostatic and magnetic propagation; vacuum tubes; radio frequency; audio frequency; power supply systems; speakers; testing equipment.

LENGTH OF COURSE

ABOUT three months in the day classes and six months in the evening classes are required for the completion of the Radio Service Course.

TUITION FEE

THE tuition fee is $94, payable $7 per week for day classes, or $4 per week for evening classes. 10 per cent discount will be allowed when the full tuition fee is paid in advance. An advance payment of $10 is required at the time of enrollment, and $20 of the tuition fee is payable when the class begins.

$94.00 9.40 $84.60

RESIDENT SCHOOL

Advanced Service

THIS advanced course has been inaugurated as a result of actual demand in the form of requests from servicemen and mechanics in the field who have good fundamental training and who have been engaged as technicians for some time. It is their desire to advance themselves by keeping pace with the latest developments. They also desire to equip themselves with service knowledge for the new innovations of sound and home "talkie" equipment and television receivers, centralized Radio and multiple set antenna installations.

Former graduates of this and other schools have also made requests for instruction covering developments made since their graduation.

Graduates of this course have the ability to perform work of a more advanced nature than that of the average service man or technician. This type of radio man is in the minority at present.

In every line of endeavor there is a group of successful people who are always forging ahead—who advance themselves by training and foresight. It is to such men that this course appeals. The course is particularly a means for that group in the radio field, who have already a foothold in the form of knowledge and experience, but who desire to equip themselves for bigger and better jobs or to advance their own business to greater success.

Requirements for admission to the course are a Graduation from the regular Service Course, or by examination covering equivalent work.

Considerable time in this course is given over to Home Talkies and the fundamentals of Television as well as public address and sound systems.

This course is given only in the New York School.

LABORATORY EQUIPMENT

THE laboratory for this course is equipped with oscillographs, special factory test equipment for both receivers and vacuum tubes, precision measuring devices and various types of meters.

SUBJECTS COVERED

REVIEW of fundamentals; meters; bridge circuits and tests; tubes; radio receiver circuits; diagnosis of receiver troubles; vacuum tube voltmeter; oscillators; multiple antenna systems; sound systems; interference and its elimination; light, movies and fundamentals of television.

Students receiving instruction in repair and adjustment of various types of receivers

LENGTH OF COURSE

THREE months' time is required in the evening classes for the completion of the Advanced Service Course.

TUITION FEE

THE tuition fee is $60, payable $4 per week for the evening classes. 10 per cent discount will be allowed when the full tuition is paid in advance.

RESIDENT SCHOOL COMMERCIAL

Radio Operating—

INCLUDING MARINE, AVIATION AND POLICE RADIO

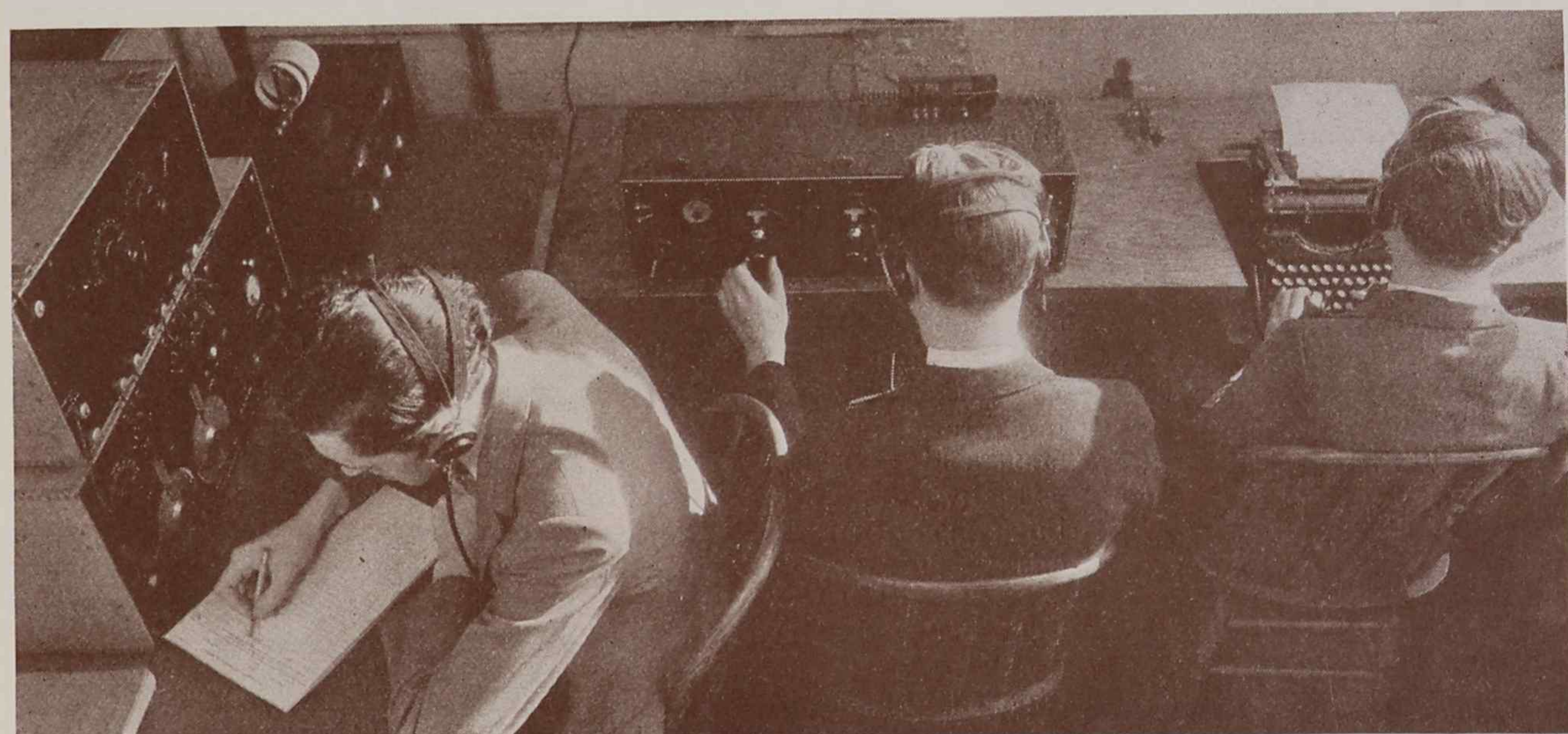
[FOR EXTENSION COURSE SEE PAGE 13]

MARINE RADIO OPERATING

THE Commercial Radio Operating Course will train the student to take the Department of Commerce examination for a Commercial Radio Operator's license, second class. This license permits the operator to work radio aboard ship, coastal stations, aviation and police radio ground and mobile stations. Holders of radiotelegraph operator licenses of the first, second and third class may qualify to operate radiotelephone stations by passing the regular radiotelephone operator examination of the class desired and having their licenses so indorsed.

SUBJECTS COVERED

EVERY phase in connection with Marine Operating is thoroughly taught, such as Methods of Abstracting and Accounting of Radiograms, Dispatching of Messages, Radio Laws and Regulations, Radio Bearings, Domestic and International Rates, Official Log reports, etc. All these subjects are covered in a systematic and efficient manner by instructors who have had years of experience and understand the importance of practical training.



Receiving and transcribing commercial traffic messages

Practical instruction is given in radio telegraphy beginning at the slowest speeds for beginners and gradually working up to a point of efficiency where actual inter-communication, comparable with that of present marine radio work is attained. This instruction is made possible by our excellent facilities, enabling students to simulate actual procedure and conditions in handling traffic found at sea.

In addition a "Radio Room" is maintained where students have the opportunity of "listening-in" on ship and coastal stations. The apparatus consists of short, medium and long wave receivers, making it possible for the student "tuning-in" to cover a range of from 17 to 20,000 meters and distances up to 3,000 miles in daylight.

CODE INSTRUCTION

THERE are five code classes. In Class Number One the student learns how to transmit and receive the Continental Morse or "Radio" code up to 5 words per minute; Code Class Number Two qualifies him to receive up to 9 words per minute; Code Class Number Three from 9 to 14 words per minute; Code Class Number Four from 14 to 18 words per minute and Code Class Number Five qualifies the student to receive and transmit 22 words per minute with accuracy.

The code and technical classes supplement each other and are so conducted as to enable the student to complete both subjects at the same time.

TECHNICAL INSTRUCTION

THE technical instruction is divided into two sections. The first section covers general electrical and radio theory and the second section covers the theory and practice of commercial transmitters, receivers, direction finders, etc.

The subjects covered in the first section of the technical instruction are as follows: Static Electricity—Electron Theory of Electricity—Simple Electrical Circuits—Series and Parallel Circuits—Primary and Secondary Cells—Magnetism—Electromagnetic Induction—Generators—Motors—Transformers—Inductance—Capacitance—Resonance—Wave Propagation—Development of the Vacuum Tube—The Vacuum Tube as an Amplifier—Grid and Plate Rectification—The Vacuum Tube as an Oscillator—R. F. Amplifiers—Oscillation Control—Screen Grid Tubes—A. F. Amplifiers—The Superheterodyne Receiver.

The subjects covered in the second section of the course include Transmitters, Receivers and Direction Finders of various types and their integral units.

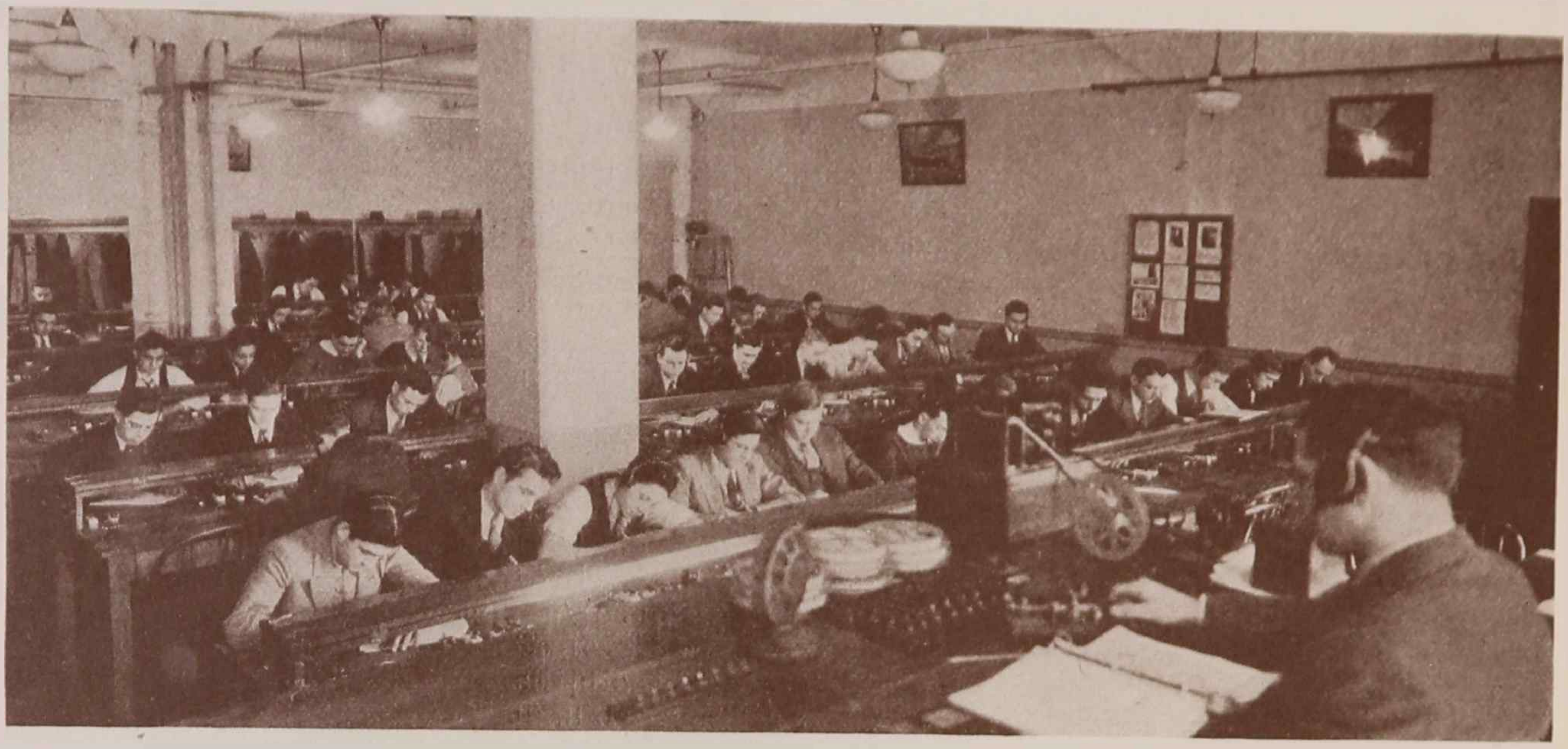
Some of the subjects in aviation radio are: radio aids to blind flying; bonding the airplane; weather reporting by radio; shielding ignition systems of airplane motors; airplane dispatching via radio; wavemeters and frequency monitoring equipment; meteorology for aviation radio operators, etc.

GOVERNMENT EXAMINATIONS

The government maintains, under the Federal Radio Commission, a number of radio supervisor's offices throughout the country which, among their other duties, examine all applicants for radio operator's license.

Applicants for operator's licenses are examined for their ability to transmit and receive the telegraph code, and knowledge of technical subjects, the percentages for which are given as follows:—

Complete diagrams of a ship's radio installation	10%
Transmitting Apparatus	20%
Receiving Apparatus	20%
Motors and Generators	10%
Storage Batteries	10%
Radio Laws and Regulations	20%
General Principles of Electricity	10%
	100%



The code room where students acquire the speed and accuracy in sending and receiving code messages necessary to obtain a Government license

LABORATORY INSTRUCTION

THE laboratory is equipped with various types of marine transmitters including standard 2 K.W. spark, 25 watt emergency tube set, 200 watt CW, ICW transmitter, 500 watt self rectifying transmitter, 750 watt intermediate and long wave CW—ICW transmitter and 2 K.W. arc, two direction finders as well as an aviation beacon, communication receiver and plane transmitter and various types of receivers which include short, intermediate and long wave models.

Wavemeters, Measuring instruments, Motor Generators, Starting Boxes as well as various other pieces of accessory equipment are all a part of the complete laboratory equipment.

This course is open to all students of either sex who are over sixteen years of age and have grammar school education or its equivalent. Special knowledge of electricity, mechanics or higher mathematics is not required for admission.

Students who are qualified may enter the course at any time after the course begins provided they can show satisfactory proof of previous training or experience in the subjects already covered.

COMMERCIAL RADIO OPERATING COURSE—CLASS SESSIONS

DAY classes in Commercial Radio Operating are in session mornings and afternoons.

Evening classes in Radio Operating are in session on scheduled days, Saturdays and holidays excepted.

Classes are conducted throughout the entire year. The R.C.A. Institutes do not suspend classes for summer vacations.

TUITION FEE

THE tuition fee for the Resident School Commercial Operating Course, which includes instruction for 26 weeks in the day classes, or 52 weeks in the evening classes, is $210, payable $8 per week for day classes, or $5 per week for evening classes. An advance payment of $10 is required at the time of enrollment, and $20 of the tuition fee is payable when the class begins.

Extension Courses *for* HOME STUDY

HOME instruction by mail often obtains results where other methods fail. There are many reasons for this, chief among which is the fact that the student can concentrate on that part of a lesson which is difficult to understand. If the student has difficulty with some phase of the lesson at home he can review the subject until he is thoroughly familiar with it. The student may purchase equipment to provide the practical application of the lessons.

A New Enrollment Plan—"Pay As You Learn"

THE most liberal and flexible ever offered an Extension Course student—No obligation to complete the course selected, nor to pay for it in full—Instruction is furnished in Groups of Lessons—You receive lesson material and instruction service as you pay for each Group individually—Each Course is offered for its practical value, and progress depends entirely upon the Student.

The R.C.A. Institutes' Extension Courses are designed primarily for instruction and training of individuals already employed in the Electrical and Radio industries or in merchandising the products of those industries.

Extension Courses may be started at any time. Each course contains a thorough treatment of its subject.

Every lesson presents a clear exposition of the subject with suitable illustrations for ready assimilation of the facts by the student. Examination questions at the end of the lesson have been selected to test the student's grasp of the subject so that he may be given help and advice if necessary. Examination papers are graded and returned to the student.

A pamphlet of the Bureau of Education, United States Department of the Interior, listing 73 institutions of college grade which give instruction by mail declares, "Home Study in universities and colleges is now a proven success."

To become thoroughly familiar with a subject one must work with it. It is not sufficient to read and study; a certain amount of practical work must be done as well. Many people believe that because they know why a device works they can operate it. R.C.A. Institutes has available equipment in kit form for practical work which the student may purchase at special prices.

In order to serve the beginner in radio and the man of experience equally well, three Extension Courses of instruction have been prepared by the R.C.A. Institutes. The courses with the minimum number of lessons in each are outlined below:

Sound Course	65 lessons in 11 Groups
Commercial Radio Operating	61 lessons in 10 Groups
Radio Service	49 lessons in 9 Groups

PRACTICAL HELPS

PROVISION has been made for answering carefully and promptly any queries students may ask on the various phases of their work. Students and graduates have used this department to good advantage after becoming engaged in commercial work and the resultant solution of many "stickers" has often turned an apparent loss into a substantial profit.

The essence of the Institutes' instruction is clarity. Complicated theories are not expounded in any course, and only such mathematics as tend to make clearer and simpler the various subjects taught are included in the instruction. The instruction is of a practical nature so that with a small assortment of apparatus the theory taught can be readily applied.

Many of the lessons make use of charts to which the student may refer for convenience or for review. Much time and needless effort is thus saved for more productive work. Summaries are also included in convenient form whenever practicable.

FREE POST-GRADUATE COURSE

Students are entitled to a two weeks' post-graduate course without charge at one of our resident schools if taken within three months after completing the Extension Course.

R.C.A. Institutes' Resident Schools have no dormitory facilities. Students from out of town must provide their own living accommodations. Convenient location may be secured at reasonable rates.

EXTENSION COURSE

Sound

COMMERCIAL SOUND EQUIPMENT FOR THEATRES AND FOR RECORDING—HOME TALKIES—HOME RECORDING—PUBLIC ADDRESS SYSTEMS—RECORDING AND BROADCASTING STUDIOS—HISTORY AND FUNDAMENTALS OF TELEVISION

[FOR RESIDENT SCHOOL COURSE SEE PAGE 5]

SOUND pictures have arrived and are now established in every city and hamlet throughout the country. To-day the sound motion picture industry requires a large staff of skilled technicians for the maintenance and repair of sound picture apparatus.

Practically every theatre requires at least two operators and in addition a trained service man must be provided for territories where there are many theatres, to diagnose trouble and to supervise repair work. As new theatres contract for sound equipment trained installation men are needed. In addition, clubs, hospitals, schools, and other institutions equipped or to be equipped with sound pictures will also require trained men in the industry. Home talking movies promise to provide a still larger field.

A student taking the Extension Course in Sound is introduced to the fundamental principles and laws of photo electricity, light and sound.

SOUND RECORDING

A BRIEF history of sound recording and the up-to-date methods used in the industry are covered. The conversion of sound energy into electrical energy and electrical energy into sound energy are explained along with disc recording and synchronization of sound on disc equipment.

In film recording variable area and variable density are the two methods in use at the present time. The principles of operation and the advantages and disadvantages of each are discussed. The student becomes acquainted with the proper methods of synchronizing sound-on-film as well as sound-on-disc.

While on the subject of sound-on-disc, various turntables, such as the synchronous, non-synchronous, non-synchronous triple and twin turn-tables, theatre phonographs and other devices are discussed.

The subjects given under sound heads include the following: exciter lamps; photocells; exciter lamp assemblies; optical systems; sound gates; damping devices; threading; adjustments; chain drives; lubrication and others.

Sound Pictures and Television depend on electronic tubes for amplification. In view of the importance of these tubes to both arts several lessons are devoted exclusively to electronic devices.

The underlying principles and theory of electronic tubes are described and advanced to a study of the characteristics of typical tubes. In this part of the course many characteristic curves of typical tubes are outlined. Several charts of values help the student in reference work. Much work is devoted to amplifier circuits, and methods of interstage and output coupling are discussed.

The following topics are found in the vacuum tube lessons: the vacuum tube as an amplifier; two-element or rectifier tubes; three-element tubes; heater type tubes; screen grid tubes; symbols; resistance, transformer and impedance coupling; classification of circuits; voltage and power amplification; parallel operation of tubes; push-pull tubes; vacuum tube rectifiers; replacement of tubes. Several commercial amplifiers, and other electronic devices are described and illustrated, in order to familiarize the student with the apparatus.

Under the subject of sound the student is taught the nature of sound; its production; loudness; frequency and tone quality. Other topics are wavelength; speech; hearing; sound as a form of energy; matter and energy; electrical, light, chemical, heat and mechanical energy.

APPARATUS ASSOCIATED WITH SOUND EQUIPMENT

A LESSON on Motion Picture Machines contains the following topics: Commercial projectors; the intermittent mechanism; the shutter; Simplex incandescent equipment; Motiograph, Powers, and Baird projectors; RCA and ERPI portables; cue sheets and reel changing. Other lessons deal with the operation of motion picture machinery, the care and manipulation of controls, and the running of the show.

The following subjects are treated under Principles of Motion Picture Projection: film speed; projectors; high intensity lamps; operation of the arc; the condenser lens; the path of light from arc to aperture; cored carbons; the lamphouse; three conditions of the spot on the aperture; motor control and wiring of arc lamps; the Strong lamp for advertising matter; fire traps; the take-up clutch; four stages in exposing plates and films; light and time; opacity and other topics.

TUITION FEE

THE Extension Course in Sound includes a minimum of 65 lessons divided into 11 Groups, and the Tuition Fee is $11 per Group, or $121 for 11 Groups of Lessons.

Supplementary Groups of Lessons are available, at $11.00 per Group, especially arranged for students who are not adequately prepared in the fundamentals of electricity and radio.

The student receives instruction service for a period of sixty days after his last payment.

EXTENSION COURSE

Commercial Radio Operating

INCLUDING AVIATION—BROADCASTING—MARINE

[FOR RESIDENT SCHOOL COURSE SEE PAGE 9]

MARINE OPERATING

THE Commercial Radio Operating Course is wide in scope and covers practically every phase of radio work.

Code instruction is included to enable the student to prepare for a Government License examination. Code practice kits may be purchased separately where the student does not possess such apparatus.

As in other courses, the lessons at the beginning of the Radio Operating Course deal with fundamentals. For example, the work covers the Fundamental Units of Electrical Measurement, the Symbols commonly used in radio work, and instruction especially prepared for the man having little or no technical training.

Lessons are presented on Resistance and Conduction and Simple Electrical Circuits with interesting and valuable discussions on Ohm's law—the temperature coefficient of metals—use of potentiometers and rheostats—insulators—circular mil area of conductors and its relation to current carrying capacity. Series and parallel circuits are treated at some length with illustrations and sample problems which make this work easy.

In some branches of radio work, especially broadcasting, commercial ship and shore station operating, and in the elimination of interference, an operator, to be successful, must possess a fair knowledge of motors and generators. Realizing this fact, we have included a series of lessons on D.C. Motors, D.C. Generators and Motor Generators. In these lessons the student finds easily understood information on the various types of electrical machines, the Principle of Commutation, the care and use of motors and generators and the theory of alternating current.

Because of the widespread use of alternating current, transformers are found in the majority of receiver circuits and in many other services. The lesson on Transformers makes clear the details concerning design, construction and use of transformers.

The student is taken through the closely related subjects of Inductance and Capacity where he learns about both inductive and capacitive reactance, the principle of dielectric action and the choking effect of an inductance coil, etc.

The text on Secondary Cells and Storage Batteries affords an excellent understanding of the elements of electrochemistry, and besides this, practical work on the maintenance of storage batteries, both Edison and the lead-acid type, is presented. For the student who desires to obtain a radio operator's license and enter the marine radio service, this lesson is important and valuable, for shipboard battery installations are emphasized.

A subject frequently slighted by textbooks is that of Graphs as used for recording and indicating purposes. A full lesson on this subject explains how curves are plotted from a series of meter readings.

Sound waves—Harmonics—Beat notes—Frequency—Electromagnetic Wave Propagation—The Oscillatory Circuit—Damping—Decrement—Resonance—Tuning—Spark Discharge—These are only a few of the topics covered.

Vacuum Tubes—Thousands of radio men know that the pentode tube gives a high power output with a relatively low plate power input. Thousands more know that the screen grid tube has a high amplification factor. But how many know just why? This lesson tells you why in an easily understandable manner. The fundamental part of vacuum tube instruction deals with—Electron Emission—thermionic Currents—Ionization—Space Charge—Rectifiers—the Filament, Grid and Plate, etc. Modern receiving tubes are covered in this text and charts showing their characteristics are included.

Receiver Circuits—Simple Regenerative Receivers—Crystal Detector Circuits—the Superheterodyne—Principles of Neutralization—Audio Amplifiers—Neutralizing and Compensation Circuits—the Losser Circuit—Screen Grid and Pentodes—Power Packs—Filter Circuits—Standard Receiver Tests. These are a few of the subjects falling within the scope of the course.

CODE AND OPERATING

FOR the purpose of supplying the student with suitable apparatus for sending and receiving, code practice equipment may be purchased separately, consisting of a Peerless Signagraph and practice key and buzzer set.

LESSON MATERIAL

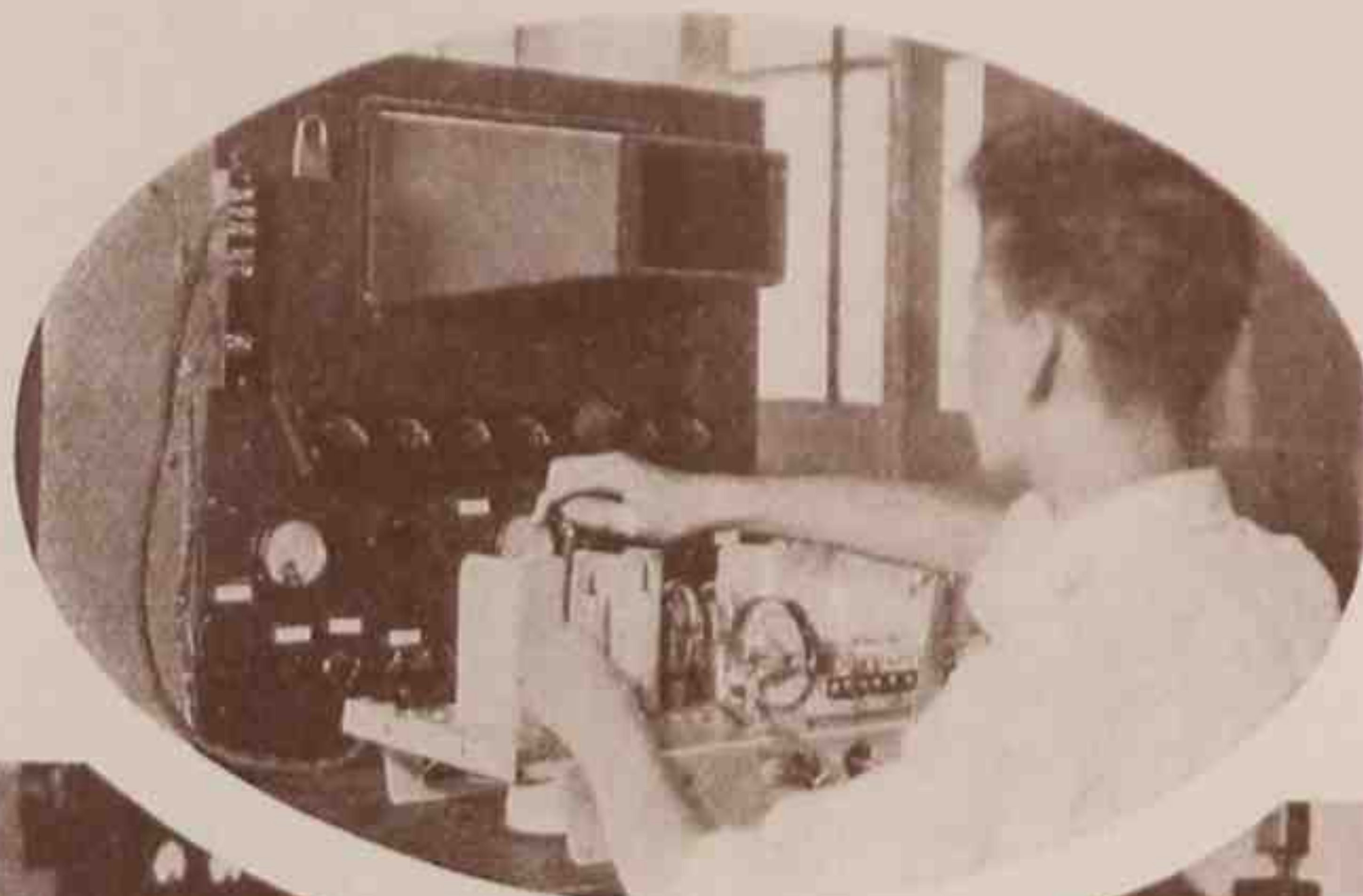
THE scope of the instruction given in the Commercial Radio Operating Course is indicated by the lesson titles, a few of which follow:—

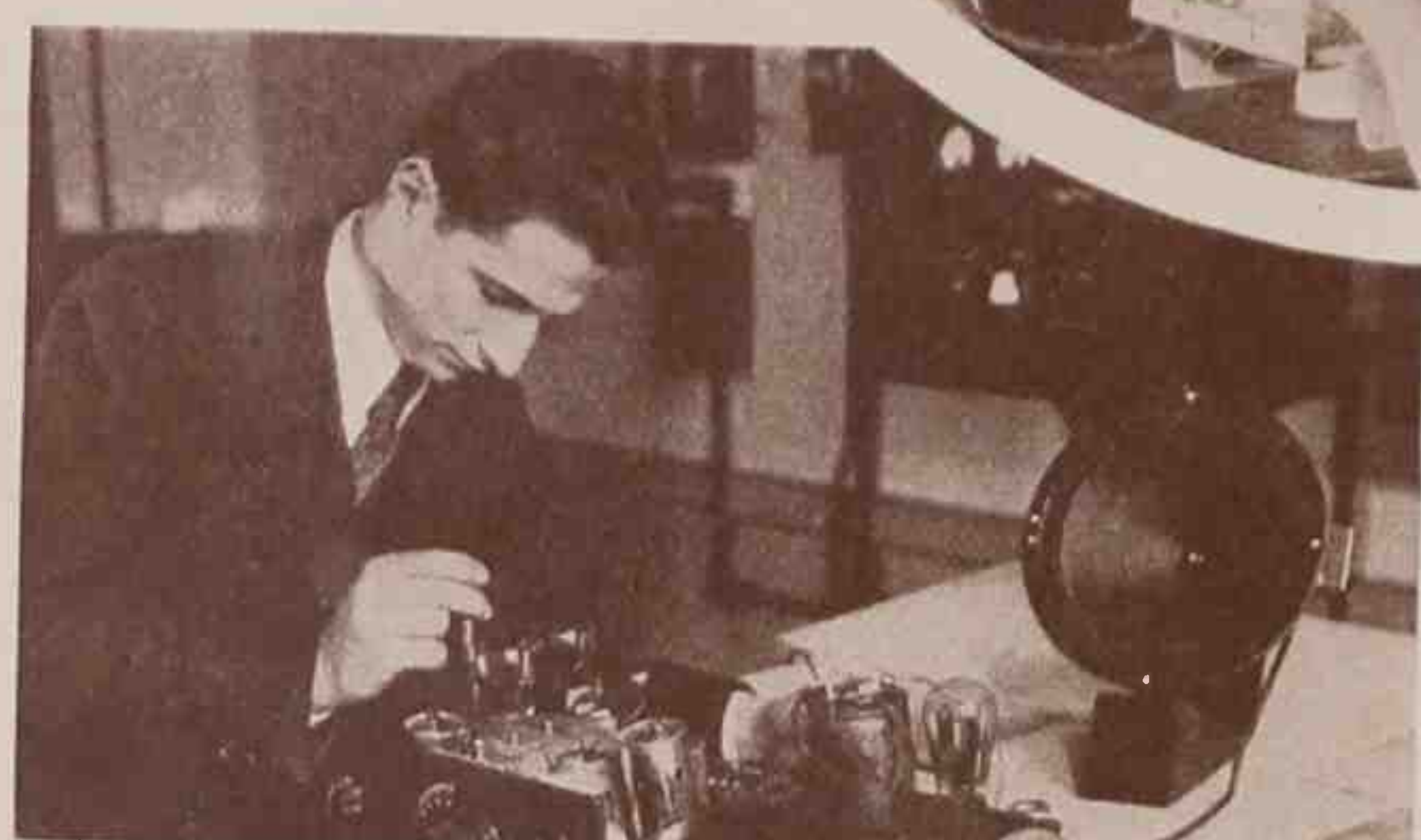
Man's Early Efforts to Communicate at a Distance—Seeing and Hearing with Sound Pictures and Television—The Electron Theory—Static Electricity—How Current Flow Depends on Resistance and Conductance—Faraday's Discovery of Electromagnetic Induction—The Relation of Electric Current to Magnetism—Graphs—D-C Generators—Alternating Current—The Motor Generator—Use of Storage Batteries on Shipboard—The Airplane—A Mobile Radio Station—A-C Motors—Power Transformers—Spark Transmission—Arc Transmitters—Fundamentals of Radio Reception—Vacuum Tubes—Commercial Long and Short Wave Receivers—Development of the Superheterodyne—Radio Direction Finder or Radio Compass—Battery Eliminators.

Instruction on transmission and various types of transmitters are included in:—Vacuum Tubes used in transmitting—Vacuum Tube Transmitters—Short Wave Transmitters—Broadcast Transmitters (Modulation)—Radio Aviation Equipment—Aviation Radio Equipment for Two-Way Communication—W.E. Equipment (9B—Police—Aviation)—Commercial Tube Transmitters—Radio Transmitters used for Telephone and Telegraph.

AVIATION RADIO

SUBJECTS special to aviation are treated in:—Bonding the Airplane—Shielding Ignition Systems of Airplane Motors—Radio Compass and other Navigational Instruments used in Aviation—Radio Aids to Blind Flying and Blind Landing—Wavemeters and Frequency Monitoring Equipment—Principles of Meteorology for Aviation Radio Operators—Weather Observations at Aeronautical Radio Stations—Weather Reporting by Radio—Weather Maps and Forecasts for Flyers—International Air Regulations—Airplane Dispatching via Radio.





Oval—Oscillograph method of adjusting receiver circuits. Left—The assembled receiver undergoing an output test. Right—Assembling a loud speaker

RADIO BROADCASTING

THIS section of the course is devoted to a systematic analysis of the various fundamental circuits of a broadcast transmitter and their control.

With the elementary part of the course finished the student is prepared to take up the more advanced work, dealing with radio broadcasting equipment and studio methods.

This instruction is presented in illustrated form with a detailed description of the operation of apparatus included which, together with the two weeks' post graduate work at a resident school, enables the Extension Course student to get a working knowledge of broadcasting station apparatus. The study commences with the voice frequency energy impinged upon the diaphragms of various types of microphones and continues with discussions of suitable amplifiers, monitoring systems, and the almost universally used Heising system of modulation. At this point the radio frequency portion of the transmitter is introduced with practical considerations concerning the constant frequency piezo electric quartz crystal oscillator and its associated frequency doublers and amplifiers. With the function of each part firmly fixed in mind, the student is given general descriptions of modern broadcast transmitters in order that he may better understand just how the various circuits work together.

TRANSMITTERS

SCHEMATIC circuit diagrams and legends of all parts of the commercial continuous wave telephone and telegraph transmitters and the spark and arc transmitters are included in this part of the course which embraces a number of lessons. The diagrams given are acceptable in the government examination for commercial operator license. Aircraft and Broadcast transmitters are likewise treated in this group.

Aside from these features of the course, the student is permitted to avail himself of the benefits of our technical service and consultation department where he may find an answer to any logical question falling within the scope of his course. Furthermore, the students' service department supplies experimental equipment and replacement parts at special students' discount prices.

TUITION FEE

THE Commercial Radio Operating Course includes a minimum of sixty-one lessons divided into ten Groups, and the tuition fee is $10 per Group or $100 for ten Groups of Lessons.

The student receives instruction service for a period of sixty days after his last payment.

Students completing the Extension Course are entitled to a two weeks' post graduate course at one of our Resident Schools without charge.

EXTENSION COURSE

Radio SERVICE —

BROADCASTING RECEIVERS—HOME TALKIES—HOME RECORDING—HISTORY AND FUNDAMENTALS OF TELEVISION—INTERFERENCE ELIMINATION

[FOR RESIDENT SCHOOL COURSE SEE PAGE 7]

THE radio service course comprises a series of technical lessons especially prepared for the student interested in the servicing and repair of radio receivers and accessory equipment.

Home laboratory kits and test equipment for practical work may be purchased separately.

Among the first lessons of this course are those dealing with the Fundamental Units of electrical measurement and the Symbols commonly used in radio work. The presentation of these lessons at the outset removes the necessity of previous electrical or radio training, thereby making the course available to the man with limited or no technical training.

Having in mind the rudiments necessary for a thorough understanding of radio, the student proceeds to the elementary lessons on radio principles and theory. These elementary lessons may be regarded as foundation lessons for they deal with the basic principles upon which the simplest circuits are laid.

A lesson on radio physics dealing with the substance and electrical nature of matter is included in the elementary group of lessons followed by a practical discussion of Magnetism, Electromagnetism and Electromagnetic Induction.

The instruction in the course continues with a lesson on Primary Cells and Dry Batteries which are so commonly used for innumerable purposes in electrical and radio circuits.

Resistance and Conduction and simple Electrical Circuits are also treated in a practical manner, thereby bringing into use the knowledge gained from previous lessons. Ohm's law, in its many forms and series and parallel circuits, are the major topics of these lessons.

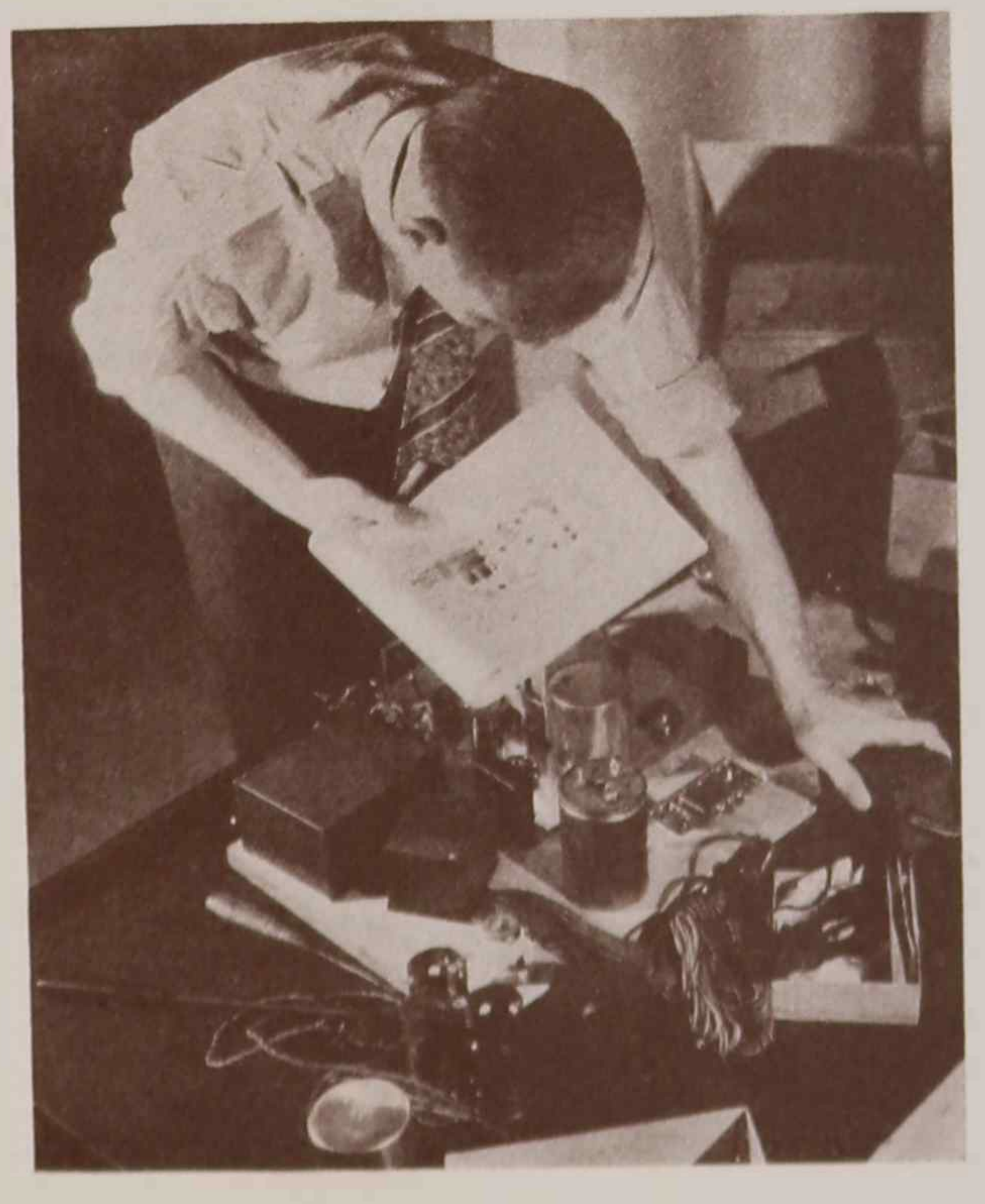
With a knowledge of simple circuits, magnetism and electromagnetic induction, the student is then taken through the subject of Alternating Current, where he learns the exact meaning and application to radio of such terms as phase, cycles, frequency, alternations, power factor, and others.

Receiver Circuits embrace regenerative receivers—audio amplifiers—stabilization in r-f circuits—tuned radio frequency—screen grid and pentode circuits—detector action—power packs—superheterodyne receivers.

Magnetic and Dynamic Speakers is devoted to the basic operation of the two types, their advantages and causes of trouble, method of testing and trouble-shooting.

The use of Set Analyzers, General Test Equipment, Testing Procedure and Diagnosis Logic is set forth in a special group of lessons, a knowledge of which enables the student to perform satisfactory and profitable service work. Complete instruction on the Construction of a Modulated Oscillator, a Vacuum Tube Voltmeter, a Grid Dip Meter and other instruments is made a part of this group. Instruction is also given in interference elimination; home talkies and automobile receivers.

Aside from these many features, the student is privileged to avail himself of the services of our technical consultation department which is operated for the exclusive benefit of regularly enrolled students.



The Home Study Student laying out a pentode tube receiver list of parts preparatory to assembling

TUITION FEE

THE Service Course includes a minimum of forty-nine lessons divided into nine Groups, and the tuition fee is $9 per Group, or $81 for nine Groups of Lessons. Upon completing the course the student is entitled to a two weeks' post-graduate course at one of our resident schools without charge.

TERMS AND CONDITIONS GOVERNING EXTENSION COURSES

(1) The tuition fee shown for each course is on a cash basis, and no other terms are offered than the equal payments specified.

(2) Only one payment for one Group of lessons will be accepted at a time, and examination sheets on all lessons received by the student must be submitted for correction within sixty (60) days after the *last* payment made.

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(4) No apparatus or other equipment is included with an extension course now offered, but suitable kits may be purchased separately by the student when desired, thus taking advantage of cash prices.

(5) No responsibility shall be assumed by the Institutes on account of any statements or representations other than those contained in the enrollment application, and no person is authorized to modify such statements or representations except the President of the Company. Representatives of the R.C.A. Institutes, Inc., are authorized to accept only the first payment for tuition and it is requested that applicants make such payments in the form of money orders or checks payable to the R.C.A. Institutes, Inc.

(6) If the instruction and lesson material is not confined to the student's personal use, the Institutes may suspend or terminate instruction and the agreement governing the same without liability of any nature whatsoever and/or for refund of any payments made.

(7) R.C.A. Institutes, Inc., reserves the right to change its outline of courses, tuition fees, enrollment requirements and make any other changes that are deemed advisable, without advance notice.

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(12) The R.C.A. Institutes, Inc., provides the educational facilities for instruction and training in Radio. The commercial application of this training is determined by the individual student according to his desires and the opportunities available.

ORIGINAL

S. O. 759979 5M 2-16-'33

Application for Enrollment in EXTENSION COURSES (HOME-STUDY)

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☐ **SPECIAL COURSE**

DO NOT USE THIS SPACE

I would prefer to complete my two-weeks' post graduate course in the resident school at ☐ New York; ☐ Chicago

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Dated..19........ ....
(Signature of Applicant)

Recommended by........................

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Nearest Express Office..

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RCA INSTITUTES -INC-

CATALOG No. 3302

Printed in U S. A. 2-33

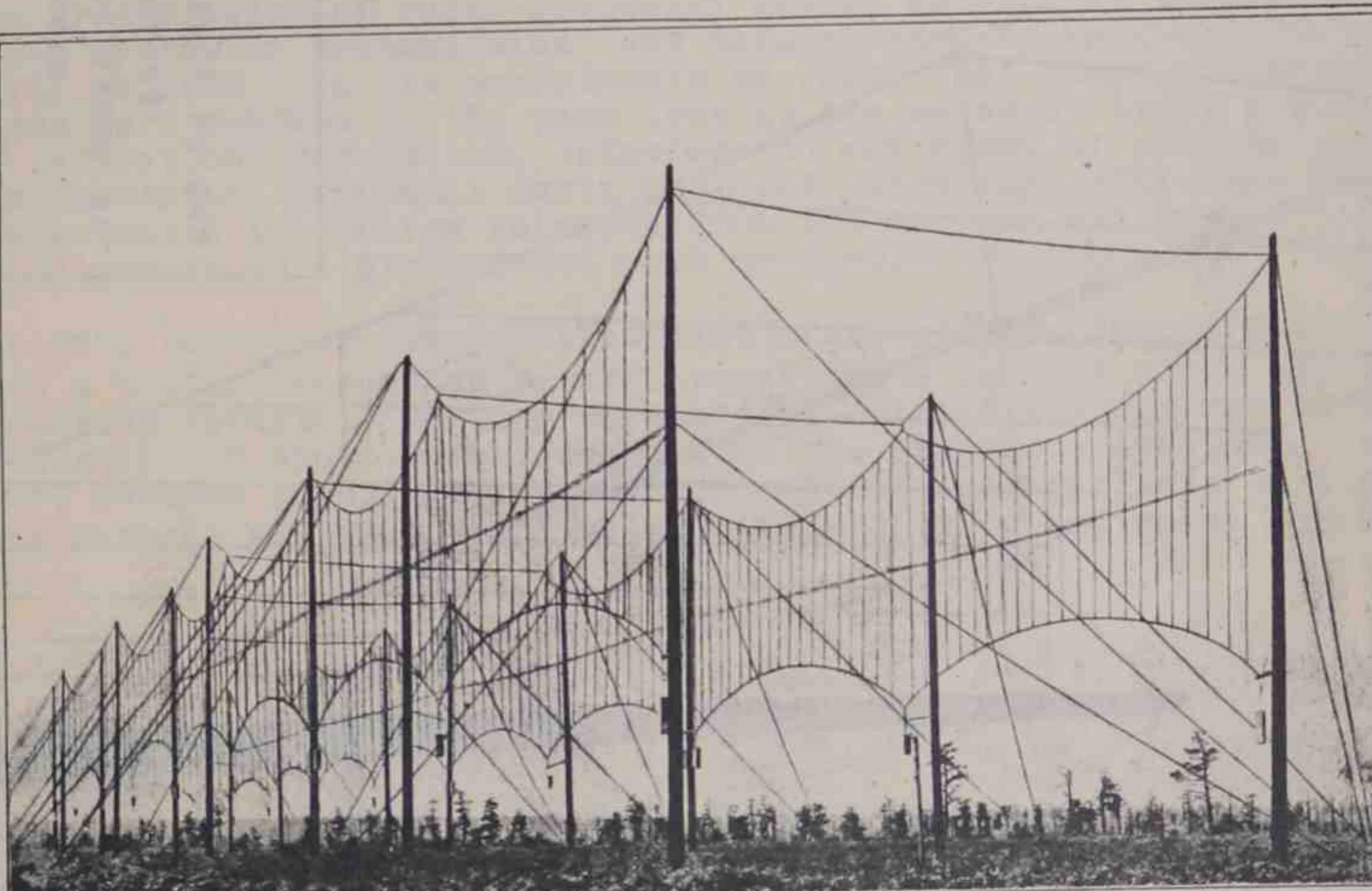
S. O. 759979

America's Oldest Radio School

RCA INSTITUTES INC.

A Radio Corporation of America Subsidiary

HOME OFFICE
75 Varick Street, New York

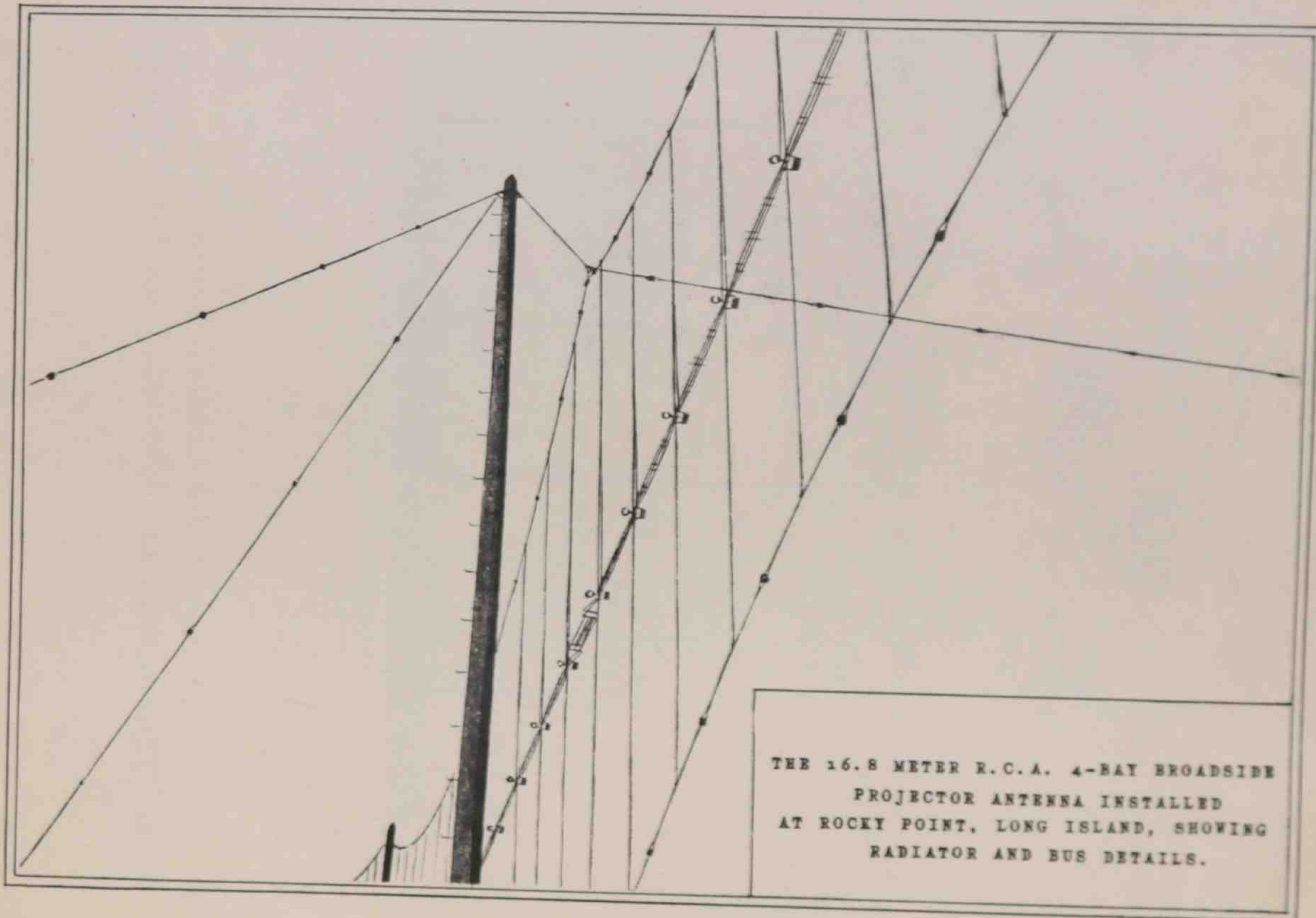


THE 16.8 METER R.C.A. 4-BAY BROADSIDE PROJECTOR ANTENNA INSTALLED AT ROCKY POINT, LONG ISLAND.

Point-to-Point Communication
Beam Transmission and Broadside Projector Antennas

VOL. 32 No. 1

Dewey Classification R325.1



THE 16.8 METER R.C.A. 4-BAY BROADSIDE PROJECTOR ANTENNA INSTALLED AT ROCKY POINT, LONG ISLAND, SHOWING RADIATOR AND BUS DETAILS.

America's Oldest Radio School

RCA INSTITUTES -INC-

A Radio Corporation of America Subsidiary

HOME OFFICE
75 Varick Street, New York

POINT-TO-POINT COMMUNICATION
BEAM TRANSMISSION AND BROADSIDE PROJECTOR ANTENNAS

The transmission of radio-frequency energy by what is termed the "beam system of transmission" was demonstrated by Heinrich Hertz as early as 1888. In his experiments he found that short electrical waves were subject to the same laws as the waves of light relative to reflection, refraction, interference and speed of propagation. In his laboratory equipment Hertz employed parabolic reflectors which concentrated the energy released from the antenna and caused it to be projected in a directional path or beam.

Marconi, realizing the possibilities of short-wave transmission by such a system, conducted several experiments in 1896 which gave promising results. Because of the difficulties encountered in the production of short-wave lengths with the apparatus available at the time, further investigation was not carried on regardless of the fact that Marconi was able to prove with transmitting equipment connected

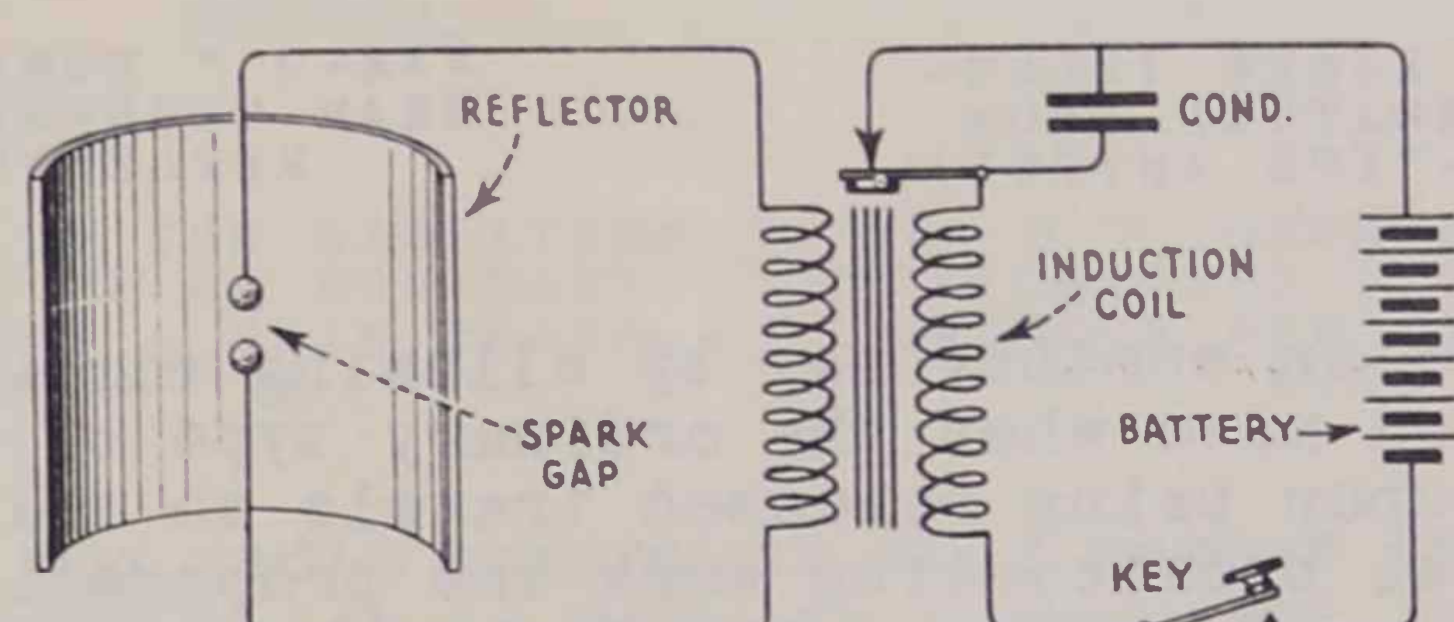


Fig. 1 - SIGNALS FROM THIS OSCILLATOR CAN BE INTERCEPTED BY A RECEIVER WHEN THE APERTURE OF THE TRANSMITTING REFLECTOR IS POINTED TOWARD THE RECEIVING ANTENNA.

as shown in Figure 1 that the propagation of signals over a distance of $1\frac{3}{4}$ miles was of greater intensity than when the ordinary elevated antenna system was employed. In fact, with the latter only one-half mile was reached.

A factor which discouraged further research with short-wave beam transmission was the progress made with long waves which, at the time, seemed to be so comparatively simple that attention was diverted from short-wave work and all efforts were concentrated upon further development of the long-wave systems.

In explanation of Figure 1 the spark gap of the electrical oscillator was placed in the focal plane of a solid metal reflector and the signals from the oscillator could only be intercepted by the receiver when the aperture of the transmitting reflector was pointed toward the receiving antenna. When it was desired to transmit only in one direction the reflector of the transmitter was directed toward the receiving station which consisted of a concave reflector with the receiver mounted in such a position as to intercept the reflected radiations which arrived ahead of or behind the focus of the reflector.

Perhaps before going into more detail it would be well to give an elementary comparison to illustrate the idea of transmission, first, by means of the ordinary elevated antenna system, and second, the beam system. The old familiar analogy of dropping a stone in the center of a pool of water and then observing the ripples or waves on the surface which traveled over the entire area in circles represents the manner in which the energy released from the elevated antenna is disseminated throughout space.

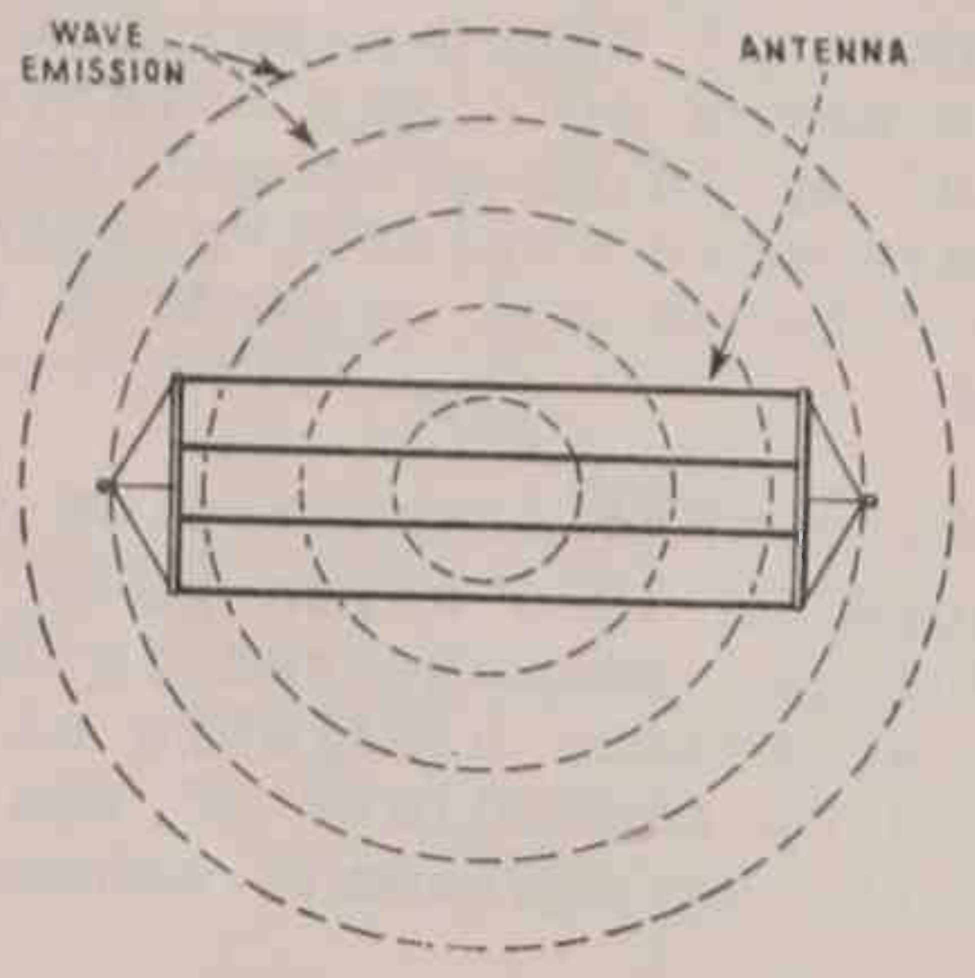


Fig. 2 - CIRCULAR LINES ILLUSTRATE THE WAVE EMITTED FROM AN ORDINARY FLAT-TYPE ANTENNA.

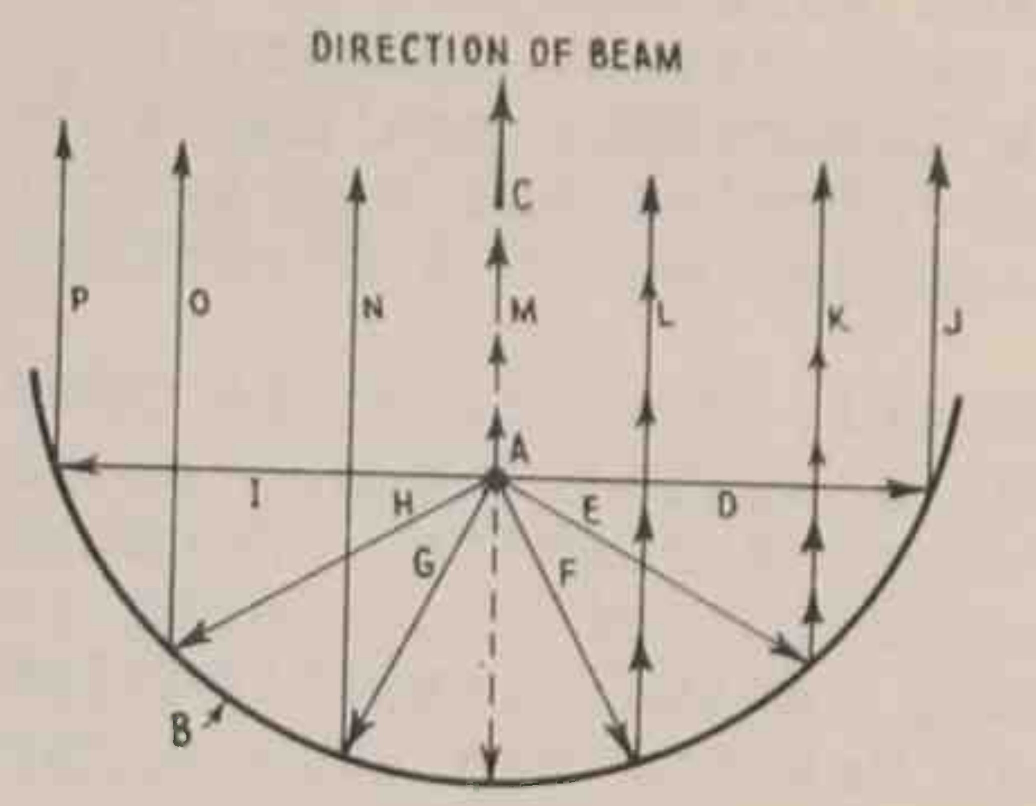


Fig. 3 - FUNDAMENTAL IDEA OF BEAM TRANSMISSION UTILIZING REFLECTOR MARKED B.

Figure 2 shows this in another way by allowing circular lines to illustrate the emitted wave when the ordinary type of antenna is utilized. The energy upon being released travels to all points of the compass. In general broadcasting work the propagation of energy in this manner is desirable because the greatest number of receiving points are to be reached for any given transmission and although a comparatively small amount of power is required to operate the receiver, still an enormous amount of power must be generated by the transmitter to enable the requisite energy to be picked up by a remote receiver when employing this system, which is sometimes called the omni-directional method of transmission. (Omni means all.)

In beam work, however, the omni-directional propagation of energy is avoided; the principle involved is to concentrate the energy released from the antenna and project it along a narrow angle by the use of a reflector which deflects the energy causing it to proceed in some predetermined direction. If a distant receiving point lies within the arc of that angle, it will receive considerable more energy than would be the case if the same power should be allowed to spend itself throughout the 360 degrees of a circle. Since this energy follows the laws of light reflection, refraction, etc., a reflector is placed behind the radiating antenna to prevent the power leaving the antenna from traveling in any but the desired direction.

Figure 3 shows the fundamental principle of beam transmission. The radiating antenna A is placed in the focus of the reflector B. The waves starting at A tend to move in all directions; those moving toward the reflector B designated by the letters, D - E - F - G - H and I strike the parabolic reflecting surface and are reflected in the direction J - K - L - M - N - O - P. The radio waves have now been changed in direction because of the influence of the reflector upon them and caused to move with and augment the energy which is traveling in the direction of the arrow C.

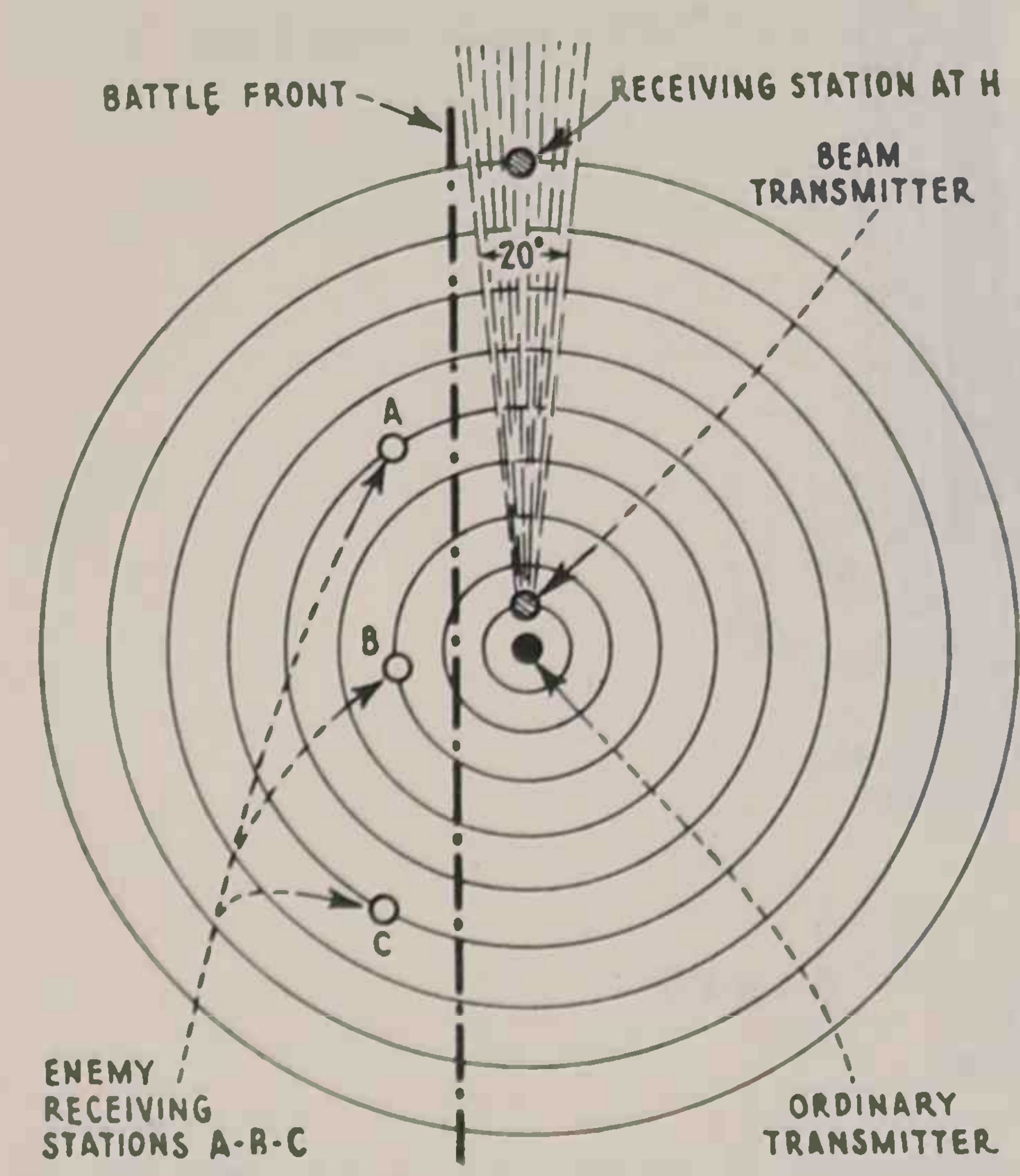


Fig.4 - COMPARING THE RADIATION CHARACTERISTICS OF AN ORDINARY ANTENNA SYSTEM AND A BEAM TRANSMITTER.

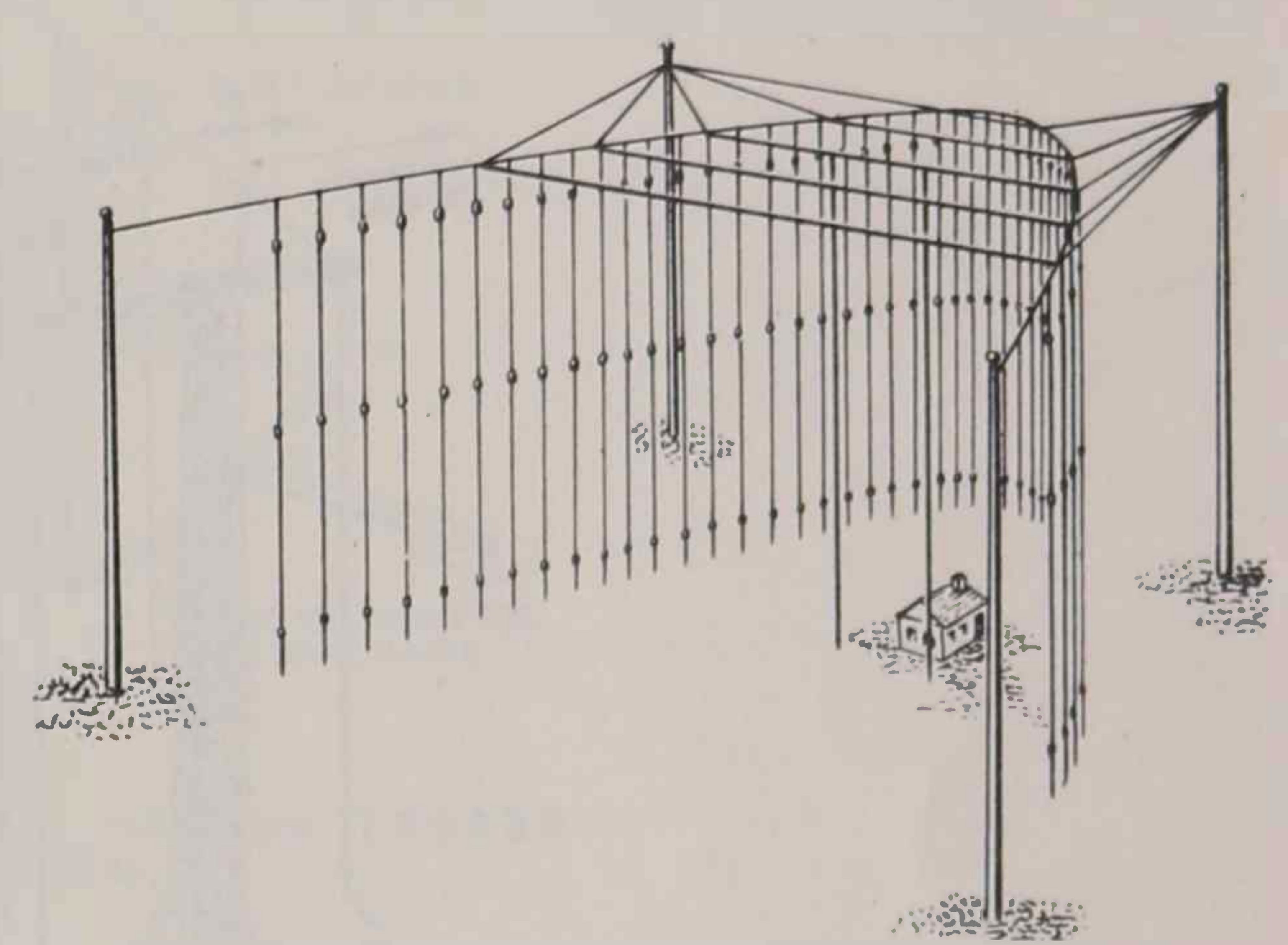


Fig.5 - GENERAL LAYOUT OF A BEAM TRANSMITTER WITH THE TRANSMITTING ANTENNA AND PARABOLIC VERTICAL WIRE REFLECTOR.

The focusing of the radio energy in this manner results in an intensive beam of energy which in regular commercial equipment may vary between 10 and 20 degrees in width. The reflector can be arranged so this beam of energy is directed toward any desired point of reception with little or no energy traveling in the opposite direction.

The World War which was responsible for many inventions was also the cause of reviving the interest in beam and short wave work because of the desirability of establishing secret communication channels along the battle front.

Figure 4 is another diagram comparing radiation between the ordinary elevated antenna system and the directional or beam arrangement. This diagram brings out the value of the beam system especially as a means of secret communication. For example, assume the broken line represents a battle front and the circles A, B and C represent enemy radio receiving stations. With the ordinary elevated antenna system, represented by the heavy black dot, signal energy would be radiated in all directions and the enemy stations A-B-C would be within easy range of all radio communication.

The use of the beam method, however, would change all of this; decreased power could be used and still have sufficient energy to reach the radio receiver placed at H, and because of the directional characteristics of the beam system the enemy stations A, B and C would be unable to intercept the signals. The need of secret communication during war, therefore, can be said to be one of the causes of considerable progress with beam transmission.

The data obtained in the earlier experiments of this work proved to be valuable material as a foundation. The old types of reflectors

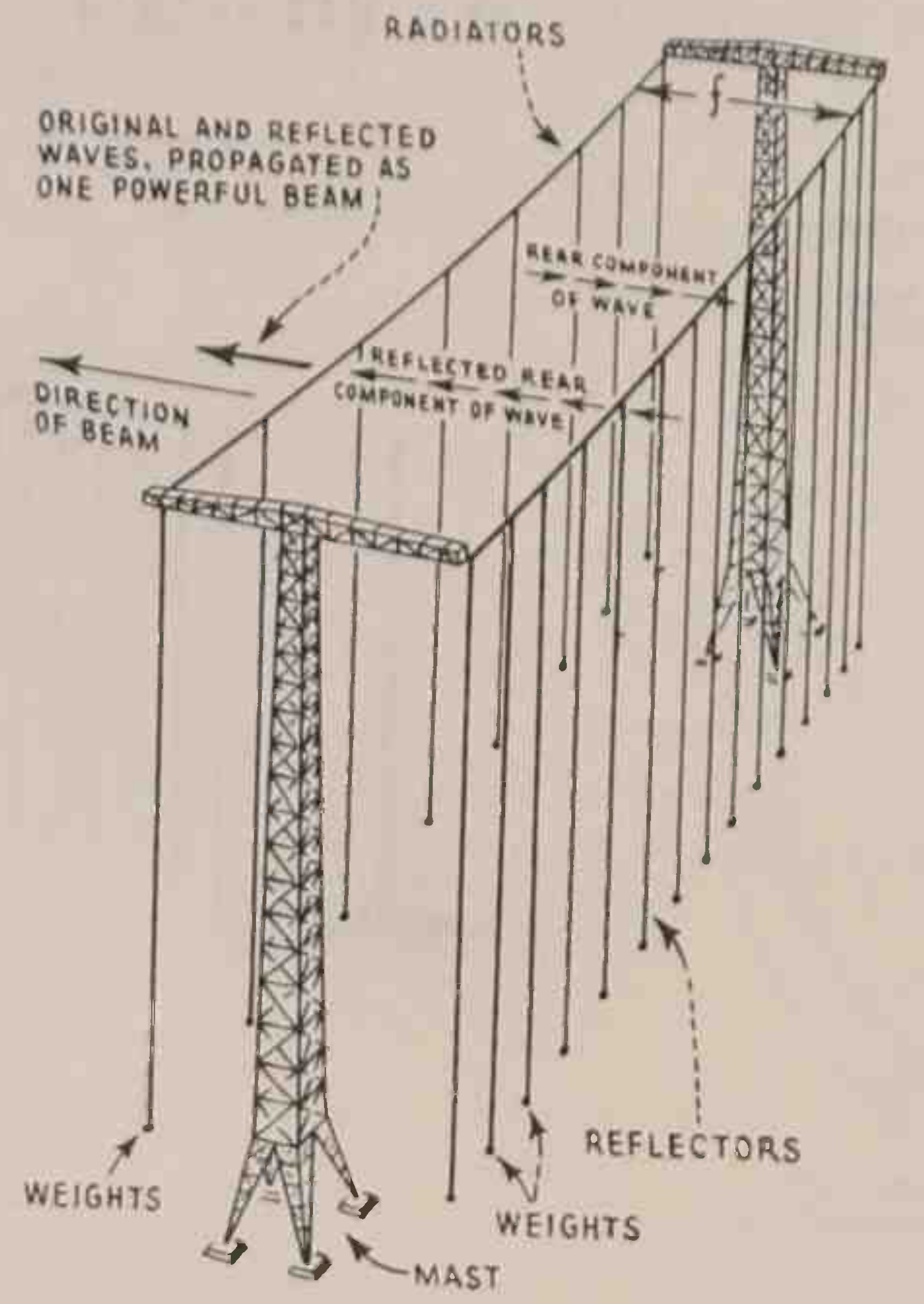


Fig. 6 - ONE NETWORK OF VERTICALLY SUSPENDED WIRES IS KNOWN AS THE "REFLECTOR" AND THE OTHER THE ANTENNA OR "RADIATOR"

and spark transmitters, however, were soon eliminated as more knowledge was acquired concerning the behavior of the shorter waves. The solid metal reflectors were replaced by a comparatively small number of wires which were placed parallel to the antenna and spaced around it on a parabolic curve of which the transmitting antenna constituted the focal line.

By the use of the three element vacuum tube short waves were more easily produced and the power available at the higher frequencies was many times greater than was possible with the spark transmitters employed in early experiments. Figure 5 is a drawing of a transmitting station together with the transmitting antenna and the parabolic vertical wire reflector with which many experiments were conducted in 1923.

A year later experiments were conducted with a different form of beam antenna. Figure 6 shows the essential features of this later type. The antenna comprises two distinct networks of vertically suspended wires; one of these networks is called the "reflector" and the other the "antenna" or "radiator".

The reflector carries twice the number of wires as the radiator and the two units which comprise the antenna system as a whole are spaced one-quarter of a wavelength apart and maintained at this distance by the horizontal cross arms of the supporting masts. The radiator and reflector wires, as can be seen, hang vertically from insulated horizontally supported cables and are prevented from swaying by a system of weights.

The system comprising the reflector is suspended at the rear of the radiating unit which is opposite to the direction in which transmission is to take place. The radiators (beam antenna) may be considered as nothing more than a multiple tuned short wave antenna with the addition of back screening, this screen having previously been called the reflector.

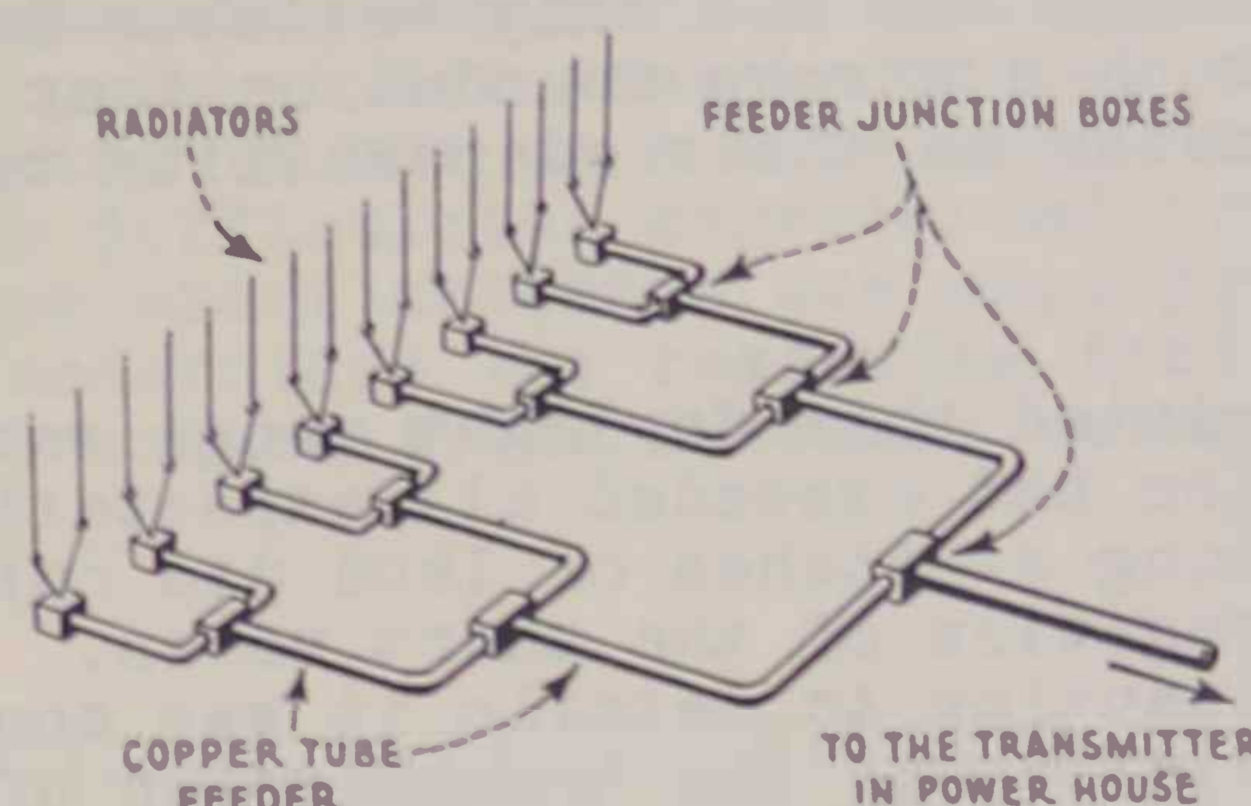


Fig. 7 - A SECTION OF THE LECHER FEED SYSTEM.

Each of the vertical radiators are energized in exact phase by what is known as "Lecher Feed", a section of which is shown in Figure 7. The Lecher feed is simply a system by which the paths for the power from the transmitter are made exactly equal and, therefore, the phase of oscillations will be identical along the entire system. The radiators are led into the coupling boxes in pairs, and each coupling box contains base coils of such inductive and capacitive values as to provide the proper degree of resonance between the various sections comprising the entire unit.

Relative to the functioning of the form of antenna shown in Figure 6 , the wave emission moves forward in the normal direction as well as in the opposite direction which is to be expected where a vertical aerial is employed. The emission in the opposite direction, that is, the rearward component of the emitted wave, instead of dissipating its energy in space by radiation is prevented from doing so by the network of reflector wires.

The rearward component is deflected upon striking the reflector system, that is, re-radiated forward — opposite to its original direction and in the desired direction of propagation. The reflected energy thus re-enforces the forward component of the emitted wave and thereby increases the power desired to be projected toward the point of reception. This action is shown by large and small arrows which indicate the forces involved.

For the reception of signals transmitted by the beam method an antenna system of practically similar design is utilized as a collector of the radio-frequency signal energy for the receiving apparatus. It is located in such a manner that the wires which correspond to the radiating unit of the transmitter become the collector section for supply energy to the beam receiver because it faces the plane of propagation of the beam leaving the transmitter.

At the rear of this collector is suspended the reflector unit which is identical in construction to that utilized for the transmitting antenna. This reflector acts in a similar manner upon the energy received, that is, it intercepts an additional amount of energy from the propagated wave front and reflects it forward to the collector unit where it re-enforces the signal strength as a whole.

For a number of years a general impression regarding the behavior of short waves was that their daylight range was variable and short and that the night time range was not only variable but freaky. This idea seemed to have such a strong foundation that short waves seemed doomed for a time insofar as their adaptability to commercial use was concerned.

Marconi, however, insisted that daylight range was reliable and that night time transmission had exceeded all expectations. Further, that mountain ranges and long stretches of land did not present any serious obstacles to the propagation of the short waves. Through consistent research and close attention to details it was soon discovered that Marconi was right, relative to the transmission of short waves, and that the strength of the signals which could be received during daylight varied definitely and regularly in accordance with the mean altitude of the sun over the space or region intervening between the transmitting and receiving stations, and that the coefficient of absorption for short wave lengths was a function of the time, as well as the particular season of the year and the relative geographical location of the stations.

To further analyze the electrical construction of beam reflectors and the manner in which they concentrate the radiated energy into a beam it can be interpreted in somewhat greater detail by observing Figure 8 which will be used to more fully explain the principle of waves from a parabolic reflector. This, in reality, is the top view of the type of reflector shown in Figure 5 which is in the form of a section of a parabolic cylinder. The wave from this form of reflector is somewhat similar to a parallel beam of light which has passed through an opaque screen. Theoretically, if the transmitting antenna is situated in the focal axis G, the reflected rays will all be parallel (JN, UH, XV, YZ) and will be parallel to the axis of the parabolic cylinder TM. However, this is the ideal result and is only approximated in practice. The transmitting antenna at the focus G is a vertical antenna as shown in Figure 5 and the energy radiated from this point is re-radiated by each wire dropped from the parabolic suspension CBA, Figure 8 , by virtue of the fact that each one is tuned to G. It follows from the theory of a true parabola that any distance such as GKO or GPL is equal to GB+BG, thus it is obvious that the re-radiation from all the wires along the parabola CBA will reach the aperture CA in phase with each other. Therefore, re-enforcement takes place in the direction GM and interference in the direction BT.

In reviewing this action we can understand that the energy to be radiated originates at the transmitting antenna at G, is re-radiated by wires suspended from the parabola CBA, and the re-radiated waves reenforcing each other in the direction GM are blocked out in the direction BT. In this analysis the ends of the reflector have been considered to be C and A, respectively, and energy radiated in the direction GW would not have any part of the reflector in its path, and hence would not be diverted from its course, but would continue in the direction GW. Except for leakage, as shown at GW, practically all the energy is reflected over a small angle in the direction GM, therefore, to minimize the leakage it is only necessary to increase the width of the aperture CA, which in other words means the extension of the parabola, as shown at R and S by the curved dotted lines. If this is done the side leakage is reduced and the radiated beam is made narrower.

As is generally known, one of the serious obstacles in the reception of radio signals is "static". This is especially true during summer months. Another generally known fact is that static is not so predominant on the very short wavelengths and at wavelengths as low as 10 meters heavy static is not as a rule encountered. When long antennas are used the difficulties experienced from static are more noticeable than when short antennas are employed. From the foregoing it is possible to understand the reasoning that prompted experimentation with directive transmitting antennas using wavelengths much

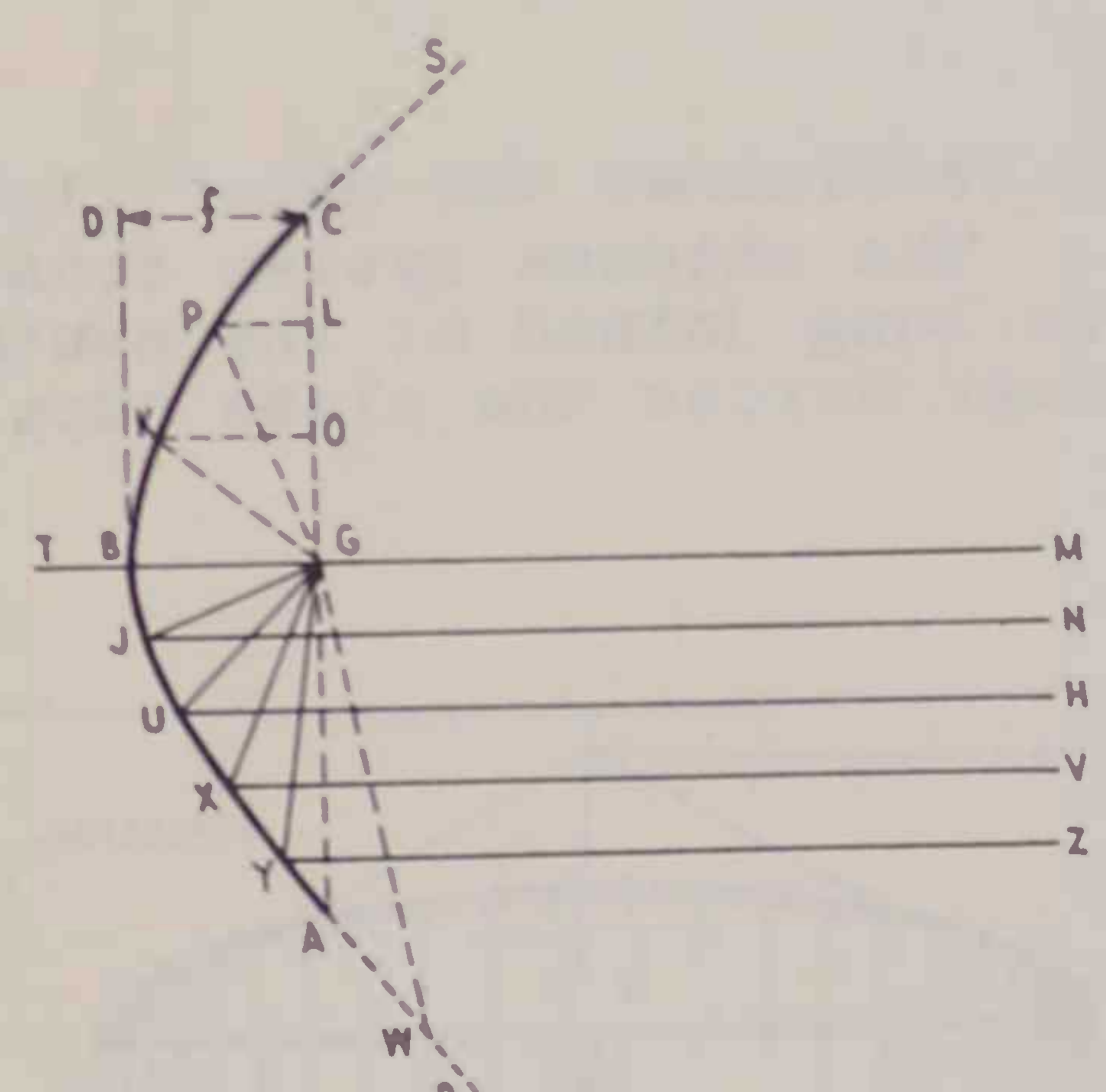


Fig. 8 - SHOWING HOW A REFLECTOR CONCENTRATES THE RADIATED ENERGY INTO A BEAM.

lower than 100 meters. Thus during the last couple of years extensive experimentation has been carried on with beam transmitters at wavelengths of 10 meters, 5 meters and down to the ultra short waves.

Figure 9 shows the oscillating circuit used to generate the high-frequency energy and this diagram also shows the method of coupling the oscillatory circuit to the antenna. The Hartley type of oscillatory circuit was employed and a 50-watt tube used for an oscillator. The plate circuit inductance consisted of one turn of heavy copper wire about 7 inches in diameter and the grid inductance was of the same size. A similar coil was used in series with the antenna as a means of coupling the antenna to the oscillatory circuit. The internal capacity between the elements of the tube, together with the external inductance, completed the oscillatory circuit. In fact

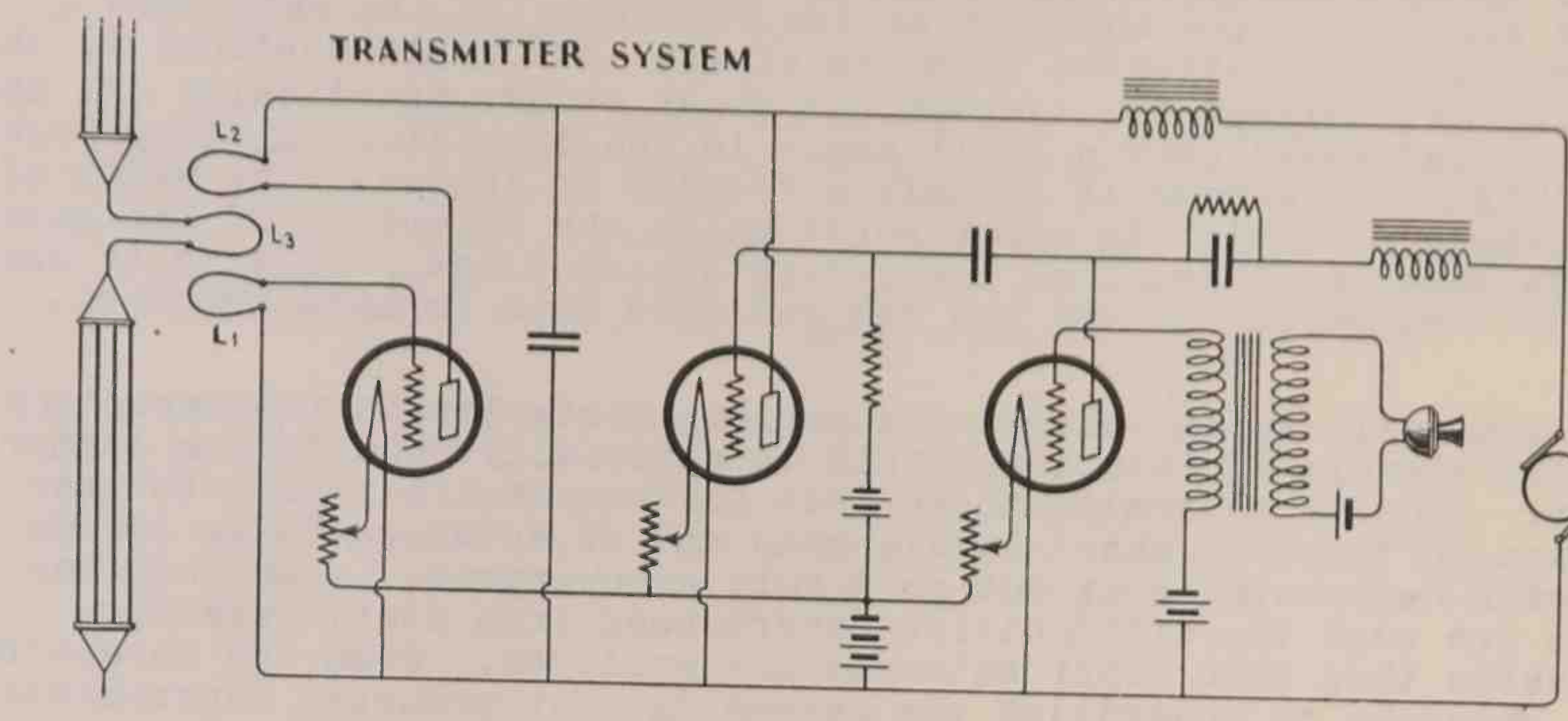


Fig. 9 - OSCILLATING CIRCUIT COUPLED TO A REFLECTOR TYPE ANTENNA SYSTEM FOR TRANSMITTING VOICE SIGNALS.

this internal capacity determines the upper limits of the frequencies that can be developed. The antenna system consisted of two cage antennas, each 1.8 meters long joined at the center through the coupling coil. The condenser across the plate supply is simply a radio-

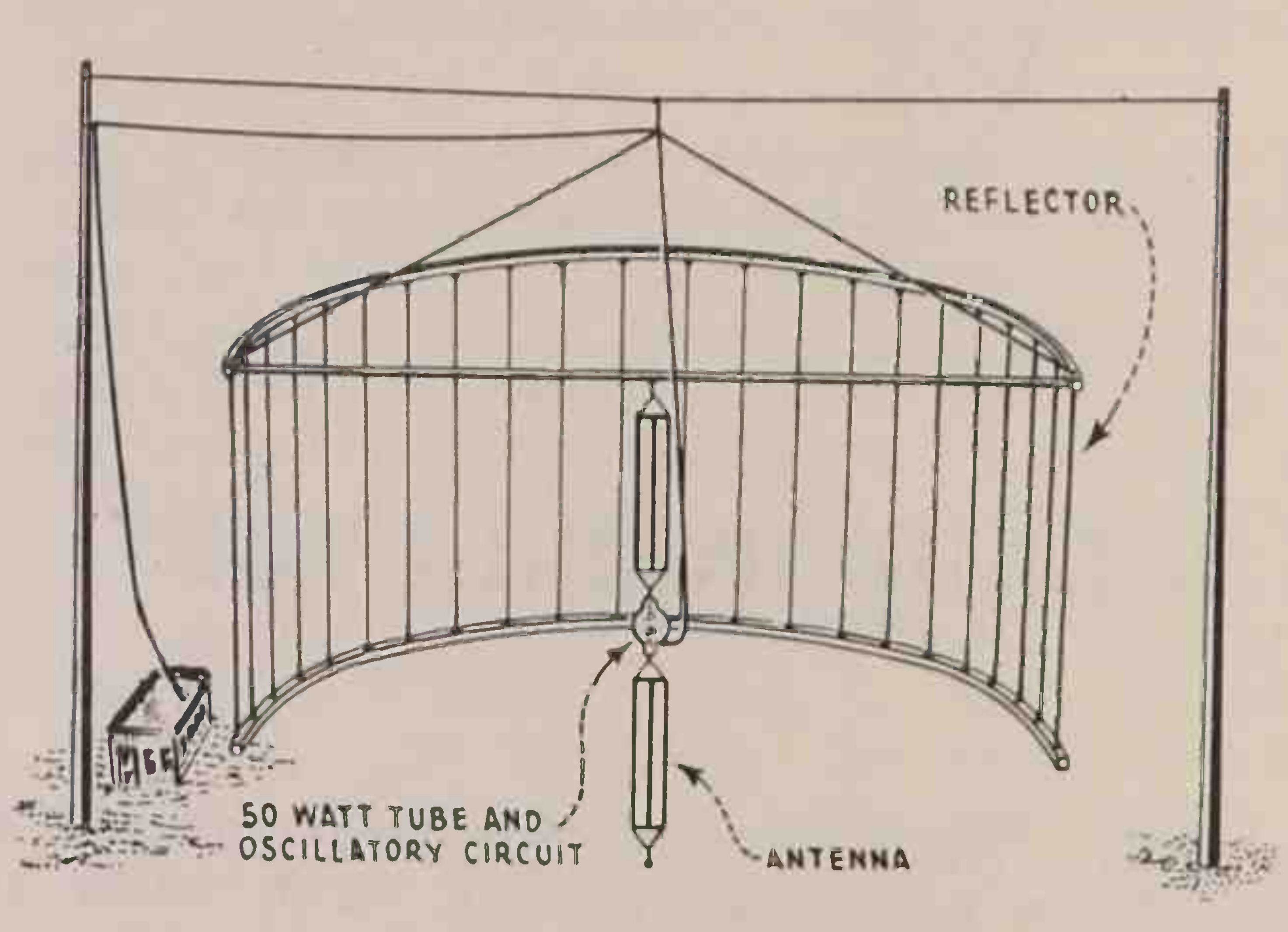


Fig. 10 - THIS ANTENNA SYSTEM IS SUSPENDED IN FRONT OF THE PARABOLIC REFLECTOR.

frequency by-pass condenser. Figure 10 shows the antenna system suspended in front of the parabolic reflector in such a manner that it forms the focal line of the parabola. The vacuum tube and its associated circuits are mounted in a little cage at the mid-point of the antenna and insulated from it. The power supply leads to the tube are brought from one side in a cable, as shown. The parabolic reflector was formed by 40 wires, spaced one foot apart, in the form of a parabola and each one tuned to a wavelength of 10 meters.

The focal distance (BG, Figure 8) was made $\frac{1}{4}$ of a wavelength, or 2.5 meters. The receiving set employed is shown in Figure 11. The antenna consisted of two vertical pieces of No. 12 copper wire joined at their mid-point by a single turn coil. The secondary coil of this receiver was a single loop of wire 12 inches in diameter and this

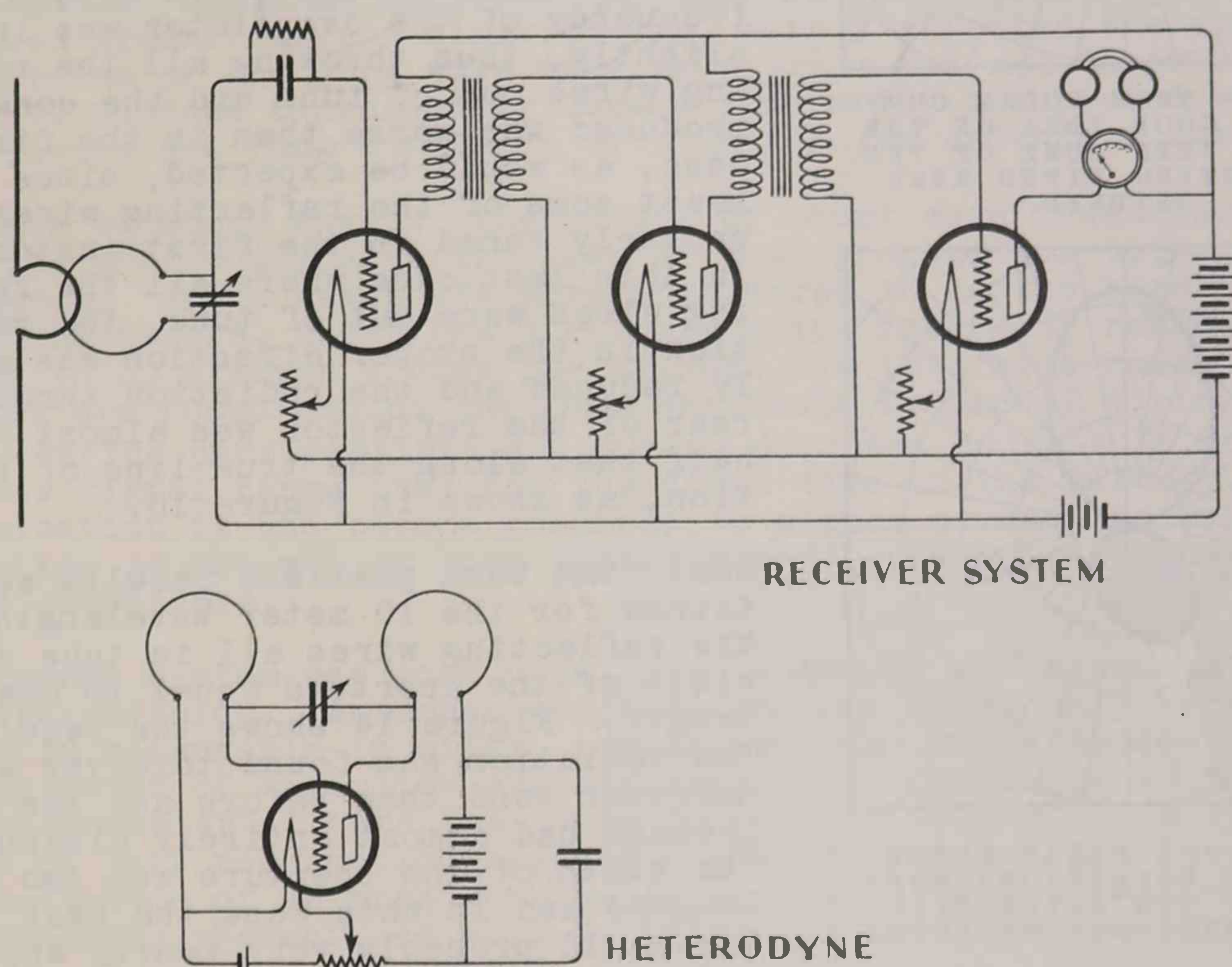


Fig. 11 - THE ANTENNA FOR THIS RECEIVER CONSISTS OF TWO VERTICAL LENGTHS OF NO. 12 COPPER WIRE JOINED AT THEIR MID-POINT BY A SINGLE TURN COIL.

secondary was tuned by a two-plate variable condenser of .00005 microfarad maximum capacity. Since the waves radiated from the transmitter were unmodulated (of continuous amplitude) it was necessary to use a separate heterodyne to produce an audible beat note in the receivers. This separate heterodyne (oscillator) had plate and grid inductances of a single turn each and a two-plate variable condenser was connected from grid to plate. The detector was succeeded by two steps of audio-frequency amplification. By means of this directional transmitter, and the receiver described, it was possible to obtain data relative to the directional characteristics of this type of system.

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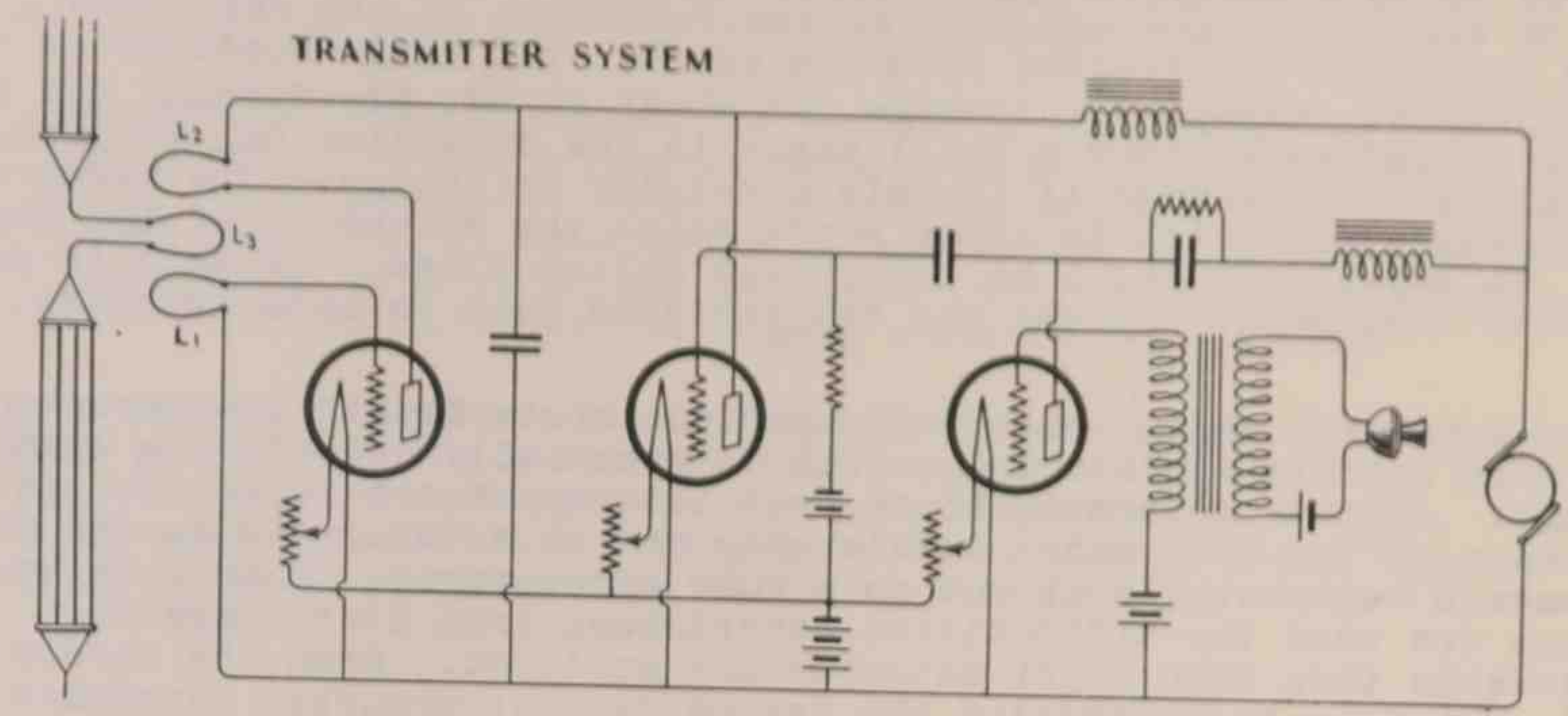

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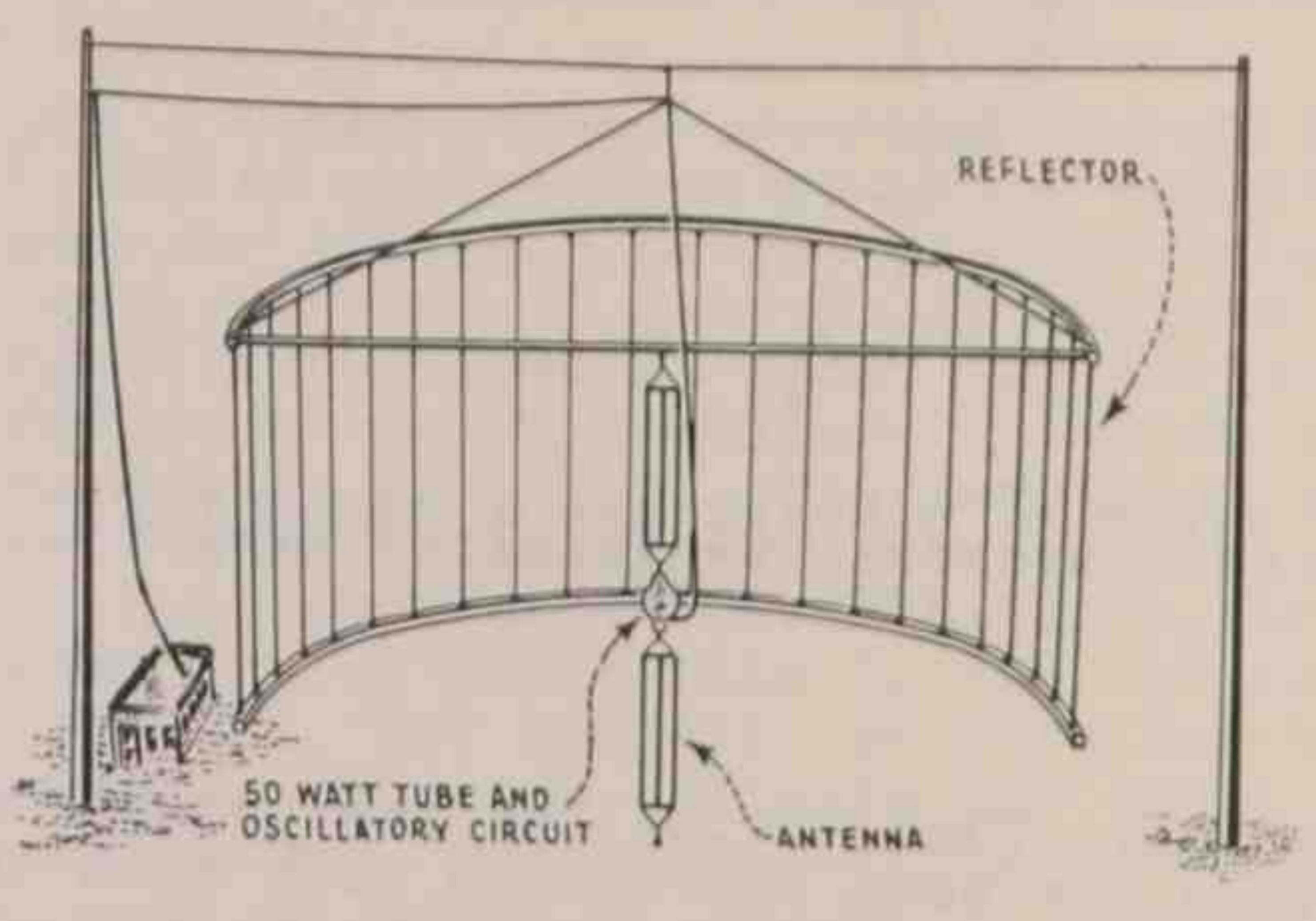

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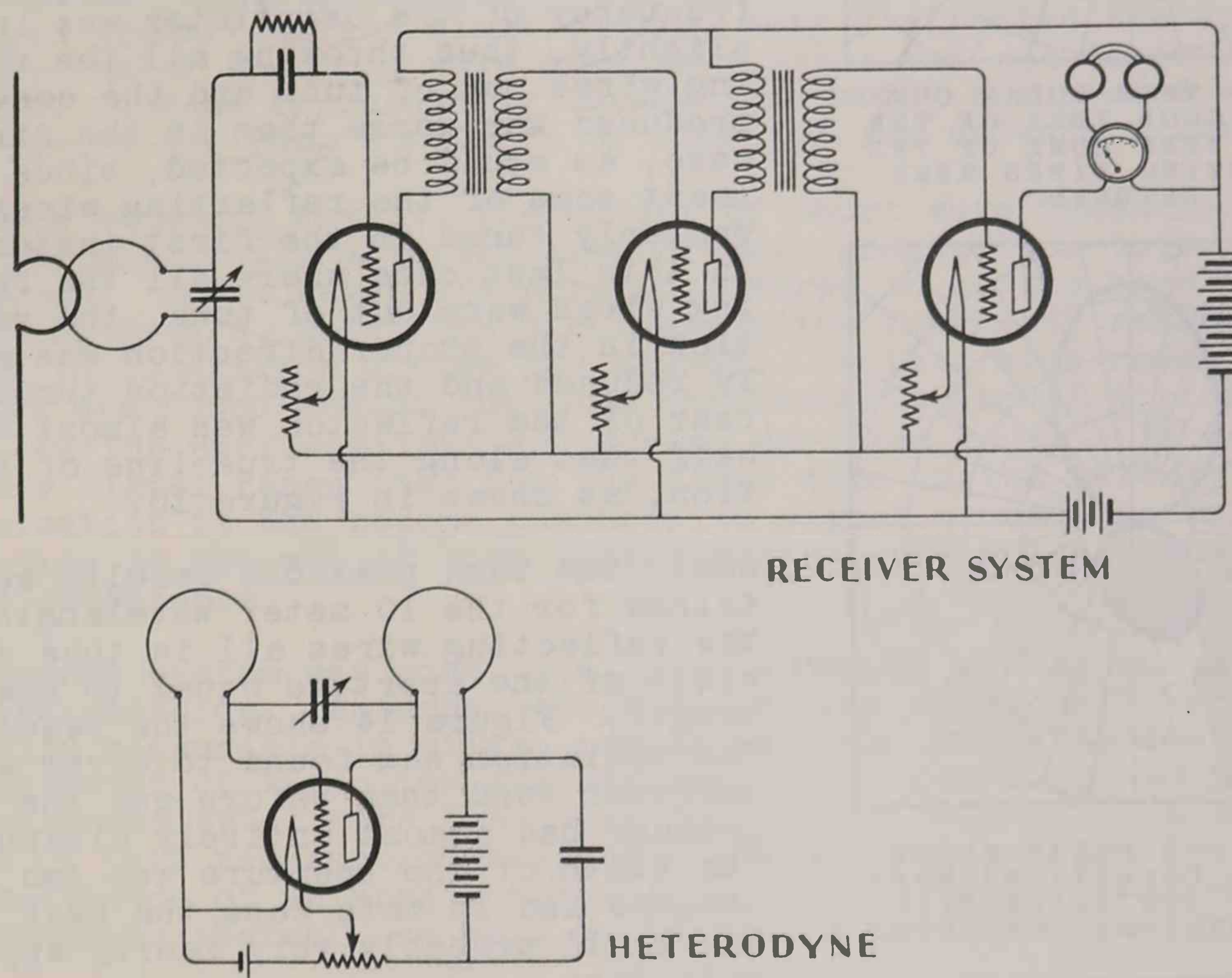

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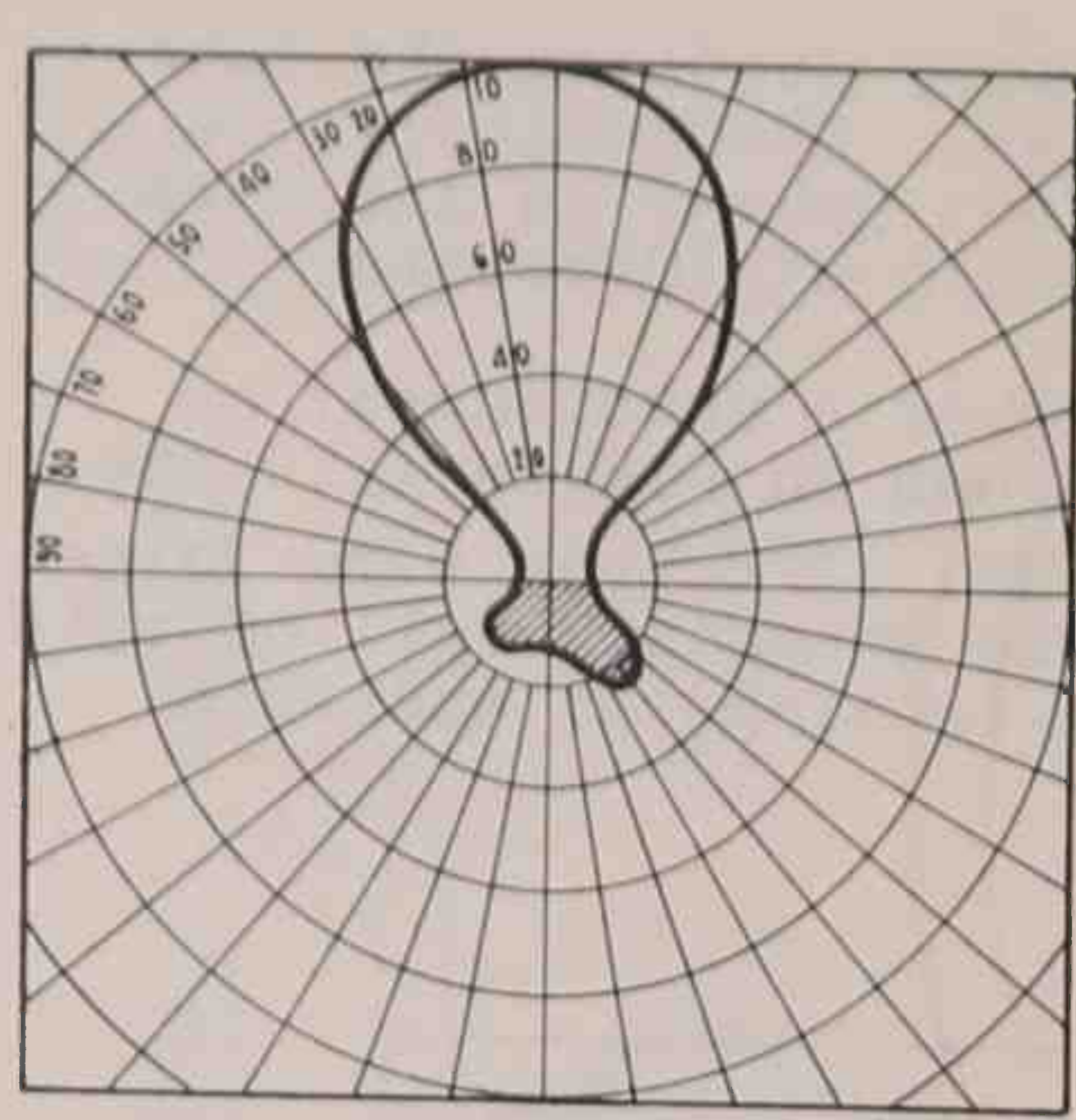

Fig. 12 - THIS POLAR CURVE GIVES A GOOD IDEA OF THE ACTION WHEN SOME OF THE REFLECTING WIRES WERE DETUNED.

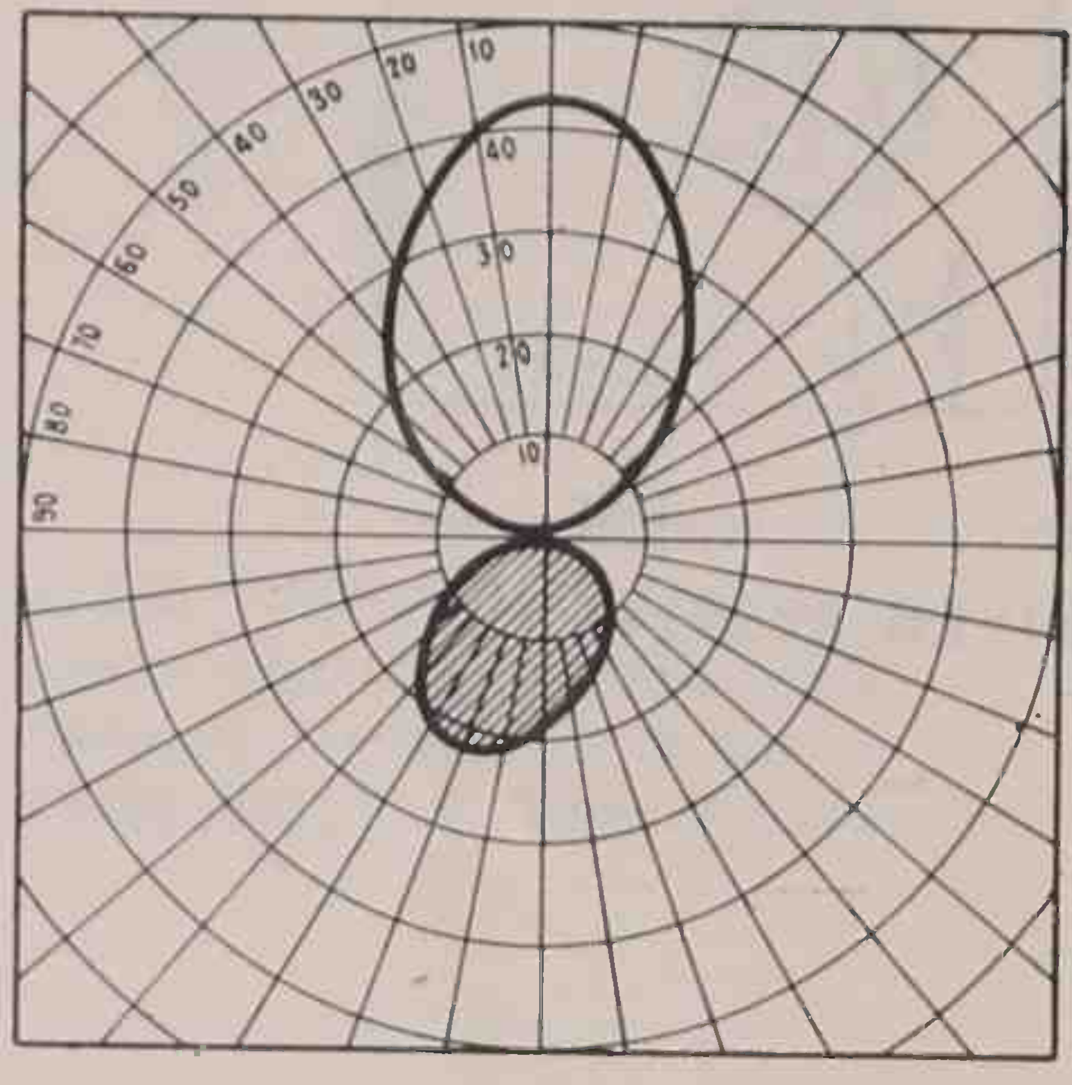

Fig. 13 - A POLAR CURVE SHOWING CONDITIONS WHEN ALL OF THE REFLECTING WIRES WERE OUT OF TUNE.

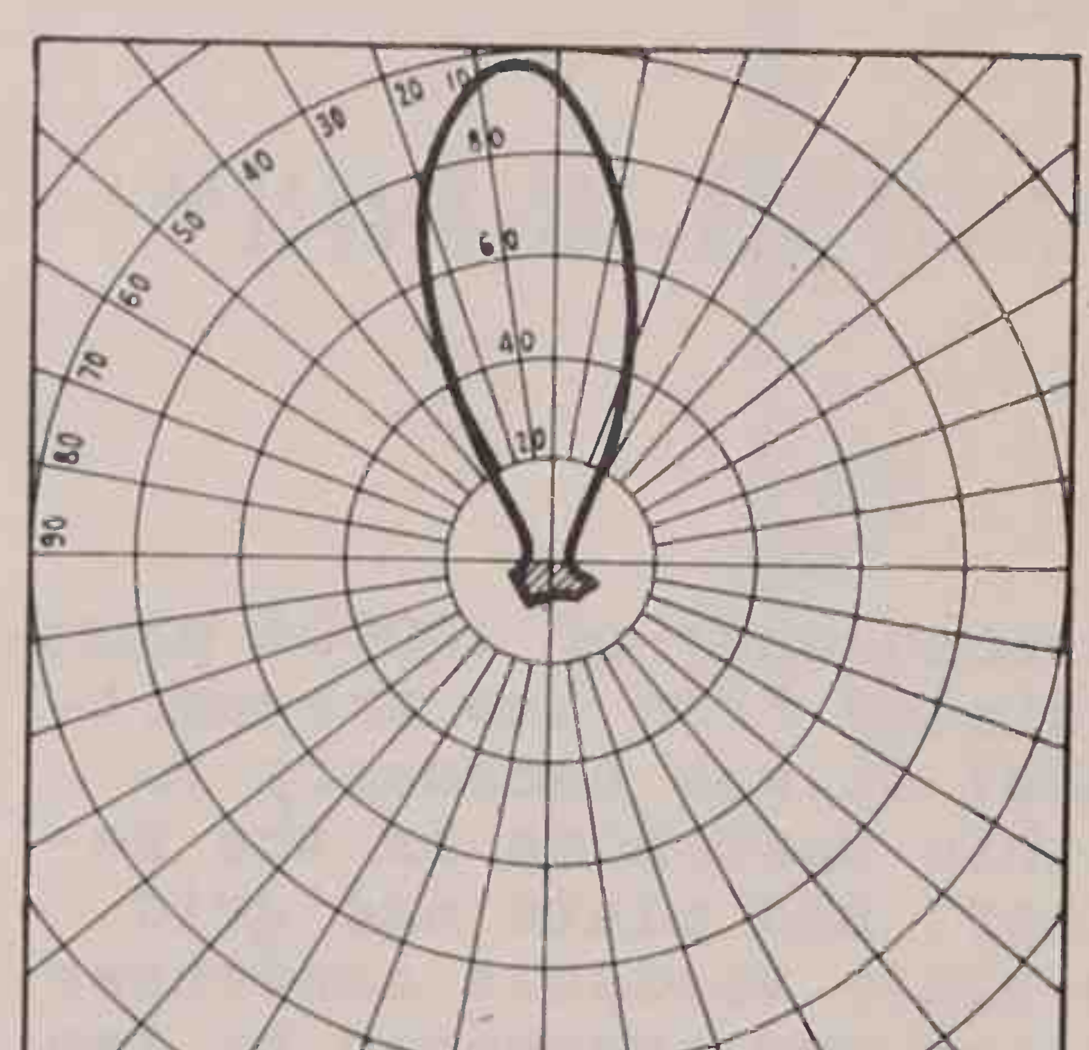

Fig. 14 - THE BEST POSSIBLE CONDITION FOR A 10-METER WAVELENGTH WITH ALL OF THE REFLECTING WIRES IN TUNE.

The polar curve shown in Figure 12 gives a good idea of the action of the system when the reflecting wires were detuned. In this instance they had not all been cut to the proper length and thus were not all properly tuned to the 10 meter wave radiated at the source. The portion shown in cross section in the diagram is the back-leakage due to the untuned condition of the reflector, and the shape of the curve in the direction of propagation is quite broad. When all the wires were tuned to 10 meters, the frequency of the oscillator was increased slightly, thus throwing all the reflecting wires out of tune and the condition produced was worse than in the first case, as would be expected, since at least some of the reflecting wires were properly tuned in the first instance. In this last case where all the reflecting wires were out of tune, the radiation in the proper direction was greatly reduced and the radiation through the rear of the reflector was almost one-half that along the true line of reflection, as shown in Figure 13.

Next, the best possible results were obtained for the 10 meter wavelength with the reflecting wires all in tune and the width of the aperture equal to one wavelength. Figure 14 shows the result. The radiation was found to cover a much narrower band than before and the back leakage had almost entirely disappeared. The width of the aperture was two wavelengths and in this case the back leakage would probably very nearly approximate zero.

There can be no question of the many advantages gained by the beam method of transmission for military, naval and commercial practice. At the present time considerable experimental work is being conducted in connection with trans-oceanic and point to point radio-telephony systems. As was previously stated there would be no advantage in the use of beam transmission in radio broadcasting of musical or voice programs unless transmission was desired to take place from some central point to a predetermined distant point; for example, between two different countries such as England and America, and then only when the program was to be re-broadcast in the regular manner.

THE R.C.A. BROADSIDE PROJECTOR ANTENNA FOR LONG DISTANCE COMMUNICATION BY SHORT WAVES

Prior to the introduction of short-wave transmission, long distance radio communication was conducted almost exclusively in the wavelength range of 5000 to 30,000 meters. The frequency spectrum corresponding to this wavelength covers from 10,000 to 60,000 cycles. The basic laws of wave propagation, as well as design constants covering antenna and terminal equipments for the long wave system, were well established. A signaling spectrum of 10,000 to 60,000 cycles imposed a consequential limitation of one-quarter wavelength as the practical physical length of the antenna system. These lengths reduced to feet cover the range of 4100 to 25,000 feet, or roughly 1 to 5 miles. Antenna refinements, such as multiple tuning and equalized ground current distribution, merely affected the electrical efficiencies of the long wave antenna systems and not their size. The long wave antenna consequently became inherently associated with high steel towers and long stretches of high tension antenna wires.

Influence of Short Waves. The advent of short wave transmission found the previously accepted laws of wave propagation to be entirely inadequate. Short waves are here considered to be the band between 10 and 100 meters, which has a corresponding frequency range of 3 million to 30 million cycles per second. In this wide range of frequencies are found groups that are particularly useful during daylight, during part daylight and during darkness hours. So effective is their signal range that for the first time in the history of radio communication it has become possible to signal around the world. A revolution in the art of long distance radio communication at once became inevitable.

The antenna system was most vitally affected by reversion to short wave transmission. Antennas whose dimensions previously were of necessity measurable in miles, now became measurable in feet. The huge antennas of the older systems were often out-distanced by single wire antennas which were less than 75 feet in length. The logical result of this remarkable physical concentration was the development of a multitude of antenna combinations; quarter wave, half wave, and odd multiples thereof, as well as reflector and directive types.

The state of the art having thus briefly been outlined, the directive antenna known as the R.C.A. Broadside Projector Antenna, will now be described.

Constructional Features. This Broadside Projector Antenna, shown on the front cover page, consists essentially of two rows of equally spaced vertical radiators extending in parallel lines for a distance varying from 3 to 12 wavelengths depending upon the desired degree of directivity. Each row is energized from a common central horizontal feeder bus, the bus in turn being energized by a transmission line. The feeder bus, as shown on the inside front cover page, is bridged by a tuning coil at each vertical radiator. The radiators are so disposed that they form in effect a half wave antenna with a tuning coil at the centre of each. When arranged for sleet melting each radiator element consists of a hairpin loop, otherwise the radiator element is a straight vertical wire. The radiators are arranged to produce electrical and mechanical symmetry with respect to the central feeder bus.

The illustrations on the front and inside cover pages are views of a 4-bay 16.8 meter antenna installed at Rocky Point, New York. Two long rows of wooden poles support catenary cables broken up effectively by insulators. The cables in turn support the vertical radiator elements. These two parallel rows of poles, cables and radiator elements represent the antenna proper and its reflectors spaced five quarter wavelengths apart. Unlike the high towers of other beam systems, this antenna uses only wood poles one and one-eighth wavelengths high.

These broadside directive antennas are designated as 1-bay, 2-bay and 4-bay antennas, the significance of which is the indication of degree of directivity. A 1-bay antenna is arbitrarily taken as 3 wavelengths wide. A 2-bay antenna would correspondingly be 6 wavelengths and a 4-bay antenna 12 wavelengths wide. The greater the number of co-acting vertical radiators, the greater the energy concentration. A 4-bay antenna is consequently more directive than a 2-bay, and a 2-bay more than a single bay.

Change of Direction of Directivity. One of the advantages of a 4-bay broadside directive antenna is the means it provides for altering the direction of the beam. Change of direction of the beam is accomplished by regulating the phase relations of the currents fed to the individual bays. The resultant radiated energy pattern may thus be made to assume an acute angle to the line of poles rather than the normal broadside pattern. This feature is of advantage when more than one circuit is to be covered by a single broadside projector antenna.

Transmission Lines. The signal energy of the transmitter is fed to the broadside directive antenna over transmission lines which may be several thousand feet in length. Means are thus provided for locating the antenna on smooth cleared ground, free of local obstructions at the source of generation of the radio-frequency signaling currents. The phasing adjustments for the transmission lines are accomplished by a local tuning system in a coil house located at the center of each bay of the antenna.

Sleet Melting Circuit. The provision of sleet melting facilities for an antenna of the directive type, having in the case of a 4-bay unit 192 radiating elements, presents an interesting problem. The radiating elements must be so connected electrically that they operate in parallel when normally energized for transmission, and in series when connected for sleet melting.

When sleet melting is not required each individual radiator may be a single wire. Each single wire radiator is then normally terminated at the feeder bus end of the bus tuning coil. Geometrically the center bus then resembles a ladder whose rungs are the tuning coils but with the addition of a radiator wire extending beyond each end of the bus tuning coil.

When sleet melting is provided the single wire radiator must be replaced by a hairpin loop. Each hairpin loop requires two tuning coils, each having double the inductance of the non-sleet melting arrangement since the coils operate in parallel for transmission. Across the terminals of each hairpin loop is connected a sleet melting condenser. This condenser allows the hairpin loop to be energized in parallel from the bus for transmission, and interrupts the sleet melting current path causing it to flow through the hairpin loop. Radio-frequency choke coils are also disposed to keep the signaling circuits and sleet melting circuits electrically separate although actually interconnected. A single-phase 60-cycle transformer with voltage regulating tap in its primary circuit, supplies 150 amperes to each hair-pin loop and tuning coil. This current is sufficient to melt a heavy incrustation of ice in a few minutes.

Basic Theory of Operation. When two or more simple vertical antennas are arranged symmetrically in a row at fixed spacings of less than $\frac{1}{4}$ wave separation and simultaneously energized, at or near their resonant frequencies, their energy radiations will cancel along the line of the antennas and add in both directions at right angles to the line; namely, broadside radiation will result. The greater the number of radiating elements the more concentrated will be the broadside radiation. If now a second parallel line of antennas be so spaced with respect to the first line that the energy radiation of the second line reaches the first line at its crest, the two independent waves will add in one direction and cancel in the other, causing the resultant radiation to be uni-directional. This is the function of the second row of masts in the broadside projector antenna.

To insure that all independent vertical antenna elements are simultaneously energized and radiating in synchronous phase relationship, it is necessary that the feeder system be adjusted for infinite velocity. This condition is realized by relative proportioning of the radiator lengths, by adjustment of the central feeder bus capacity and by suitable connection to the transmission line load coils. When the energy drain from the feeder bus is at the proper rate, the feeder system acts as a concentrated line without standing waves or reflection. If the energy in the feeder bus is subject to traveling or reflected waves, it is obvious that the radiator elements will not be energized simultaneously in the same phase relationship and consequently the directivity of the radiating system will be largely destroyed.

EXAMINATION QUESTIONS

1. Who first experimented with reflectors in the transmission of radio-frequency energy?
2. What is the advantage of beam transmission?
3. Is beam transmission desirable for radio broadcasting?
4. Draw a simple diagram showing how radio waves are deflected.
5. Why is a second row of antenna elements used in the broadside projector antenna?
6. How is it possible to keep the signaling circuits and sleet melting circuits independent electrically when they are actually interconnected?
7. What does the term "bay" indicate in connection with directive antenna systems?
8. In brief what is the Lecher feed system?
9. Name some advantages of a short-wave directive system over the long-wave type.
10. Describe a type of antenna system used at the receiving end to intercept signals transmitted by the beam method.

SENATOR MARCONI EXPERIMENTING WITH ULTRA SHORT WAVES AND DIRECTIVE ANTENNA SYSTEMS FOR POINT-TO-POINT COMMUNICATION.

COURTESY ELECTRONICS

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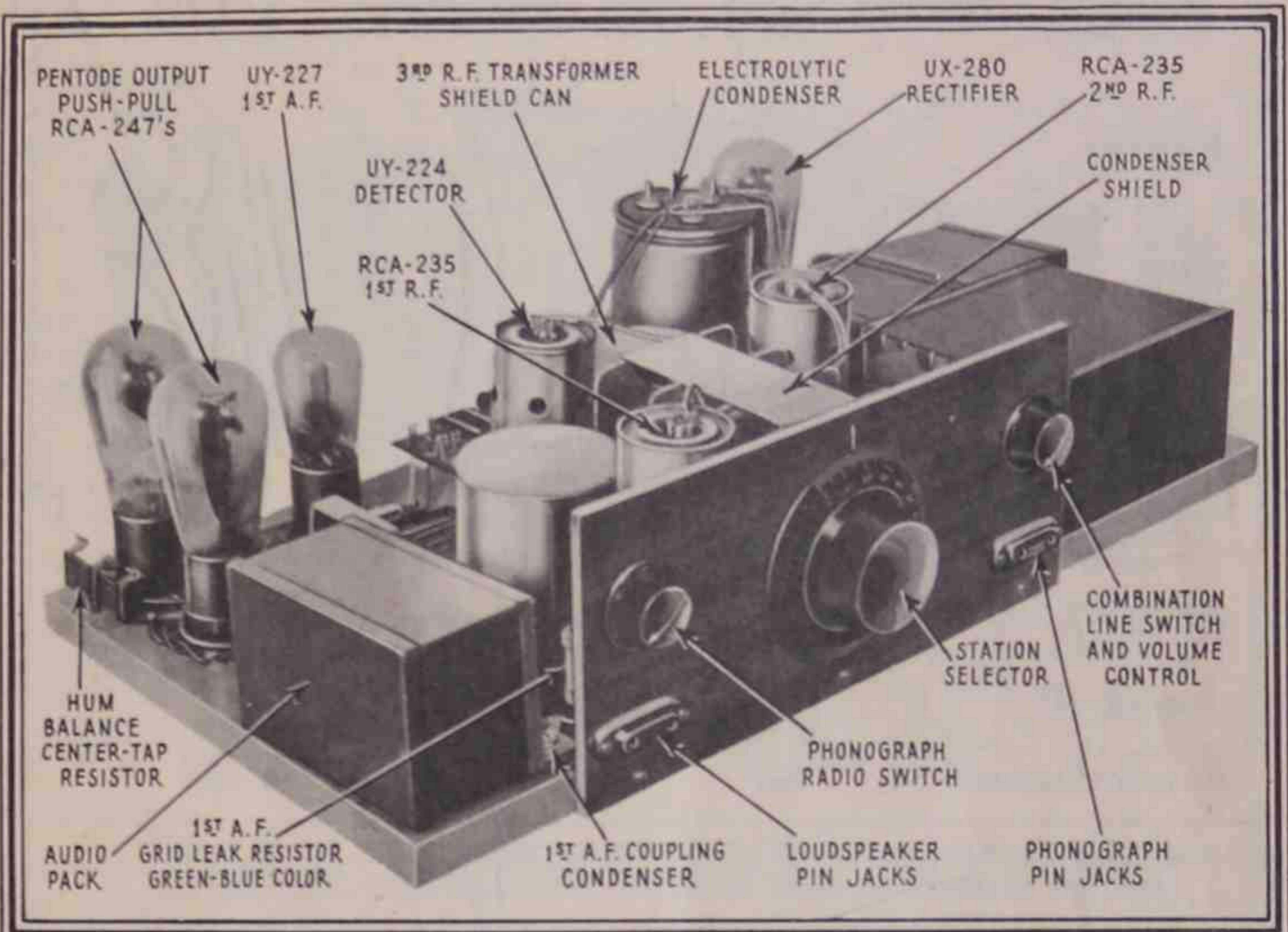
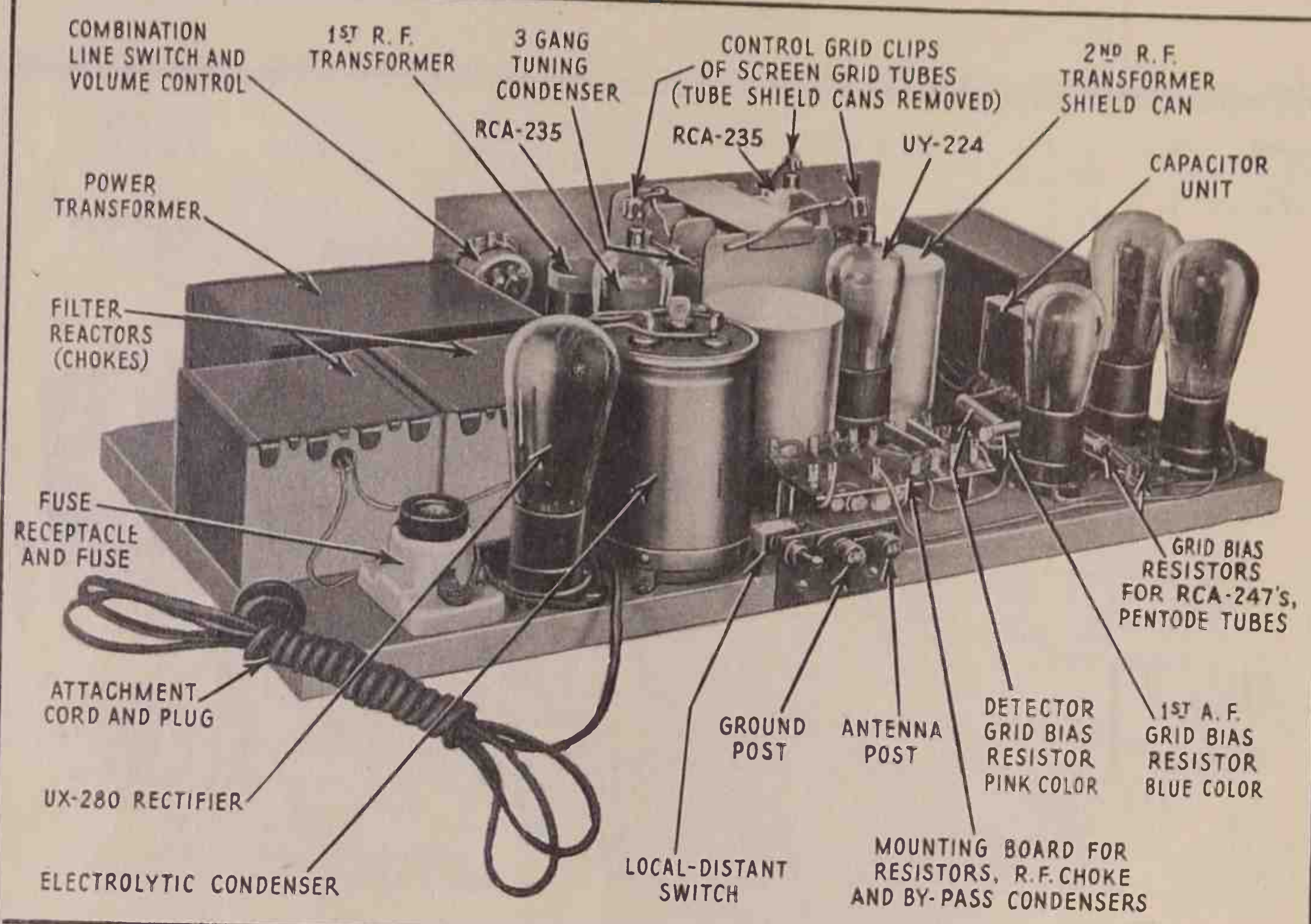


FRONT VIEW SHOWING THE A.C. KIT OF PARTS COMPLETELY ASSEMBLED

CONSTRUCTIONAL DETAILS OF THE A.C. PENTODE RECEIVER

VOL. 36*1

DEWEY CLASSIFICATION R 361.1



REAR VIEW OF RCA INSTITUTES' KIT RECEIVER. THE THREE SHIELD CANS ARE REMOVED TO SHOW DETECTOR AND R.F. AMPLIFIER TUBES IN PLACE

HOME OFFICE: RCA INSTITUTES INC. 75 Varick Street, New York.

CONSTRUCTIONAL DETAILS OF THE RCA INSTITUTES' A-C SCREEN-GRID RECEIVER WITH PENTODE OUTPUT

GENERAL TOPICS. The first thing of importance to mention is that no work should be done on the kit until you have first read through this entire lesson. Radio principles about which you have studied in other lessons are incorporated in the 7 tube a-c operated screen-grid receiver which you will construct and the practical side of this work now comes in the actual assembly and wiring of the receiver and adjustment of its radio-frequency circuits for maximum selectivity and sensitivity. And, of course, there is the tuning-in operation that follows after the set is completely finished and installed and the power is switched on. After unpacking the box, carefully check over all of the various pieces of equipment necessary for the construction of your screen-grid receiver to be sure that the parts received correspond to the items on the list of parts included with the kit.

In addition to the parts actually needed to build your a-c receiver there are extra UX sockets and an amperite resistor and mounting included in the kit which is for those students who do not have an a-c electric power line available to operate their set and, therefore, wish to built the receiver circuits to operate entirely from batteries.

Additional items not furnished with the kit and to be obtained by the student are as follows:-

Vacuum tubes:	2 type	RCA-235
	1 "	UY-224 or UY-224-A
	1 "	UY-227
	2 "	RCA-247
	1 "	UX-280

Antenna and ground equipment.
Loudspeaker. (Either an a-c dynamic type or magnetic type speaker may be used with this set, but better results should be obtained with the use of a good a-c dynamic type.)
Soldering iron and sufficient rosin core solder or solder and flux consisting of alcohol and rosin.
Small roll of friction tape.
Baseboard. 11$\frac{3}{4}$" wide x 23$\frac{1}{4}$" long and about $\frac{3}{4}$" to 1" thick. (This board should preferably be of plywood to avoid warping.)

(Pentode Kit #30)

Note that this receiver is designed to provide satisfactory operation when Radiotron tubes of the specified types are used. Or, Cunningham tubes of equivalent types will also give satisfactory performance. Make certain that all of the tubes are in good operating condition by testing them or having them tested. It is important to use two RCA-247 power tubes having nearly the same characteristics, that is, they should be closely matched in order to work efficiently in push-pull relation. One way to test tubes for operation is to insert each tube in succession in the proper socket of some receiver that is operating satisfactorily and tuned to a broadcast station. A tube which is O.K. will give satisfactory reception.

Before inserting a tube of unknown condition in a receiver it is always best to determine whether or not any electrodes in the tube are short-circuited. If two electrodes should touch each other it might result in damage to certain parts. Tests for shorts are provided on some types of commercial tube testers or if no such instrument is at hand a simple continuity test circuit could be set up by placing a dry cell in series with a 1.5 volt lamp, or you could connect in series a battery and voltmeter of suitable range. With the two open test leads from the respective ends of the test circuit you would proceed to touch, in succession, each pair of electrode prongs on the tube base. If a short existed either the lamp would light, or the voltmeter would read depending upon which test circuit was used. There is also another simple means for testing for shorts and that is by using your headphones supplied with the kit and placing a dry cell in series with it. Whenever the two open ends of this test circuit are touched to two points along a circuit or across parts and there is a path formed through which current can flow a click will be heard in the phones. No click would indicate that there is no path for the current and it would be known that the circuit under test is open or the parts do not touch as the case may be.

Although either a UY-224 or UY-224-A may be used in the detector stage it is best to use the UY-224-A if possible because it is a quick heating tube.

<u>THERE ARE 8 PARTS TO THIS LESSON.</u> This construction lesson is divided into eight parts as follows:

Part 1. Constructional details and assembly.
" 2. Identification of parts and electrical ratings.
" 3. Wiring of the socket power unit (S.P.U.) which includes the power transformer, rectifier, heater and filaments, filter system, and voltage divider.
" 4. Wiring of the plate circuits of the tubes in the receiver proper and the screen-grid circuits.
" 5. Wiring of the r-f circuits, control grids, antenna, local-distance switch, and phonograph-radio switch.
" 6. Wiring of the cathode circuits, volume control, grid bias resistors, and by-pass condensers.
" 7. Practical operation of the set after the wiring is completed and the set is installed.
" 8. Placing the r-f circuits in resonance with one another.

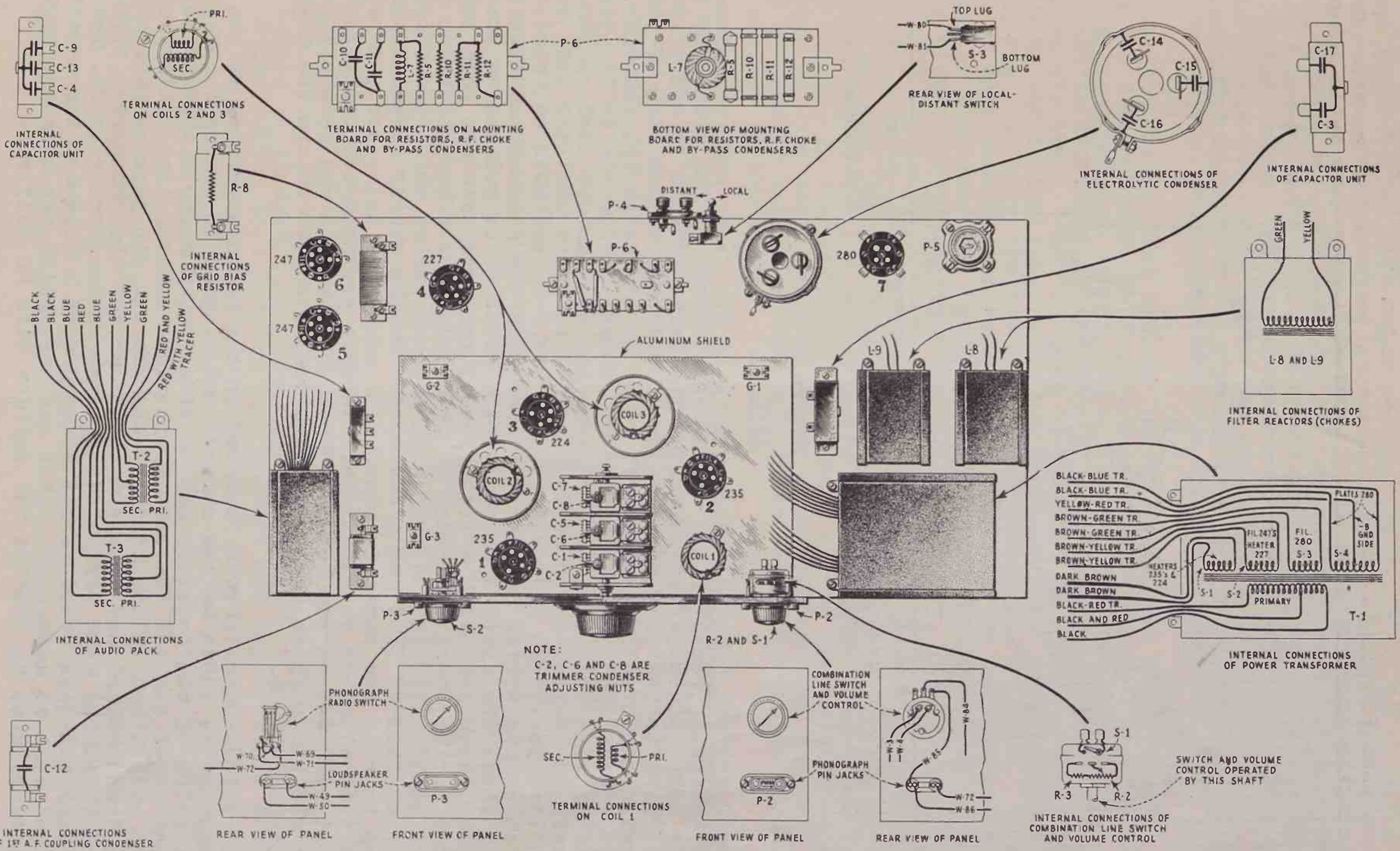

C-9
C-13
C-4
INTERNAL CONNECTIONS OF CAPACITOR UNIT
PRI.
SEC.
TERMINAL CONNECTIONS ON COILS 2 AND 3
C-10
C-11
L-7
R-5
R-10
R-11
R-12
P-6
TERMINAL CONNECTIONS ON MOUNTING BOARD FOR RESISTORS, R.F. CHOKE AND BY-PASS CONDENSERS
BOTTOM VIEW OF MOUNTING BOARD FOR RESISTORS, R.F. CHOKE AND BY-PASS CONDENSERS
TOP LUG
W-80
W-81
S-3
BOTTOM LUG
REAR VIEW OF LOCAL-DISTANT SWITCH
C-14
C-15
C-16
INTERNAL CONNECTIONS OF ELECTROLYTIC CONDENSER
C-17
C-3
INTERNAL CONNECTIONS OF CAPACITOR UNIT
R-8
INTERNAL CONNECTIONS OF GRID BIAS RESISTOR
DISTANT
LOCAL
P-4
P-6
247
6
227
4
247
5
280
7
P-5
GREEN
YELLOW
L-8 AND L-9
INTERNAL CONNECTIONS OF FILTER REACTORS (CHOKES)
BLACK
BLACK
BLUE
RED
BLUE
GREEN
YELLOW
GREEN
RED AND YELLOW
RED WITH YELLOW TRACER
T-2
SEC. PRI.
T-3
SEC. PRI.
INTERNAL CONNECTIONS OF AUDIO PACK
ALUMINUM SHIELD
G-2
G-1
L-9
L-8
COIL 3
3
224
COIL 2
C-7
C-8
C-5
C-6
C-1
C-2
235
2
235
1
G-3
COIL 1
P-3
S-2
P-2
R-2 AND S-1
BLACK-BLUE TR.
BLACK-BLUE TR.
YELLOW-RED TR.
BROWN-GREEN TR.
BROWN-GREEN TR.
BROWN-YELLOW TR.
BROWN-YELLOW TR.
DARK BROWN
DARK BROWN
BLACK-RED TR.
BLACK AND RED
BLACK
PLATES 280
-B GND SIDE
FIL 247'S HEATER 227
FIL. 280
S-3
S-4
HEATERS 235's & 224
S-1
S-2
PRIMARY
T-1
INTERNAL CONNECTIONS OF POWER TRANSFORMER
NOTE:
C-2, C-6 AND C-8 ARE TRIMMER CONDENSER ADJUSTING NUTS
C-12
INTERNAL CONNECTIONS OF 1ST A.F. COUPLING CONDENSER
PHONOGRAPH RADIO SWITCH
W-70
W-72
W-69
W-71
LOUDSPEAKER PIN JACKS
W-49
W-50
REAR VIEW OF PANEL
P-3
FRONT VIEW OF PANEL
SEC.
PRI.
TERMINAL CONNECTIONS ON COIL 1
P-2
FRONT VIEW OF PANEL
COMBINATION LINE SWITCH AND VOLUME CONTROL
PHONOGRAPH PIN JACKS
W-3
W-4
W-85
W-84
W-72
W-86
REAR VIEW OF PANEL
S-1
R-3
R-2
SWITCH AND VOLUME CONTROL OPERATED BY THIS SHAFT
INTERNAL CONNECTIONS OF COMBINATION LINE SWITCH AND VOLUME CONTROL

Figure 1

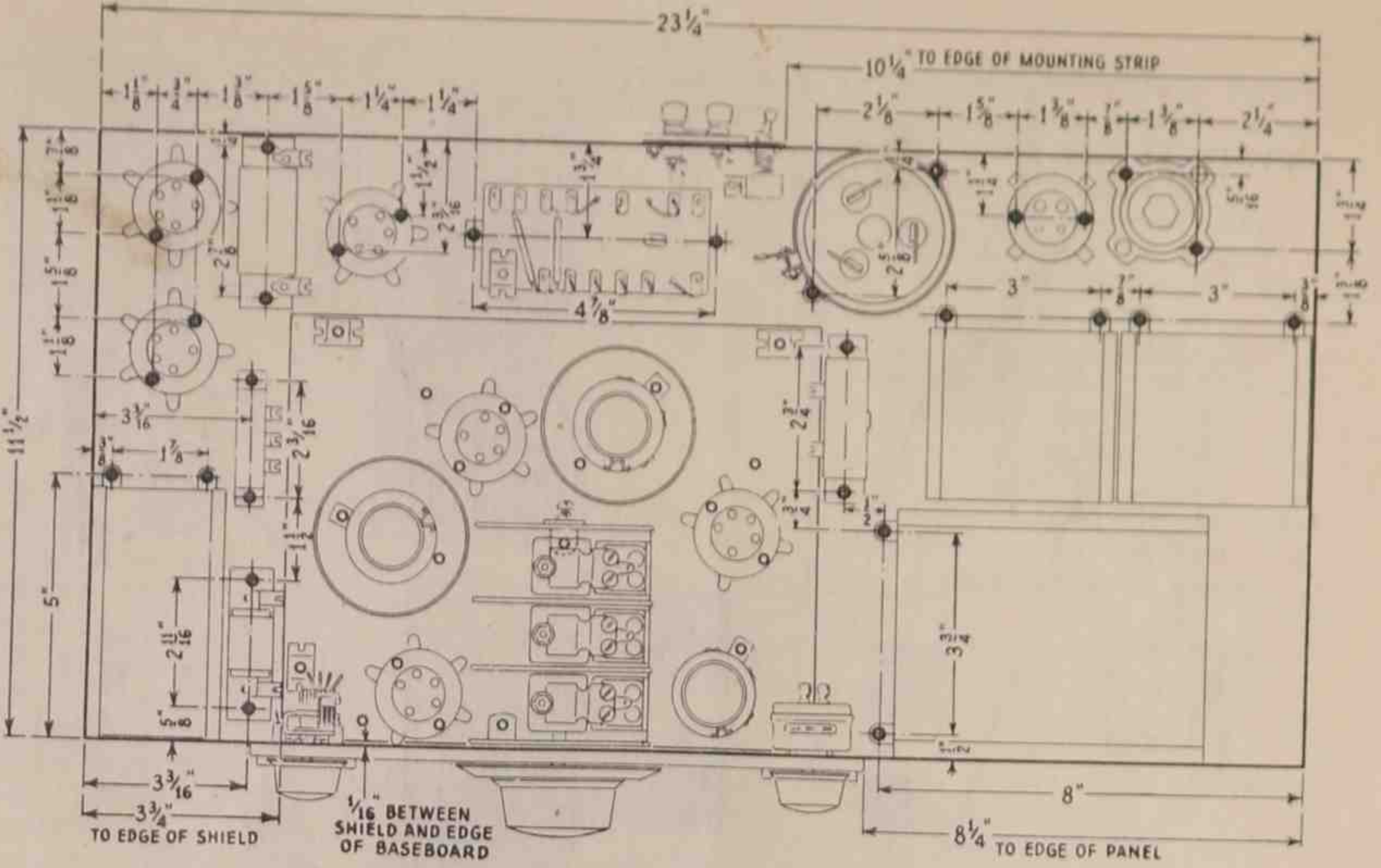


Figure 2

PART 1

CONSTRUCTIONAL DETAILS. Photographs of the front and rear views of the assembled receiver are shown respectively on the front and inside cover pages. After unpacking the parts proceed to identify them according to the drawing in Figure 1 which is a plan view of the set showing pictorially the general relation of the parts, and with each part identified by a key letter and number. Reference to the parts list in this lesson gives the names and key numbers used on the drawings. Parts not shown in Figure 1 are tube and coil shields and five resistors marked R-4, R-6, R-7, R-9, and R-13 but these are shown on the wiring diagrams. Figure 2 is the dimensional plan view that shows the exact location of the parts to be mounted on the wooden baseboard. With a light pencil mark indicate the hole positions on the board according to the dimensions after which you can make small holes in the wood with a punch, or an awl, or a sharp-pointed nail so that the brass screws may be easily screwed into the wood to hold the parts in place. All necessary holes are punched in the flat aluminum shield plate. We have arranged the parts in a particular way on the board so that the circuits may be easily traced out for the purpose of instruction and, also, to obtain the most efficient results.

The various parts must be mounted on the board according to the arrangement as shown on the dimensional diagram in Figure 2, or else the operation of the receiver may be affected. The parts that go on the front panel include the phonograph-radio switch, the combination a-c line switch and volume control, and the two pin-jack boards; one for the loudspeaker cord tips and the other for the phonograph pick-up cord tips. The word "PHONO" is stamped on the latter board. The loudspeaker pin-jack board is not stamped with a name and let us add that if you wish to darken its outer surface, which has been smoothed off, it can be done by rubbing the surface with an oily rag.

The holes in the thin metal strip which holds the bakelite Antenna-Ground post terminal board and the Local-Distance toggle switch are punched so that these parts can be mounted in only the correct way and this is easy to determine. This mounting strip or plate is screwed to the edge of the baseboard in the position shown on the dimensional diagram. The toggle switch is secured to the plate by first placing the hex nut on the threaded portion and then inserting the latter in the hole after which the round knurled nut is screwed on and pulled up tight. The antenna and ground post screws are backed up by lock washers, soldering terminals and small hex nuts.

The bakelite tuning dial is made in two parts, the knob and the round portion on which the division scale is stamped. To mount the dial on the condenser shaft unscrew the knob, loosen brass screw, slip dial on the shaft in the correct position, tighten nut and then screw on the knob. The "O" mark on the dial should line up with the thin line cut in the panel when the condensers are at maximum capacitance, that is, with their rotor plates completely in mesh. Thus, with "O" dial setting the receiver is tuned to the lowest frequency station of the broadcast band and at division "100" the set is tuned to the highest frequency station in this range.

The knobs for the phonograph-radio switch and the combination volume control and "OFF-ON" line switch are held on their respective shafts by set screws. It will require a small screw driver to tighten these screws. In the event that the knob on the combination volume control and line switch should loosen from constant use the set screw could be made to take a better hold on the shaft by filing a small flat surface on the shaft.

The photographs of the finished set show how the control grid clips are soldered to the short wires which connect to terminal lugs on top of the 3-gang condenser. An assortment of different colored wires is furnished with the set. You may use the colored wires for the circuits according to our suggestions on the wiring charts or, if you prefer, you may work up a color scheme of your own. The two round wooden bushings furnished with the kit are to be used under the screw holes of resistor R-8 to raise it slightly above the board. Satisfactory results when soldering will be obtained if you use either rosin-core solder or flux consisting of alcohol and rosin used with regular soft solder or wire solder. The electrolytic condenser can is held by a clamping ring placed around its lower end. Place a soldering lug under the head of the clamping screw before drawing up the nut after which the can should be screwed to the baseboard.

The wiring up of the set is begun as indicated in Part III by preparing each set of filament and heater wires, first twisting the wires in pairs and then cutting them to a given length after which the ends should be scraped clean and tinned and finally each one should be soldered either to a terminal or spliced and taped as the case may be. Follow the wiring diagrams and charts exactly and cut the wires to their proper lengths the first time to avoid waste. Each length of wire should be placed around or between parts as illustrated and its length can be approximated by holding it in the position that it will finally occupy before cutting it. Arrange the leads from each r-f coil so that these wires will come through the slotted hole in the side of the shield can when in place. It is best to loosen a part temporarily when soldering on wires if this will make the work of soldering the connections easier to perform.

PART 2

IDENTIFICATION OF PARTS AND RATINGS. Refer to Figures 1 and 3.

The reference key numbers in the first column below are the same as those used on the drawing in Figure 1 which shows the parts and the schematic diagram in Figure 3.

KEY NO.	RATING	NAME
C-1	18-325 mmfd.	1st r-f tuning condenser.
C-2	4-50 "	" " trimmer condenser.
C-3	.1 mfd.	R-F by-pass, cathodes of r-f amplifiers.
C-4	.1 "	R-F by-pass, screen-grids of r-f amp. and det.
C-5	18-325 mmfd.	2nd r-f tuning condenser.
C-6	4-50 "	" " trimmer condenser.
C-7	18-325 "	Det. tuning "
C-8	4-50 "	" trimmer "
C-9	.1 mfd.	R-F by-pass, around det. grid bias resistor.
C-10	50 mmfd.	" " , between detector plate and ground.
C-11	50 "	" " , detector plate choke and ground.
C-12	.01 mfd.	Coupling capacitor, det. plate to a-f grid.
C-13	.1 "	R-F by-pass around grid bias resistor R-7.
C-14	8.0 "	1st filter (Electrolytic) condenser.
C-15	8.0 "	2nd " " "
C-16	8.0 "	3rd " " "
C-17	1.0 "	By-pass across R-11 and R-12.
L-1		Pri. of 1st r-f transformer. (Antenna coil.)
L-2		Sec. " " " " " "
L-3		Pri. " 2nd " "
L-4		Sec. " " " "
L-5		Pri. " 3rd " "
L-6		Sec. " " " "
L-7		Detector plate choke coil.
L-8		Filter reactor. 13 henries.(Choke or inductor.)
L-9		" " " " " " "
R-2	20,000 ohms	Volume control resistor. Variable portion.
R-3	300 "	" " " Fixed "
R-4	28,000 "	Detector grid bias resistor. (Color code is red with gray tip, orange dot.)
R-5	500,000 "	Detector plate series resistor.
R-6	500,000 "	1st a-f grid resistor.(Color code is green with black tip, yellow dot.)
R-7	2,800 "	1st a-f grid bias resistor. (Color code is blue with white tip.)
R-8	730 "	Grid bias resistor for the 247's in push-pull.
R-9	60 "	Filament potentiometer (resistor with mid-tap) across the 247 filaments to suppress hum.
R-10	16,000 "	Voltage divider resistor drops high plate voltage supplied to 247's to value required for plates of 235's, 224 and 227.
R-11	16,000 "	Voltage divider resistor drops voltage to value required for screen grids of 235's and 224.
R-12	6,000 "	Voltage divider resistor between screen grids and low side or -B side of S.P.U.
R-13	1,000 "	R-13 in shunt with R-8 provides bias on 247's. (Color code of R-13 is brown with black tip, red dot.)

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Identification of Parts. (Cont'd).

KEY NO.	NAME
T-1	Power transformer. (S-1 supplies heaters of 235's and 224; S-2 supplies filaments of 247's and heater of 227; S-3 supplies 280 filament; S-4 supplies high voltage to 280 plates; Pri. connects to a-c socket through cord and plug and fuse.
T-2	A-F interstage transformer. Push-pull input transformer consists of Pri. and mid-tap Sec.
T-3	Output transformer. Push-pull output transformer consists of mid-tap Pri. and Sec.
S-1	Line switch or "OFF-ON" switch.
S-2	Radio-Phonograph switch.
S-3	Local-Distance switch.
P-1	Power attachment cord and plug.
P-2	Phonograph tip jacks. Terminal board.
P-3	Speaker tip jacks. Audio Output. Terminal board.
P-4	Terminal board for "ANT-GND" and "Local-Distance" switch.
P-5	Line fuse and fuse block; 3 amp. fuse.
P-6	Resistor-Condenser mounting board with det.plate choke.
Socket 1	235 tube. 1st r-f amplifier.
" 2	235 " . 2nd " "
" 3	224 " . Detector.
" 4	227 " . 1st a-f amplifier.
" 5	247 " . Push-pull "
" 6	247 " . " " "
" 7	280 " . Rectifier.
G-1	Ground terminal.
G-2	" "
G-3	" "

The complete schematic diagram of the receiver and socket power unit is given below in Figure 3.

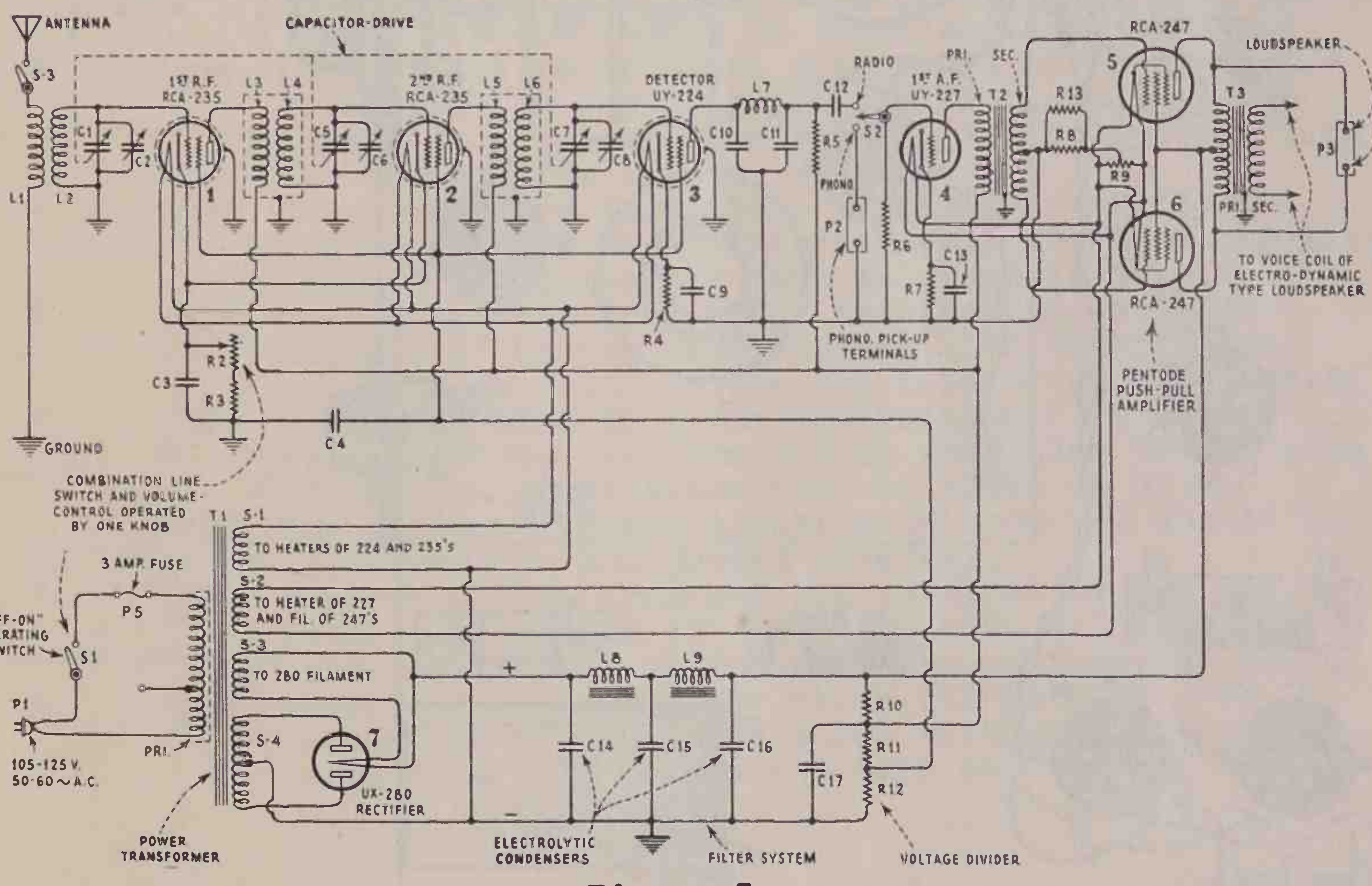

Figure 3

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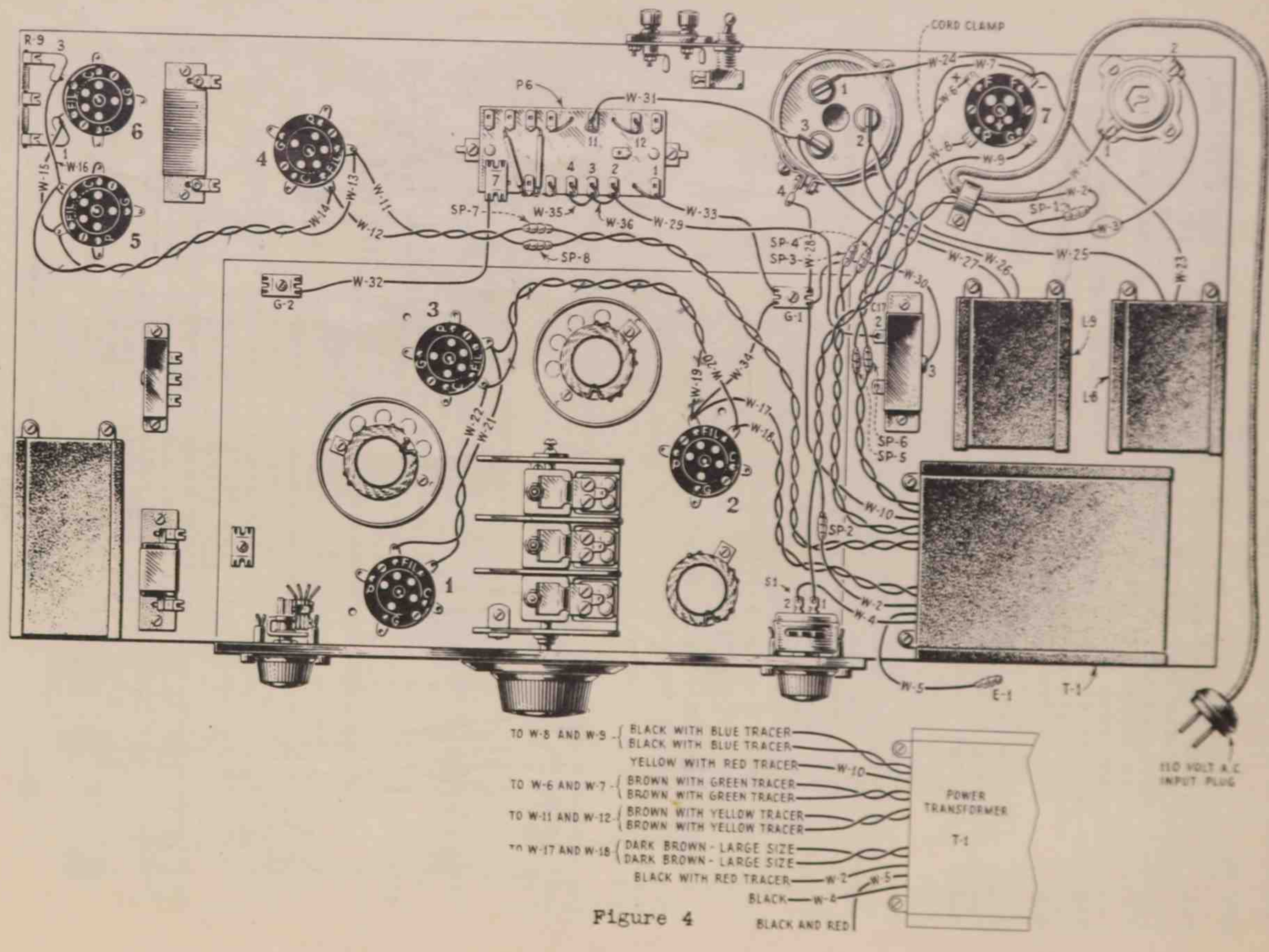


Figure 4

PART 3

WIRING OF SOCKET POWER UNIT: THIS INCLUDES POWER TRANSFORMER, RECTIFIER, FILTER SYSTEM, VOLTAGE DIVIDER, HEATERS AND FILAMENTS. Refer to Figure 4.

This section of the set first to be wired includes the circuits which supply a-c and d-c voltages to the various tubes throughout the set and consists of the a-c line supply cord and plug, power transformer, rectifier tube and filter system. There are resistors on P-6 to be wired at the same time, some of these being part of the voltage divider. Just follow the wiring diagram carefully and use red colored wires and green twisted wires where we have indicated them on the charts, otherwise you may use your own color scheme. Connection wires W-1 to W-36, inclusive, are as follows:-

WIRE COLOR	WIRE NUMBER	CONNECTION
Green	W1	Connect either wire of power cord to fuse socket terminal #1.
Twisted	W2	Make a connection between the other wire of the power cord and the black with red tracer wire coming out of the power transformer T-1. Solder and tape ends of W2 as shown at splices SP-1 and SP-2.
"	W3	Connect a wire between fuse socket terminal #2 and line switch terminal #1.
"	W4	The black wire coming from power transformer T-1 should be connected to terminal #2 of line switch S-1
"	W5	Wire W5 is the black and red wire from power transformer T-1 and is not used when the set is supplied with specified voltage from power lines and, therefore, its end should be taped as shown at E-1.
"	W6	Connect a wire from the + terminal of rectifier socket #7 to one of the brown with green tracer wires from power transformer T-1. Splice and tape as shown at SP-3.
"	W7	Connect a wire from the - terminal of rectifier socket #7 to the other brown with green tracer wire from T-1. Splice and tape as shown at SP-4.
"	W8	Connect a wire from the P terminal of rectifier socket #7 to one of the black with blue tracer wires from T-1. Splice and tape as shown at SP-5.
"	W9	Connect a wire from the G terminal of rectifier socket #7 to the other black with blue tracer wire from T-1. Splice and tape as shown at SP-6.
"	W10	The yellow with red tracer wire from T-1 should be connected to G-1 ground terminal.
"	W11	Connect a wire from one FIL terminal of 1st a-f socket #4 to one of the brown with yellow tracer wires from T-1. Splice and tape as shown at SP-7.
"	W12	Connect a wire from the other FIL terminal of socket #4 to the other brown with yellow tracer wire from T-1. Splice and tape as shown at SP-8.

CONNECTION

Green Twisted W13 Connect a wire from one FIL terminal of socket #4 to one FIL terminal of push-pull socket #5.

" W14 Connect a wire from the other FIL terminal of socket #4 to the other FIL terminal of socket #5.

" W15 Connect a wire from one FIL terminal of socket #5 to the one FIL terminal of socket #6.

" W16 Connect a wire from the other FIL terminal of socket #5 to the other FIL terminal of socket #6.

" W17 Connect one of the large size brown wires coming from T-1 to one of the FIL terminals of 2nd r-f socket #2.

" W18 Connect the other large size brown wire coming from T-1 to the other FIL terminal of socket #2.

" W19 Connect a wire from one of the FIL terminals of socket #2 to one of the FIL terminals of detector socket #3.

" W20 Connect a wire from the other FIL terminal of socket #2 to the other FIL terminal of socket #3.

" W21 Connect a wire from one FIL terminal of socket #3 to one FIL terminal of 1st r-f socket #1.

" W22 Connect a wire from the other FIL terminal of socket #3 to the other FIL terminal of socket #1.

W23 Connect the yellow wire of filter choke L-8 to the -F terminal of rectifier socket #7.

W24 Connect a wire from -F socket #7 to one of the terminals (#1) on top of the electrolytic condenser.

W25 Connect the green wire of choke L-8 to terminal (#2) on top of electrolytic condenser. If this green pigtail wire does not reach the terminal, splice on a short length of connecting wire.

SEE EXTRA SHEET REMOVED

W26 Connect the yellow wire of choke L-9 to terminal (#2) on top of the electrolytic condenser.

W27 Connect the green wire of choke L-9 to terminal (#3) on top of the electrolytic condenser.

W28 Connect a short wire from the lug (#4) on the clamping ring of the electrolytic condenser to G-1 ground terminal.

W29 Connect a wire from terminal #2 of capacitor C-17 to terminal #2 on top of the resistor mounting board P-6.

W30 Connect a wire from soldered terminal #3 at rear of capacitor C-17 to G-1 ground terminal.

W31 Connect a wire from terminal #3 of electrolytic condenser to terminal #11 on resistor mounting board P-6.

W32 Connect a wire from G-2 ground terminal to terminal #7 on resistor mounting board P-6.

W33 Connect a wire from G-1 ground terminal to terminal #1 on resistor mounting board P-6.

W34 Connect a wire from G-1 ground terminal to either one of the FIL terminals of socket #2.

W35 Connect a short bared wire between terminals 2, 3, and 4 on resistor mounting board P-6.

W36 This refers to the same short wire explained above for #35.

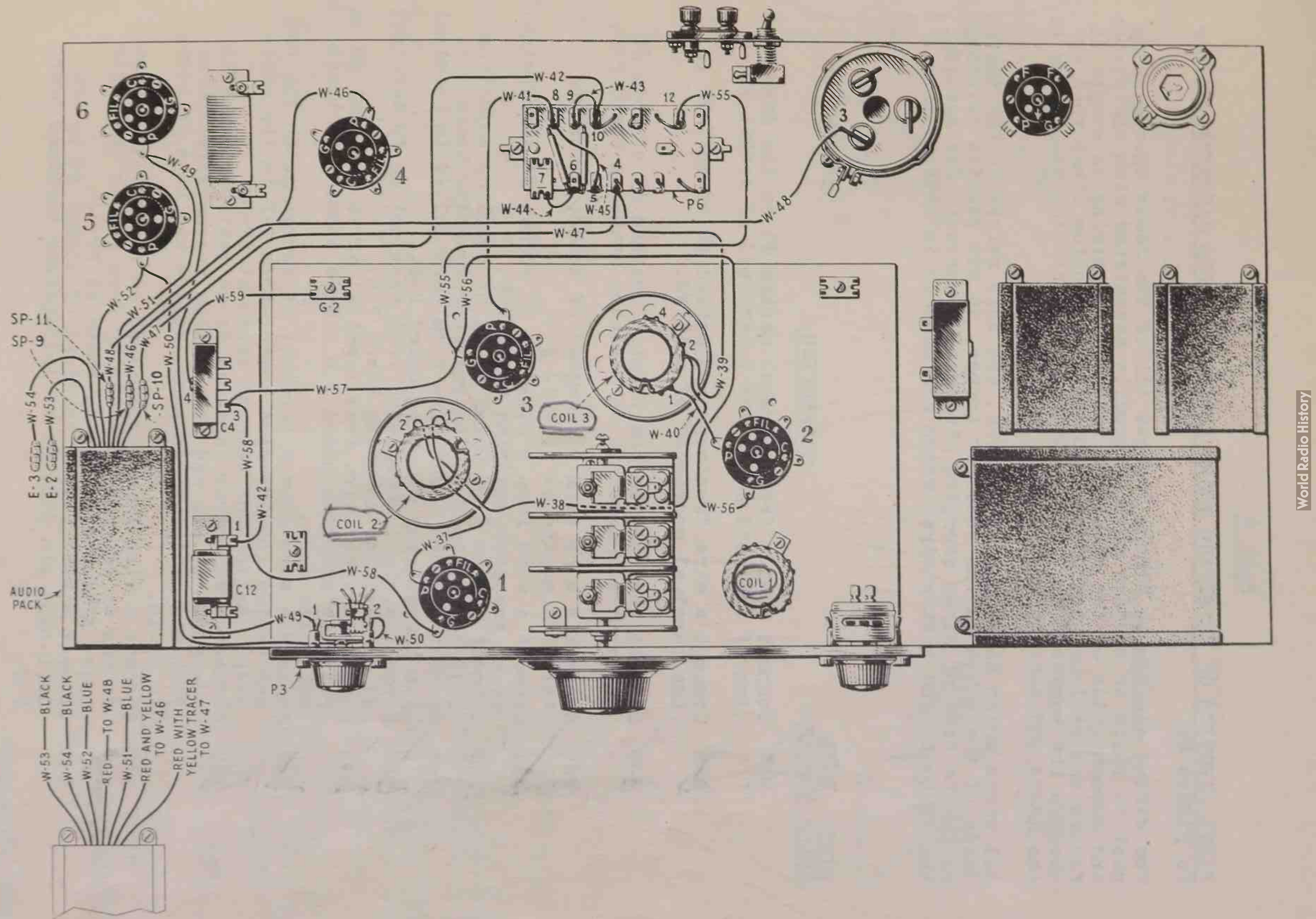

6
5
4
3
2
1
W-42
W-43
W-41
8 9
10
12
W-55
W-46
W-49
6
7
4
5
W-44
W-45
P6
W-48
W-47
W-52
W-51
W-59
G-2
W-55
W-56
SP-11
SP-9
W-48
W-46
W-47
W-50
SP-10
W-54
W-53
E-3
E-2
W-57
C4
COIL 3
W-40
W-39
W-58
W-42
COIL 2
W-38
W-56
W-37
COIL 1
C12
AUDIO PACK
W-49
W-50
P3
W-53 — BLACK
W-54 — BLACK
W-52 — BLUE
RED — TO W-48
W-51 — BLUE
RED AND YELLOW TO W-46
RED WITH YELLOW TRACER TO W-47

Figure 5

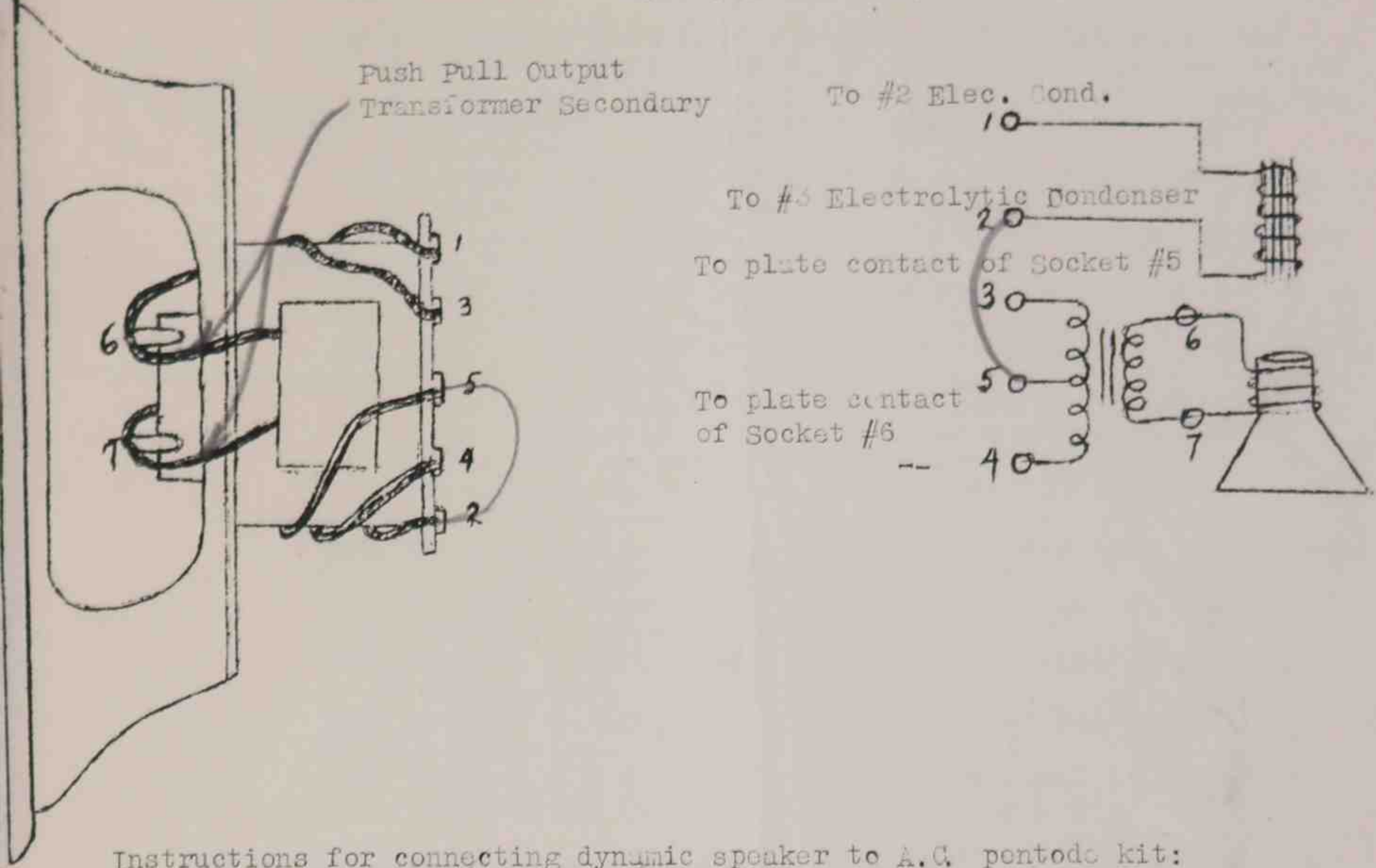
PART 4

PLATE CIRCUITS OF RECEIVING TUBES AND SCREEN GRID CIRCUITS. Refer to Figure 5.

The wiring diagram in Figure 5 shows all of the leads that must be pust in place to connect up the circuits associated with the plates and screen-grids of the receiving tubes. This wiring is simple to follow and will not require any special instruction other than to observe the suggestions already outlined for accuracy in placing on the leads and care in soldering.

All wires which carry direct current, and this refers to the plate leads of the tubes in the receiver proper, do not require twisting as in the case of wires carrying alternating current, for example, the filament and heater wires which are made up in twisted-pair.

WIRE COLOR	WIRE NUMBER	CONNECTION
	W37	Connect a wire from terminal marked #1 on the drawing of r-f coil #2 to the P terminal of socket #1.
	W38	Connect a wire from terminal marked #2 of coil #2 to the terminal marked #2 of coil #3.
	W39	Connect a wire from the terminal marked #2 of coil #3 to terminal marked #4 on resistor mounting board P-6.
	W40	Connect a wire from P terminal of socket #2 to the terminal marked #1 of coil #3.
	W41	Connect a wire from P terminal of socket #3 to terminal #8 on resistor mounting board P-6.
	W42	Connect a wire from terminal #1 of coupling capacitor C-12 to terminal #10 on resistor mounting board P-6.
	W43	Connect a short bared wire from terminal #9 to terminal #10 on resistor mounting board P-6.
	W44	Connect a short bared wire from terminal #6 to terminal #7 on resistor mounting board P-6.
	W45	Connect a short wire from terminal #5 to terminal #8 on resistor mounting board P-6. Wire should not touch condenser case.
	W46	Connect a wire from P terminal of socket #4 to the red and yellow (50-50) wire coming from T-2 in the audio pack. Splice and tape as shown at SP-9.
Red	W47	Connect a wire from terminal #4 on resistor mounting board P-6 to the red with yellow tracer wire coming from T-2 in the audio pack. Splice and tape as shown at SP-10.
"	W48	Connect a wire from terminal #3 on electrolytic condenser to the red wire coming from T-3 in the audio pack. Splice and tape as shown at SP-11.
	W49	Connect a wire from P terminal of socket #6 to the left-hand pin jack #1 of loudspeaker terminal board P-3.



Instructions for connecting dynamic speaker to A.C. pentode kit:

First, Remove W-26 and W-27 of L-9 from terminals 2 and 3 of electrlytic condenser - See figure 4 Lesson 36 #1.

Second, Connect terminal 1 of dynamic speaker to terminal 2 of electrolytic condenser and connect terminal 2 of dynamic speaker to terminal 3 of electrolytic condenser.

Third, Remove W-48, W-51, and W-52 - See figure 5, Lesson 36 #1.
Remove W-49 and W-50 - See figure 5 - Lesson 36 #1.

Fourth, Connect terminal 5 to terminal 2 on dynamic speaker

Fifth, Connect terminal #3 of dynamic speaker to plate contact of socket #5.

Sixth, Connect terminal #4 of dynamic speaker to plate contact of socket #6.

WIRE COLOR	WIRE NUMBER	CONNECTION
	W50	Connect a wire from P terminal of socket #5 to the right-hand pin jack #2 of loudspeaker terminal board P-3. Note that terminal board P-3 is to be used for connecting in a magnetic type loudspeaker. (Read explanation below.)
	W51	Connect one of the blue wires coming from T-3 in the audio pack to P terminal of socket #6.
	W52	Connect the other blue wire from T-3 in the audio pack to P terminal of socket #5.
	W53	Wire W-53 is one of the black wires coming from T-3 in the audio pack and should be taped up as shown at E-2.
	W54	Wire W-54 is the other black wire from T-3 in the audio pack and should also be taped up as at E-3. Note that leads W-53 and W-54 are to be used for connection to the voice coil of an a-c electrodynamic speaker if this type is used. If a speaker of this type is not used tape up the ends as shown at E-2 and E-3. Read explanation below.
	W55	Connect a wire from G terminal of socket #3 to terminal #12 on resistor mounting board P-6.
	W56	Connect a wire from G terminal of socket #3 to G terminal of socket #2.
	W57	Connect a wire from G terminal of socket #3 to terminal #3 of capacitor C-4.
	W58	Connect a wire from G terminal of socket #1 to terminal #3 of capacitor C-4.
	W59	Connect a wire from G-2 ground terminal to soldered connection #4 on rear of capacitor C-4.

REMOVED SEE EXTRA SHEET

Method of Connecting Loudspeaker to Set. Although the loudspeaker is not to be connected until the receiver is completely wired and assembled let us mention at this time that if a magnetic type loudspeaker is used the speaker cord tips should be inserted in the pin jacks at the left of the panel as shown in Figure 11. Figure 12 shows how to connect the voice coil leads of an a-c electrodynamic type speaker providing it is not supplied with an input a-f transformer. The two wires W-53 and W-54 come from the secondary winding of the a-f output transformer T-3 in the set and the signal current induced in this winding is delivered directly to the voice coil. This type of speaker would contain a field supply transformer and rectifier tube as indicated in the sketch or in some types a dry-disk rectifier would be used instead of a tube to change the a-c to d-c for energizing the field coil. Most of the completely equipped a-c electrodynamic speakers on the market have an input a-f transformer in addition to the field supply transformer, rectifier, and speaker itself. With a complete assembly leads W-53 and W-54 would be taped and remain unused and the cord tips to the input a-f transformer of the electrodynamic speaker would be inserted in the pin jacks at the left of the panel like the speaker cord in Figure 11. As Figure 12 illustrates, the receiver and electrodynamic speaker each have their own power attachment cord and plug for inserting in some convenient socket or outlet in the a-c lighting system.

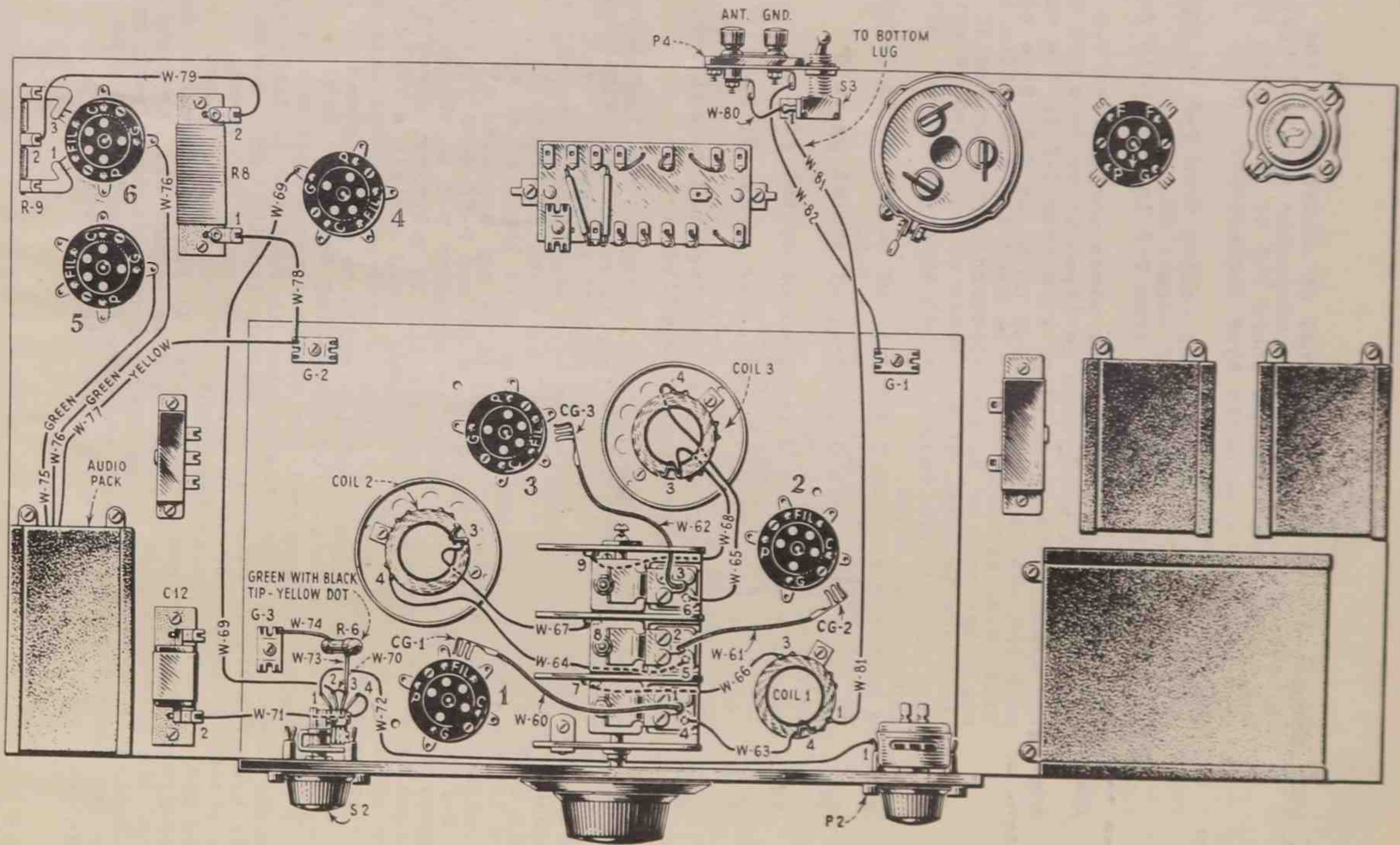

ANT.
GND.
P4
TO BOTTOM LUG
S3
W-80
W-81
W-82
W-79
3
2
1
R-9
6
W-76
2
R8
1
W-69
4
5
W-78
G-2
G-1
GREEN
GREEN
YELLOW
W-75
W-76
W-77
AUDIO PACK
COIL 3
CG-3
3
2
COIL 2
W-62
W-68
W-65
GREEN WITH BLACK TIP - YELLOW DOT
C12
G-3
W-74
R-6
W-73
W-70
CG-1
W-67
W-64
CG-2
W-61
W-66
COIL 1
W-81
W-69
W-72
W-71
W-60
W-63
1
S 2
P2

Figure 6

PART 5

WIRING OF R-F CIRCUITS, CONTROL GRIDS, ANTENNA, LOCAL-DISTANCE SWITCH, AND PHONOGRAPH-RADIO SWITCH. Refer to Figure 6.

The radio-frequency circuits are especially critical as to the placing of the wiring, hence, this should be done exactly as we recommend in the diagram. In your wiring job you will find it easier to wire up certain parts on the front panel by removing the dial and loosening the panel and then slipping the panel slightly forward. Also, you can loosen the gang condenser and turn it on its side temporarily to get at the terminal connections underneath. This sort of practical work should be arranged to suit your convenience. Note that there are three soldering lugs located underneath the gang-condenser and also three lugs on top for making convenient connections to the stator plates. Lugs marked 1, 2, 3, 4, 5, and 6 connect to stator plates of the respective tuning condensers, whereas 7,8, and 9 are brass strips, connecting to the rotor plates. Note that lugs 4, 5, and 6 are on the underside.

WIRE COLOR	WIRE NUMBER	CONNECTION
Red	W60	One end of this wire should be soldered to a control grid clip CG-1 and the opposite end to terminal lug #1 on top of the 1st r-f tuning condenser. Measure the length of wire W-60 carefully so that it will reach to the cap on the RCA 235 tube when the tube is in place in socket #1.
"	W61	One end of this wire should be soldered to the second control grid clip CG-2 and the opposite end to terminal lug #2 on top of the 2nd r-f tuning condenser. Also measure the length of this wire carefully so that it will reach to the metal cap on the second SG tube when the tube is in place in socket #2.
"	W62	One end of this wire is soldered to the third grid clip CG-3 and the opposite end to terminal lug #3 on top of the 3rd r-f tuning condenser. This wire must reach to the metal cap on the SG detector tube when it is in place in socket #3. This wire may be run through the small hole in the side of the condenser.
	W63	Connect a wire from terminal (#4) located at top of tubing of coil #1 to soldering lug (#4) located at lower right side of 1st tuning condenser.
	W64	Connect a wire from terminal (#4) of coil #2 to soldering lug (#5) located at the lower right side of 2nd tuning condenser.
	W65	Connect a wire from terminal (#4) of coil #3 to soldering lug (#6) located at lower right side of 3rd tuning condenser.
	W66	Connect a wire from terminal (#3) of coil #1 to top end of thin brass trip (#7) located underside just in back of the 1st r-f tuning condenser plates. The brass strip serves as a spring pressing against rotor plates and for a ground connection.

WIRE COLOR	WIRE NUMBER	CONNECTION
	W67	Connect a wire from terminal (#3) located at top of tubing of coil #2 to top end of thin brass strip (#8) located underside just in back of the 2nd r-f truning condenser plates.
	W68	Connect a wire from terminal (#3) located at top of tubing of coil #3 to top end of thin brass strip (#9) located underside just in back of the 3rd r-f tuning condenser plates.
	W69	Connect a wire from G terminal of socket #4 to terminal #2 (second leaf from left) of phonograph-radio switch S-2.
	W70	Connect a very short bared wire between terminals #2 and #3 (second and third leaves from left) of phonograph-radio switch S-2.
	W71	Connect a wire from terminal #4 (fourth leaf from left) of phonograph-radio switch S-2 to terminal #2 of coupling capacitor C-12.
	W72	Connect a wire from terminal #1 (first leaf on left) of phonograph-radio switch S-2 to left-hand pin jack #1 of "PHONO" terminal board P-2.
	W73	This wire is one of the stiff pig-tail wires on the end of the tubular type resistor R-6 and should be soldered to terminal #3 of phonograph-radio switch S-2. Resistor R-6 should be mounted vertically. The color code for this resistor is green with black tip, yellow dot.
	W74	This wire is the other pig-tail on resistor R-6 and should be soldered to G-3 ground terminal.
	W75	This wire is one of the green wires coming from T-2 in the audio pack and should be connected to G terminal of socket #5.
	W76	This wire is the other green wire from T-2 in the audio pack and should be connected to G terminal of socket #6.
	W77	This wire is the yellow wire from T-2 in the audio pack and should be connected to G-2 ground terminal.
	W78	Connect a wire from G-2 ground terminal to terminal #1 on resistor R-8.
	W79	Connect a wire from terminal #2 on resistor R-8 to the midtip terminal #2 on resistor R-9 after first soldering the two off-set lugs attached to the ends of R-9 to F and F terminals of socket #6.
	W80	Connect a wire from "ANT" post lug to top lug of switch S-3.
	W81	Connect a wire from bottom lug of switch S-3 to terminal #1 of coil #1. This terminal is the second one at the left of the bracket.
	W82	Connect a wire from "GND" post lug to G-1 ground terminal.

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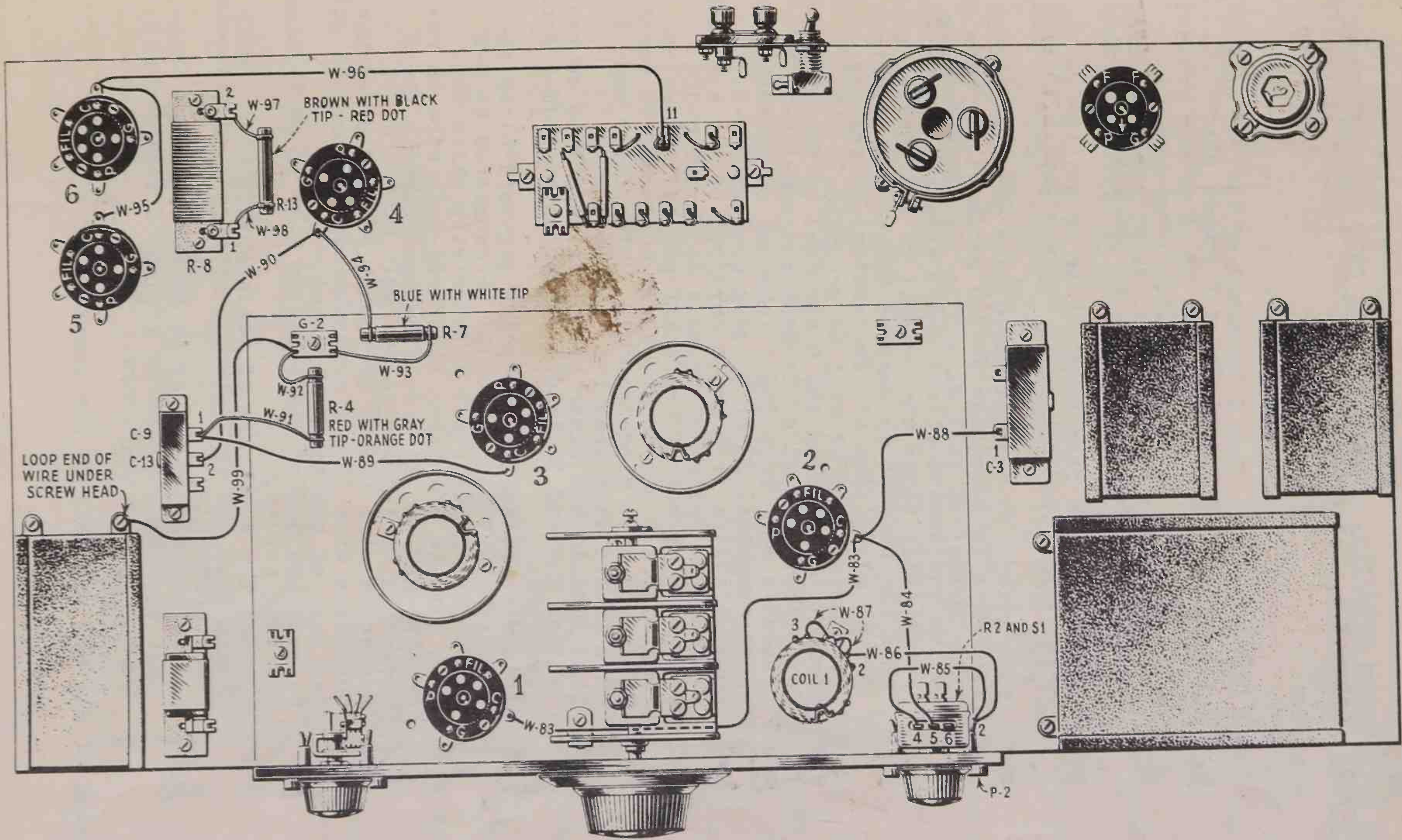

Figure 7

PART 6

WIRING OF CATHODE CIRCUITS, VOLUME CONTROL. GRID BIAS RESISTORS, AND BY-PASS CONDENSERS. Refer to Figure 7.

WIRE COLOR	WIRE NUMBER	CONNECTION
	W83	Connect a wire from C terminal of 1st r-f socket #1 to the C terminal of 2nd r-f socket #2.
	W84	Connect a wire from terminal #5 of volume control R-2 to the C terminal of 2nd r-f socket #2.
	W85	Connect a wire from terminal #4 of volume control R-2 to right-hand pin jack #2 of "PHONO" terminal board P-2.
	W86	Connect a wire from terminal #2 of coil #1 to the right-hand pin jack #2 of "PHONO" terminal board P-2.
	W87	This refers to a short bared wire which should be soldered to terminals #2 and #3 in either side of the bracket of coil #1 and to the soldering lug which you should attact under the head of the machine screw which holds the bracket to the tubing. Hence, when the bracket is screwed to the flat aluminum shield plate then all connections to the lug or to terminals#2 and #3 will be grounded.
	W88	Connect a wire from the C terminal of 2nd r-f socket #2 to terminal #1 of by-pass condenser C-3.
	W89	Connect a wire from the C terminal of detector socket #3 to terminal #1 of by-pass condenser C-9.
	W90	Connect a wire from the C terminal of 1st a-f socket #4 to terminal #2 of by-pass condenser C-13.
	W91	This wire is one of the stiff pig-tail wires on resistor R-4 and it should be connected to terminal #1 of by-pass condenser C-9. (The color code for R-4 is red with gray tip, orange dot.)
	W92	This wire is the other stiff pig-tail wire on resistor R-4 and it should be connected to G-2 ground terminal.
	W93	This wire is one of the stiff pig-tail wires on resistor R-7 and it should be connected to G-2 ground terminal. (R-7 is blue with white tip.)
	W94	This wire is the other stiff pig-tail wire on resistor R-7 and it should be connected to the C terminal of 1st a-f socket #4.
	W95	Connect a wire from C of socket #5 to C of socket #6.
	W96	Connect a wire from C of socket #6 to terminal #11 at rear of the terminal board.
	W97	Connect one end of the resistor R-13 to #2 terminal of resistor R8.
	W98	Connect the other end of resistor R13 (brown with black tip, red dot,) to the other end of resistor R8 (terminal #1).
	W99	Remove paint from leg of AF transformer and connect wire from ground #2 to leg of transformer, that is, under the screw.

The wiring of all the circuits is now completed.

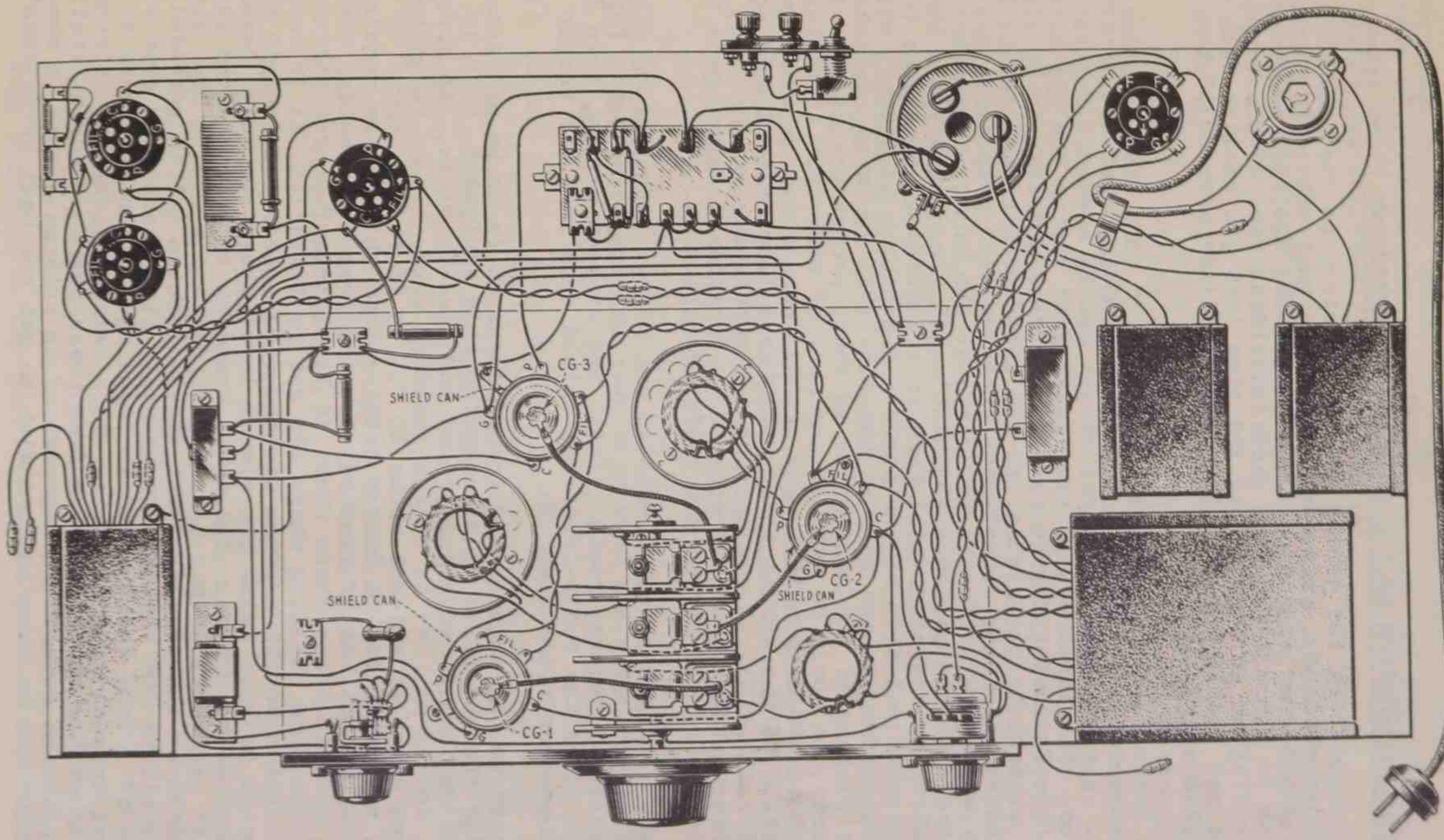

Figure 8

PART 7

PRACTICAL OPERATION OF THE SCREEN-GRID RECEIVER.

After completing the wiring of all the circuits they should be carefully checked. While doing this you must not permit anything to distract your attention, or else you may overlook an error. It is best to place a check on each individual wire of the complete wiring diagram in Figure 8 at the time that you examine each wire on the set itself and in this way you will be assured of having inspected every wire.

It is advisable to check over a circuit of this kind sometime after the construction and wiring have been completed but not immediately after. A very sound practical reason can be advanced for this suggestion. For instance, if you finish your wiring one day wait until the following day to go over the work and then do it slowly. Never attempt to check when you are tired or fatigued for it is invariably in such circumstances that one will make omissions, or errors which are difficult to locate at the time. If you will exercise a little patience and wait until the next day the whole lay-out of the receiver will take on a different appearance to you; in fact, the relation of the parts and circuits in general will be much clearer to you than at the time when you were concentrating on the placing of the many wires in their proper positions. In a few words, it could be said of any form of work that if mistakes occur they are more quickly and easily found a day or so after the completion of the actual work. The facts just related hold equally true for all kinds of engineering and manufacturing work and, hence, in large organizations the work of an individual seldom gets the final check by the person who performed the work.

When the wiring has been completed according to the wiring diagrams and all of the work has been gone over and inspected again for cold-soldered joints, rosin joints, and correct wiring, then it is time to place the radio-frequency shield cans in their proper positions over coils 2 and 3.

In regard to the antenna and ground leads it is to be understood that the various parts which comprise this equipment, such as the insulators, the antenna and ground and lead-in wires, the ground clamp, and so on, may be of any standard make. It is suggested that you erect an antenna about 50 ft. to 75 ft. in length to obtain best results. A longer antenna than this may be required in certain locations if remotely located from broadcasting stations. Or, in certain cases where there is local interference originating within the same building where the set is installed, it is recommended that a longer antenna be used with a shielded lead-in wire which will help to raise the signal level above the noise level and thus improve reception. The metal braiding on the shielded lead-in wire, if used, may or may not be grounded and which is best can be determined by the results. The local-distance switch provided with the kit allows the receiver to maintain its selectivity even with the use of a long antenna and in localities which are close to powerful broadcasting stations. This switch allows the antenna to be disconnected when receiving from these nearby powerful stations. The length and general arrangement of an antenna system is something that can be experimented with to get the best arrangement for

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a given location. An indoor antenna can be easily made by installing about 50 ft. of ordinary bell wire around the picture moulding. Water pipes where available are generally used for grounds and gas pipes should be avaoided for this purpose.

Placing the Set into Operation. The receiver is now ready for operation and applying power from the a-c mains. Follow the procedure given below to place the set in operation:

(a) First connect the loudspeaker to the receiver. The connections for either a magnetic type or a-c electromagnetic type are indicated in Figures 11 and 12, respectively.

(b) Now connect the antenna lead-in wire and ground wire to binding posts marked "ANT" and "GND", respectively.

(c) Next insert the tubes in their proper sockets according to the picture diagram of the set in Figure 1 and place the tube shields in position. Then place each clip respectively on the metal cap on top of each 235 and the 224 tube. Each clip with its wire forms the connection to the control-grid of a tube and is the wire through which the signal energy passes. It is important that the two RCA-247 pentode tubes be closely matched to insure good reproduction.

(d) Be sure that the operating switch has been in the "OFF" position during this time. Now insert the plug attached to the electric cord from the power transformer in the lighting socket of the a-c supply, or any convenient outlet in the house-lighting system. Before plugging in on the a-c line be sure the "OFF-ON" or line switch on the upper right of the front panel is in the "OFF" position as just mentioned. To place the switch in this position turn the knob as far as it will go to the left.

(e) If you do not already know the voltage and frequency of the a-c supplied to your premises make inquiry from the district office of the electric company to ascertain if the alternating current is of proper voltage and frequency for your set, that is, 105 to 125 volts a-c at a frequency of 50 to 60 cycles.

(f) Next place the phonograph-radio switch in the radio position by turning the knob at the upper left on the front panel to the left.

(g) Now turn the operating switch to the "ON" position which is done by turning the upper right-hand knob to the right until you hear it click. By further turning this knob to the right you regulate the volume. Now place the "LOCAL-DISTANT" switch in the "DISTANT" position by throwing the toggle switch toward the GND post. Power is now on the receiver circuit and it will require a brief interval for the tubes to warm up. Turn the volume control about half way to the right and begin adjusting the "Station Selector," which is another name for "Tuning Dial." At some position on the dial, as it is rotated slowly across the scale, a signal should come through from some station whose transmitting frequency is within the range of your receiver, or the broadcast range, as we commonly refer to it.

CAUTION: Never allow any part of your body to come into contact with open wiring or terminals while the power is on as a disagreeable shock may be experienced. Keep clear of the three terminals on top of the electrolytic condenser.

Important Points about Operation:

Oscillation. From your previous study of radio receiving circuits you know that maximum volume of a given signal is obtained at a point just before oscillation starts. A slight amount of oscillation will probably be noticed when the volume control is set at or near maximum. This is especially true when tuning at the lower frequencies, but in this receiver any tendency toward oscillation can be controlled by use of the volume control knob.

Volume Control. The use of the 235 variable mu tubes in place of the regular screen grid 224's in the r-f stages of a receiver allows for better control of volume. The maximum signal may be as great when using either type of tube but the volume control has a greater effect when using 235 tubes. If the signal should be too strong at any time and it cannot be reduced by regulating the volume control it is suggested that the antenna switch be changed to "LOCAL" position and then readjust the volume control to give the desired volume.

Overloading. Since the 247 type tube gives maximum undistorted power output with only about 16 volts (peak a.c.) input (grid bias), whereas 245 tube requires about 40 volts input, it is quite possible that the output of the 1st a-f stage (on a strong signal) will be more than the 16 volts necessary for maximum output. Excessive input grid voltage will cause distortion of the reproduction which is especially noticeable at low audio frequencies. This condition can be corrected by reducing the volume with the volume control or by use of the local antenna switch as previously suggested. A condition of this kind simply indicates that the amplifier ahead of the output stage has a greater amplification (sensitivity) than is necessary to get the maximum possible undistorted output of the 247 tubes on a strong signal. If the volume were reduced to eliminate this overloading of the output stage, the receiver would still deliver more power output than when using the regular 245 power tubes.

Sensitivity. The greater amplification of a 247 tube over a 245 accounts for the increased sensitivity of this receiver when using 247 pentode tubes instead of 245's in the output. Hence, it is possible to overload the 247's on local signals but this is to be considered an advantage since it also gives greater output on weaker signals.

Audio Whistle. A steady whistle in the loudspeaker which is not affected by tuning the receiver is an indication of audio oscillation. To prevent this condition make sure the case of the audio transformer is well grounded with wire W-99. Scrape the metal clean on the mounting leg of the transformer case to which the bare end of wire W-99 loops around under the screw head which holds the transformer in place in order to make a good metal to metal contact for this ground.

Electrolytic Condenser. The receiver will begin to operate when the tubes have warmed up and the electrodes of the electrolytic condenser have been formed. This may take several minutes and may be accompanied by considerable hum. However, if the electrolytic condenser buzzes continually it is an indication that the condenser is broken down due possibly to abnormally high voltage in the circuit. Several possible causes for high voltage are as follows: too high a line voltage; open bias resistor or poorly soldered connection in the push pull stage; or, an open high voltage lead. When the cause of the breakdown has been removed the condenser will heal itself, that is, electrodes will properly form to prevent a direct passage of current through the condenser.

PART 8

LINE-UP ADJUSTMENTS OF THE RADIO-FREQUENCY CIRCUITS. See Figure 1.

Each of the tuned radio-frequency circuits are balanced, or placed in resonance with one another, by means of a small variable condenser, the capacitance of which can be altered very easily by a simple adjustment. A condenser used for this purpose is called a "trimmer" condenser, or "line-up" condenser, and is connected in parallel to the main tuning condenser of the r-f circuit and the process is called aligning, synchronizing and phasing.

The small line-up condensers in your set are located on the top of the 3-gang condenser assembly. Notice the position of the three small hex nuts, and that each one is used to adjust a trimmer condenser. By turning the nut one way or the other the distance between the two plates of the trimmer condenser is changed. It is made either greater or less, and in this way the condenser's capacitance is varied. Let us again repeat that the three small condensers are connected in parallel to the main tuning condensers and their purpose is to compensate for any lack of agreement in resonance between the three r-f circuits which might be due to slight variations in parts, or wiring of the r-f amplifier. It is absolutely necessary to have the three r-f circuits in synchronism throughtout their tuning range before the receiver can operate with maximum sensitivity or selectivity.

The procedure for synchronizing the r-f circuits is as follows:

(a) Tune in a station whose frequency is not less than 1200 kc. If you already possess a modulated oscillator this may be used in place of an actual broadcast signal since the oscillator sends out a note having a modulation of uniform character. A modulated oscillator can be constructed very easily according to the circuit diagrams and constants of the parts as shown in Figures 9 and 10. If you intend to do very much testing and adjusting of receivers it will repay you to build a modulated oscillator because it can be used any time and at any place in the absence of a radio signal and, moreover, the audio modulation of an oscillator of this type is of uniform character as just stated. Its use enables one to make more satisfactory adjustments.

(b) Now tune in the signal carefully from the broadcasting station, or from the modulated oscillator, and adjust the trimmer condenser connected with the r-f circuit of the detector. The nut for this condenser is the last one toward the rear of the gang condenser. The nut should be turned either one way or the other until a maximum value of signal is obtained from the loudspeaker. Make this adjustment carefully because it is very critical. It is preferable to use a socket wrench on this nut, but if one is not at hand you can use pliers but be very careful not to burr up the edges of the nut. Remove the socket wrench or the pliers from the nut before judging the adjustment.

(c) Next adjust the trimmer condenser attached to the tuning condenser associated with the 2nd r-f amplifier stage. The nut for this adjustment is the middle one of the three and it should be turned until the signal comes in loudest in the same manner that the detector trimmer condenser was adjusted.

(d) This time the trimmer condenser associated with the 1st r-f amplifier is adjusted for maximum signal strength in precisely the same way as in the case of the other two trimmer condensers. The adjustment nut for this condenser is the first one toward the front of the gang condenser.

(e) It is recommended that the adjustments be gone over carefully a second time in order to check up the work and any further changes that are considered necessary should be made at this time.

(f) After the second set of adjustments have been made the line-up of the three r-f circuits should be correct and the receiver ready for efficient operation. It is important that these adjustments be made with the "LOCAL-DISTANT" switch in the "DISTANT" position. There are no other adjustments required for this receiver except those you have just made for synchronizing the r-f circuits. Normal operation of the set should be obtained upon satisfactory completion of this work. Let us mention re that if the socket wrench used is de of an insulating terial, such as bakelite for instance, a has a le at least 6" long it would be necessary to remove the ench each time an adjustment was made because the so-called body capacity effect would not then affect the adjustment. After the trimmer condensers are adjusted place the narrow alumin shield plate on the co enser fra as shown in the rear view photograph of the set.

ODU ED OSCIL TOR. The circuit diagrams of two modulated oscil- ators are sho sc ematically in Fi res 9 and 10, one being battery operated and the other electrically operated from he a-c power line. All that is required to set the oscillator system in Fi re 9 into oscillation is to pl on either an a-c or d-c power line of 110 volts. A pick-up coil consisting of 4 turns of No. 18 rubber-covered wire is wo over the large coil and when the end of the pick-up wire is connected to the antenna terminal post of the receiver the pick-up circuit carries the oscillator signal energy from the oscillator to the receiver. A satisfactory signal is often obtained by first wrapping a rubber band around the antenna post and then wrapping the end of the pick-up wire once or twice over the rubber band. The pick-up coil must be thoroughly insulated from any direct electrical connection with the wiring or parts of the oscillator circuit to guard against a possible short circuit. The oscillator may be placed six feet or more away from the receiver, or at a distance that you find **will give a reasonably loud signal.**

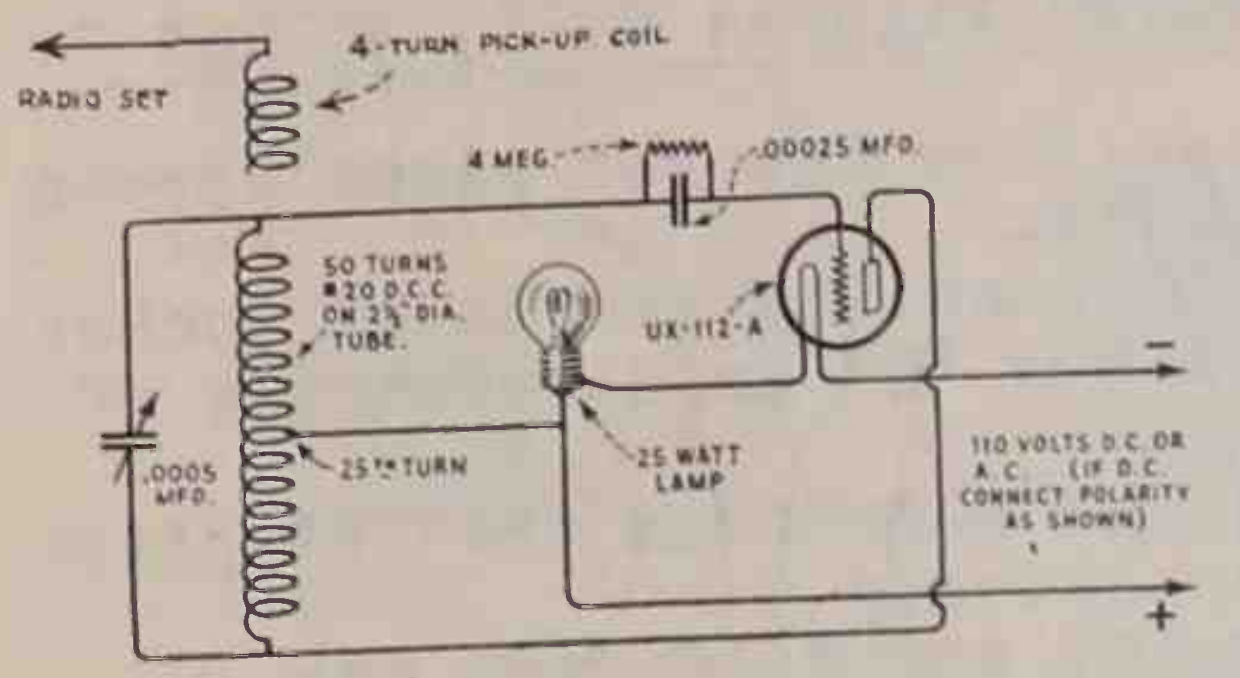

Figure 9

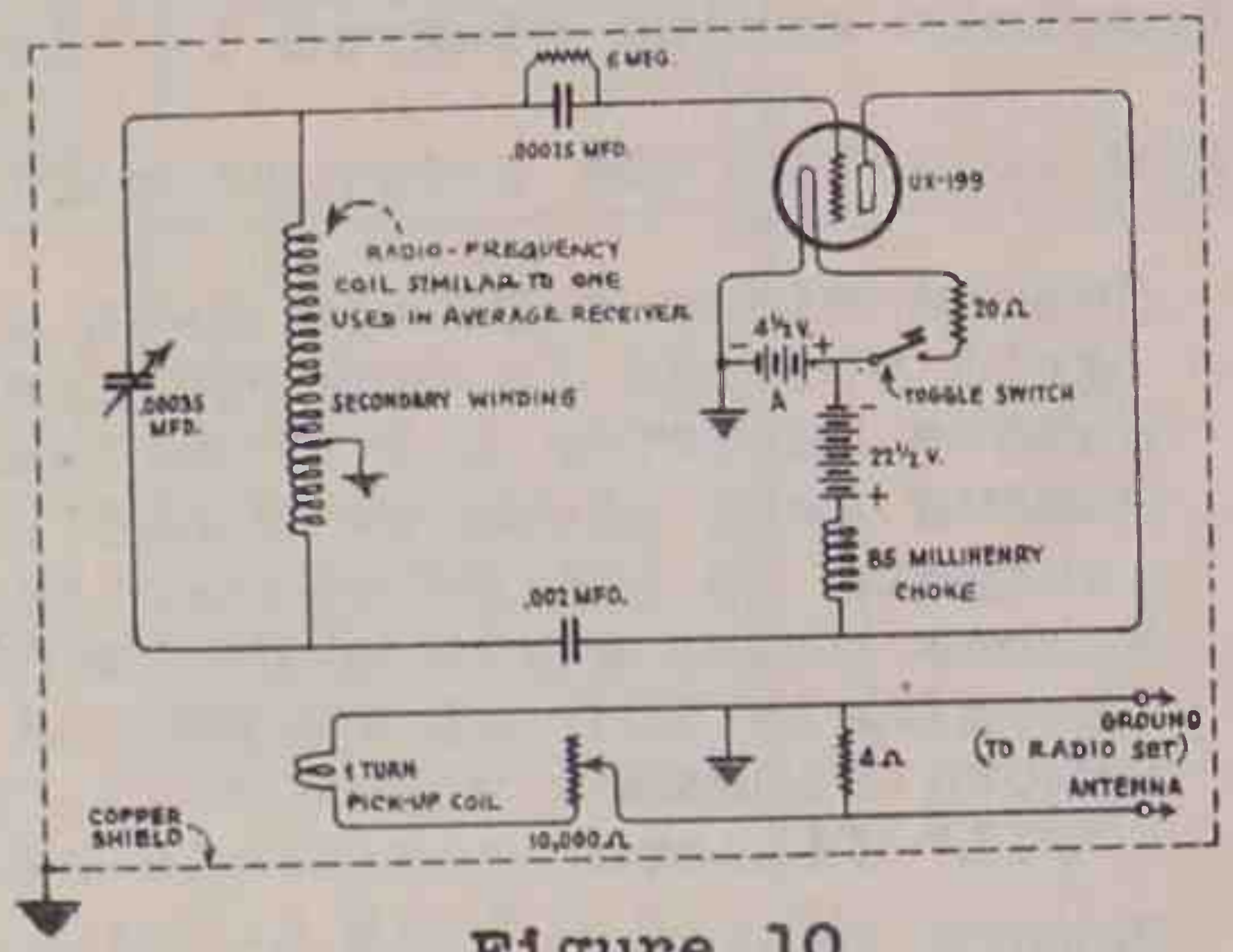

Figure 10

<u>SUMMARY.</u> If the receiver fails to operate after all instructions have been specifically carried out, or if it operates but gives abnormal results, then the trouble is possibly due to a mistake in the wiring, a defective tube, or loudspeaker cord, or speaker, or fuse, or some one of the parts in the set may not function. Since every part furnished in the kit is carefully tested before shipment you should make every effort to find any existing trouble before assuming that the cause of failure is in one of the parts. Recheck the antenna system, tubes, wiring and all soldered joints to make certain that the electrical connections are good.

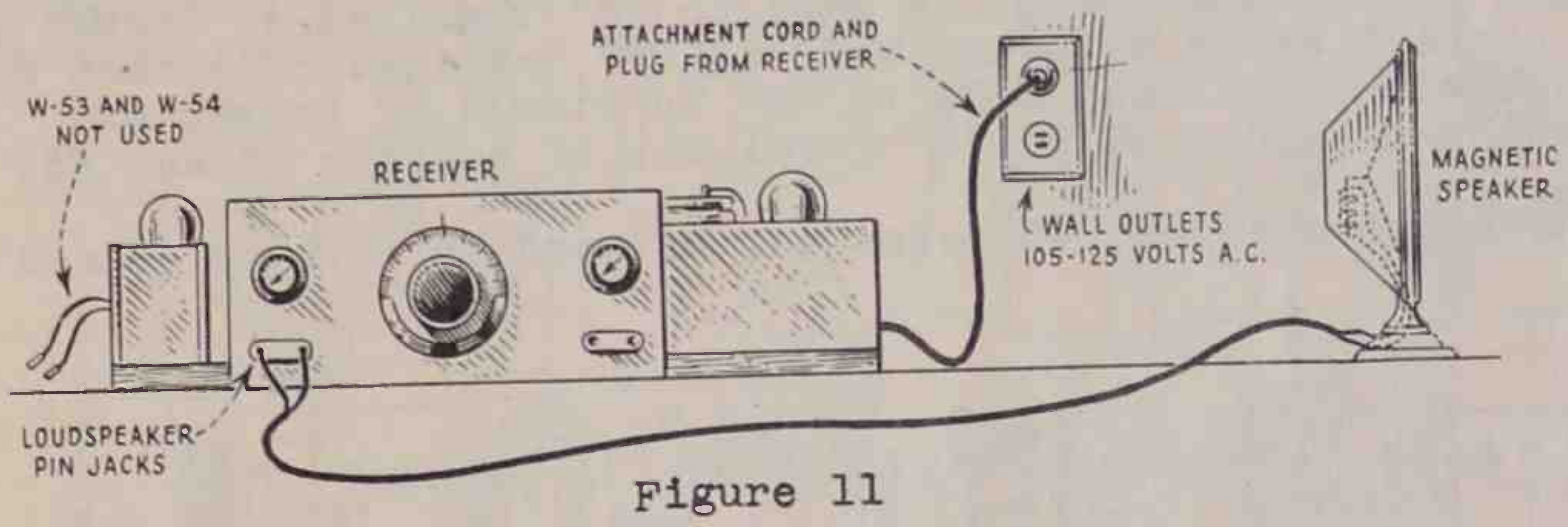

Figure 11

The sketches in **Figures** 11 and 12 show how loudspeakers of different types should be connected to your set. To use the receiver's amplifier to reproduce phonograph records first insert pick-up leads in the pin jacks at lower right of front panel and then turn the knob at upper left to the right.

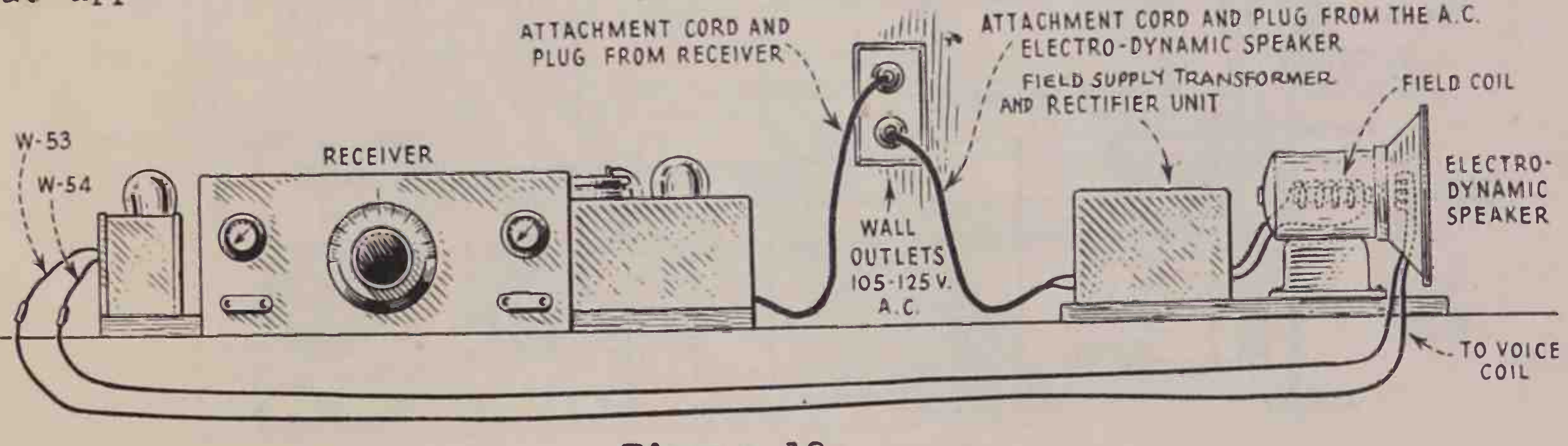

Figure 12

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INSTRUCTIONS FOR ADAPTING 245 TUBES IN THE PUSH-PULL OUTPUT.

If a student desires to use 245 power tubes in push-pull sockets #5 and #6 of his a-c receiver it can be easily done by making a few minor changes as outlined below. The schematic diagram with the circuit adapted for 245's is shown in Figure 13 while the complete wiring diagram is shown in Figure 14.

How to alter the original wiring shown in Figures 4, 5, 6, and 7:

Remove wires W-95 and W-96 altogether from the set since screen grid voltage is not required for 245's.
Remove resistor R-9 from the "FIL" filament terminals of socket #6.
Remove grid wires W-75 and W-76 from the "G" grid terminals of sockets #5 and #6 respectively.
Remove plate wires W-49, W-50, W-51 and W-52 from the "P" plate terminals of sockets #5 and #6 respectively.
Remove filament wires W-13, W-14, W-15, and W-16 from the "FIL" filament terminals of sockets #5 and #6 respectively.
Remove resistor R-13 by disconnecting its pigtail leads, marked W-97 and W-98, from the terminals of R-8. Wires W-78 and W-79 must remain connected to R-8 and R-9 as shown.
Remove UY sockets #5 and #6 from the board.

How to rewire the output for the 245's as shown in Figure 14:

Mount UX sockets #5 and #6 in place according to Figure 14.
Connect resistor R-9 in place to "F" terminals of socket #6.
Connect grid wires W-75 and W-76 to "G" terminals of sockets #5 and #6 respectively.
Connect plate wires W-49 and W-51 to "P" terminal of socket #6, and connect wires W-50 and W-52 to "P" terminal of socket #5.
Connect wires W-13 and W-14 to "F" terminals of socket #5.
Connect W-15 and W-16 to "F" terminals of sockets #5 and #6.

With the above changes 245 tubes may be used in sockets #5 and #6.

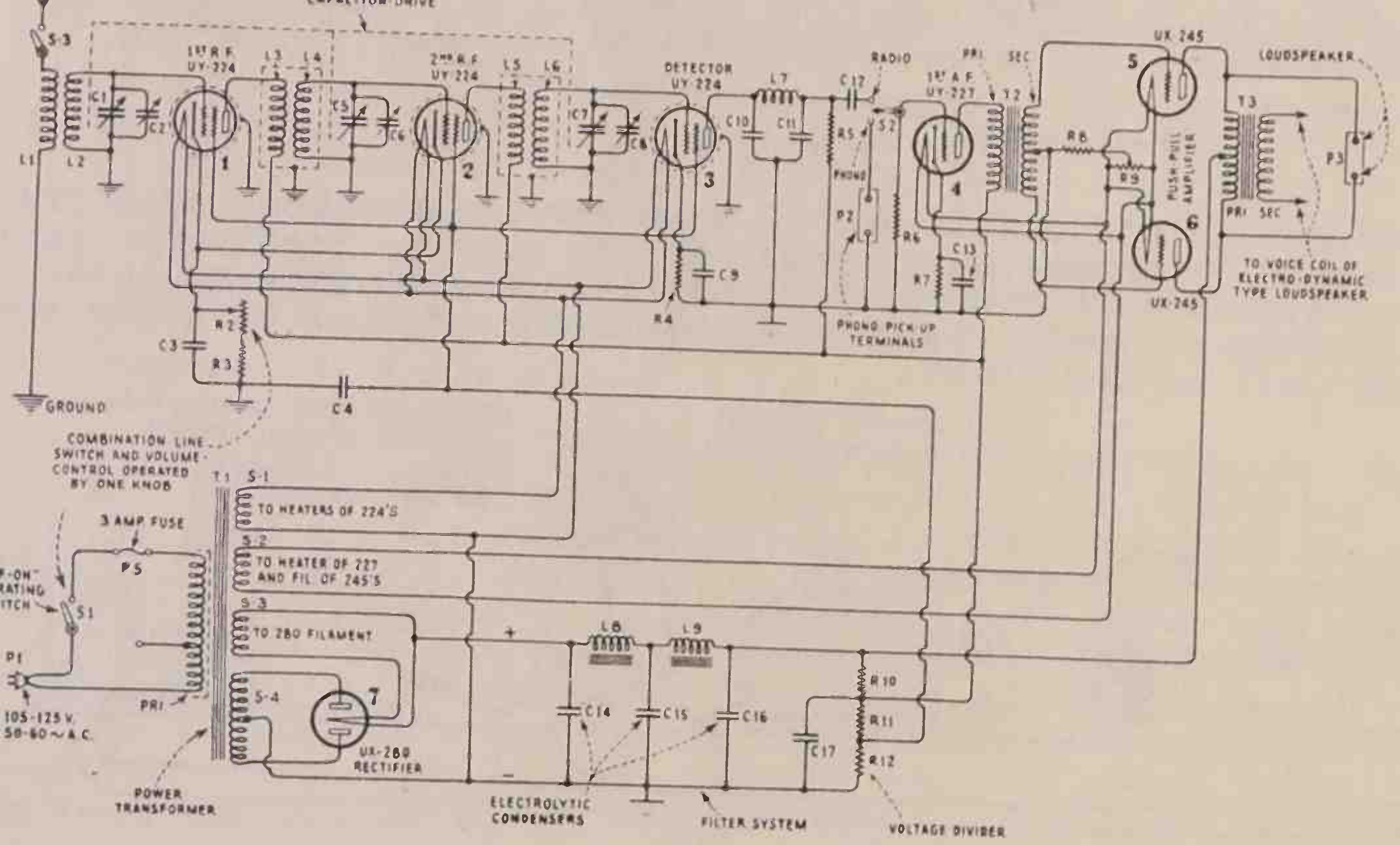

Figure 13

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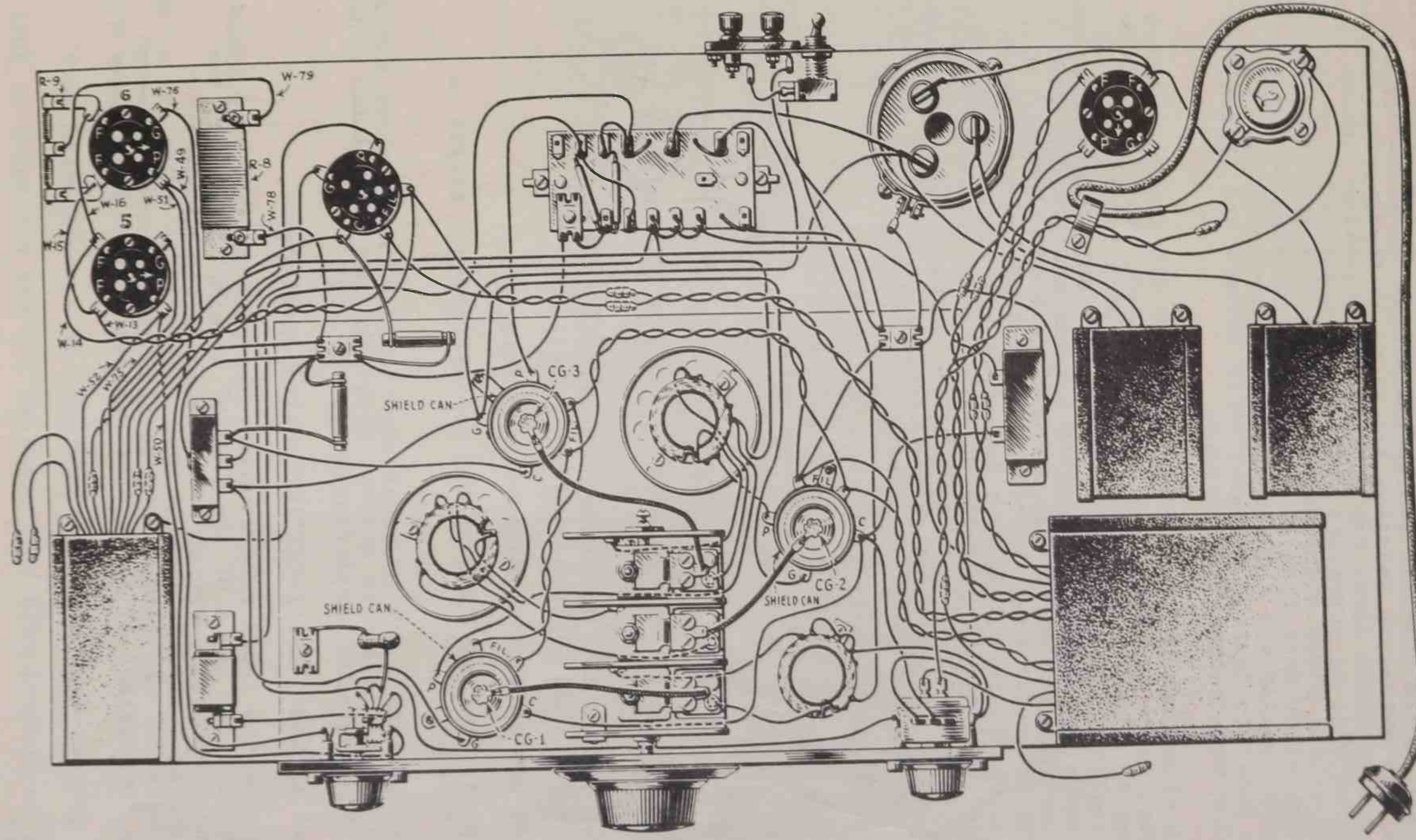

Figure 14

Additional Points About The Kit. An examination of Figure 8 shows that all of the filament and heater wiring is of twisted pairs of wire. This method of twisting the wires is absolutely essential so that the magnetic lines set up by the alternating current flowing in the wires will be cancelled out for all practical purposes by the action of the field surrounding one wire upon the field around the adjacent wire. Note that either end of a twisted pair may be soldered to either one of the filament or heater terminals on a tube socket since polarity is no consideration in heaters and filaments when supplied with alternating current.

Special attention is to be directed toward the radio-frequency transformers. There are three r-f coils supplied, two of which are exactly similar in appearance. The transformer which is different is packed separately in a box and is the 1st r-f or antenna coil. It has a few less turns of secondary wire than the 2nd and 3rd r-f coils which are alike and are packed together. Shield cans are used only with the 2nd and 3rd coils and, therefore, the shield bases should be in place before the brackets holding these coils are secured to the board. Remember to place the cup-shaped aluminum shield bases in position under the 2nd and 3rd r-f coils before screwing the coil brackets down tight. The shield cans for covering these coils should be placed in position when the wiring is completed.

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EXAMINATION QUESTIONS

1. Why are filament and heater wires made up in twisted-pair?

2. Name the different windings of the power transformer and tell what each is used for.

3. What precaution should be made when soldering leads to the terminal lugs of small fixed condensers?

4. What are trimmer condensers used for?

5. Explain how you lined up the radio-frequency stages in your set.

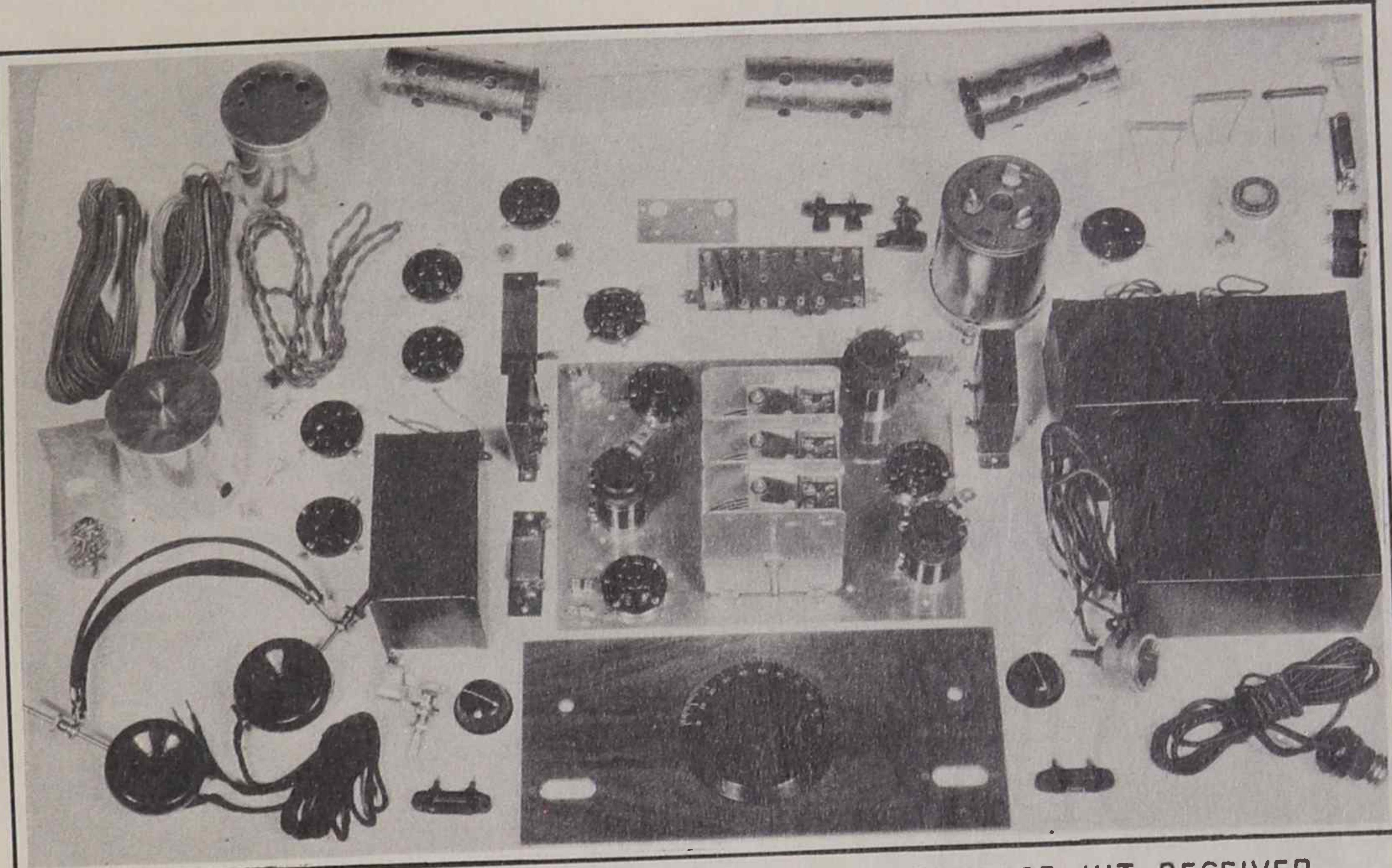
6. When getting a set of tubes together for the receiver should you be particular in any way about the two power tubes used in the push-pull amplifier stage and why?

7. What is the "LOCAL-DISTANT" switch used for?

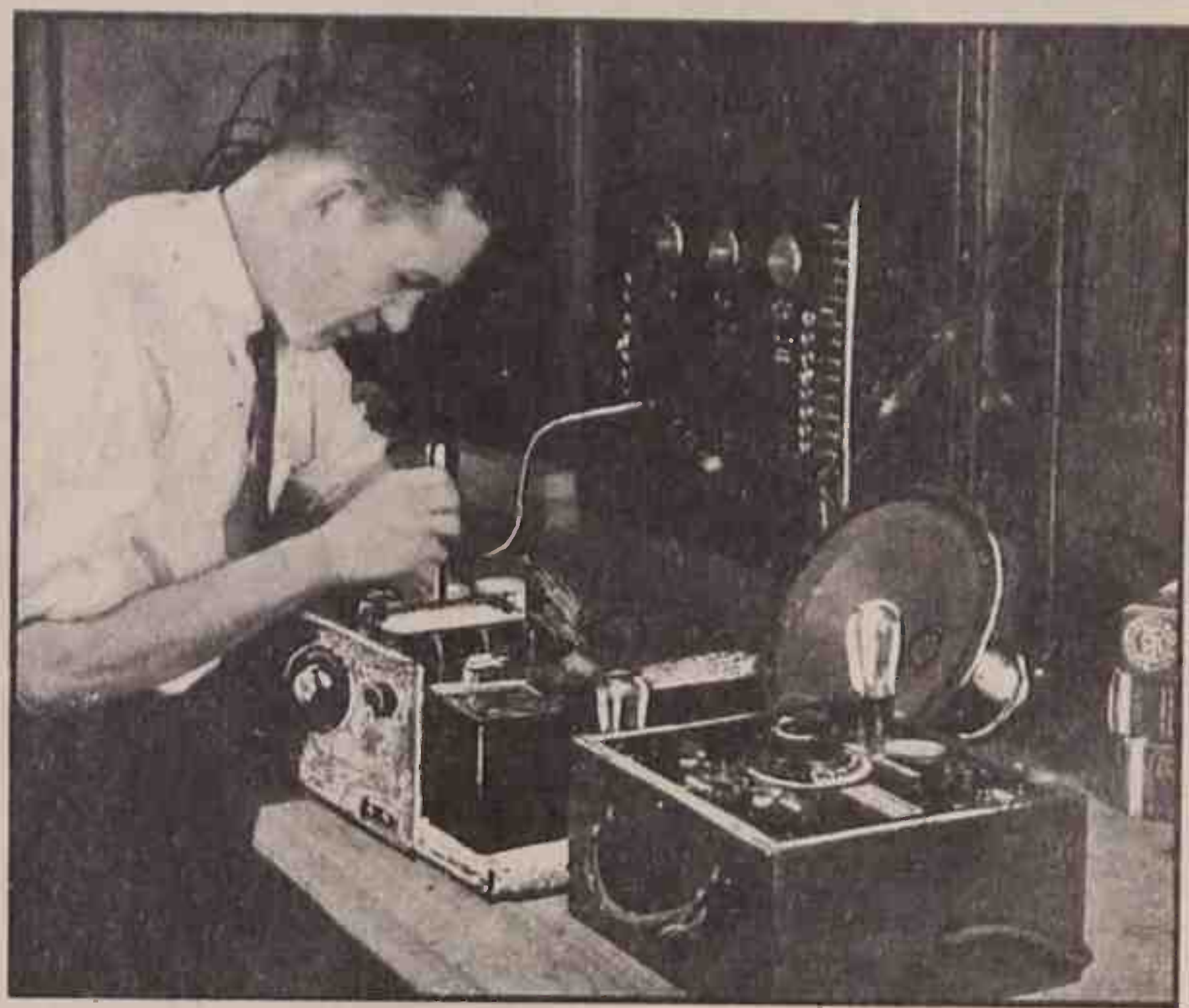
8. Suppose the leads from a phonograph pick-up unit were plugged into the pin jacks of the "PHONO" terminal block and the phonograph-radio switch were placed in the phonograph position. Explain through what circuits the music and voice currents of the record reproduction would travel to reach the loudspeaker if an electro-magnetic type speaker were used.

9. In general what are the advantages of a screen-grid set?

10. How is control grid bias obtained for the r-f tubes in your set?



PARTS REQUIRED FOR ASSEMBLING THE A.C. PENTODE KIT RECEIVER



THE STEADY SIGNAL OF THE OSCILLATOR IS BEING USED TO ADJUST THE COMPENSATING CONDENSERS

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The Tuned-Grid, Tuned-Plate Circuit

Vol.14#11 Dewey Classification R140

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The Tuned-Grid, Tuned-Plate Circuit

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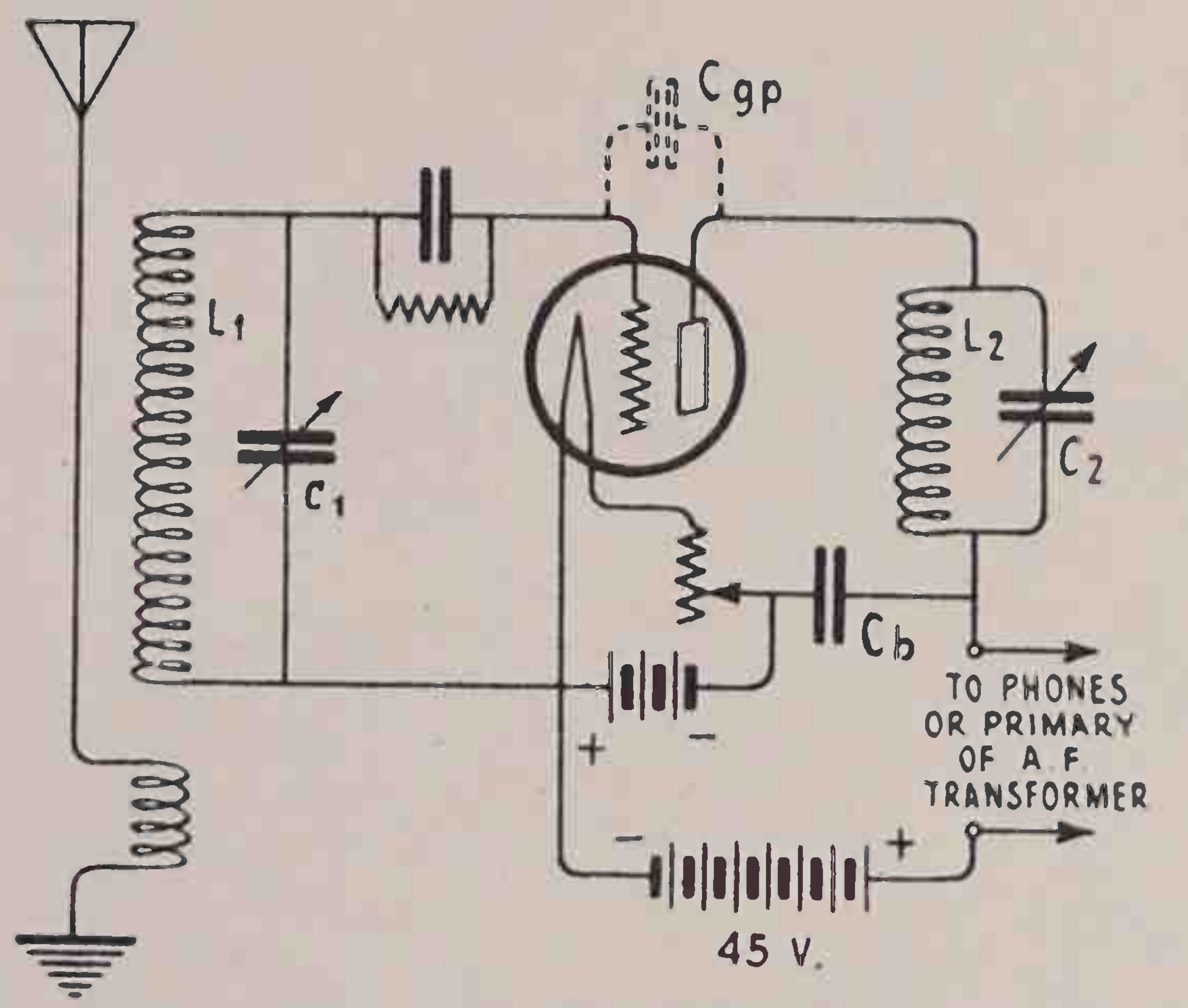

Figure 1.

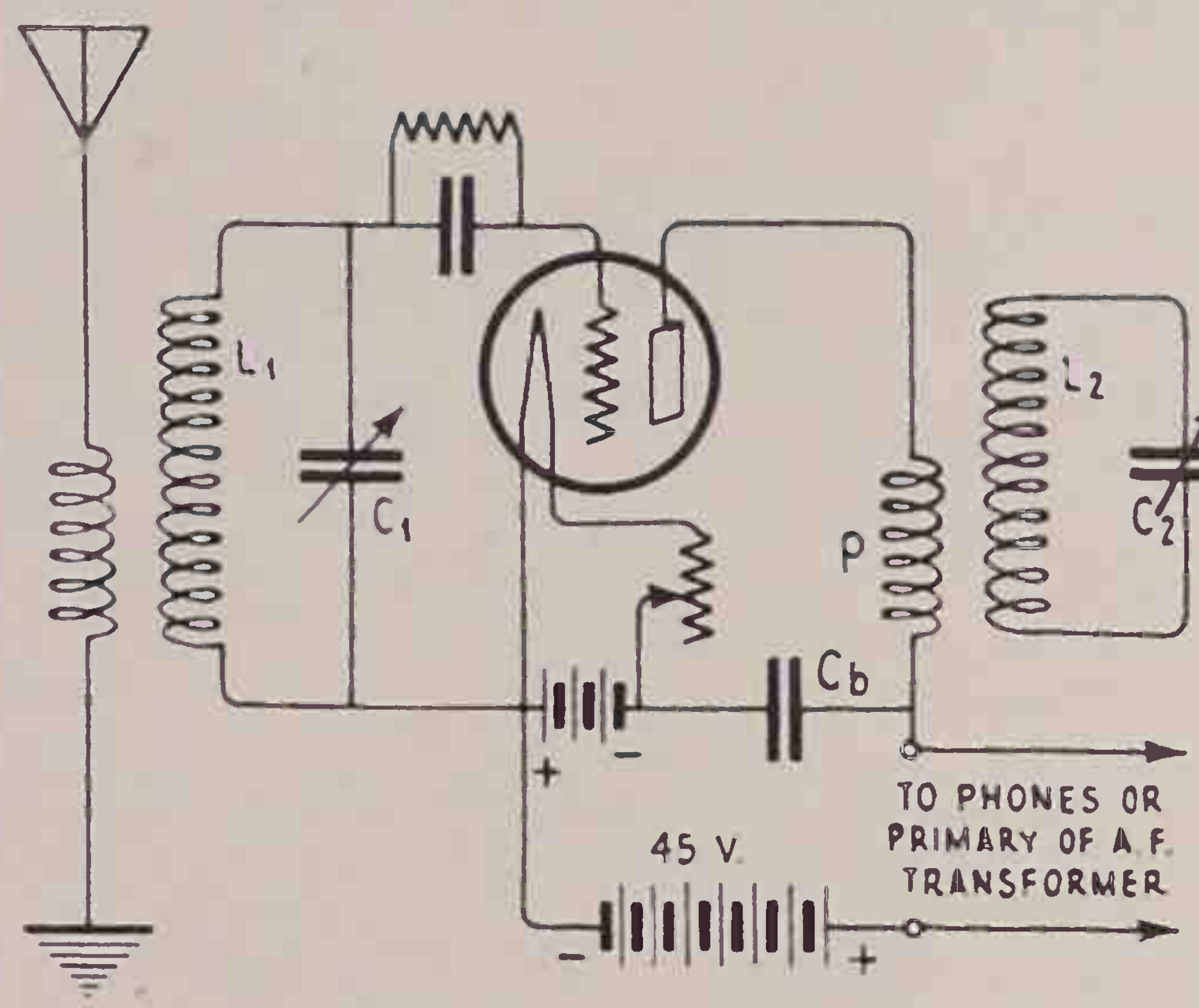

Figure 2.

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THE TUNED-GRID, TUNED-PLATE CIRCUIT

Up to the present we have dealt with a number of receivers, each employing a regenerative vacuum tube detector. With one exception, all of these receivers made use of a tickler coil in order to secure the feed-back necessary to regeneration and its allied phenomenon, oscillation. In each instance feed-back was secured by virtue of electromagnetic induction, and the principal difference in these circuits lay in the manner of controlling feed-back. Such control, of course, is necessary in order to maintain the tube at its most advantageous adjustment for the reception of broadcasting, that is, at the point of maximum regeneration.

It is the purpose of this lesson to deal with a circuit arrangement which will give rise to regeneration and oscillation in a vacuum tube, and it is important inasmuch as it has a direct bearing upon the greatest problem encountered in radio-frequency amplification, a subject with which we shall soon concern ourselves. This problem is how to prevent oscillation in a radio-frequency amplifier, and this lesson will serve as an introduction to the causes of oscillation in such circuits.

The circuit dealt with in this lesson is that of a vacuum tube detector and, when properly adjusted, it will enable the user to secure regeneration and oscillation. As a regenerative detector tube circuit it is as sensitive and selective as any heretofore described, but it is of little practical value due to the difficulty encountered in controlling feed-back and for that reason is seldom used today. When it is desired to introduce regeneration into a vacuum tube detector, one of the tickler coil circuits already described is utilized. It is described herein, not because it is especially valuable as a regenerative detector circuit, but because it leads directly to important considerations entering into the functioning of radio frequency amplifiers.

This circuit, which is shown schematically in Figure 1, is known as the tuned-grid tuned-plate circuit; the origin of the name being obvious after a single glance at the schematic wiring diagram. The grid circuit of the tube is tuned by the inductance L_1 and the condenser C_1, while the plate circuit is tuned by the inductance L_2 and condenser C_2.

The tube will oscillate readily when the grid and plate circuits are both tuned to the same wavelength; and by de-tuning the plate circuit so that it is no longer tuned to the same wavelength as the grid circuit, the tube can be stopped from oscillating and adjusted to the point of maximum regeneration.

Oscillation takes place despite the fact that there need be no electromagnetic coupling between the plate and grid coils, as was necessary in the other regenerative detector circuits with which we have dealt. As a matter of fact, in the actual lay-out of the apparatus in the receiver the plate and grid coils are deliberately placed at right angles to each other, thereby reducing the electro-magnetic coupling between them to practically zero. If no electro-magnetic coupling exists between the plate and grid coils it is obvious that no electro-magnetic induction can take place between them and thus effect feed-back from the plate to the grid circuit. Yet the tube oscillates and, therefore, feed-back must in some manner take place; and this feed-back does take place through the inter-electrode capacity of the vacuum tube.

As we proceed with this subject of feed-back through the inter-electrode capacity of a vacuum tube, bear in mind the fact that any two conductors which are fairly close together and insulated from each other are capable of functioning as an electro-static condenser.

Let us consider, then, the placement of the electrodes in a three-element tube. As you know, the tube has three metallic electrodes; a filament, a grid, and a plate. The metal filament is encircled by a wire mesh (the grid) and this, in turn, is surrounded by a metal plate. These electrodes are carefully insulated one from the other and the spacing between any two of them is but a fraction of an inch. Here, then, we have fulfilled the conditions necessary for the formation of an electro-static condenser, as given above; that is, two or more conductors insulated from each other closely spaced.

Three such condenser effects exist within a three-electrode vacuum tube; namely, the plate-filament capacity, grid-filament capacity and plate-grid capacity; and it is the plate-grid capacity with which we are chiefly concerned in this lesson. The presence of the plate-grid capacity is indicated in dotted lines as Cpg in the schematic wiring diagram. Bear in mind that no actual condenser is connected between the plate and grid of the tube. Those dotted lines are simply to assist you to visualize the existence of the tube's plate-grid capacity. On the other hand, do not permit the fact that it is shown in dotted lines lead you to believe that this plate-grid capacity is more or less imaginary or unimportant. It is very real and the complications that arise from its existence has caused more than one radio engineer to burn the midnight oil seeking ways and means of overcoming it.

The plate-grid capacity is very small in the average vacuum tube, being of the order of 0.000008 mfd. for the ordinary 201A type of tube. Small as this capacity is, however, it provides a path for the flow of radio-frequency current from plate to grid of the tube. Any transfer of energy from plate to grid of the tube constitutes feed-back whether it is accomplished inductively, as by the use of a tickler coil, or by means of the electro-static capacity of a condenser. Furthermore, when the feed-back voltage is in phase with (of the same polarity as) the signal voltage being impressed upon the grid of the tube, it strengthens, or reinforces, the signal voltage. Should the opposite be true, that is, should the feed-back be of opposite polarity to the signal voltage, it will weaken the signal even to the point of completely nullifying it. However, the feed-back through the plate-grid capacity is invariably in phase with the signal voltage, so that when the feed-back is sufficiently great, oscillation will result.

Needless to say, no current will flow through a condenser unless voltage is applied to it and, furthermore, such voltage must be of an alternating nature. Therefore, in the case of condenser Cpg no current will flow through it because of the voltage impressed upon it by the "B" battery, for the voltage of the "B" battery is steady and unvarying.

However, when an incoming signal impresses its voltage upon the grid of the tube, the consequent radio-frequency variations in the plate current do, in effect, cause a radio-frequency variation of the plate potential. Or, in other words, the radio-frequency voltage impressed upon the grid of the tube causes a corresponding radio-frequency potential to appear in the plate circuit. This radio-frequency variation of the plate potential is impressed upon the tiny condenser formed by the plate and grid, and the net result is feed-back through this capacity from plate circuit to grid circuit; the amount of feed-back depending principally upon the strength of the radio-frequency voltage present in the plate circuit.

Ordinarily this voltage is not great enough to cause sufficient feed-back for regeneration and oscillation and, therefore, this feed-back via the plate-grid capacity must be supplemented by additional feed-back secured in other ways as, for instance, by means of a tickler coil.

But if the radio-frequency voltage present in the plate circuit can be strengthened sufficiently, then the feed-back due to the plate-grid capacity will be increased to the point where regeneration and oscillation will result without the presence of any feed-back other than that which takes place by virtue of the plate-grid capacity.

This can be done by including in the plate circuit an inductance, L_2, and tuning this inductance by means of a condenser, C_2, to resonance with the particular radio-frequency being dealt with.

When radio-frequency current flows through the inductance L_2, the magnetic lines of force surrounding this coil rise and fall in accordance with the variations in current strength and, in so doing they create a secondary, or self-induced voltage. The strength of this self-induced voltage, which is often termed the inductive reactance voltage, depends primarily upon the value of the inductance and the strength of the current flowing therein. In this instance, the value of inductance L_2 is determined and fixed by the wavelength range to be covered when used with condenser C_2 of a given capacity. Therefore, the strength of the inductive reactance voltage will depend upon the strength of the r.f. current flowing through this inductance.

Inasmuch as the inductance L_2 and condenser C_2 form an oscillatory circuit, the greatest flow of radio-frequency current will take place in this circuit when it is tuned to resonance with the radio-frequency current flowing in the plate circuit. The inductive reactance voltage developed across the inductance, L_2, will then be at its maximum value and will result in maximum feed-back through the plate-grid capacity, and this feed-back will be sufficient to cause the tube to oscillate.

If the oscillatory circuit, L_2C_2, is de-tuned from resonance with the radio-frequency component of the plate current, the radio-frequency current flowing in circuit L_2C_2 will, of course, decrease and therefore the inductive reactance voltage developed across L_2 will decrease. Any reduction of this voltage developed across L_2 means a reduction of the voltage applied to the plate-grid capacity, Cpg, which in turn results in a decrease in feed-back. When the plate circuit is de-tuned sufficiently the feed-back will be reduced to the point at which the tube ceases to oscillate and becomes regenerative. Thus, the tuning of the plate circuit becomes a regeneration control for, by adjusting the degree of resonance of the tuned plate circuit, L_2C_2, the tube can be made to oscillate or to regenerate.

Before commencing the wiring of this receiver it will be necessary to mount, in addition to the apparatus listed in lesson V36#7, a tuned radio frequency transformer. This instrument should be mounted near the rear left-hand corner of the baseboard and, furthermore, it should be placed at right angles to the three-circuit tuner mounted upon the panel. By so placing the radio-frequency transformer, inductive coupling between it and the three-circuit tuner is reduced to a minimum.

Having mounted the RF transformer, begin wiring by connecting its primary (the small coil of ten turns of wire) to the antenna and ground binding posts. Connect a wire between the +A binding post on the terminal strip and the positive filament terminal of the tube socket. The -A binding post on the terminal strip is now connected to a terminal of the detector's filament rheostat and the other terminal of this rheostat is connected to the negative filament terminal of the tube socket. Connect the grid condenser to the grid terminal of the tube socket. The grid leak is, as usual, inserted in the clips provided for it on the grid condenser. The secondary of the tuned RF transformer is the larger of the two coils comprising this instrument. The end of the secondary which is next to the primary coil, i.e., the "low" end, should be connected to the positive filament lead. The end of the secondary coil opposite the primary coil, i.e., the "high" end, should be connected to the grid condenser. The variable tuning condenser mounted at the left of the panel should now be connected in parallel to the secondary of the tuned RF transformer. When doing this be careful to connect the stator plates of the condenser to the "high" end of the secondary and the rotor plates to the "low" end of the secondary.

Of the three coils which comprise the three-circuit tuner only the secondary is made use of in this circuit, the primary and tickler coils being left disconnected. A connection is now made between the plate terminal of the tube socket and one of the secondary terminals of the three-circuit tuner. The other secondary terminal is connected to a tip-jack. The remaining tip-jack is connected to the B+Det binding post on the terminal strip. The variable tuning condenser which is mounted to the right of the panel should now be connected in parallel to the secondary coil of the three-circuit tuner. In doing this it would be advisable to connect the stator plates of this condenser to that end of the secondary coil which is connected to the plate terminal of the tube socket. The rotor plates should then be connected to the opposite end of this (secondary) coil. The 0.001 mfd. fixed condenser is the by-pass condenser shown as C_b in Figure 1. One terminal of this condenser is connected to the filament circuit as shown, while its other terminal is connected to the same tip-jack to which one terminal of the three-circuit tuner secondary is connected.

When the apparatus is connected in accordance with the above instructions, the secondary of the RF transformer becomes the grid coil, L_1, and the tuning condenser connected in parallel to this coil is the grid tuning condenser, C_1. Also, the secondary of the three-circuit tuner is the plate tuning coil, L_2, and the variable condenser in parallel to this coil is the plate tuning condenser, C_2.

As in previous lessons, if the audio-frequency amplifier is used, as recommended, the wires connecting to the two tip-jacks are connected instead to the primary terminals of the first AF transformer. Take care that the wire which connects to the B+Det binding post on the terminal strip is connected to the B terminal of the AF transformer. The plate terminal of the tube socket should be connected, through the inductance L_2, to the P terminal of the AF transformer.

The operation of this receiver does not differ greatly from that of other types of regenerative detectors. There are two controls, namely, the variable condenser, C1, which enables the user to tune the grid circuit of the tube to the wavelength of the desired signal; and the variable condenser, C_2, which serves to tune the plate circuit of the tube, and which functions as a regeneration control.

Oscillation takes place when the grid circuit, L_1C_1 and the plate circuit, L_2C_2, are both tuned to the same wavelength. Oscillation in the detector tube can be controlled by de-tuning the plate circuit from resonance with the frequency of the incoming signal, and so, by proper manipulation of the plate tuning condenser, C_2, the detector tube can be adjusted to the point of maximum regeneration.

Changes in the tuning of the plate circuit are apt to affect the tuning of the grid circuit. Therefore, when altering the tuning of the plate circuit in order to adjust the detector tube to the point of maximum regeneration, it will be necessary to make minor re-adjustments in the tuning of the grid circuit in order to keep this circuit in resonance with the desired signal.

The secondary of the tuned RF transformer, L_1, and the secondary of the three-circuit tuner, L_2, are very nearly alike in their values of inductance; and the same holds true for the two variable tuning condensers, i.e., for any given setting they will be nearly alike in their values of capacity. Therefore, when the dials of the tuning condensers read alike, the two tuned circuits which these condensers control will be tuned to practically the same wavelength, and oscillation will result.

The grid circuit of the tube, L_1C_1, must be tuned to exact resonance with the signal it is desired to receive. To stop the tube from oscillating and adjust for maximum regeneration, de-tune the plate circuit.

Decreasing the filament current of the detector tube below its normal value will prove of material aid in preventing oscillation; thus, the detector tube rheostat can be used as a supplementary oscillation control by which the tube can be adjusted for maximum regeneration. Do not, however, decrease the detector tube's filament current too much, because too great a decrease in its value will greatly impair the sensitivity of the tube. On the other hand, care should be exercised not to increase the filament current of the detector tube, or any tube for that matter, above its normal value, for by so doing the life of the filament will be shortened. The exact manner in which the detector rheostat can be used in adjusting the detector tube for maximum regeneration can best be determined by experiment. It should be borne in mind, however, that the plate tuning condenser, C_2, is the main oscillation control and the detector filament rheostat should only be used to secure the final adjustment of regeneration.

<u>Tuning the Plate Inductively</u>. The circuit with which we shall deal in the following paragraphs is a continuation of the receiver just described in the preceding pages of this lesson. That the two circuits are quite similar is at once evident from a comparison of Figure 2 and the circuit diagram, Figure 1, yet the circuit shown in Figure 2 incorporates an elaboration of the preceding hook-up which is of prime importance in tuned radio-frequency amplification. The manner in which these two circuits differ from each other lies in the fact that the tuned oscillatory circuit, L_2C_2, instead of being directly connected into the plate circuit of the detector tube, is coupled to the plate circuit by means of coil P. Despite the fact that the tuned oscillatory circuit, L_2C_2, is no longer connected in the plate circuit of the detector tube, nevertheless it serves to tune the tube's plate circuit due to the fact that it is coupled thereto.

It is a well known fact that when two such oscillatory circuits are placed in inductive relationship to each other, the electrical characteristics of each will influence the electrical characteristics of the other. Incidentally, it might be well to mention that by "electrical characteristics" is meant resistance, inductance and capacity and the allied phenomenon of resonance arising from their inter-related functionings. The extent to which electrical characteristics of the coupled circuits involved will influence each other will depend to a great extent upon the degree of coupling existant between these circuits. To elaborate upon the foregoing statement let us state that if the coupling between the circuits is tight their effect upon each other will be pronounced, while if the coupling is loose this mutual reaction between the circuits will be less evident; and when the coupling between them is made very loose their reaction upon each other becomes negligible.

Consider, then, the coil P, Figure 2, and the tuned oscillatory circuit, L_2C_2. You will note that no provision has been made for tuning coil P, and, by disregarding its natural period or wavelength, we may consider it, as far as our purposes are concerned, as being untuned. This coil is inductively coupled to coil L_2 which, in conjunction with the variable condenser, C_2 forms an oscillatory circuit. By virtue of the values of inductance and capacity of L_2 and C_2 respectively, this tuned circuit may be resonated to any wavelength between 200 meters and 550 meters by varying the capacity of the variable condenser C_2.

Because of the inductive coupling between coil P and the oscillatory circuit, L_2C_2, the tuning of this oscillatory circuit will make itself felt upon coil P and, in effect, will tune coil P to approximately the same wavelength as that to which circuit L_2C_2 is resonated.

In this manner, circuit L_2C_2 serves to tune the plate circuit. Although it is not connected to the plate circuit of the tube by direct wire connection as in Figure 2, it is, nevertheless, connected to the plate circuit by magnetic lines of force, i.e., it is coupled to the plate circuit.

A somewhat different angle from which to regard this phenomenon is from the viewpoint that when dealing with alternating currents, whether they be of high or low frequency, it is not necessary to employ metallic conductors in order to secure a connection between two or more circuits. Direct metallic connections may be dispensed with and the circuits "connected" by utilizing magnetic lines of force; and when two or more circuits are so connected by magnetic lines of force, they are said to be "inductively coupled".

When circuits are connected by means of metallic conductors the efficacy of such connections is determined by the resistance, or, conversely, the conductivity of such connections. A similar determining factor is encountered when two or more circuits are "connected" by magnetic lines of force, i.e., coupled, inasmuch as the effectiveness of the "connection" is dependent upon the degree of coupling employed.

Thus, even as in Figure 1, circuit L_2C_2 tunes the plate circuit of the tube due to its coupling thereto, and the extent to which its tuning will influence the plate circuit will be determined by the degree of coupling between it and the coil P. If coil P is closely coupled to coil L_2 the influence of circuit L_2C_2 upon the plate circuit will be pronounced, but as the coupling is loosened its influence upon the plate circuit becomes less and less until, when the coupling is made sufficiently loose, the influence of circuit L_2C_2 upon the plate circuit becomes negligible.

When the grid and plate circuits are tuned to the same wavelength and with tight coupling between coils P and L_2, the tube will oscillate and otherwise behave in a manner similar to that of the preceding hook-up shown in Figure 1. But, in addition to those effects noted in the operation of that receiver, it will be found that adjustment of the coupling between coils P and L_2 provides us with an additional and very effective oscillation control.

To convert the hook-up of Figure 1 to the circuit shown in the wiring diagram of Figure 2, only one simple change in the plate circuit wiring is necessary. To make this change, disconnect from the plate circuit the tuned circuit, L_2C_2, and substitute for it the coil P. More specifically: Trace the wire that leads from the plate terminal of the detector tube socket to the secondary of the three-circuit tuner (L_2). Disconnect this wire from coil L_2 and connect it instead to one of the terminals of the tickler coil. The wire which leads from one of the tip jacks (or the P terminal of the first stage AF transformer, depending upon whether or not an audio amplifier is used) to the other terminal of coil L_2 is now disconnected from this coil terminal and connected instead to the remaining terminal of the tickler coil. In this way, the coil which was formerly employed as a tickler coil now becomes the primary P of the tuned r.f. transformer composed of the coil P and the tuned secondary coil, L_2. Moreover, as this primary coil is rotatable, we have a convenient means of varying the coupling between the primary and the secondary coils.

When making the changes described above, care should be exercised that the condenser, C_2, which is ordinarily connected in parallel to coil L_2, remains connected to this coil, and that no other changes in the wiring of the plate circuit are inadvertently made except those alterations mentioned.

When first putting the receiver in operation, place the primary (tickler) coil, P, parallel to the secondary coil, L_2, thus securing the maximum available coupling between the two. Then proceed to operate the receiver as in the preceding lesson. As before, the grid circuit, L_1C_1, must be tuned to resonance with the desired signal and, with maximum coupling between the coils P and L_2, the detector tube will oscillate when the tuned plate circuit is brought into resonance with the grid circuit. As in the receiver first described (Figure 1), oscillation can be stopped and the tube adjusted for maximum regeneration by de-tuning the plate circuit.

A more effective control of oscillation, however, is secured by varying the coupling between P and L_2. By loosening the coupling between these two coils the tube can be stopped from oscillating and brought to the point of maximum regeneration. Conversely, tightening the coupling will increase regeneration and finally result in oscillation provided, of course, that the grid and plate circuits are in resonance.

The proper procedure, therefore, for tuning in a station is to use maximum coupling between coils P and L_2 while varying the two varibale condensers until the desired signal is heard. Then loosen the coupling between P and L_2 until the detector tube stops oscillating. At this point a slight final re-adjustment of the plate and grid tuning condensers may be necessary.

While tuning in stations operating on differing wavelengths take note of the value of the coupling necessary for maximum regeneration at each different wavelength. It will be found that this critical degree of coupling will vary according to the wavelength of the station being received; and that the coupling between coils P and L_2 necessary for maximum regeneration is greater for the longer wavelengths. In other words, the longer the wavelength of the station being received the tighter must be the coupling between coils P and L_2 in order to secure maximum regeneration and, conversely, as the receiver is tuned to shorter wavelengths the degree of coupling necessary for maximum regeneration becomes less.

EXAMINATION QUESTIONS

1. How does feed-back take place in the circuit shown in Figure 2?
2. What is the purpose of coil P in Figure 2?
3. State briefly two ways in which regeneration can be controlled.
4. How is the plate circuit tuned in Figure 2?
5. What advantage is derived from making the coil P, in Figure 2, rotatable?
6. What is the purpose of the tuned circuit L_2C_2?
7. When the plate and grid circuits in Figure 2 are both tuned to the same wavelength, how can oscillation be prevented?
8. How is oscillation controlled in Figure 1?
9. (a) What are the three principal internal capacities in a vacuum tube?
   (b) Are these capacities large or small?
10. What is the purpose of condenser C_1 in Figure 1?