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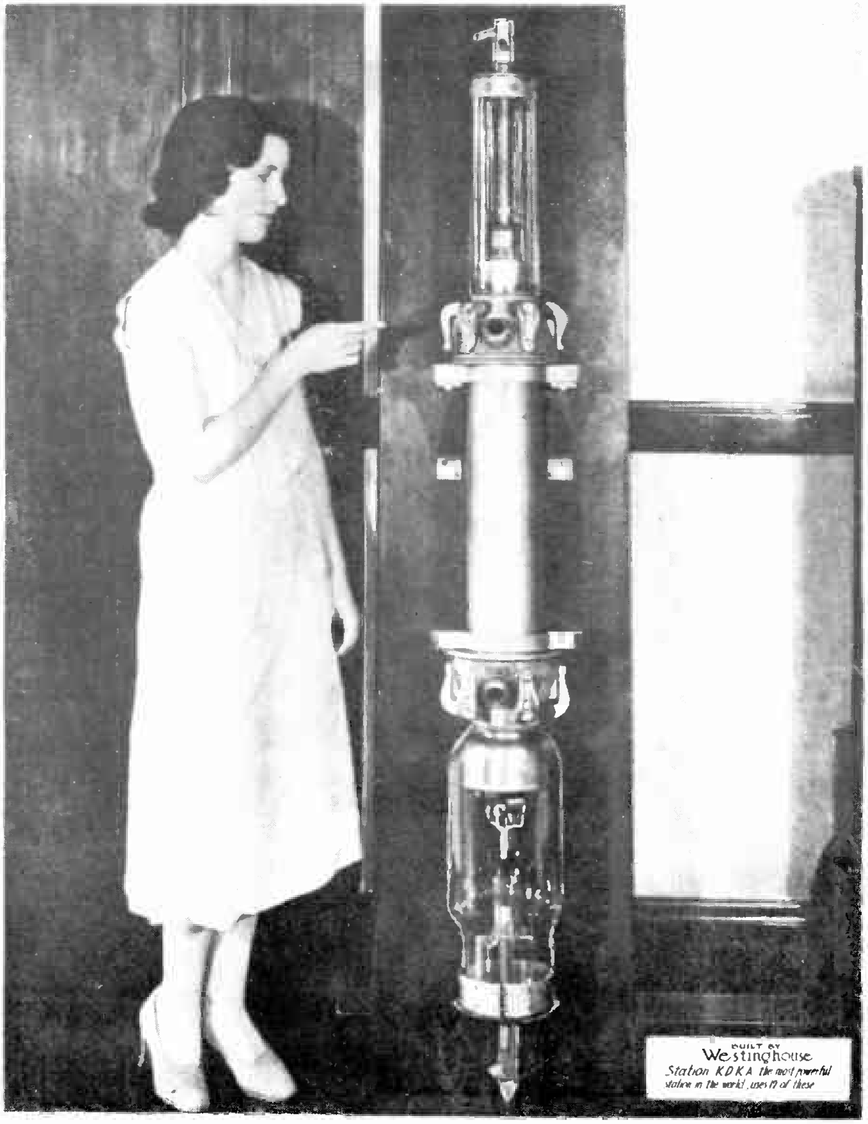

Air-Cooled and Water-Cooled Transmitting Tubes

Measuring Vacuum Tube Characteristics -

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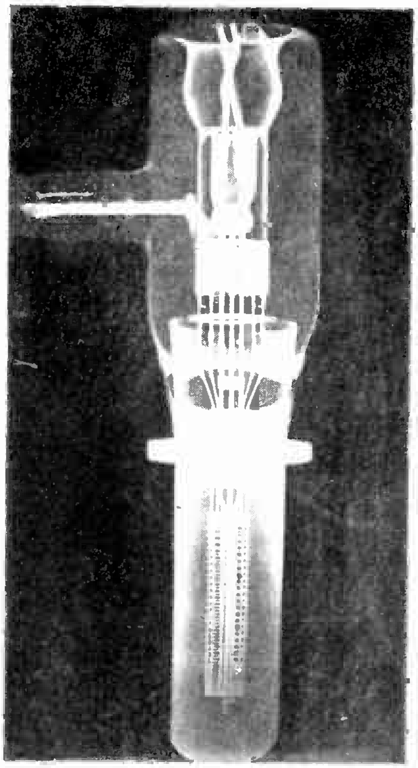

X-RAY PHOTOGRAPH OF A UV-858
WATER-COOLED TUBE

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AIR-COOLED AND WATER-COOLED TRANSMITTING TUBES
MEASURING VACUUM TUBE CHARACTERISTICS

In this lesson we review standard types of vacuum tubes used in transmitting equipment. Also, we give worked-out examples of the most frequently used constants by which the characteristics of vacuum tubes of the same type may be compared when operating under exactly similar conditions — these are amplification constant, plate impedance and mutual conductance.

100 WATT TUBES: TYPES UV-203-A, UV-211, 845, 850, 852, 860, WE-211-D, 242-A, and 276-A.

The 100 watt tube is manufactured in nine types which differ only in plate impedance and amplification constant or number of electrodes. A photograph of a 100 watt tube is shown in Figure 1 All types are operated at similar filament voltages.

The UV-203-A is intended for amateur and experimental use where voltage amplification is desired. The UV-211 is used extensively in commercial transmitting circuits for oscillators, amplifiers, or modulators. The 845 is better adapted to audio frequency and modulator work than the above mentioned types. An inspection of the characteristic chart shows that the filaments of both tubes normally draw 3.25 amperes at 10 volts, the plate power dissipation being 100 watts when operating either tube as an oscillator at its normal plate potential of 1000 volts.

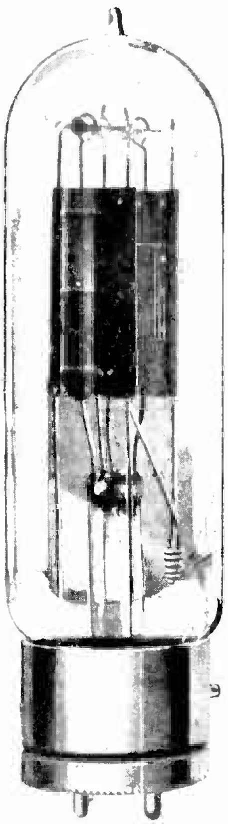


FIG. 1- 100-WATT TUBE

The UV-211 requires a very strong mechanical construction and rigid support of all the electrodes since it is used in many marine tube transmitters.

These transmitters must stand up under severe operating conditions at sea. The plate is mounted on four separate rods imbedded in the glass stem of the tube. Small helical springs attached to the upper end of the supporting rod hold the filament wire and maintain it at the proper tension, thus protecting it from shocks. An elaborate spring suspension for the filaments of small power tubes is unnecessary.

The UV-203-A possesses a very desirable characteristic which protects it from overload. If under any conditions the tube should stop oscillating or lose its negative bias the plate current would not greatly exceed its normal value, as when oscillating. This result is due to the high plate resistance of the tube. On the contrary, however, as in the case of the UV-211 tube, its plate current at zero grid would rise to such excessive values that overheating of the plate would be sure to occur, and in a short time serious damage would result. This inherent plate current characteristic of the UV-211 is due to the low plate resistance of this tube.

Certain types of modern tube transmitters utilize a crystal-controlled master oscillator, several stages of intermediate amplification, and a main power amplifier system. A 50 watt tube is often used with the quartz crystal. The tube supplies power and the crystal controls the frequency at which the continuous oscillations are generated. Experience has proven that for the reliable operation of crystal controlled oscillators, it is essential that low plate voltage be applied to any tube working in conjunction with the crystal. Low voltage permits the transmitter to be operated without fear of subjecting the crystal to excessive voltage which might cause it to crack or shatter. When

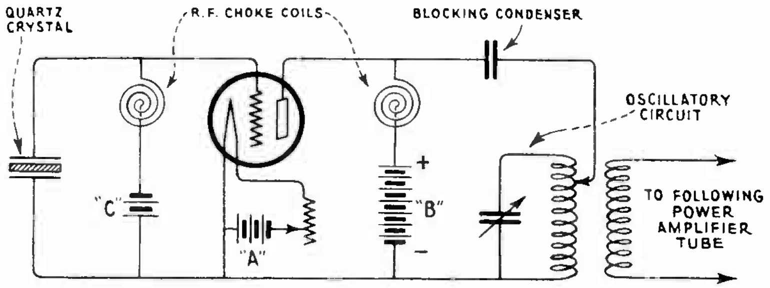


FIG. 2 - 100 WATT TUBE IN A CRYSTAL-CONTROLLED CIRCUIT

used in a crystal circuit the 100 watt tube is usually worked at 500 volts d.c. or at half normal voltage. The schematic diagram in Figure 2 shows a 100 watt tube connected in a crystal-control circuit. It is preferable to use alternating current to heat the filament and in certain commercial sets this a.c. is supplied by means of slip rings on the motor armature connected to a step-down transformer. A center tap on the transformer secondary should be used for plate and grid return leads. Filament voltage is usually controlled through a rheostat placed in the primary side of the heating transformer. When it is necessary to use direct current to energize the filament then it should be remembered to connect the plate return lead to the positive filament terminal. As in the case of all X-L filaments a voltmeter should be provided to check the e.m.f. applied.

If an overload decreases the electron emission in this tube, the activity of the filament may be restored by the reactivation process which simply requires that the filament be heated for a period of ten minutes or longer at the rated filament voltage, but with no plate voltage. If necessary the filament voltage may be raised to 12 volts, but no higher.

A protective fuse which should blow at about .2 to .25 ampere is usually inserted in the plate circuit. Remember that no fuses should ever be placed in a grid circuit since a blown fuse would be equivalent to opening the grid circuit and thus removing the negative bias. A plate voltage rheostat is quite necessary in order that the plate voltage may be lowered so as to protect the tube or other parts in case incorrect adjustments are made, which is likely to happen when first calibrating a new circuit or making regular adjustments in a circuit. The plate voltage may be increased from 1000 volts normal to 1250 volts only when using these tubes in a transmitter circuit in which the tubes are not actually modulating, i.e., when used in a non-modulated c.w. telegraph transmitter.

The UV-203-A and UV-211 are frequently used at wavelengths of less than 100 meters. Precautions should be taken in every case to keep the currents at safe values, but especially is this true in the case of tubes working in short-wave circuits. The 850, 852 and 860 are, however, better adapted to high-frequency work than the 203-A or 211. The RCA-850 is a four-element screen-grid tube, having the same plate voltage and filament characteristics as the 203 or 211 and using the same socket. This makes available a vacuum tube for high-frequency work in the 100 watt class which does not require plate voltages as high as those of the 852 or 860.

100 WATT SPECIAL SHORT-WAVE TRANSMITTING TUBE, TYPE UX-852

The UX-852 tube illustrated in Figure 3 is designed for use as an oscillator or power-amplifier in transmitting circuits operating on 5, 20 and 40 meters. It is also well suited for use as a crystal-controlled oscillator by operating it at less than the rated plate voltage. This tube has a very low inter-electrode capacity made possible by its special construction. Its plate to grid capacity is only 3.3 micromicrofarads as compared to 8.0 mmfd.for the UX-210. Observe in the photograph how the plate and grid electrodes are mounted on separate stems with the connecting leads entering the glass envelope through opposite sides. The filament leads are brought to the prongs on the tube base as in the ordinary tube.

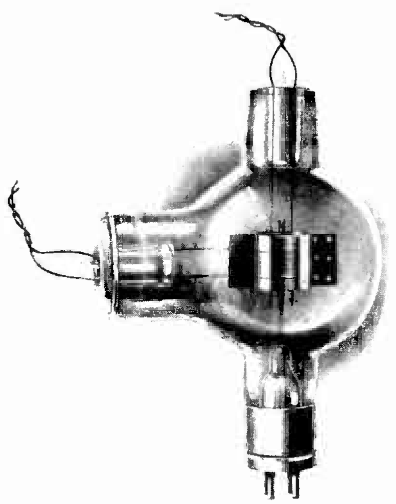


FIG. 3 - TYPE UX-852

On 20 meters, the tube will oscillate with stability and under certain conditions will deliver power on 0.7 of a meter.

The double end or T-shaped glass envelope with leads coming out at safe distances from one another prevents damaging base flashes. Connections to each of the grid and plate electrodes is made through two large stranded leads brought out from each stem as we have just mentioned.

These parallel leads permit large circulating currents to be carried safely at the high frequencies and therefore it is imperative that both leads be always used. The X-L filament used in the tube gives a high electron emission. The filament power is rated at 32.5 watts. The tube base should always be mounted so that the filament wire will occupy a vertical position. Alternating current should be supplied to the filament whenever possible. Plate and grid return leads should be connected to the electrical center (center tap) of the filament heating winding of the power transformer.

Although the normal plate voltage for the tube is 2000 volts, this voltage may be raised to 3000 provided the plate dissipation does not exceed 100 watts. Radiating fins on the plate permit a very large heat dissipation at this point. Because of the impracticability of measuring the output of a tube working on short wavelengths its correct operation may be judged sufficiently accurate by observing the plate. Plate temperature should never be permitted to increase above a certain value that would cause it to become more than cherry red in color. If the plate is heated to a cherry red, this color may be taken as an indication that the energy dissipated in heat is equivalent to 100 watts, resulting from electron bombardment of the anode or plate. Remember that whenever a circuit employing this tube is adjusted, the tube loss, that is, the difference between output and input, must always be kept within the safe limits of 100 watts.

The filament of this tube may be reactivated, like the X-L filaments of tubes previously mentioned, by operating at the normal filament voltage for ten minutes or longer with the plate voltage supply disconnected. The activity of the filament may be accelerated by increasing the filament voltage to 12 volts, but no more. In cases where an overload has liberated a large amount of gas this reactivation process will not be successful.

A fuse of the proper size to blow at 10 amperes should be inserted directly in series with the plate supply lead in order to protect the grid, wiring, etc., from overheating when improper adjustments of the circuit have been made. As we have cautioned before a fuse should never be placed in the grid circuit of any tube, because if it should accidently open or blow it would remove the grid bias from the tube with the result that the plate current would immediately run up to a dangerous value.

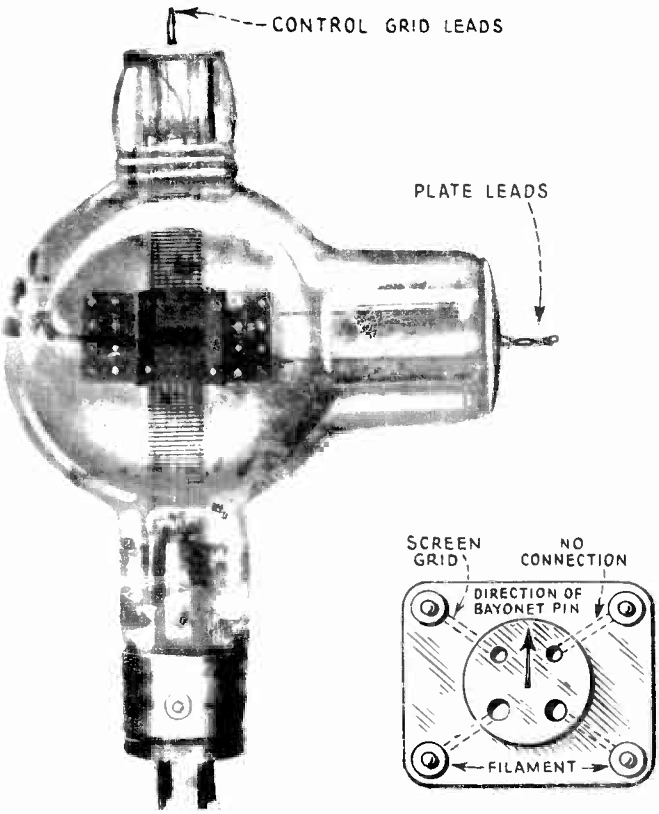
UX-860 FOUR-ELEMENT TUBE, OUTPUT 100 WATTS.

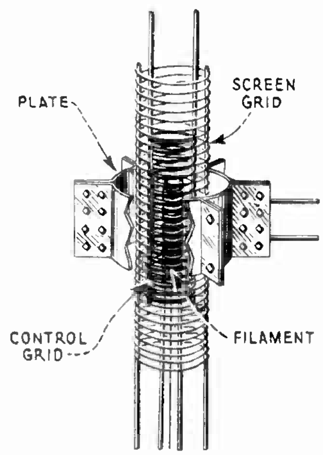
The RCA-860 tube is especially designed for use as a power amplifier in transmitting circuits of the high radio-frequency or short-wave type. The high-frequency transmitters send out continuous wave (c.w.) telegraph signals which cover wavelength ranges as low as 15 to 50 meters, or 20,000 to 6,000 kilocycles. This frequency band may also be expressed as from 20 to 6 megacycles. One megacycle is equal to one million cycles.

This 100 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 undesirable 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 70,000 ohms, or from a separate d-c source. The resistance method, using about 70,000 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





ABOVE: ARRANGEMENT OF UX-860 ELECTRODES

LEFT: SOCKET CONNECTIONS OF UX-860

FIG. 4 - THE 100-WATT UX-860 TRANSMITTING SCREEN-GRID TUBE

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 a 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 500 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-860 is shown in Figure 4. The UX-860 requires 3.25

amperes at 10 volts for the filament and 2000 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-861, 858 and WE-251-A.

250 WATT TRANSMITTING TUBE, TYPE UV-204-A.

The large UV-204-A tube illustrated in Figure 5 has an output rating of 250 watts and it also utilizes an X-L filament. The normal plate voltage is 2,000 and the filament is rated at 42.5 watts, drawing 3.85 amperes when supplied with the specified terminal e.m.f. of 11 volts. The maximum safe plate power dissipation is 250 watts. A very high emission is obtained by the use of the thoriated filament; this emission reaches approximately 5 amperes with the filament voltage at 11. The high emission permits the tube to perform very satisfactorily in telephone circuits because the complexities of speech and musical sounds cause large peak values of current.

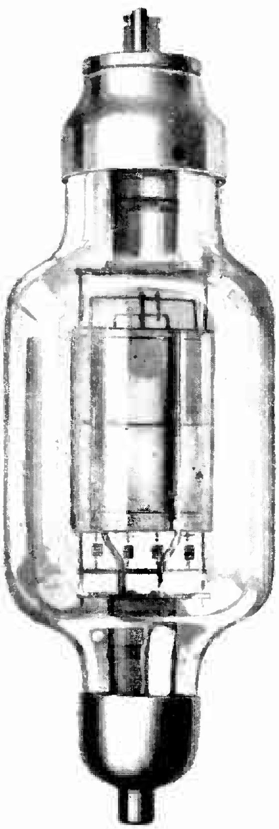


FIG. 5 - TYPE UV-204-A

Two or more 250 watt tubes are sometimes arranged in multiple (parallel) to provide a greater output than that afforded by the use of several smaller tubes. The "Converted P-8" commercial tube transmitter, found on many ships, employs two tubes of this type arranged "back to back" and obtaining their plate excitation from a.c. at 500 cycles supplied from a 500 cycle a-c generator feeding into a step-up power transformer. The note received from a transmitter of this kind whose c.w. is modulated according to the characteristics of a 500 cycle a-c current is somewhat similar to a 500 cycle spark set using a quenched gap. The theory is briefly as follows: The two tubes are connected with their plates to opposite ends of the transformer secondary. Only the positive halves of the alternating current cycles will be utilized. When one plate is positive the other is negative and it is obvious that only that tube which receives a positive half cycle will be active in generating the continuous high-frequency oscillations. Thus each tube alternately generates c.w. energy whose modulation is similar to the wave form of the 500 cycle a.c. This is called "full-wave self-rectification".

Since the positive voltages constantly fluctuate between zero and maximum and zero values according to the wave form of the a-c output of the transformer, then it follows that the resultant modulation produced by rectifying both halves of an alternating current power supply will appear as shown by the curve in Figure 6. There are four completely modulated groups shown in this curve. Each complete modulation produces one click in the receiving head set and since a 500 cycle a.c. is supplied and two tubes are working "back to back", the radiated wave will consist of 1000 completely modulated groups per

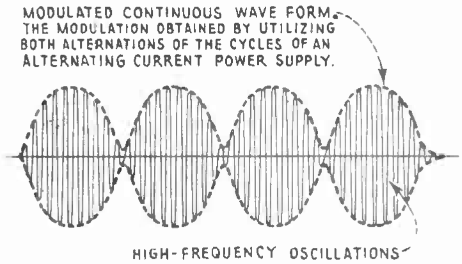


FIG. 6 - MODULATION PRODUCED BY RECTIFYING BOTH HALVES OF AN A-C POWER SUPPLY

second, hence 1000 clicks per second will be heard in the head set. This is known as a 500 cycle note and the tone has somewhat the characteristics of a spark transmitter employing a quenched gap as previously mentioned.

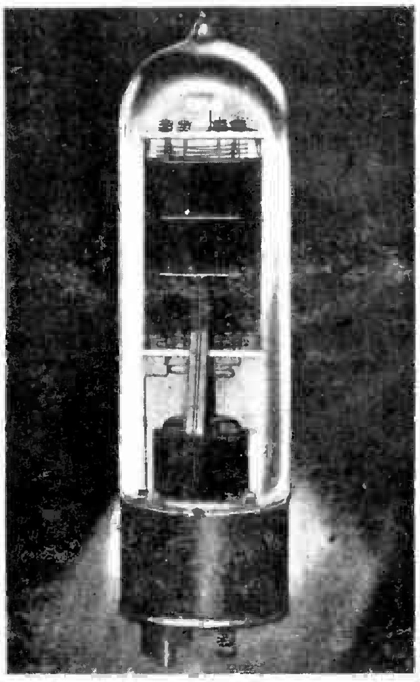


FIG. 7 - WESTERN ELECTRIC 212-D

A tube of similar output rating to the 204-A is manufactured by the Western Electric Company under the number 212-D. In mechanical construction, the tubes are somewhat different in that the 212-D is a single ended tube rather than double ended. The amplification con stant of the 212-D is lower and is better adapted to operate as a modulator than the 204-A. A photograph of this tube is shown in Figure 7.

THE UV-849 AND WE-270-A

These two tubes are very similar in their characteristics and both are adapted for use as oscillators, modulators, r-f power amplifiers or audio amplifiers. They are both of the double ended variety, the 849 being shown in Figure 8 and the WE-270-A shown in Figure 9.

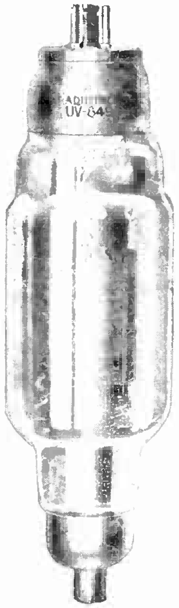


FIG. 8 - TYPE UV-849

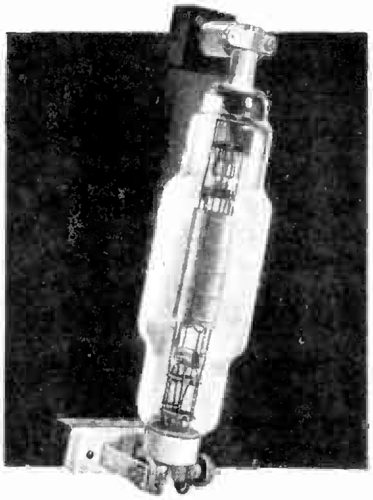


FIG. 9 - WESTERN ELECTRIC 270-A

THE UV-861 FOUR-ELEMENT TUBE, OUTPUT 500 WATTS.

Model UV-861 is a four-element tube of the screen grid type, designed for use as a power amplifier in transmitting circuits. It may also be used as an oscillator and is especially adapted for use in short-wave transmitters. One or more tubes of this type are used in the final power amplifier stage and work directly into the antenna. The

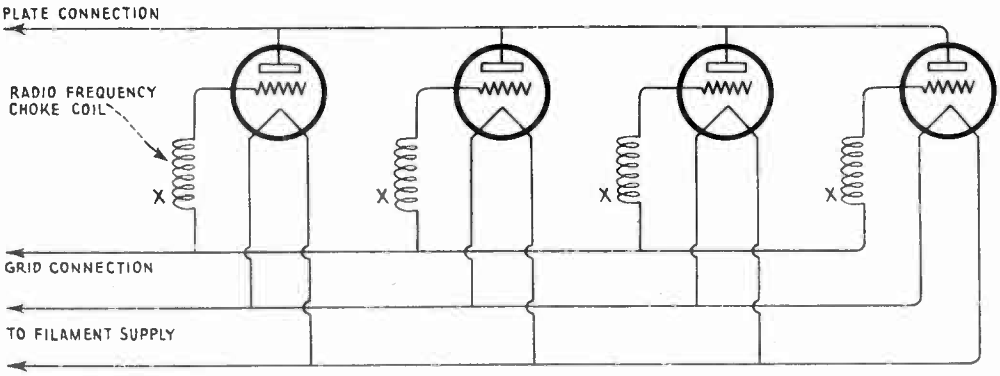


FIG. 10 - WHERE R-F CHOKE COILS MIGHT BE PLACED IN GRID CIRCUITS

input voltages for the UV-861's are supplied by one or more UX-860's located in the intermediate stages. The UV-861 is also constructed with a shield grid, and consequently the use of stabilizing methods in the radio-frequency circuits is likewise unnecessary as in the case of the UX-860. The normal screen-grid volts for this tube is 750 volts. The inter-electrode capacity is reduced to 0.05 mmfd. by the use of the screen grid. In certain types of transmitters the UV-861 plate is energized by a d-c double commutator generator having two 1500 volt windings arranged in series to deliver the normal 3000 volts. A plate current of approximately 0.5 ampere will be drawn at this plate voltage. Power tubes are usually provided with a plate voltage rheostat

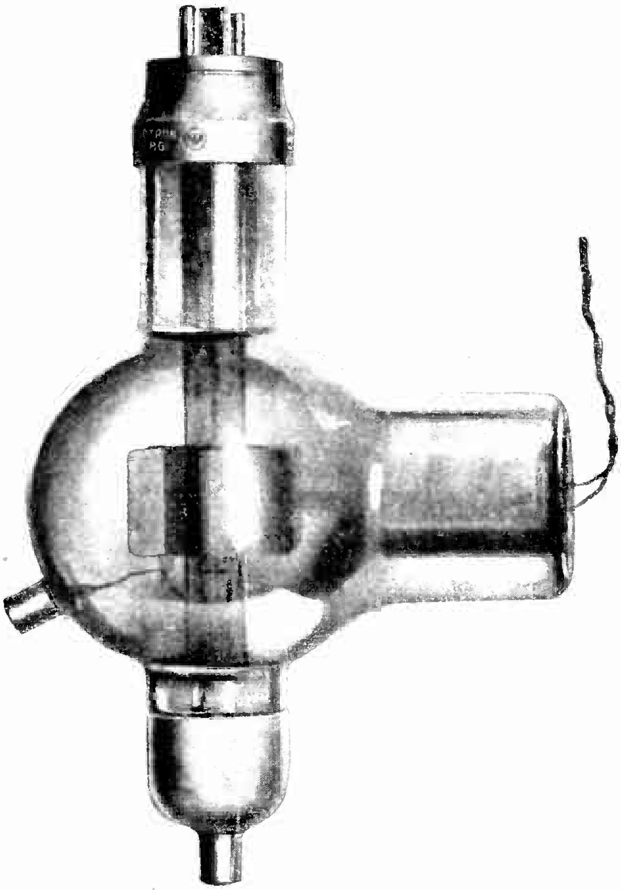


FIG. 11 - PHOTOGRAPH OF A TYPE UV-861 TUBE

so that during the process of tuning the transmitter the plate voltage may first be reduced and then later increased to normal as the various radio-amplifier stages are adjusted for maximum output in the antenna. The normal d-c plate current is 172 milliamperes, but under certain conditions of service this current reaches values as high as 350 ma. The X-L tungsten filament takes 10 amperes at a normal terminal e.m.f. of 11 volts.

In a majority of transmitting circuits, power tubes are connected in parallel, which is also known as multiple arrangement. The actual manner in which tubes are connected in parallel is in itself a simple method of connecting all the grids together and all the plates together. The filaments are energized from the same source of supply. When power tubes are operated in multiple, a small radio-frequency choke coil or a resistance of suitable size, for instance, one with a resistance of from 10 to 100 ohms should be inserted in the grid circuit of each tube as shown in Figure 10. These coils, or resistors (if used) should be placed as close as possible to the grid terminal of the socket for the purpose of suppressing parasitic oscillations. The unwanted oscillations are ultra-high frequencies which would circulate through the circuits and cause undesirable effects if no provision were made to suppress them. They are set up under certain resonant conditions existing between the tubes and the coupled circuits.

An amplifier circuit may consist of six or more tubes connected in multiple in order to supply an antenna system with a large power; the sum total of the watt output of the individual tubes used in the system. Multiple arrangement provides a practical means for dividing the load among several low-powered tubes, and in this way the need for a very large expensive tube and power plant is eliminated. A photograph of the UV-861 is shown in Figure 11.

1000 WATT TRANSMITTING TUBE, TYPE UV-851.

One of the largest sized air-cooled transmitting tubes has an output rating of 1000 watts. This power is obtainable without any increase in plate voltage over the 250 watt tube. The plate of the UV-851 requires 2000 volts d.c. and its plate power dissipation is 750 watts when the tube is worked as an oscillator.

We have already explained about the high efficiency of a thorium filament over a pure tungsten filament. This difference in materials, however, may be better appreciated after reviewing the following facts in regard to the practical operation of the UV-851. The X-L filament of this tube requires a power consumption of 170 watts to give a total electron emission of approximately .20 ampere whereas, on the other hand, a pure tungsten filament requires at least 600 watts to give an equal electron emission. In the latter case, that is, with a tungsten filament, the high emission could be obtained only by considerably overheating the tube; the additional power required would have to be dissipated at the plate. When operated under certain conditions this tube is capable of delivering a radio-frequency output of 1 kilowatt or more.

The mechanical construction of the 1000 watt type tube differs somewhat from that of the ordinary tube. There are four parallel filament wires used, each wire being supported by a helical spring to maintain proper tension at all times. The grid is constructed of a heavy square mesh of molybdenum wire, it being mounted in a frame which is anchored to the plate structure with an insulator for the purpose of holding the grid in correct mechanical relation to the plate. The heat generated by the plate or anode is dissipated with the aid of narrow wings attached to the plate. These thin metal pieces are called "radiating fins". A similar tube is manufactured by the Western Electric Company listed as type 251-A.

20 KILOWATT WATER-COOLED TRANSMITTING TUBES UV-207 AND UV-858.

These tubes are adaptable to either broadcast or telegraph transmitting circuits. Although the 20 kw. tube is one of the largest of the family of vacuum tubes, yet it functions exactly similar to its smaller brothers in the lower power classes. The tube is well suited for use as an oscillator, power-amplifier, or modulator. The enormous power which this water-cooled tube is capable of delivering can be appreciated by noting the magnitude of its various operating voltages. For instance, the plate is energized with 15,000 volts and the current in the plate circuit when the tube is oscillating is 2 amperes or 2000 milliamperes. The radio-frequency current, or oscillations generated by this tube, circulates through the grid circuit and reaches values up to 30 amperes. A grid d-c current of about 100 milliamperes can be safely carried by the grid. The filament e.m.f. is 22 volts which gives a filament current of nearly 52 amperes. A

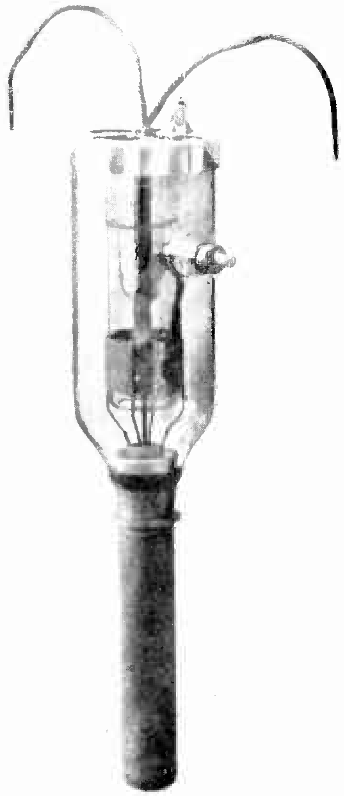


FIG. 12 - A 20 KILOWATT WATER-COOLED TUBE

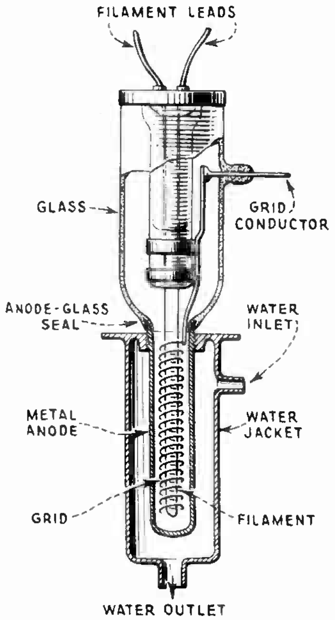


FIG. 13 - TUBE AND WATER-JACKET ASSEMBLY

filament starting resistance is necessary in order to raise the filament temperature gradually, and when the normal operating point is reached the plate voltage is automatically applied.

While the rated output of these tubes is 20 kw. the maximum safe plate dissipation is 10 kw. It will be recalled that lost power is generally dissipated in heat. The long copper cylinder shown at the bottom in the photograph of the tube in Figure 12 is the anode or plate. By inserting the anode in a water-cooled jacket the heat produced at the plate is quickly extracted. The complete water-jacket assembly is so arranged that a flange screwed to the threaded portion of the plate holds the plate in the jacket and special precautions are taken to insure a water tight joint by the use of a suitable gasket of rubber or other material between the flange and jacket. The tube is supported only by the water jacket — see Fig. 13.

There is sufficient space between the inside of the jacket and the copper cylinder or plate to permit a column of water to circulate freely around the plate for the extraction of heat generated at this point. About two or three gallons of water per minute is constantly pumped past the surface of the copper anode and through the system from cooling coils. The water circulation is maintained by electrically driven centrifugal pumps. The temperature of the water is usually measured after it has passed the hot anode. This is known as the outlet temperature, 70 degrees Centigrade generally being set as the limit. It is obvious then that the thermometer is located at the point of highest water temperature. The cooling water is never permitted to boil nor are air pockets allowed to form around the anode which might cause overheating of the water. This condition

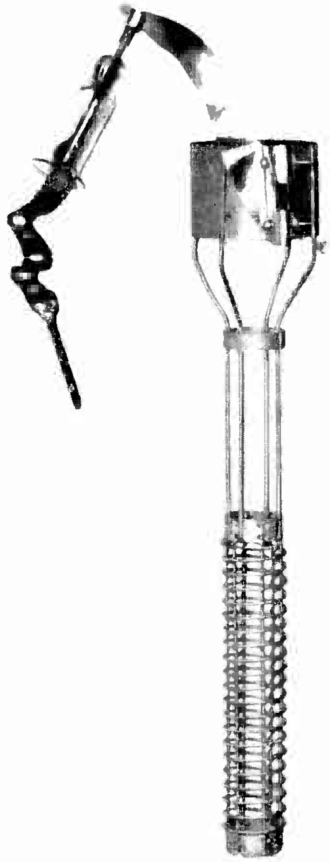


FIG. 14 - GRID CONSTRUCTION

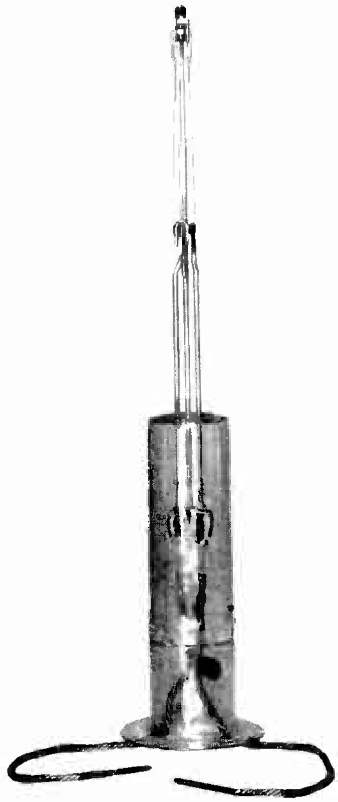


FIG. 15 - CATHODE CONSTRUCTION

would be evidenced by a singing or buzzing noise from the jacket while the power is on, this noise indicating the presence of steam bubbles at the surface of the anode.

Only water surrounds the metal anode and as can be seen in the photograph the other elements are supported by the glass cylinder with the conductors brought out at safe distances from each other. A simple cross-sectional sketch of the water-cooled vacuum tube is shown in Figure 13. The grid and cathode of a 20 kw. tube are shown in Figs. 14 and 15 respectively. It can be seen in Fig. 13 that the plate itself is a hollow cylinder with filament and grid mounted inside. An air-tight seal is made between the copper edge of the cylinder and the glass shell. The tube is very thin and delicate where this union between glass and metal is made.

It may be interesting to note the dimensions of this tube in order that we may compare it with the small receiving tubes which we so frequently handle. However, when we consider the immense amount of d-c power which is converted into radio-frequency power by this tube, its dimensions do not seem unduly large. The maximum overall length of the tube is 19 5/8 inches, the diameter of the glass bulb is $4\frac{1}{4}$ inches, while the weight of the tube alone is 2 pounds and 12 ounces. The dimensions given seem relatively small and are made possible because of the special means of keeping the temperature within safe limits by both water and air cooling. The air cooling is the natural heat radiation which takes place at the outside glass walls and water-jacket while the water cooling is due to direct conduction from the hot cylindrical plate to the water. It will be remembered that it is the electronic bombardment which causes the plate or anode to become the hottest element in the tube outside of the filament which is a normal condition for the latter.

An interlock or circuit breaker between the water circulating system and the electrical circuits is set to open if the water supply fails for any reason or if the tube develops trouble. The filament and plate voltages are instantly disconnected by the opening of the interlock.

Because of the high plate potential of several thousand volts, the plate must accordingly be insulated from the water tank and metal piping which is normally grounded. The use of a fairly long length of rubber hose connecting the water-jacket to the water source and also, by using pure water in the circulatory system, the insulation and resistance is built up to the order of several hundreds of thousands of ohms. This resistance is between the high potential anode, which is in direct contact with the water, and the cooling system and, in turn, the ground.

A tendency for a heavy scale or deposit to form on the outside of the anode (the scale being similar to that collecting on the boiler tubes) may be attributed to the use of water containing a high percentage of mineral matter, especially sulphates and carbonates. The chemical content of the cooling water should be determined by analysis. The water must be pure and have a fairly high specific resistance. A length of about 15 feet of $\frac{1}{2}$ inch rubber hose is all that is required with high resistance water (4000 ohms per centimeter cube) in order to build up the necessary high resistance between the jacket and the inlet and outlet pipes. A length of hose is wound around a cylindrical form with each coil of hose being located under a water-cooled tube in the transmitter.

It can be readily understood that the need of pure water is a very important feature in the operation of large broadcasting stations or any station employing water-cooling for vacuum tubes. The water used in a certain radio station had a specific resistance of only one-tenth that of the water recommended for such purposes.

The table below shows the chemical content held in solution in this water, and we give this list for those of our students who may be interested in work of this kind.

	Per 100,000	Grains Per Gallon
Silica	1.08	.63
Iron oxide alumina	.25	.15
Calcium carbonate	2.16	1.26
Magnesium carbonate	5.00	2.92
Potassium carbonate	3.86	2.25
Sodium sulphate	3.65	2.14
Sodium chloride	14.00	8.17
Total Solids	30.00	17.52

Specific Resistance 359 ohms.

If the composition of cooling water is such that scale cannot be avoided then it is obvious that the tubes must be removed and cleaned at frequent intervals, the frequency of cleaning depending, of course, upon the rate at which the deposit is formed. The danger of accidental breakage is always entailed in the removal of these tubes because they are apt to stick in the water-jacket. A gentle twisting back and forth and at the same time raising the tube carefully will usually loosen it sufficiently to permit its removal.

In order that the glass envelope will not be subjected to an electrostatic strain the external wiring from the transmitter circuits and the leads attached to the electrodes are kept at reasonably safe distances from the glass.

You will recall that glass is a dielectric material, hence, electrostatic strains set up by the relatively large oscillating currents are likely to puncture the comparatively thin walls of the glass. Again observe the photograph of the 20 kw. tube and note how the two filament leads are brought out at the top whereas the grid conductor comes through the center of the glass bulb. If the filament leads swing and strike the glass at any time trouble would arise from corona, resulting in almost certain puncture of the glass.

A transmitter employing tubes of this power may have the oscillating frequency, allocated by the Radio Commission at Washington, maintained within the prescribed limits of 50 cycles by the use of a quartz crystal. A circuit consisting of a quartz crystal, an oscillatory circuit, and a low-power amplifier tube, may be set up to supply the initial oscillating current of the desired frequency. This frequency, after being stepped-up through several stages of intermediate amplification, finally provides a satisfactory amount of radio-frequency voltage for excitation of the grid of the 20 kw. tube

A special tube of the water-cooled variety for use on high frequency has been developed and is known as the UV-858. An x-ray photograph of this tube is shown on the inside front cover page.

MEASURING VACUUM TUBE CHARACTERISTICS

There are several constants by which vacuum tubes of similar type may be compared when operating under exactly similar conditions. We will explain in the following paragraphs how to calculate the amplification constant, plate impedance and the mutual conductance. Although these constants do not enable us to determine exactly how a particular tube will perform in a circuit under certain operating conditions, yet they do provide a very convenient means for us to determine the relative efficiency to be expected from tubes of similar type.

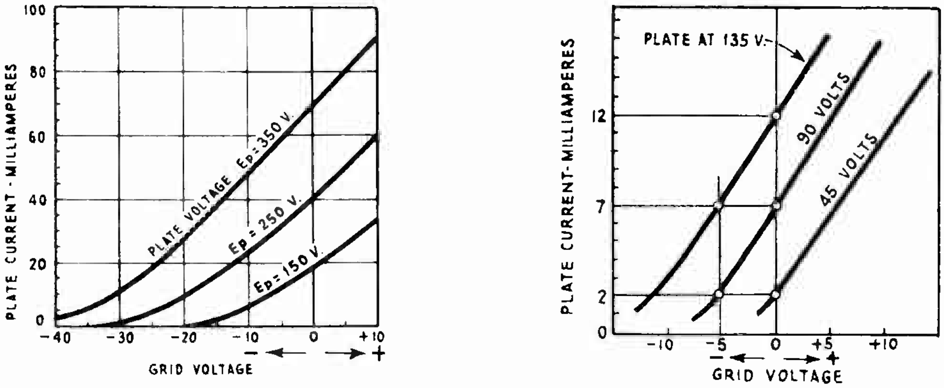


FIG. 16 - CHARACTERISTIC CURVES OF A UX-210 TUBE

<u>AMPLIFICATION FACTOR OR CONSTANT. Mu</u> (μ) is the symbol for this constant. <u>Amplification constant may</u> be defined as the measure of the effect of the grid voltage on the plate voltage, or stated more fully, it is the ratio of the change in plate voltage to a corresponding change in grid voltage which produces the same effect in the plate current. This relation may be expressed as a formula in the following manner:

$$\text{AMPLIFICATION CONSTANT} = \frac{\text{CHANGE IN PLATE VOLTAGE}}{\text{CHANGE IN GRID VOLTAGE}}$$

With the aid of the curves at the right in Figure 16 we will work out an example that will enable anyone to calculate the amplification factor of any tube whose characteristic curve is available. The three curves show the characteristics of the same tube, a UX-210 tube. when worked at three different plate potentials. The first curve is the 135 volt curve, the second 90 volts and the third 45 volts.

In our example let us consider only the 135 and 90 volt curves in order to find the ratio of change in plate voltage to a corresponding change in grid voltage which would give a change in plate current exactly similar for each grid and plate variation. Reference to the curves tells us that when working the tube with the grid at zero potential the flow of plate current is 12 ma. (milliamperes) with the plate at 135 volts. It is readily seen that by reducing the plate voltage from 135 to 90, a difference of 45 volts, we obtained a reduction in plate current of 5 ma.

Let us now locate a point on the 135 volt curve which tells us the value of plate current for a grid bias of negative 5 volts. To do this we follow the vertical line upward from the —5 location on the bottom horizontal line (the line upon which the grid voltages are marked) until the vertical line crosses the curve. Beginning at the point of intersection we follow the horizontal line to the left until it meets the vertical line upon which the plate current values are marked. The plate current value is seen to be 7 ma. However, this same 135 volts, as previously shown with the grid at zero potential, gives a plate current of 12 ma. Hence, it should be clear that with the tube operating under these two different grid voltages, zero and −5, the plate current dropped from 12 to 7 ma. Observe now, that we have the same value of change of plate current, or 5 ma., for two different plate voltages, 135 and 90, corresponding to the two different grid voltages, zero and −5. Briefly, it could be stated that it required only 5 volts change of grid to make the same plate current change that was obtained by a difference of 45 volts on the plate.

Any set of values might be taken from the curve for our example, providing these values are somewhere along the linear or straight portion of the curve. It will be recalled that amplification is obtained by working a tube at some location where the slope of the curve is a straight line.

The numerical values in the preceding paragraphs may now be substituted in the formula and then solving we get:

$$\text{AMPLIFICATION FACTOR} = \frac{135 - 90}{5 - 0} = \frac{45}{5} = 9$$

Then 9 is the amplification constant of this particular 210 type tube.

PLATE IMPEDANCE. This constant is the measure of the change in plate voltage to the resultant change in plate current under conditions of a constant grid potential. The term "constant" means that grid voltage remains unchanged or fixed during the procedure of plotting the characteristic curve. Note that grid voltage will not be varied this time, as for instance, in the case of preceding explanation. In this example we can use the same plate voltages and plate current values as in the foregoing examples, when the plate voltage was lowered from 135 to 90 and it was shown that the plate current decreased from 12 to 7 ma.

After first changing milliamperes to amperes, all of the necessary values can be substituted in the plate impedance formula as follows:

$$\text{PLATE IMPEDANCE} = \frac{135 - 90}{0.012 - 0.007} = \frac{45}{0.005} = 9000 \text{ ohms.}$$

Note: 12 ma. = 0.012 ampere.
7 ma. = 0.007 ampere.

Then 9000 ohms is the plate impedance for this particular tube.

MUTUAL CONDUCTANCE. The mutual conductance value of a tube is a good indication of the efficiency of a tube used as an amplifier, because this value represents the effect of the applied grid voltage upon the plate current. Now then, a certain relationship exists between the plate current and grid voltage which the characteristic curve shows in pictorial form. This relationship is when the quotient of the change in plate current divided by the change in grid voltage produces a certain change in question in plate current, providing the plate voltage is maintained consistent. Or, it can be said that mutual conductance is the ratio of the amplification factor (mu) to plate impedance. This statement may be written:

$$\text{MUTUAL CONDUCTANCE} = \frac{\text{AMPLIFICATION CONSTANT}}{\text{PLATE IMPEDANCE}}$$

We shall again use the curves of the UX-210 tube to obtain our working values. Observe that with the plate at 90 volts the plate current is 7 ma. and with the plate at 45 volts the current is only 2 ma Thus, a 45 volt reduction on the plate causes a 5 ma. reduction in current. It can also be seen from the curve that it requires the grid to be changed 5 volts (that is, from a zero value to −5 volts) in order to effect a similar change of 5 ma. in plate current. Of course, the plate voltage must in this case remain constant or unchanged when the grid voltage is shifted from zero to −5.

To work out this example we must multiply the 5 ma. change in plate current by 1000, or 5 x 1000, and then divide this result (5000) by the required grid voltage change of 5 volts: we then have $\frac{5000}{5} = 1000$.

Then 1000 micromhos is the mutual conductance for this tube when operating at these particular "B" and "C" voltages, that is to say, at 90 volts plate and zero grid.

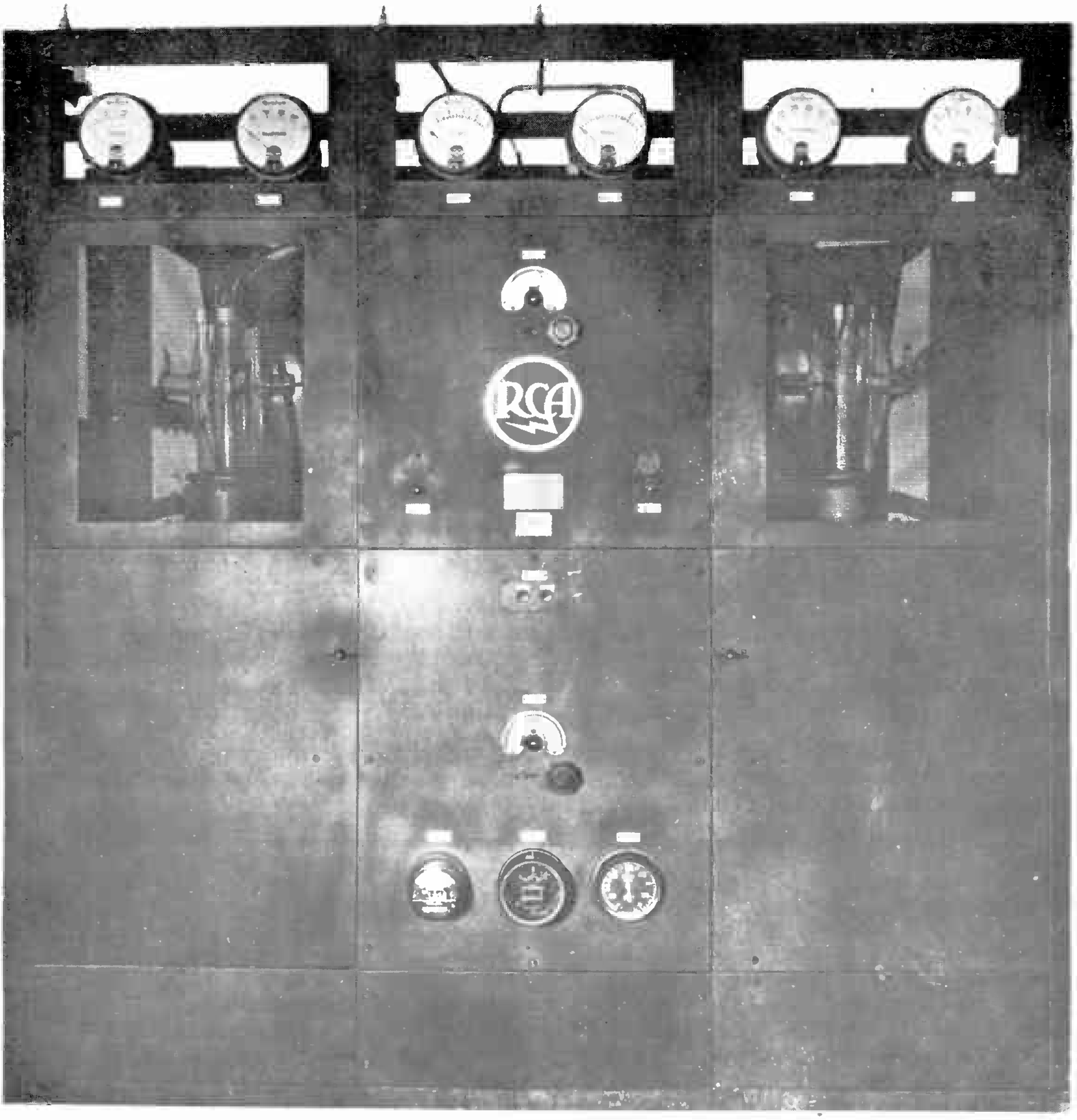
The unit "micromhos" expresses the conductance value which is the opposite to resistance. Resistance is measured by the unit "ohm", and notice that "ohm" is spelled backwards or "mho" to express conductance. Furthermore, the prefix "micro" indicates a millionth part of the unit "mho".

Any change in either plate voltage or grid voltage will cause the mutual conductance to vary, and consequently mutual conductance can be expressed only for one set of conditions, that is, with the tube working at particular "B" and "C" voltages.

At the left in Figure 16 are three curves which show the characteristics of a UX-210 when operated with plate voltages of 150, 200 and 350 volts respectively.

EXAMINATION QUESTIONS

1. What is the advantage of class C amplification over class A?
2. Where is class A amplification generally employed?
3. Why cannot class C amplifiers be used in audio-frequency work?
4. What is the advantage of a single tube of large rating over several small tubes giving the same total rating?
5. How may several power tubes of similar type be connected in order to supply a large output power to an antenna system?
6. Draw a simple sketch showing three tubes connected in the manner suggested by your answer to Question 5 immediately above.
7. Should a fuse be placed in series with the grid of a power tube and why?
8. (a) What practical indication have you that a tube has reached its limit of plate temperature and what limit should never be exceeded?
   (b) What actually causes a plate to become hot and show color?
9. What features make it possible to build and operate a tube of such relatively small dimensions but having the enormous power rating of 20 kilowatts?
10. How is the high voltage plate of a water-cooled tube maintained at a safe operating potential with regard to the water supply tank and other parts which are normally grounded?



50-KILOWATT HIGH-POWER AMPLIFIER.

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