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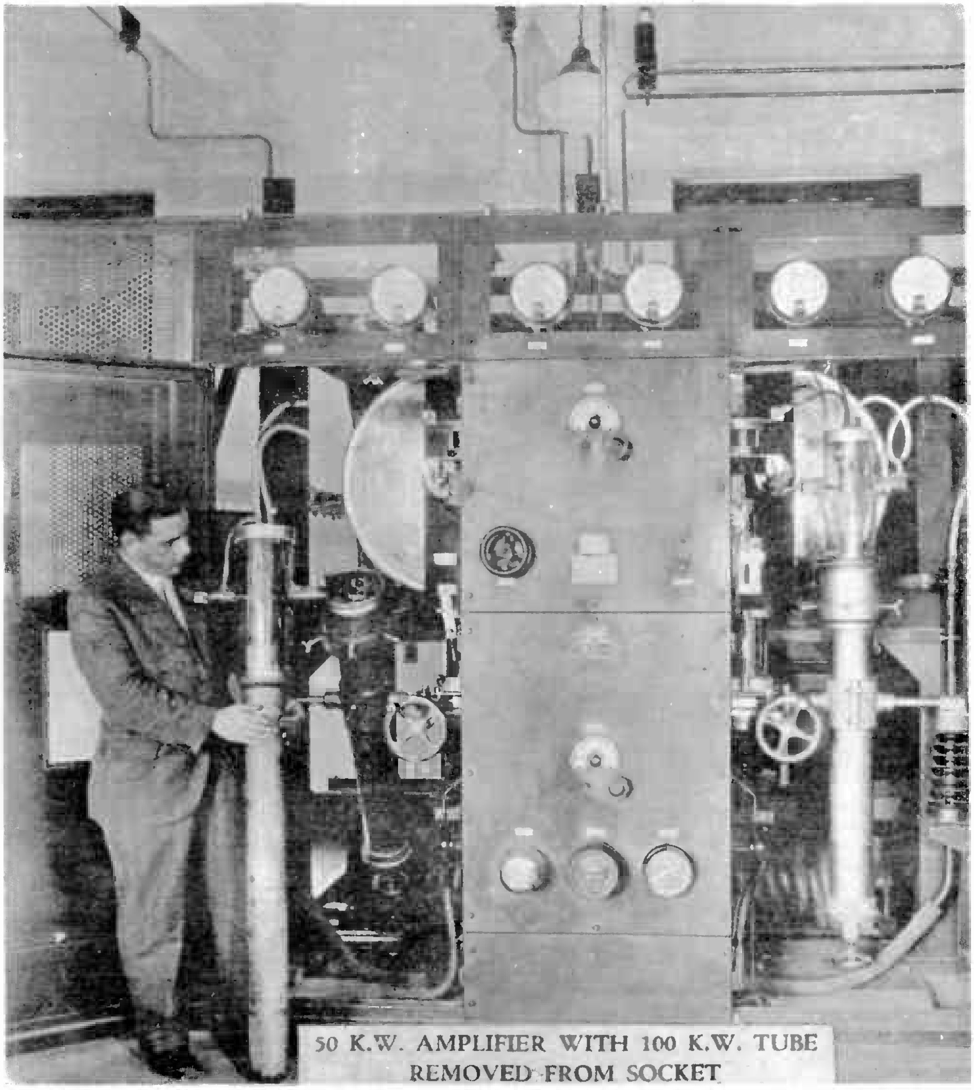

50 K.W. AMPLIFIER WITH 100 K.W. TUBE REMOVED FROM SOCKET

Vacuum Tubes Used in Transmitting

- Class A, B and C Amplifiers -

Dewey Classification R 130

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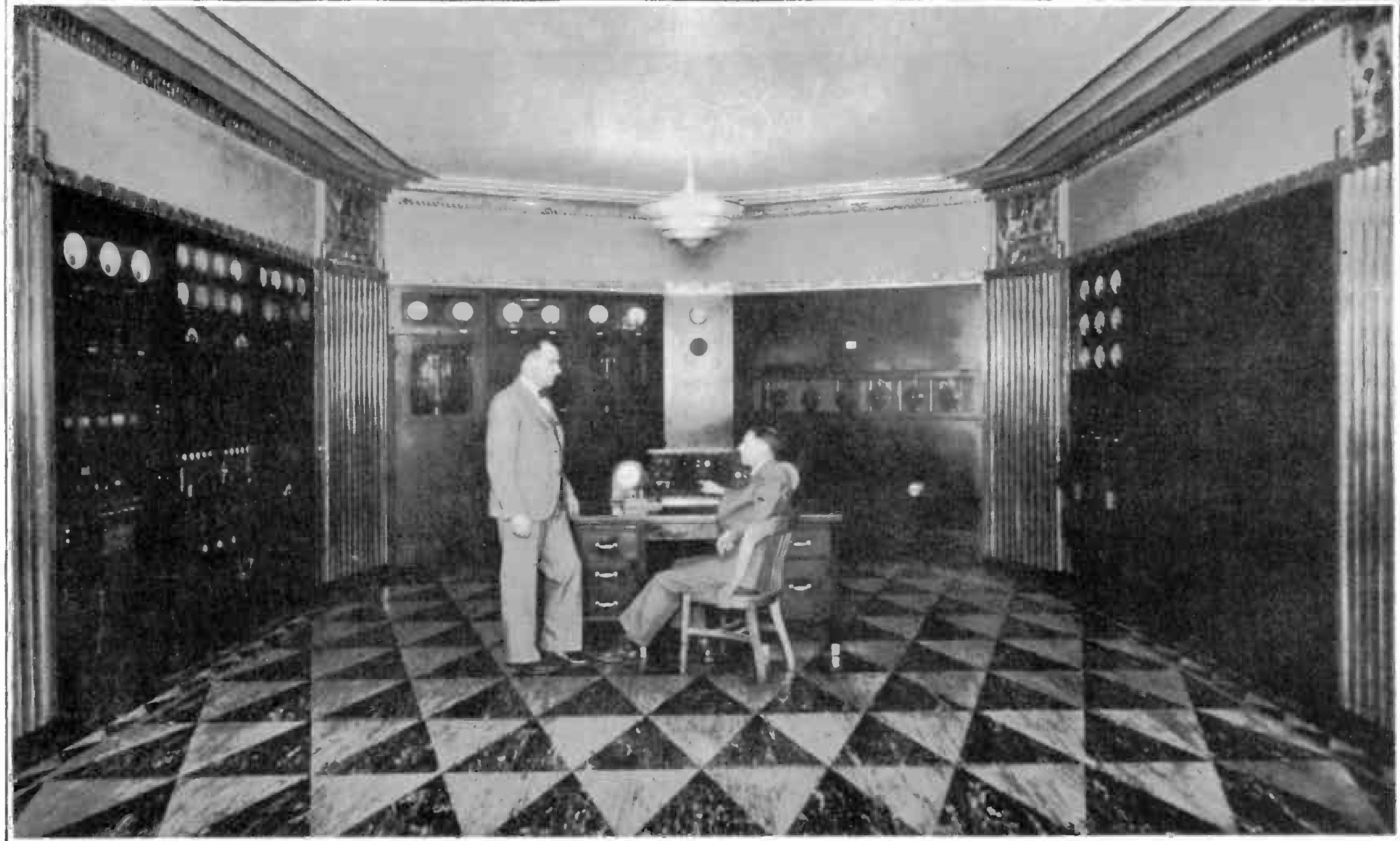

INTERIOR VIEW OF WEAF'S NEW BROADCASTING STATION LOCATED AT BELLMORE, LONG ISLAND.

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VACUUM TUBES USED IN TRANSMITTING
CLASS A, B AND C AMPLIFIERS

The development of power vacuum tubes has kept pace with the demands for a high percentage of efficiency in the operation of all equipment used in radio communication, both in the field of telegraphy and telephony. All power tubes are rated for their power output. In the following paragraphs we will treat on the various tubes from the smallest one which is accorded a place in the power class, the 7.5 watt type, upward and including the water-cooled type rated at 100 kilowatts.

Before dealing with any specific types we will review some important features regarding vacuum tubes in general and especially about power rating. The three circuits associated with the three-electrode tube are the filament, plate and grid.

During the normal operation of a tube the grid and plate become electrically charged bodies and since they are suspended within the glass envelope in a position surrounding and facing the filament both grid and plate necessarily exert their individual influences upon the electrons given off by the filament. Remember that any electron ejected by the filament is actually in clear free space and being a negative charged particle it is subject to the influence of any body with an electric charge upon it, for such bodies set up electrostatic lines of force between themselves and other bodies. It will be noted that the ends of the grid and plate circuits outside of the tube are always attached to some specified point along the filament circuit. These connections are called the grid and plate return leads, and represent the low voltage or low potential side of the vacuum tube circuit. Thus, in tracing out the complete continuity of either the grid or plate circuits, we would find that they embrace part of the filament. Consequently, the current flowing in either the grid or plate must complete its path through the filament and also through the vacuous space within the tube by virtue of the electrons. Considering the filament circuit alone it is easy to see that it is simply a conductive circuit or we may call it a closed metallic circuit through which the heating current flows.

The filament circuit includes, in general, a rheostat or fixed resistor to regulate the voltage at the filament terminals, and there is also the equipment necessary to provide the electromotive force. In many cases this source of e.m.f. consists of a storage battery or d-c generator, or if the filament is heated with alternating current the battery is replaced and the filament is attached to a low voltage coil on a power transformer. The filament, we may then say, is the electron emitting electrode and it is also known as the "cathode".

The plate circuit includes, in general, a high voltage source of supply which may be a "B" battery, or a d-c generator, or a rectifier device to supply plate voltage. The plate is the positively charged electrode in the tube and it is therefore called the "anode". We have mentioned heretofore that the plate functions to attract the emitted electrons and so, when the grid is excited with a fluctuating voltage, the electron flow is varied and thus the plate in our tube serves to supply a fluctuating or a pulsating direct current to operate any device inserted in the plate circuit. The device we refer to may take the form of an inductance, or transformer, or resistor. Such a device constitutes the "load" on the vacuum tube. Power is required to operate the load device in the plate circuit and hence the plate circuit is known as the "output" circuit.

Next we have the grid circuit which is known as the "input" circuit. The grid circuit is so named because the grid receives its excitation voltage from the currents flowing through this circuit which is always connected between grid and filament. The grid circuit consists of either tuning elements, an inductance and condenser for example, or simply the secondary winding of a transformer. In some circuits fixed condensers are inserted in series with the grid and resistors connect the grid to filament. These condensers should have the correct capacity because the input voltages, that is, excitation voltages, must be carried through them without opposition. Bear in mind that the grid is the controlling electrode, because when supplied with electric potentials (called the input voltages) it will act to regulate the quantity of electrons reaching the plate.

The whole action of any vacuum tube is dependent mainly upon the tiny electrons which are liberated or expelled by the hot filament. These electrons are attracted by the positively charged plate and make up and actually constitute the plate current. Thus, when a plate is maintained at a positive potential it will exert a continuous attraction for the electrons emerging from the hot filament.

The value of plate current necessary to insure the normal operation of a tube is governed by the quantity of electrons pulled to the plate. If we are called upon at any time to summarize briefly the various factors which control the amount of the electron energy reaching the plate we could state these factors as follows:

1. The value of the positive d-c voltage supplied to the plate.

2. The operating temperature of the filament.

3. The value of grid bias used and grid excitation voltage.

4. The degree of vacuum existing in the chamber within the glass envelope.

All three-electrode tubes function on the principle that when an alternating or fluctuating voltage is impressed upon the grid the amount of electrons passing through the vacuous space from filament to plate will be made to vary, thus the plate direct current fluctuates constantly and regularly between certain maximum and minimum limits, depending upon the frequencies and intensities of the voltages impressed upon the grid.

While we are relating facts which are more or less general in regard to our vacuum tubes, it may prove both interesting and instructive to point out the similar effects set up in a circuit by either a pulsating direct current or an alternating current.

Although a fluctuating or alternating voltage on the grid causes the plate current to vary in strength from its normal value to either greater or lesser values, yet it must be understood that this plate current can flow only in one direction. The conduction of electrons within the tube is in the direction only from filament to plate. Thus the plate current flow is unidirectional and it should be easy to understand, then, that it cannot be called a pure alternating current. However, we do call the instantaneous variations of the plate current the "a-c component". It can be shown that these variations do produce all of the effects of an alternating current; as, for instance, they set up a changing magnetic field surrounding a coil inserted in the plate circuit and produce a reactance voltage across or between the opposite ends of the coil. Moreover, by the use of a suitable coil (i.e., inductance) and a condenser the changing plate energy is capable of placing an electrostatic charge in the condenser and the latter then can be used to couple the plate circuit with some neighboring circuit. You will recall from your early studies that reactance voltage is the direct result of a coil's opposition voltage (or, as it is called "reactance voltage") which is set up by changing magnetic lines of force cutting back and forth through the same turns of wire which produced these magnetic lines. That is, the magnetic lines react back upon the turns which set up these lines. This effect produced upon a circuit by a coil when it carries a current which is constantly varying in strength is known as "self-induction". The voltage generated is known as the "induced voltage of self-induction".

Now let us consider some facts concerning the metal which is used in the manufacture of the filament wire. A tremendous amount of study and research has been going on steadily in the laboratories of tube manufacturers to find a metal or combination of metals which would give off an abundant supply of electrons for the least expenditure of heating current.

The three materials used to any great extent are tungsten, oxide coated platinum and X-L, or thoriated tungsten. Tungsten was the metal generally used before Dr. Irving Langmuir discovered that the rare metal, thorium, was especially rich in electronic energy. He showed that a thorium-coated tungsten filament heated to a temperature of 2,300 degrees Centigrade provided an electronic emission more than ten thousand times as great as a pure tungsten filament heated to the same temperature. Filament wire may be either coated with an oxide, or the wire is more often treated throughout with the rare material, thorium. So, with a comparatively low heating current, the modern power tube filament gives off a vastly greater supply of electrons than was formerly thought possible. While the fact that the X-L filament requires a much lower power to insure a proper operating temperature than would be the case if other materials of equal practical value were used, yet another quality that this special wire possesses is that the total electron emission for a given power consumption is comparatively long. Thus the expectance of tube life is prolonged many hours. It is agreed that the operating life of a vacuum tube is one of the most important features. Life expectations show up wide variations with respect to operative conditions and to some extent with individual tubes of similar type. These facts outline in general the essential requirements of the filament wire used in power vacuum tubes.

The manufacturer designs the filament of a tube to have the correct length and thickness using a certain material so that when a specified e.m.f. is impressed across the filament terminals the required current will flow and heat the wire to proper operating temperature.

The life of a thorium treated filament is naturally limited for the electron energy is obtained at the expense of the thorium. It is to be expected, then, that during operation of a transmitting set the filaments of the various tubes are constantly evaporating, or being used up, as it were. Electron energy driven off the surface of the wire is replaced by the diffusion of thorium down inside the wire. The thorium apparently boils out and while the actual amount of thorium lost at any given moment is very small to be sure, yet the filament will eventually lose its emission. That is to say, the useful life of the tube will end when the supply of thorium inside the filament is exhausted. Of course, the disintegration and evaporation of the thorium will be very rapid if the filament is operated at too high a temperature. Any power tube is likely to be subjected to a short overload, and in such events the X-I filament type has proven capable of withstanding three times its normal voltage without a burn-out.

Gases are given off by the plate when the tube is overloaded and under such conditions the tube will show considerable color. To reduce the possibility of a hot plate giving off gases during its normal life, the X-L filament type tubes are constructed with molybdenum plates which during the manufacturing process are heated to extremely high temperatures by means of a high-frequency furnace. That is, the eddy currents set up due to high-frequency induction tend to heat the metal parts. Other internal parts of the tube are also brought to high temperatures when the plate undergoes this treatment and thus all metallic parts are heated to a higher point than they ever reach during normal operation. Electron emission is usually lowered temporarily in the event of a severe plate overload, but this condition can often be rectified by the reactivation or rejuvenation process which is explained in the next paragraph. Reactivation cannot be resorted to if an air leak occurs in the tube. A purplish or pink glow can be taken as an indication that an air leak exists, whereas a distinctly blue glow would suggest gases had been released from the metal parts within the tube.

While the tube with a low emission is of no practical use it may still have its relatively inert tungsten wire intact and in this case the wire is capable of carrying sufficient current to heat and light up to its usual degree of incandescence. It is often possible to restore a tube in this condition to give additional hours of service by a very simple process called "rejuvenation." This process consists of forcing metallic thorium from the inner recesses of the filament wire to its surface by heating the wire to a temperature slightly above normal for about 15 minutes with the plate circuit open. Voltage must not be supplied to the plate during this operation. This re-activation of the filament should be carried on with the voltage about 15% above the normal as specified by the manufacturer, and in many instances we have given the exact limit for many types of power tubes in the discussions which are to follow.

CLASS "A", "B", AND "C" AMPLIFIERS

The power rating of vacuum tubes used in transmitting equipment is dependent upon the manner in which they are used. There are three different ways in which vacuum tubes are used in transmitting circuits. In discussing the operation of tubes in a transmitter, it would be necessary to state how each tube was being used. This would entail rather lengthy explanations were it not for the fact that to each method of using a tube a letter has been assigned. These letters are the first three of the alphabet; viz., Class A amplifier, Class B amplifier and Class C amplifier or oscillator.

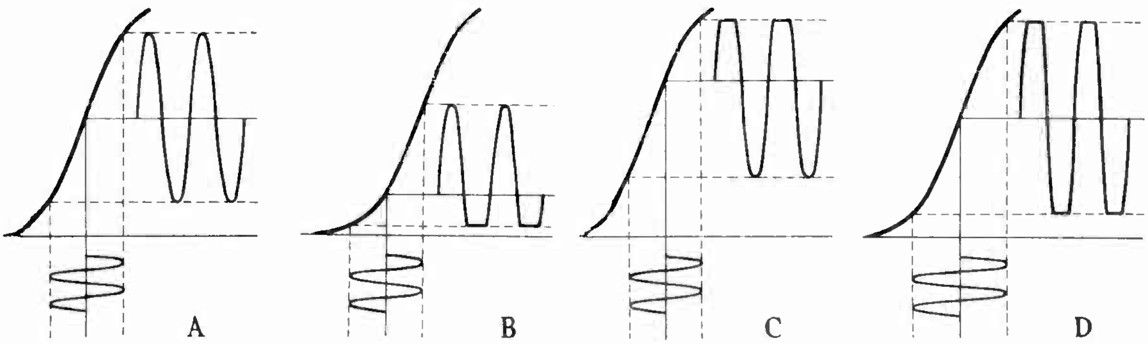


FIG. 1 - (A-B-C-D) CURVES USED TO EXPLAIN CLASS "A" AMPLIFIERS

CLASS "A" AMPLIFIER. The Class A amplifier may be defined as follows: The Class A amplifier is an amplifier which operates in such a manner that the complete output wave form is essentially the same as that of the excited grid voltage. The characteristics of a Class A amplifier are low efficiency and output with a large ratio of power amplification. This type of amplifier is used in most audio-frequency amplifier and modulator circuits.

It is the duty of a Class A amplifier to reproduce in its plate circuit a wave shape which is an exact replica of the wave shape of the impressed grid voltage. In order to accomplish this result it is necessary to operate the tube at that point on the grid voltage-plate current characteristic curve where the change in plate current is directly proportional to the change in grid voltage. In other words, to operate the tube that the entire plate current swing will take place over the straight line portion of the plate current curve. An example of such operation is shown in Figure 1-A. The effect of too high grid bias is shown in Figure 1-B; it will be noticed that in this case the tube operates on the lower curved portion of the characteristic curve introducing distortion.

Another type of distortion is shown in **Figure** 1-C; here the tube is operated with insufficient grid bias resulting in the grid going positive on the positive half of the grid excitation cycle with accompanying distortions.

Too high signal input voltage can also introduce distortion as shown in Figure 1-D. The operation of a tube is the same for a voltage amplifier as for a power amplifier when operating Class A, the only difference being the load in the plate circuit.

CLASS "B" AMPLIFIER. The Class B amplifier is defined as one so adjusted that the power output is proportioned to the square of the grid excitation voltage. This is accomplished by biasing the tube to

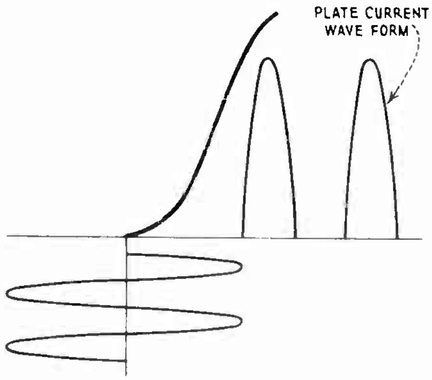


FIG. 2 - CLASS "B" AMPLIFIER CURVES

the cut-off point or nearly so. Plate current then flows only during the most positive half of the grid excitation cycle resulting in half-cycle loops of plate current, each loop representing one-half of the grid excitation cycle, see Fig. 2. During the remaining half of the grid voltage cycle no plate current flows. Since there is no flow of plate current, the plate of the tube is not called upon to dissipate energy. In other words, the tube actually works but one-half the time during the grid voltage cycle.

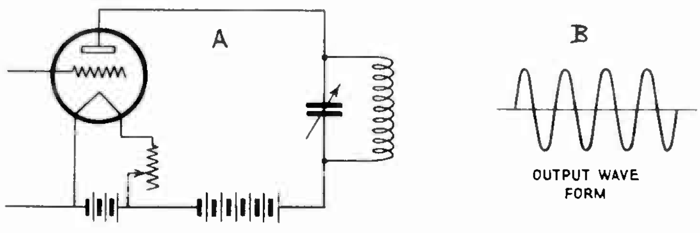


FIG. 3 - ACTION WHEN TUBE OUTPUT IS CONNECTED TO AN OSCILLATORY CIRCUIT

The operation of a tube under these conditions as an audio amplifier would be entirely out of the question as the condition shown in Figure 1-B would be accentuated since as an audio amplifier, the tube would have an aperiodic load in its plate circuit. The wave form of the current through the load would be the same as the tube plate current.

Consider now the circuit shown in Figure 3. The tube is connected in a circuit with an oscillatory circuit as the plate load. The half-wave pulsations of plate current will now be transformed into complete cycles or oscillations through the pendulum effect or fly wheel action of the oscillatory circuits, see Fig. 3-B. The amplitude of these oscillations will depend upon the amplitude of the plate circuit pulsations which in turn depend upon the value of the grid input voltage. It can, therefore, be said that the amplitude of the oscillatory current is proportional to the value of grid input voltage and since doubling the grid voltage would result in twice as much tank current the power output would be quadrupled (I^2R); hence, the definition previously given for the Class B amplifier. The power output of a tube working under Class B conditions is many times that of its Class A rating.

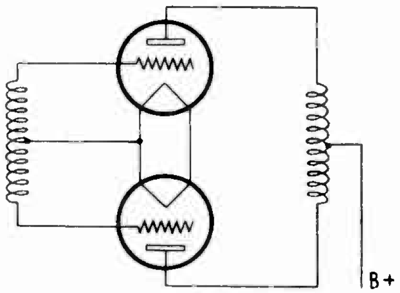


FIG. 4 - TWO TUBES WORKING AS CLASS "B" AMPLIFIERS

Thus far the Class B amplifier has only been considered from the standpoint of a radio-frequency amplifier. It is not restricted to this one use, however, since by special circuits it can also be used as an audio-frequency amplifier.

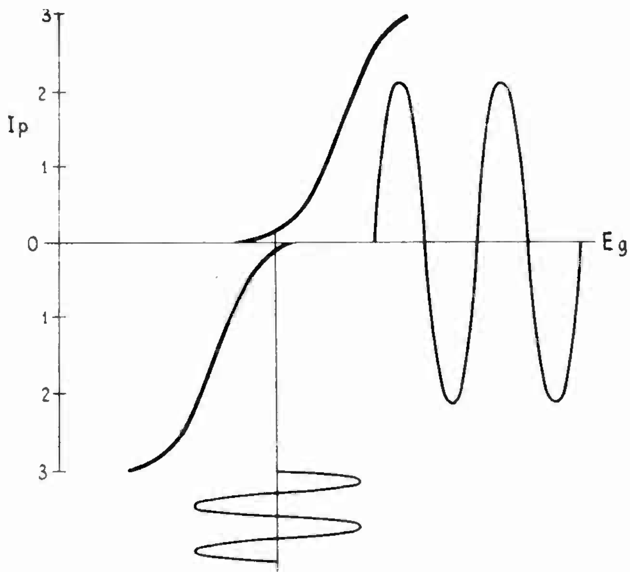


FIG. 5 - CHARACTERISTIC CURVES FOR TWO TUBES IN FIG. 4

Reference to Figure 2 shows that in a Class B amplifier plate current flows during one-half of the grid excitation cycle in the single ended (single tube) amplifier circuit. If a second tube be added and the circuit made as in Fig. 4, the characteristic curves for the two tubes will be as shown in Fig. 5. The curve for tube B is drawn bottom side up since it works on the opposite half of the grid excitation to that of tube A. The double ended Class B amplifier circuit utilizes the complete wave or both halves of the grid excitation cycle; this results in a plate output wave whose shape is a replica of the grid input wave. It should also be noted that the curves at the lower knee bend of the characteristics are opposite to each other and tend to give the effect of a straight line. This fact greatly aids in improving the wave shape in the output circuit. By connecting the two characteristics by a straight line one may think of a double ended Class B amplifier, as a single tube amplifier, Class A, whose characteristic is equal to the combined characteristics of the two tubes working Class B. Such circuits are gaining popularity, as audio output circuits in broadcast receivers, and are in general use to amplify radio-frequency signals after modulation in larger broadcast transmitters. One of the latest types of broadcast transmitters uses a Class B transformer-coupled plate modulator. The double ended Class B amplifier should not be confused with the more common push-pull amplifier. In the latter each tube is biased to work Class A and as the plate current increases in one tube a proportionate decrease takes place in the other and vice-versa; while in the Class B double ended circuit as the plate current increases in one tube no plate current flows in the other. It should also be noted that there is no plate current in either tube when no signal is applied to the grid. This also is contrary to the action of the Class A push-pull amplifier in which an equal amount of plate current flows in each plate circuit when no signal is being received. The efficiency of the Class B amplifier is 30 to 60 percent.

CLASS "C" AMPLIFIER. The Class C amplifier is a vacuum tube amplifier circuit so adjusted that the power output varies as the square of the applied plate voltage.

In order to accomplish this result in practical operation there usually is a biasing voltage applied equal to twice the value required to bring the plate current to the cut-off point.

A sufficient amplitude of grid excitation voltage is then applied to more than drive the plate current to saturation. Such operation gives loops of plate current during the most positive part of the grid excitation cycle.

An efficiency on the order of 60 to 80 percent is obtained under such conditions. Vacuum tubes are operated in this manner when used as oscillators and modulated amplifiers when plate modulation is employed as the output amplifier in radio telegraph equipments.

In Figure 6 is shown an $E_g I_p$ characteristic with a bias equal to twice the cut-off value. From this figure it will be seen that the grid excitation voltage will have reached a certain amplitude on the positive half of the cycle before plate current starts to flow. It is, therefore, evident that this plate current flow exists for less than one-half cycle. The period then during which no plate current exists is greater than one-half cycle. Because of this long period during which the plate is not called upon to dissipate energy it is possible to operate the tube at much higher efficiencies than obtainable with any other type of amplifier.

It is, of course, impossible to utilize such an amplifier for audio-frequency work. When this type of amplifier is used as the modulated amplifier in radio telephone sets, it acts in much the same manner as a pure resistance.

For this use it is customary to vary the plate voltage, the tube responding by increasing or decreasing its plate current in direct proportion to the change in plate voltage. If the plate voltage is doubled the plate current doubles and since, in a resistance the power increases as the square of the current, there will be four

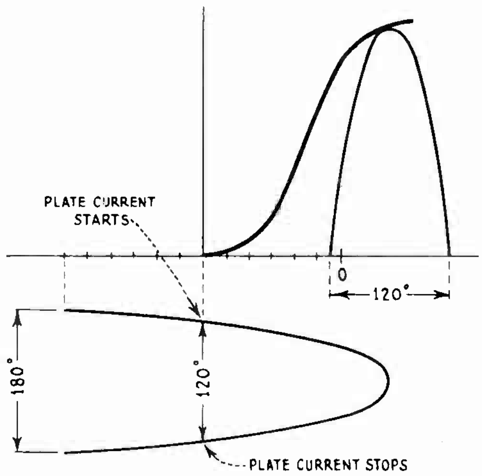


FIG. 6 - CURVES DEPICTING CLASS "C" AMPLIFIERS

times as much power or, in other words, in this type of amplifier the power output varies as the square of the applied plate voltage.

Although the alternating component of plate current may show a comparatively wide departure from sine wave form in such an amplifier, the output voltage will be practically sinusoidal.

HOW VACUUM TUBES USED IN POWER CIRCUITS ARE RATED

The power rating of vacuum tubes used in transmitting equipment is computed by the output energy of the device rather than by the input energy. A considerable part of the power delivered to the plate of a transmitting tube is wasted in heat. Transmitting tubes are used in the capacity of either an oscillator, amplifier, or modulator. A modulator tube is so named because of the specific duty which it is intended to perform, but nevertheless, it is a tube actually working with an amplifier characteristic. Hence, we can consider that transmitting tubes are divided into two general classes according to their function in a circuit; namely, "oscillator" and "amplifier." It should be noted that any type of tube may be used for either of these functions.

The power required to energize the plate of an amplifier or oscillator tube may be furnished by either a "B" battery, a direct-current generator or rectified a.c. depending upon the particular transmitting equipment. To those who study this work it is known that a vacuum tube associated with a circuit containing a suitable amount of inductance and capacity and designed to provide a feed-back of energy from the plate to grid circuits through either magnetic or capacitive coupling will be capable of generating self-sustained oscillations at a predetermined frequency. The tube used in a feed-back circuit is always known as an oscillator. The oscillations are known as continuous oscillations because they are consistent in frequency and their amplitudes are uniform in strength; such energy may be said to have a smooth-topped alternating current wave-form. It is readily seen that a line drawn through all of the amplitude peaks would be a straight line.

From the study of vacuum tube theory we learn how any voltage variation impressed upon the grid of a tube would be reflected in the plate current. Now, in a properly designed oscillator system when a radio-frequency voltage is applied to the grid the plate current continues to rise and fall in strength and, due to the feed-back action, the amplitudes of these plate changes cause further variations in grid voltage which result in corresponding variations in plate current, and so on. A slight change in plate current, as for example when a vacuum tube circuit is first placed in operation, should prove sufficient to set up the initial voltage impulse on the grid to start oscillations. In other words an oscillating current will be maintained so long as the feed-back power supplies grid voltage variations of sufficient amplitude to vary the plate current within limits which will again provide sufficient voltage in the grid circuit for grid excitation. Then in order to generate self-oscillations the amount of plate energy fed back to the grid must be more than that required to supply the losses in the grid circuit.

The point which we desire to set forth is that in any oscillating system there is always a certain amount of plate power dissipated in heat and also loss of power due to the setting up of a current flow in the grid circuit. This means that the actual power which a certain oscillator tube is capable of delivering, called its "output power", must be less than the power input of the plate. We could state this in another way by saying that a certain amount of energy is lost in any oscillatory system through the conversion of direct-current power into alternating-current power.

We must then have some means for determining the efficiency of a vacuum tube oscillator or power amplifier. The measure of the "efficiency" of our power tubes is merely a comparison between the actual power input in watts and the actual power output in watts and the expression of this value in percentage. It is well known that the efficiency of any device in percent is equal to the output divided by the input multiplied by 100. Efficiency expressed in terms of power (watts) may be written in the following way:

$$\frac{\text{WATTS OUTPUT}}{\text{WATTS INPUT}} \times 100 = \text{EFFICIENCY IN \%}$$

In Figure 7 we have the diagram of a vacuum tube radio-frequency oscillator circuit which can be used for transmitting purposes by coupling it to an antenna system in the manner shown. Other methods for keying a circuit of this kind than the one illustrated may be employed for telegraphy; for instance, keying may be accomplished by changing the grid bias from a high- to a low-operating bias. This is done to reduce the key clicks or thumps to a minimum, for when such sounds are reproduced they greatly interfere with the reception of the message. Our aim is merely to show one type of oscillatory circuit in which the plate circuit is directly coupled to the upper end

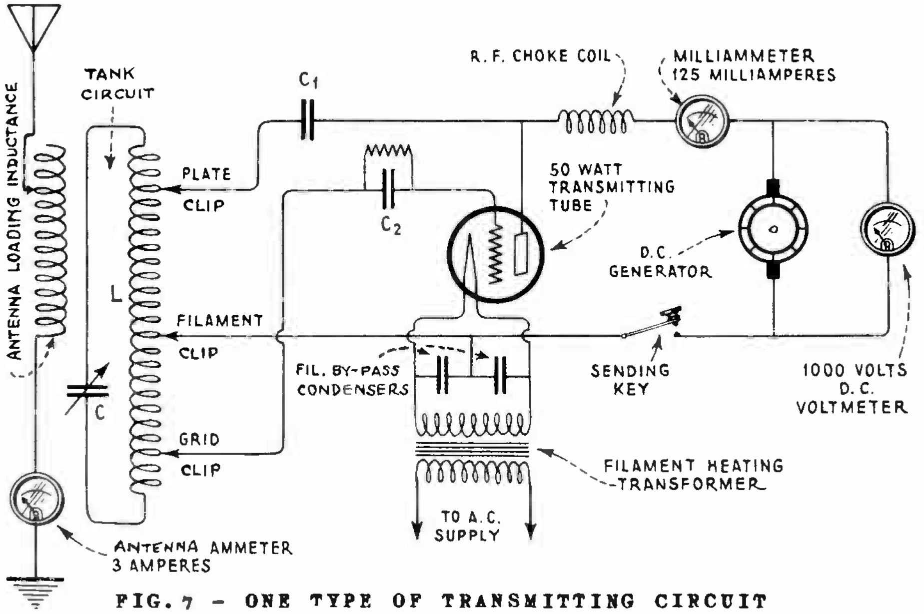


FIG. 7 - ONE TYPE OF TRANSMITTING CIRCUIT

of the oscillatory inductance L by a fixed condenser marked C1, whereas the grid is coupled directly to the lower end of L by the condenser marked C2. Although the frequency of the generated oscillations may be varied by adjusting condenser marked C, the frequency is dependent upon the combined values of L and C. Another

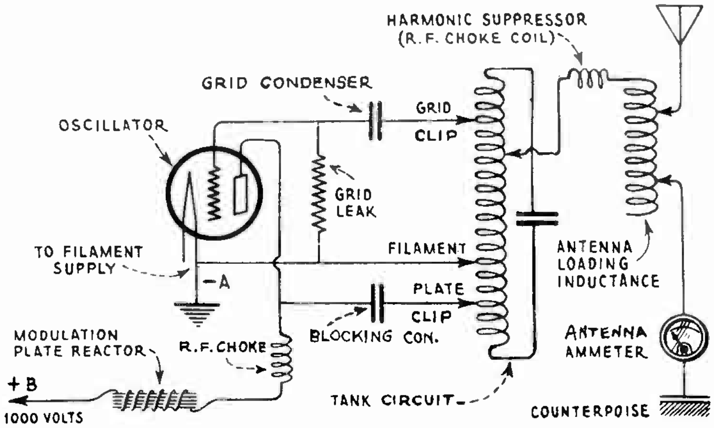


FIG. 8 - ANOTHER METHOD OF COUPLING THE OSCILLATOR OUTPUT TO AN ANTENNA

type of oscillatory circuit and vacuum tube driving an antenna system is shown in Figure 8, this circuit being part of a broadcasting transmitter. These simple circuits are given merely to suggest conventional types to assist in an understanding of the following explanation concerning efficiency and power rating of a power tube. Let us suppose that the power tube in either diagram is rated at

50 watts and, according to the electrical data chart of the manufacturer, the tube draws 125 milliamperes of plate current when the plate is operated with a positive potential of 1000 volts d.c. Then, the power in watts (W) in the plate circuit is equal to the voltage (E) times the current (I), or

$$W = E \times I$$

Note: 125 milliamperes = .125 amperes.

Then W = 1000 x .125; or WATTS INPUT = 125.

It is a simple matter to calculate the watts input. However, to compute the possible power output of this tube working into an antenna system, we find it necessary in our study to assign two arbitrary values; one for the amount of antenna current (I) which would ordinarily be indicated on the antenna ammeter, and the second for the resistance (R) of the antenna circuit. The output power in watts is conveniently expressed as follows:

$$\text{WATTS OUTPUT} = (\text{ANTENNA CURRENT})^2 \times (\text{RESISTANCE OF ANTENNA})$$

or, using the symbols: $\text{WATTS OUTPUT} = I^2 \times R$

Suppose the resistance of the antenna is known to be 10 ohms from previous experimentation, and the current as read on the antenna ammeter is 3 amperes while the 50 watt tube is active and delivering power in the form of an r-f (oscillating) current for antenna excitation. Then substituting these numerical values for the symbols I and E in the formula, we have:

$$\text{WATTS OUTPUT} = (3)^2 \times 10 = 9 \times 10; \text{or WATTS OUTPUT} = 90.$$

Setting down the output and input values in the efficiency formula and solving, we can conclude that the efficiency of this tube is equal to:

$$\frac{\text{WATTS OUTPUT}}{\text{WATTS INPUT}} \times 100 = \frac{90}{125} \times 100 = .72 \times 100 = 72\%$$

It is obvious that the actual power output of the tube itself cannot equal the power input of the plate circuit for reasons already cited. The power lost is equal to the difference between the watts input and the watts output or, in this case, the power lost is equal to 125 minus 90, or 35 watts.

The amount allowed for plate power dissipated in heat, etc., is known as "plate dissipation". This amount should not be exceeded during the normal operation of a tube and a definite limit is set, called the "safe plate dissipation". Since safe plate dissipation is really the power lost it is rated in watts. All power tube characteristics charts list the "safe plate dissipation" in watts for the various types of tubes, and it should now be understood what is meant by this term.

The 50 watt tube in our explanation has a safe-plate dissipation of 100 watts. Thus, at 35 watts dissipation, it is being operated within safe limits. Any power tube worked at such a low efficiency as to permit the plate dissipation to exceed the safe limit would be subjected to considerable abuse and in a very short time its ability to supply electronic emission would cease, hence there is only one conclusion or result, the tube's useful life would be shortened.

The interior of the glass envelope of a power tube often takes on a milky white appearance, which condition may be attributed to operating the plate for long periods at an excessively high temperature. This smoky white color indicates that certain gases have been freed from the metal plate. A plate should never be heated to show more than a cherry red.

The heat energy dissipated by the plate of large power tubes, in the one kilowatt class and upward, is normally so high that water cooling is resorted to in order to obtain a satisfactory output of power. Water cooling increases the efficiency of a power tube because it permits the use of a much smaller plate area than would otherwise be possible. A smaller plate reduces the space charge between the electrodes of the tube. It should be noted that although current is required to heat the filament, that is, energy in watts is consumed, yet it is not taken into consideration in the foregoing work on power rating.

GRID CURRENT AND GRID BIAS

Let us now recount a few facts regarding the grid circuit and the current drawn therein. Only a small grid current should be permitted to flow, and let it be remembered that any current in excess of a certain amount cannot serve any useful purpose. In fact, excessive grid current must be subtracted from the current that would otherwise flow in the plate circuit inasmuch as both the grid and plate currents originate from electrons ejected by the hot filament. Thus it is possible for the grid to consume energy which is a total waste by the excessive flow of grid current. Under such conditions the grid acts as a load on the vacuum tube resulting in a reduction of its output power. Furthermore, a large grid current will introduce distortion in any vacuum tube. Distortion is particularly noticeable in tubes used in transmitting and receiving circuits which handle speech and musical frequencies, as in broadcasting. A large grid current would most likely heat the grid causing it to emit electrons, and if this condition were allowed to occur the grid would cease to be an efficient controlling factor in providing the proper variations in plate current. Bear in mind that the electrons absorbed by the grid flow as conduction current; that is, a direct current through the wires, coils, or resistors contained in the outside circuit connected between grid and filament.

From the foregoing it should be clear why a grid must be operated at some definite negative potential maintained upon it at all times. What really happens when a high fixed negative voltage is applied to the grid is that the grid is prevented from actually becoming positive even at such moments as when a positive voltage is applied to it from the currents circulating in the grid circuit. This is readily explained, for the actual voltage upon the grid at any moment is merely the difference between the value of the negative bias and the amplitude values of the fluctuating voltages delivered to the grid from the grid circuit as just mentioned.

Accordingly, the flow of grid current must be controlled and this is easily accomplished by maintaining a permanent negative voltage upon it as already suggested. The value of this negative voltage or grid bias varies for different types of tubes and depends for one thing upon the amount of plate voltage used. The correct grid bias may be supplied by any one of the following methods:

(1) The bias may be obtained from a "C" battery inserted in the grid return lead.

(2) The grid return wire may be attached to some location on a resistor which supplies the necessary drop in potential when the current flows through the resistor.

(3) The voltage drop obtained across a resistor inserted in the negative lead of the high voltage plate supply may be utilized for this purpose.

(4) A small d-c generator especially built for this purpose is often used to give the requisite bias. The majority of transmitters in radio broadcast work employ either one of the first two methods, whereas commercial telegraph transmitters are more likely to employ one of the latter two methods.

With no negative bias on the grid of a power tube the plate current can run up to exceedingly high values, dissipating so much heat that the plate will become whitehot and cause serious damage to the tube.

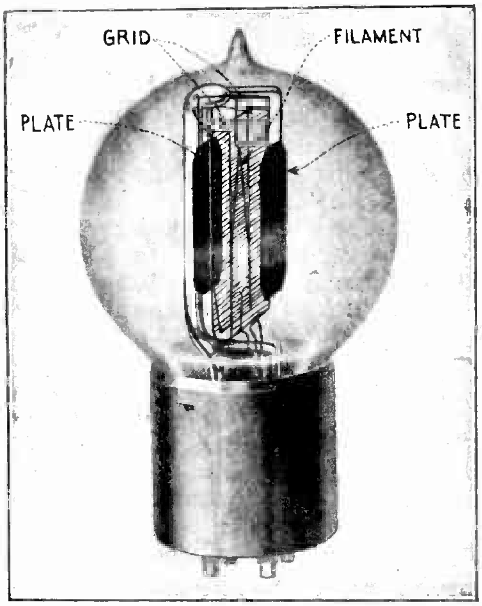


FIG. 9 - WESTERN ELECTRIC TYPE 205-D

<u>7.5 WATT TUBES:</u> { RCA-210, UX-841, UX-842, RCA-843, RCA-844 and RCA-865; WE-205-D and WE-271-A, DeFOREST TYPES 510 and 565.

The 7.5 watt tube is the smallest with a power rating. RCA-210 is particularly suited for transmitting circuits where cost and bulk of the apparatus and power supply are prime considerations. The RCA-210 tube is designed for use as an oscillator, modulator or power amplifier in transmitting equipment. The 7.5 watt tube is used in a large majority of amateur short-wave stations. It is known that under favorable conditions these tubes often supply sufficient antenna excitation to permit messages, carried by the radio waves, to be copied at the opposite ends of the world. These small tubes

are also adaptable for use in low powered aeroplane transmitters and for speech amplifiers in broadcasting equipment. When working as a speech amplifier the tube merely functions to step up the necessarily feeble voice and musical frequencies in the output of the microphone to large values before introducing these frequencies into the main modulator-oscillator circuits. The object of amplifying the voice currents is to provide the maximum degree of modulation.

The Western Electric 205-D has similar characteristics except that a lower filament voltage is required. An outline of the 205-D is shown in Figure 9.

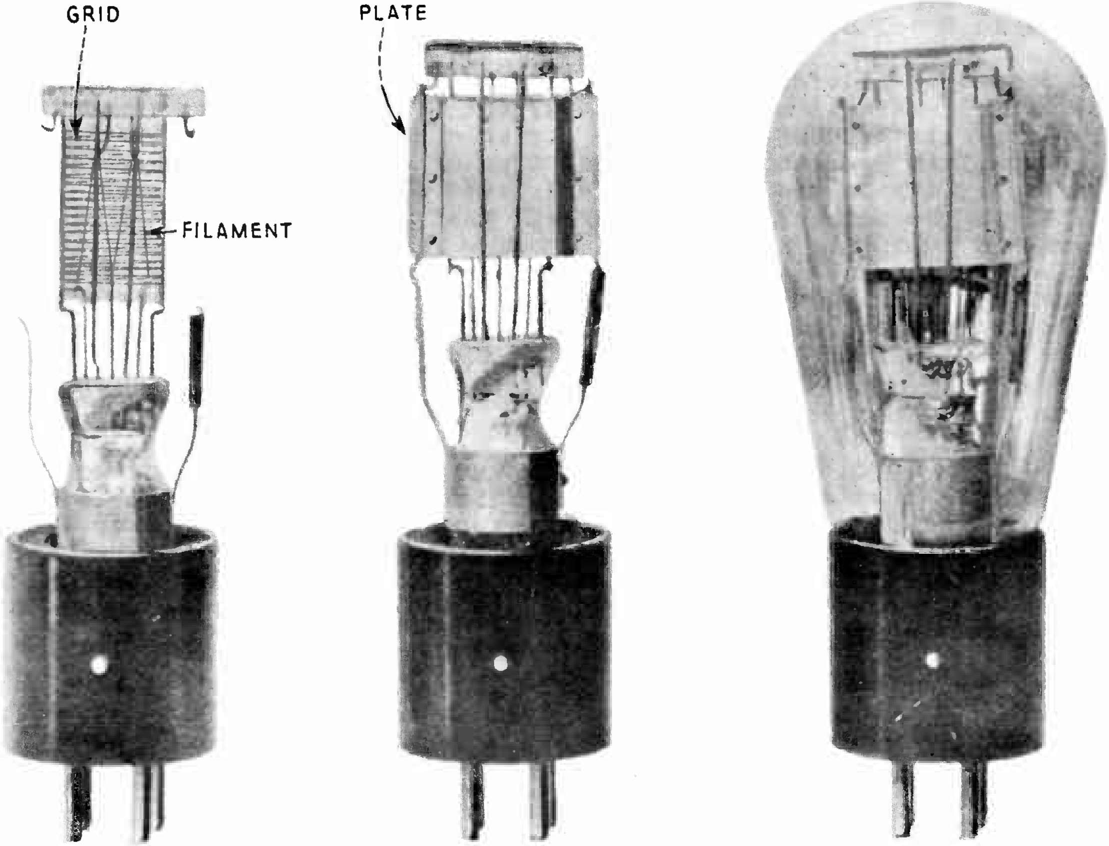


FIG. 10 - SHOWING GRID, PLATE AND FILAMENT OF UX-210 TUBE

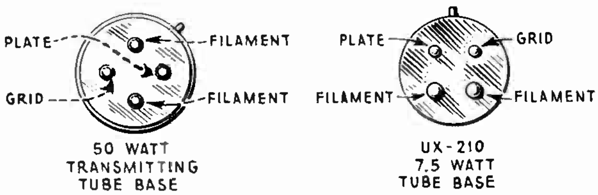


FIG. 11 - IDENTIFICATION OF PRONGS ON TUBE BASES

The views in Figure 10 show the complete tube assembly of the 210, also the grid, filament and plate construction. A sketch in Figure 11, looking at the bottom of the tube base, shows the location of the prongs. The metal shell of the socket must not be connected to ground or any other part of the circuit.

The normal output power of the RCA-210 is rated at 7.5 watts. The filament draws 1.25 amperes when operated at a filament terminal e.m.f. of 7.5 volts. Care should be exercised to operate filaments at constant voltage rather than constant current and always at the rated voltage. A filament voltmeter connected directly to the socket terminals should be used to indicate correct working con - ditions. It will be noticed that, due to the use of the X-L filament, its brilliancy is much less than that of the older type tungsten filament. A low emission tube caused by a severe overload and consequent overheating may be restored in some cases by operating the filament at its rated voltage with the plate voltage removed. This reactivation process can be accelerated by increasing the filament voltage to 9 volts, but not to exceed this value.

When possible, alternating current should be used to heat the filament, but in certain cases direct current is required, as in radio telephone sets(because of hum)and portable sets for portability of power supply. By using the RCA-843 type of tube, however, a-c filament supply may be used and hum level kept at a very low value. The RCA-843 is the same as a UX-210 except that it has a heater type of cathode requiring 2.5 amperes at 2.5 volts for its operation. The a.c. is, in most all cases, supplied through a step-down transformer and to provide voltage control a rheostat should be included in the primary circuit of the transformer. With a.c. the plate return lead should be connected to the mid-tap of the transformer secondary, whereas with the use of d.c. this plate lead is attached to the positive filament terminal.

Under normal conditions the plate voltage should never be more than 350 volts, the rated value, and with this plate e.m.f. a plate current of 50 or 60 milliamperes may be expected. The plate power dissipation should never be greater than 15 watts. When this tube is used in a non-modulated c.w. telegraph set (usually called straight c.w.) the plate voltage may be raised to 450 volts in order to obtain extreme output.

The amplification constant of the RCA-210 is approximately 7.5 and the mutual conductance value about 2,150 micromhos. Should a tube be required, however, having a higher amplification constant, but retaining the other essential characteristics of the RCA-210, a type UX-841 may be employed which has an amplification constant of 30 and a mutual conductance of 450 to 750 micromhos depending on plate voltage used. This tube is of especial value as a voltage amplifier utilizing resistance coupling and also as a frequency doubler. Let us mention at this time that mutual conductance values are useful for comparison purposes only since the values are computed with the tube operating under zero grid voltage conditions. This does not represent the usual operating condition for we know that in all practical circuits the grid voltage is maintained at some definite negative value and not at zero.

When used as an audio power amplifier or a modulator the value of the negative bias used should be sufficient to limit the plate dissipation, that is, the difference between output and input, to its normal value or 15 watts. For this service, however, it is desirable to use a tube having a lower amplification constant and a higher power output than the RCA-210. It is here that the UX-842 finds a place. This tube has an amplification constant of 3 and an output as a Class A amplifier of 3 watts. While the RCA-210 has an output Class A rating of only 1.6 watts, the UX-842 otherwise has the same operating characteristics as the RCA-210. No less than 15 volts negative should be applied to the grid of the RCA-210 tube with a plate potential of 350 volts. When calibrating a transmitting circuit it will be noticed that with certain adjustments the plate current is greater than the normal amount although the correct grid bias voltage is used. This effect may be traced to an amplifier tube which is oscillating or perhaps a radio-frequency voltage is being picked up from neighboring circuits. This condition is aggravated by the use of a grid leak having an inductive effect in the circuit. A grid leak should be non-inductive, or in other words, its effect should be that of only pure resistance.

It is advisable to insert either a small choke, or a resistance of 10 to 100 ohms, in the grid circuit of each tube when several are operated in multiple in order to prevent the setting up of ultra high-frequency oscillations.

We mentioned previously that the UX-842 is particularly suited for use in conjunction with loudspeakers in receiving circuits. When the 210 is employed in this connection the tube is called a "power audio amplifier" and is capable of delivering a tremendous output without distortion. The characteristic grid voltage-plate current curve of this tube is shown in Figure 12. The so-called "straight part" of this curve indicates that the tube is a typical amplifier, for it is easily seen that the slope of the curve follows almost a straight or linear line.

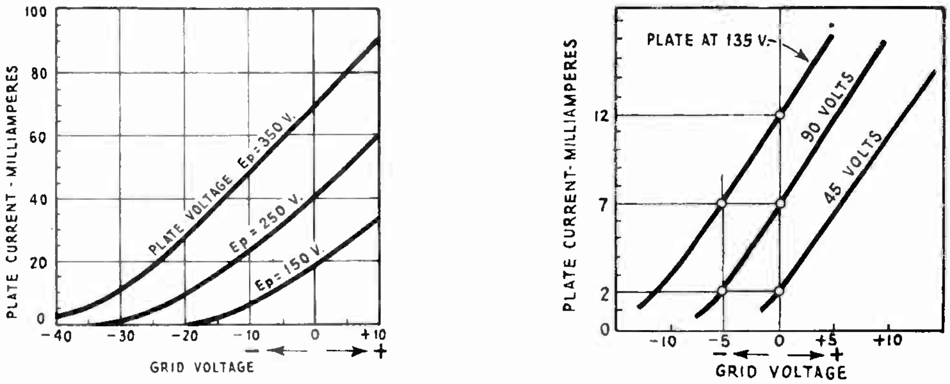


FIG. 12 - CHARACTERISTIC CURVES OF A UX-210

It should be remembered that an efficient amplifier tube provides a greatly enlarged plate current whose pulsations follow in exact accordance and repeat the wave form or modulation frequency of the signal voltages impressed upon the grid. Also, you should fully understand at this part in our course that the only function which the grid is called upon to perform is that of a control member. Any fluctuating voltage, however small, applied to it from any source will cause the electron stream passing from filament to plate (i.e., the plate current) to undergo a corresponding variation. Stated in a few words, this means amplification without distortion. Because of this inherent grid control upon the electron stream we think of the vacuum tube as essentially a voltage operated device.

The straight line variation, as shown by the curves, indicates that the UX-210 can be worked at high or low plate voltages and, with correct grid bias, will deliver the voice and musical frequencies to the loudspeaker with the naturalness of the original rendition in the broadcasting studio. Undistorted amplification is possible in vacuum tubes possessing such characteristics because large grid voltage swings can be delivered to the grid without it actually becoming positive with respect to the filament. A positive grid would attract excessive electron energy causing a large grid current and as we are already aware this undesirable condition would introduce distortion. The grid return lead of the UX-842 when used as an output audio amplifier should be connected to the negative terminal of the "C" battery. The positive terminal post of the "C" battery should be connected to the negative terminal of the filament.

As mentioned heretofore, low power tubes are used extensively in shortwave transmitters. Conservative plate voltages and power inputs should always be maintained in order to be certain that the tube will not be harmed by excessive voltages, currents, or dissipation within the tube. Abnormal conditions are usually experienced at wavelengths less than 50 meters.

The inter-electrode capacity between grid and plate of the tube provides a path of low reactance for currents of high-frequency, or at the short wavelengths. These currents have damaging effects. At long wavelengths, or low frequencies, the capacity reactances are so high that these currents are negligible. For wavelength adjustments below 10 meters great care should be exercised to prevent brush discharges in any part of the tube which are likely to cause breakdown and puncture of the tube. In order to prevent trouble of this kind it is a good rule to reduce plate voltage as the wavelength is reduced. Difficulties in operation of the 3-element 7.5 watt tube on the shorter wavelengths can be easily overcome, however, by the use of 4-element tubes RCA-844 and RCA-865. The difference between these two being that the 844 is provided with a cathode-heater type of filament.

The RCA-865 tube is especially designed for use as a power amplifier in transmitting circuits of the high radio-frequency or short-wave type. The high-frequency transmitters send out continuous wave (c.w.) telegraph signals which cover wavelength ranges as low as 15 to 50 meters, or 20,000 to 6,000 kilocycles. This frequency band may also be expressed as from 20 to 6 megacycles. One megacycle is equal to one million cycles.

This 7.5 watt tube has a plate, filament and two grids, whereas the standard three-element tube has a plate, filament and only one grid. The addition of the extra grid, called the screen or shield grid, minimizes the effects of inter-electrode capacity, that is, it prevents the so-called feed-back from plate to grid. This stabilizes the circuit in which the tube is used. Whistles, howls and other desirable effects are eliminated by the addition of the fourth element.

The theory of operation is that the control grid (the regular grid located adjacent to the filament which is found in all standard tubes) is impressed with the excitation voltages in the manner similar to that for operating any tube, but the screen grid is maintained at a neutral potential with respect to the other electrodes by suitable connection to a source of e.m.f.

The voltage for the screen grid may be obtained either from a potentiometer connected across the plate supply, from the d-c plate supply through a series resistance of approximately 25,000 ohms, or from a separate d-c source. The resistance method, using about 25,000 ohms is the most practical method for maintaining the screen grid voltage at proper value because it provides automatic regulation. When employing the resistance method, the filament supply should not be discontinued for any reason while the plate voltage is on, for this would cause the full plate voltage to be applied to the screen. When the potentiometer method, or separate source method is used the screen grid voltage should not be applied when the plate voltage is off. Under operating conditions the screen grid should never be permitted to reach a temperature which would cause it to show a color more than that of cherry red. When the screen grid is supplied with a suitable positive voltage it acts as an electrostatic screen between the control grid and the plate of the tube. The normal screen grid volts for this tube when operating either as an oscillator or r-f power amplifier is 125 volts. The need for neutralizing the radio-frequency circuits is eliminated by the use of this tube as we have just stated. A photograph of the UX-865 is shown in Figure 13. The UX-865 requires 2 amperes at 7.5 volts for the filament and 500 volts d.c. for the plate. This tube may be employed as a frequency "doubler" and intermediate power amplifier in short-wave commercial transmitters. When used for this purpose the tube's output is fed into a main power amplifier circuit which may also use tubes of the four-element type, but having a greater output power. Tubes especially designed for handling large power at high frequencies are the UV-850, UV-852, UV-860, and UV-861.

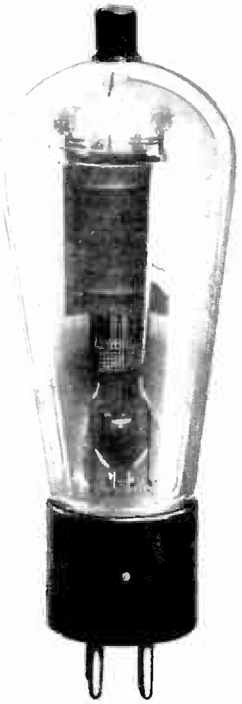


FIG. 13 TYPE UX-865

EXAMINATION QUESTIONS

1. Name as many factors as possible which govern the amount of current drawn in the plate circuit of a vacuum tube.
2. What is meant by "safe plate dissipation"?
3. (a) How is a power tube rated?
   (b) Write the formula for efficiency in terms of watts.
   (c) Suppose the output of a tube is 69 watts and the input 115 watts. Find the efficiency of this tube in percent.
4. What material is generally used for filament wire in power tubes?
5. (a) State as many reasons as you can that make the reactivation of a tube necessary.
   (b) In general, what method of procedure would you conform to in order to reactivate a tube?
6. (a) Why should amount of grid current in a power tube be controlled?
   (b) State several ways how this may be accomplished.
7. (a) How are ultra-high frequencies suppressed in coupled circuits consisting of two or more power tubes?
   (b) Of what practical importance is the four-element tube?
   (c) What is the fourth element and in a general way what is its effect within the tube?
8. Define class A, class B and class C amplifiers.
9. Why cannot single tube class B amplifiers be used in a-f amplification?
10. What is the advantage of screen-grid tubes?

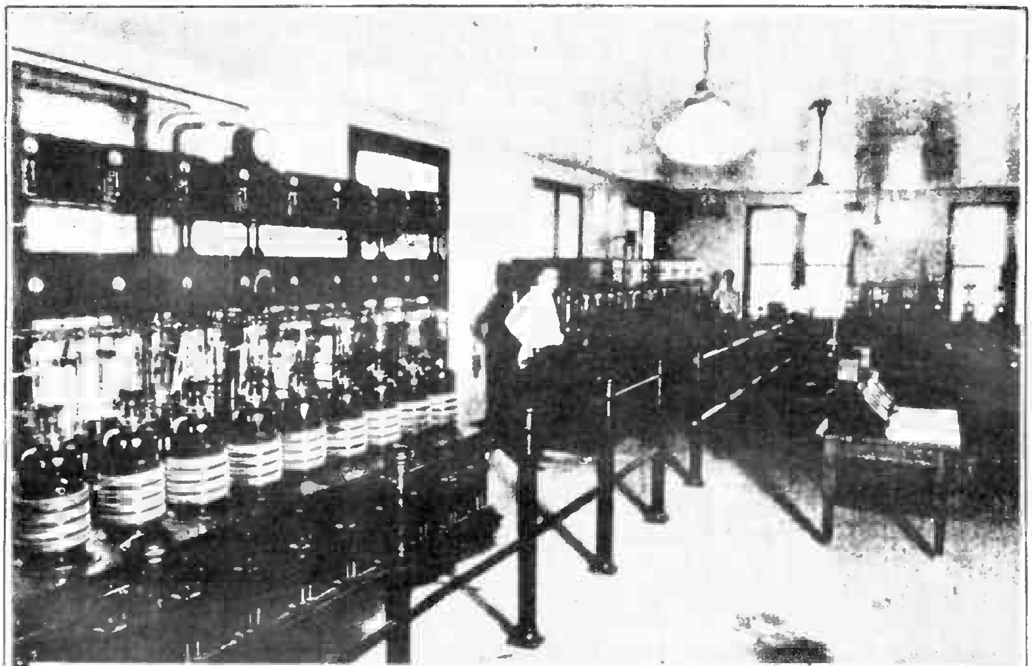
TRANSMITTING VACUUM TUBE CHARACTERISTIC CHART

GENERAL INFORMATION										CLASS "A" AMPLIFIER OR MODULATOR							
Type	Filament Volts	Filament Amperes	No. of Electrodes	Average Voltage Amplification Factor	Average Plate Resistance Ohms	Average Mutual Conductance M. Mhos.	Type of Base	Type of Filament	Type of Cooling	Maximum Plate Volts	Maximum Plate Watt Dissipation	Grid Bias (Eg) Negative Volts	Plate Milliamperes	Oscillator Input Watts per Mod. Tube	Peak Grid Swing - Volts	Power Output 5% 2nd Harmonic	Load Resistance
RCA 210	7.5	1.25	3	8	5150	1550	UX	XL	Air	425	12	35	18.0	4	31	1.6	10200
RCA 841	7.5	1.25	3	30	40000	750	UX	XL	Air	425	12	9	2.2		9	(225) (volts)	250000
RCA 842	7.5	1.25	3		2500	1200	UX	XL	Air	425	12	100	28.0	8	96	3.0	8000
RCA 843	2.5	2.5	3		5150	1550	UY	Cathode Heater	Air	425	12	35	18.0	4	31	3.0	10200
RCA 844	2.5	2.5	4	74	125000	600	UY	Cathode Heater	Air								
RCA 865	7.5	2.0	4	150	200000	750		XL	Air								
WE 205D	4 to 5	1.60	3	200 to 300	3000 to 4500		100-M or 115-B		Air	300		10 to 20	15 to 30				
WE 205E	4 to 5	1.60	3	200 to 300	3000 to 4500		100-M or 115-B		Air	350		10 to 30	15 to 30				
WE 271A	5.0	2.0	3	8.5	2850		134-A or 137-A	Cathode Heater	Air	400		25 to 30	39.0				
WE 252A	5.0	2.0	3	5.0	1700		130-B or 131-A		Air	450		65	43.0				
RCA 203A	10.0	3.25	3	25.0	6000	4200		XL	Air								
RCA 211	10.0	3.25	3	12.0	3400	3530		XL	Air	1000	75	52	.072	40	52	10.0	7000
RCA 845	10.0	3.25	3	5.0	1800	3000		XL	Air	1000	75	147	0.075	122	147	23.0	7500
RCA 850	10.0	3.25	4	550	200000	1250		XL	Air								
RCA 852	10.0	3.25	3	12	10000	1200	UX	XL	Air								
RCA 860	10.0	3.25	4	200	180000	1100	UX	XL	Air								
WE 211D	10.0	3.0		11 to 13	3000 to 4000		112-A	Oxide Coated	Air	750 1000	to 100	50 to 60	.005				
WE 242A	10.0	3.25		12.5	3500		112-A	Oxide Coated	Air	1250	100	45	0.150				
WE 276A	10.0	3.0		12	3500		112-A	Oxide Coated	Air	1250	100	50	0.125				
WE 212D	14.0	6.003		15 to 17	2000		113-A	Oxide Coated	Air	2000		30 to 80	.130		55		
RCA 204A	11.0	3.85	3	25	6300	4000		XL									
WE 270A	10.0	9.75		16	1750	9000		Oxide Coated									
RCA 849	11.0	5.0	3	19	3200	6000		XL	Air	3000	300	104	0.110	410	98	81	12000
RCA 861	11.0	10.0	4	300	143000	2100	UX	XL	Air								
WE 251A	10.0	16.0		10.3	2250	4550		Oxide Coated									
RCA 851	11.0	15.5	3	20.0	1400	15000	UV	XL	Air	2000	600	65	0.300	400	60	100	3100
WE 279A	10.0	21.0		10.0	1800	5550	142-A	Oxide Coated	Air								
RCA 1652	14.5	52.0	3	14.0	3000	47000		Tungsten	Water								
RCA 207	22.0	52.0	3	20.0	3500	5700		Tungsten	Water								
RCA 848	22.0	52.0	3	8.0	2400	3300		Tungsten	Water	10000	7500	1040	0.65	7800	1025		
RCA 863	22.0	52.0	3	50.0	7200	7000		Tungsten	Water								
RCA 858	22.0	52.0	3	42.0	8700	4800		Tungsten	Water								
WE 232A	20.0	61.0		40.0	7000	5700	132-A or 133-A	Oxide Coated	Water								
RCA 862	33.0	207.0	3	43.0	2800	17150		Tungsten	Water								

TRANSMITTING VACUUM TUBE CHARACTERISTIC CHART

R-F POWER AMPLIFIER

Type	Max. Screen Dissi- pation	Maximum Operating Plate Voltages: Modulated D-C	Unmodulated D-C	A.C. (rms)	Maximum RF Grid Current (Amperes)	Typical Operation - Class B: E_p	E_c	E_d	Unmodulated DC Pl. Cur. (Amperes)	(Watts) Peak Output	(Watts) Carrier Output	Typical Operation Class C: E_p	E_c	Output
210		350	450	450	5.0	350	50		0.030	7.5	1.9	350	50	7.5
841		350	450	450	5.0	450	8		0.036	16.0	4.0	450	30	13.0
842		350	450	450	5.0							350	150	7.5
843			450		5.0	350			0.030	7.5	1.9			
844	3	500	500	500	5.0				0.020			500	7	5.0
865	3	500	500	500	5.0	500	40	125	0.030	7.5	1.9	125	80	7.5
205D		350	350	350		350			0.015 to 0.030	20.0		350		5.0
205E		350	350	350		350			0.015 to 0.030	20.0		400	110	5.0
271A		400	400	400		400	55		0.039			450	180	
252A		450	450	450		450	90		0.060					
203A		1000	1250	1000	7.5	1000	35		0.130	160.0	40.0	1000	100	100.0
211		1000	1250	1000	7.5	1000	35		0.130	160.0	40.0	1000	200	100.0
845		1000	1250	1000	7.5	1000						1000	250	75.0
850	10	1250	1000	1000	7.5	1000	8	175	0.100	120.0	30.0	1000	150	100.0
852		2000	3000	3000	10.0	2000	150		0.060	120.0	30.0	2000	250	100.0
860	10	2000	3000	3000	10.0	2000	50	300	0.060	120.0	30.0	2000	200	100.0
211D		1750	1000	1000								750		50.0
242A		1250	1250	1250		1000	80		0.150			1000	160	
276A		1250	1250	1250		100	80		0.125			100	160	
212D		1500	2000	2000		1500			0.130	250.0		1500		2000.0
204A		2000	2500	2000	10.0	2000	70		0.143	340.0	85.0	2000	175	350.0
270A		2500	3000	3000		2500	175		0.350	350.0	83.5	3000		350.0
849		2000	2500	2000	10.0	2000	200		0.260	650.0	165.0	2000	200	450.0
861	35	3000	3500		10.0	3000	60	500	0.250	600.0	150.0	3000	200	540.0
251A		2500	3000	3000		2500	260		0.600	1000.0		3000		1000.0
851		2000	2500	2000	10.0	2000	85		0.750	1200.0	300.0	2000	200	1250.0
279A		2500	3000	2500		3000	325		0.800	2000.0		3000		2000.0
1652		6000	75000		10.0	6000	450		0.600	4000.0	1000.0	6000	1200	4000.0
207		12000	15000			12 kv	600		0.900	14000.0	3500.0	12 kv	2200	15000.0
848												12 kv	2600	15000.0
863		12000	15000		30.0	12 kv	250		0.900	14000.0	3500.0	12 kv	2000	15000.0
858		16000	20000		60.0	18 kv	450		0.900	21600.0	5400.0	18 kv	3500	22000.0
232A			20000							35000.0				35000.0
862			20000		60.0	18 kv	380		4.200	100000.0	25000.0	18 kv	4000	100000.0



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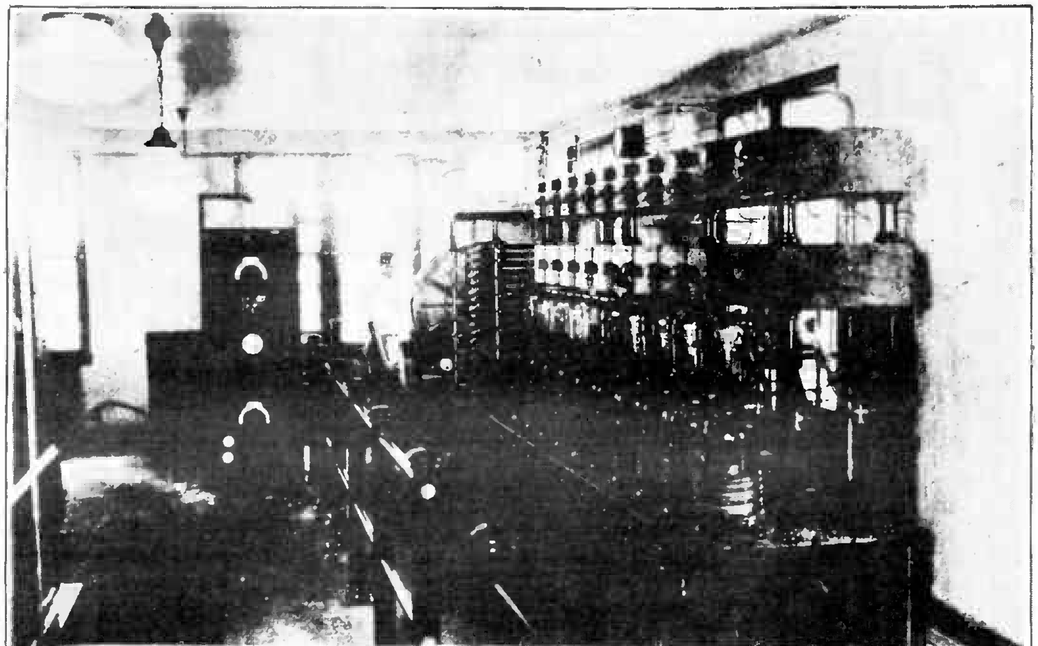

R-F POWER AMPLIFIER AND TUNING SYSTEM AT "OLD" WEAF.

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