THERMIONIC TUBES

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Quite a number of years ago, Mr. Edison brought before us an experimental lamp novelty consisting of a glass bulb containing a filament and a plate with the air exhausted. Later it was applied in a new art—now known as radio. Quite recently a third element was added, which was called a grid. Since that time there have been great strides made in this country and abroad by scientists and engineers in developing this device from a toy to a powerful instrument for uses in high power circuits.

The earlier tubes were first used as detectors and later as amplifiers, until it was found that they could be used as oscillation generators and power amplifiers. The life of these old tubes was very short, owing to the presence of gas which in time destroyed the cathode. Since that time some difficult problems have been solved in the development of these tubes.

The first one which will be taken up is the production of high vacuum within these tubes and the effect it has on their operation. Methods for production of low pressures have been devised by several people and excellent results have been obtained. I do not intend to dwell on any definite method of producing an extremely low pressure, but what I am trying to bring forward is that even if we have exhaust means for producing pressures as low as 10^{-7} bars or lower, we are still confronted with the space pressure surrounding the elements within the tube while under operation. Very little information is available concerning this point. If we exhaust a tube by baking the vessel at a temperature close to the collapsing point of glass, and then measure the pressure, we find that we have produced a vacuum as low as it is possible to obtain. We next heat up the metals within the vessel. These give off gas, thus changing the pressure. We repeat this continually by raising the plate temperature, either by radio frequency, induction, or bombardment. The induction method I will take up later on, but the bombardment method I will describe here.

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We first heat the filament—apply a positive potential on the plate and alternating potential on the grid. We will notice that there is considerable ionization present. If the vessel is of glass it is best to keep it extremely hot. I wish to emphasize that this is a method for producing tubes without the use of a "getter." By "getters" we mean the substances such as phosphorus, arsenic, sulphur, and so on. These substances, when applied to the metals and volatilized by heating them, trap the gases. They are then deposited on the walls of the tube as a film. Whether the presence of this gas containing film is reliable when working high temperature tubes is questionable. We are building tubes of extremely high capacities and it is quite obvious that we have to get rid of all the gas possible and not have the vessel contain any film holding gases.

Many interesting phenomena are observed with slight residual gasses always present even in the hardest of tubes. After running for some time with an electron current to the plate at a fixed voltage, a steady value for the pressure may be reached. If the voltage is increased, but not sufficiently to overheat the plate, the tube will harden. If the filament alone is simply heated and no potential applied to the plate, we find that the residual gas has increased. When a filament is heated and no potential applied to the plate, the tube pressure would be equally distributed thruout the vessel, except for a minute space surrounding the filament. If we apply a potential to the plate we produce a field surrounding the filament created by the electron emission. This field has a much lower gas pressure than the remaining portion of the vessel. This leads to the conclusion that these effects are due to ionized gas. At these voltages the ions are positive and their observed disappearance must be due to the fact that they are driven into the walls of the vessel. Some suggestions have been made that they are driven into the filament, but how can they be if they must be retained with the filament at 2,000°C.? So it seems advisable to give up the theory that they return to the filament.

Much data have been supplied by different investigators of the clean-up of gases, and from conclusions drawn it seems that high temperature devices clean up much more readily. For instance, take the clean-up of the tube containing a coated cathode. An experiment with this type has been made wherein the whole tube was immersed in liquid air. The electron current was maintained constant. Clean-up was slow, probably owing to the slow saturation of the walls of the tube with the gas. To facilitate a more rapid clean-up, I have placed a tungsten filament within a tube of this character, shielding the coated filament by the grid support so as to prevent the high temperature from affecting the coating on the filament. In this case liquid air was not used, letting the walls of the vessel heat up so that the gases would penetrate at this temperature. When the tube was sealed off from the exhausting means, the glass contained the gas trapped at this high temperature. I found the rate of clean-up was about the same as for a tungsten filament tube. Further, a coated filament tube which would previously work at 2,000 volts, would function properly at several thousand volts higher.

A conclusion can be drawn that coated filament using the bombardment means and other low temperature means of clean-up places them in a low voltage condition. I have not indicated any particular gas or pressure in these experiments, but merely have expressed a method which may be used, because of confusion which may arise and elaborate descriptive matter which would be required thoroly to identify any particular gas.

To produce tubes of the highest possible quality, we first have to consider what type of a tube we wish to construct. If it is a tube for receiving purposes it naturally will be of small dimensions. In case of building a tube of small dimensions we would choose for its container ordinary soft glass. The metals have to be of such a nature that under normal working conditions they will not heat themselves or the glass to such a temperature as to spoil the operation. The operating voltage must also be considered. If we take an ordinary receiving tube and apply a certain plate potential and no grid bias, we would normally consider a tube good which showed less than a micro-ampere negative grid current. Let us consider a tube of this type with its filament grid and plate, such as the Westinghouse coated filament W.D.-11 described below. We find that there is still a slight presence of gas in this tube which cannot be measured on a microammeter. This being the case, we use in this tube a filament with the least possible watts, so as not to heat the space surrounding this filament, and also use a plate potential that will not disturb the extremely small amount of gas present. To make a comparison, I will illustrate a tube such as the Westinghouse W.T-22 (see description below), which has a greater spacing between its elements. It also has a higher filament watt consumption and a higher plate potential. A tube with such space relations can be used as a power amplifier while having as much as half a micro-ampere negative grid current and

yet has a straight characteristic curve. Consider the development of still larger tubes, such as power tubes,—for instance,the Westinghouse W.T-24. Its normal rating is 250 watts. That is, it will consume 500 watts on the plate working at 50 percent efficiency. It will supply 250 watts oscillating energy or 250 watts modulated energy with a certain grid bias. Consider tubes of this character under working conditions,—two used as oscillators and three as modulators, using the constant current system of modulation. We find that under best conditions the

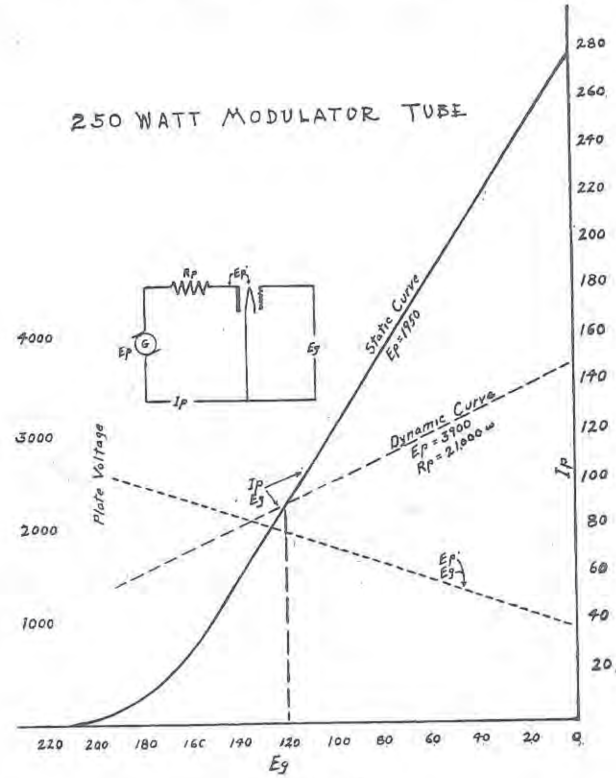


FIGURE 1

modulator tube power consumption should be the same as the oscillators, and the dynamic characteristic of these modulators should be such that the grids will not go positive when 80 percent or 90 percent modulation is desired. Great care must be taken in the design of such a tube. It must be a power-wasting device and still have good control.

There is one feature which must be especially cared for. That is the presence of gas. It must permit a current value in the neighborhood of not over 10 micro-amperes in the grid circuit. This may seem extremely low in comparison to some tubes which are being produced, but, nevertheless, the grid current is one of the greatest factors in giving good modulation. If you do not have an extremely low grid current, the modulator will oscillate at a radio frequency and will not parallel. Take three tubes all having the same characteristics. We place the tubes in a circuit at 2,000 volt plate potential, 125 volts grid bias, and find that we get 150 milliamperes plate current thru each. When we start to

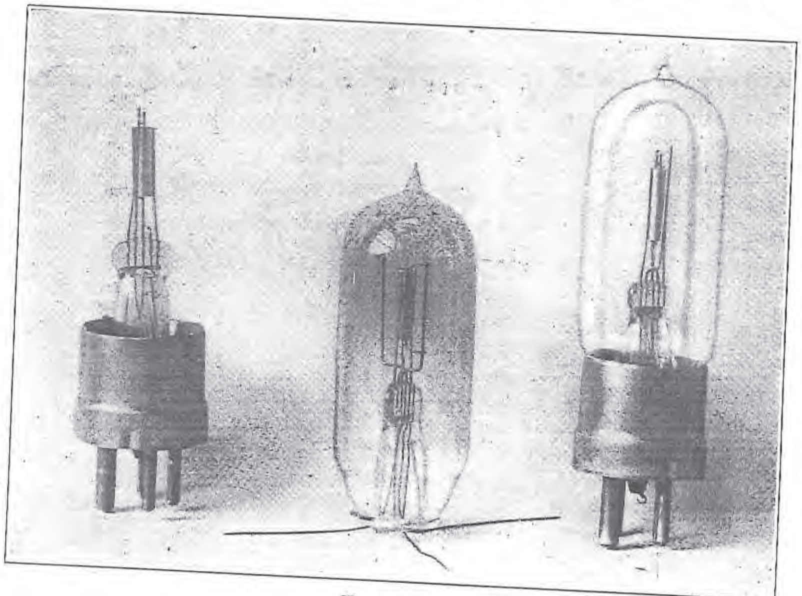


FIGURE 2

modulate at a certain frequency, the tubes will "shoot over" or start oscillating at an extremely high frequency, due to some disturbance. This action is further increased by adding more modulator tubes. To overcome this difficulty, when other tubes are not available, high frequency choke coils may be added in the plate circuit of each tube.

We have mentioned several tubes manufactured by the Westinghouse Company. It seems appropriate to give a description of their constructions and characteristics. The W.D-11 is a high vacuum tube which is used as a detector or amplifier, either audio or radio frequency. It has a particular application in the Radiola Senior and another in the Radiola Grand, both manufactured by

the Westinghouse Company. In this latter application one tube is used as a detector, three others as amplifiers at audio frequency. The detector is used at 22.5 volt plate. The amplifiers are operated at 45 to 65 volts. The filament consumption on these tubes is about 0.25 ampere at one volt, and suitable for operation on a single dry cell or on two Edison Leland primary cells (as in the Radiola Grand). The tube requires no grid bias. This tube is made as follows: The container is a soft glass bulb, sealed in a special four prong base, which makes it non-interchangeable with other types of tubes. A nickel plate 0.005 inch (0.013 cm.) thick is made into a cylinder ⅛ inch (0.32 cm.) diameter and ⅝ inch (1.6 cm.) long. The grid is a cylindrical helix 1/16 inch

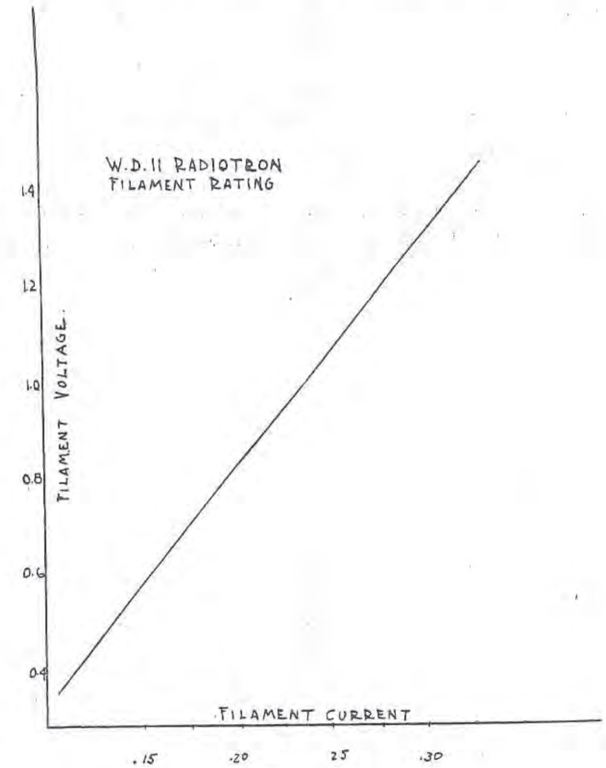


FIGURE 3

(0.16) cm.) diameter made of 0.014 inch (0.036 cm.) nickel wire. The filament is a platinum iridium strip 0.00025 inch (0.00064 cm.) by 0.005 inch (0.013 cm.) and ⅝ inch (1.6 cm.) long, coated by a special process with a barium and strontium oxide. This fila-

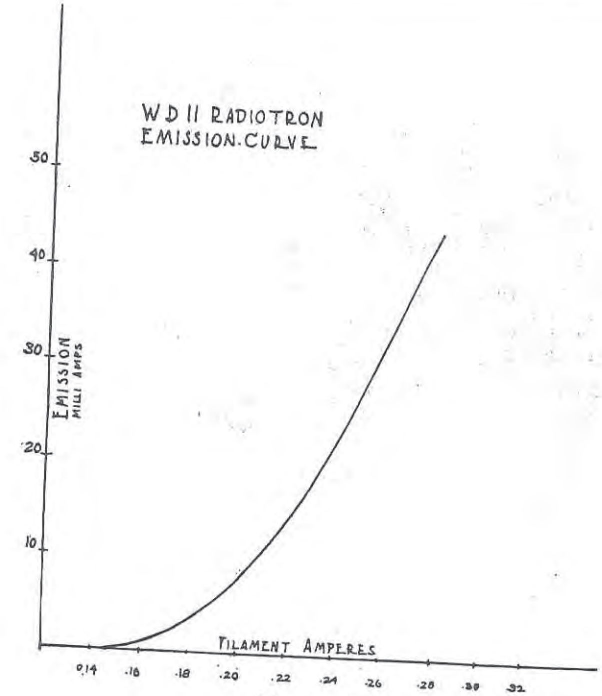


FIGURE 4

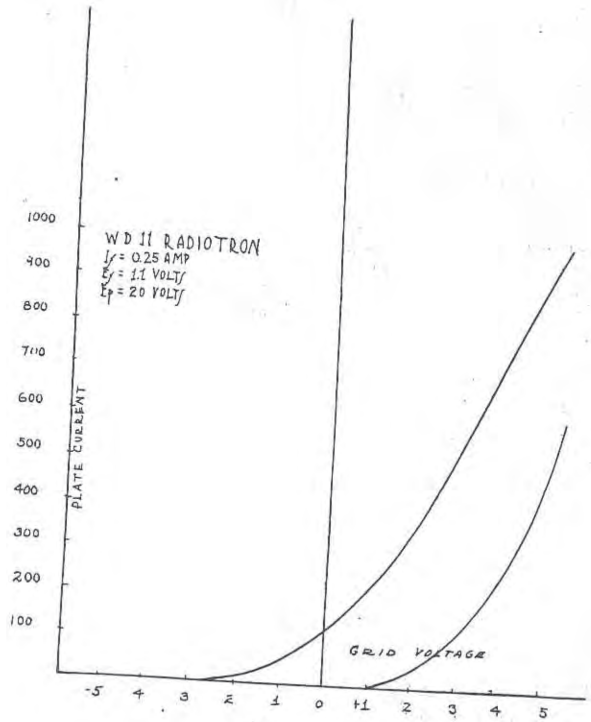


FIGURE 5

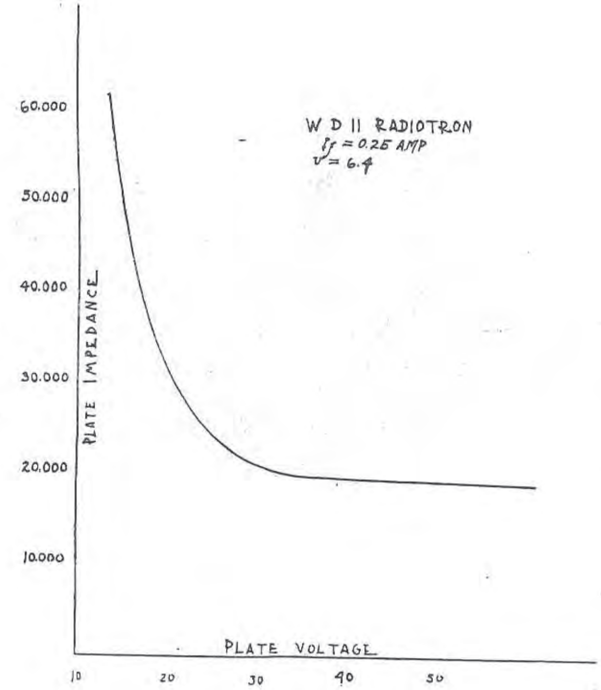


FIGURE 6

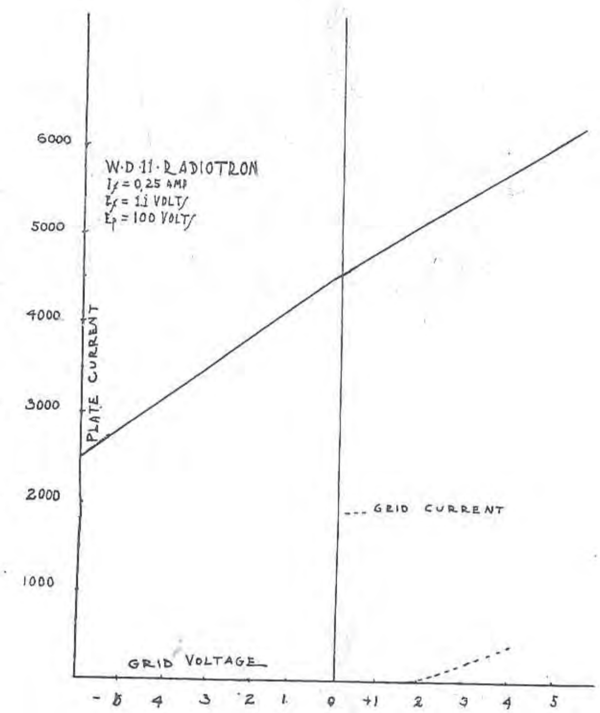


FIGURE 7

ment is held under tension by a spring. All parts are supported from a single press on nickel wire. The tubes are evacuated by a specially timed process. Induction heating is used to secure the complete removal of gasses without injury to the delicate coated filament.

The tubes are tested for grid current and filament potential. In addition, an amplification test determines by actual measurement the amount of audio frequency energy obtainable for certain grid excitation.

The tube called W.T.-22 is a 5-watt power tube used as an amplifier or an oscillator in small sets. It can be operated at 7 volts on the filament drawing about 1.25 amperes. The plate will operate on voltages from 100 to 500. The plate current is from 10 to 50 milliamperes.

This tube is placed in a soft glass container slightly larger than W.D-11 and mounted in a standard Navy type base.

The plate is 0.005 inch (0.013 cm.) molybdenum built into a rectangular box like shape, ⅞ inch (2.23 cm.) long and ¾ inch (1.9 cm.) by ¼ inch (0.64 cm.) wide. It is held on nickel supports.

A helical grid is made of molybdenum wire welded to molybdenum supports, and conforms to the shape of the plate. The filament is M-shaped and held on tungsten supports. It is made of a platinum iridium alloy coated similarly to W.D-11.

W.D-24 is a power tube used as an oscillator on a 2,000 volt direct current circuit. The filament is rated at 15 amperes at 10 volts. The plate current can go as high as 250 milliamperes.

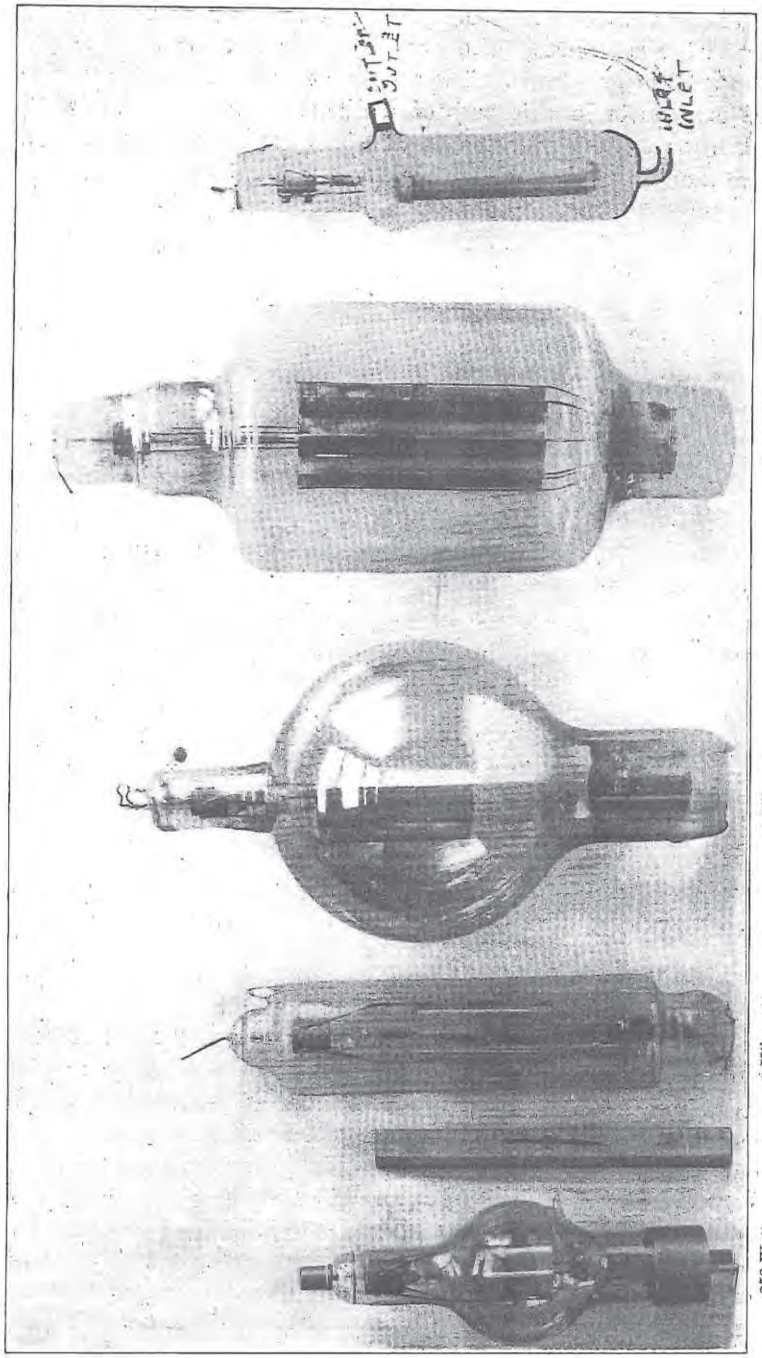
This tube is built in a hard glass container 14 inches(35.6cm.) long and 5 inches (12.8 cm.) in diameter. The grid and the filament are supported from the lower press, the plate from the upper press.

The plate is oval shaped, made of two halves joined together as two ribs. The grid conforms to this shape. The filament is V shaped and held under tension by a spring from the upper press.

Plate and grid are made of molybdenum. The filament is of tungsten. All the supports are of molybdenum. The leads are of tungsten.

W.T-25 is a modulator tube very similar to W.T-24, but with a lower plate impedance and a straight line characteristic.

The writer is also exhibiting samples of a 5 kilowatt, a 10 kilowatt, and a 25 kilowatt tube. The 5 and 10 kilowatt tubes are built in hard glass containers of suitably large size. They conform in general character to the W.T-24 except for their plate voltage, which is 10,000 to 20,000 direct current.



250 Watt Oscillator — 1 Kilowatt Rectifier — 5 Kilowatt Oscillator — 10 Kilowatt Oscillator — 25 Kilowatt Metal Tube Water Cooled

FIGURE 8

The 25 kilowatt tube has a plate sealed in the glass and forming part of the container. The glass serves only to insulate the filament and the grid leads. The plate is water cooled on the outside and is capable in this way of dissipating up to 10 kilowatt. This tube can be operated at 20,000 volts direct current with more than 2 amperes plate current.

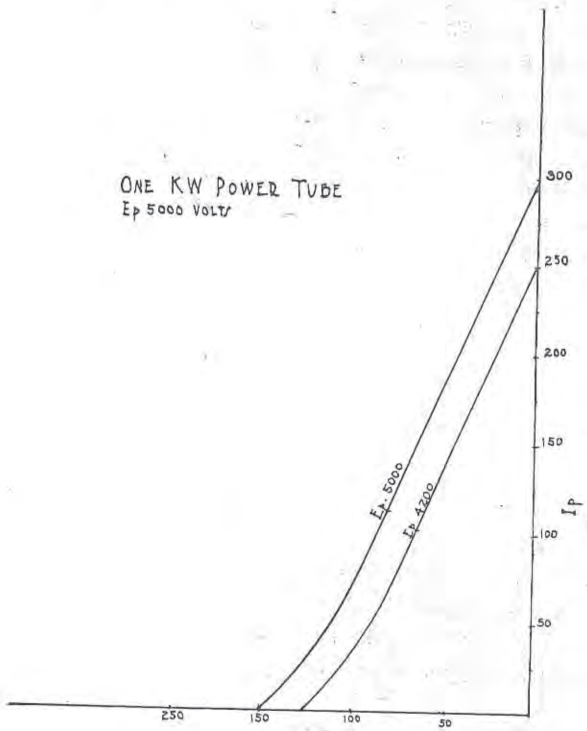


FIGURE 9

To produce tubes which have no negative grid current present is quite an interesting problem, which I believe has been quite satisfactorily solved by a method known as pre-treating of elements. The best method we have found is to heat the metals approximately up to their melting point within a vacuum furnace. In 1914 or 1915 the Western Electric Company made for their Arlington transmitter some special tubes. These tubes had a ribbon bent back upon itself, forming an oblong plate. Each end of the ribbon had a lead wire brought out. A current was passed thru this ribbon to heat and drive out the gas.

About this time the writer invented heating by high frequency.* Since then new applications have arisen. The writer will now endeavor to explain the use of this method in several applications.

Power tubes have had a number of limitations. The capacities of these tubes were limited by the size of the cathode. The energy consumed in the cathode was extremely high relative to the space energy, that is—the energy dissipated in the plate and filament circuit. This formed the limit of the capacity of the tube. These limitations made it necessary to reduce the plate current and raise the plate voltage. High voltages in power tubes are accompanied by electrostatic stresses. High frequency oscillations are liable to puncture the glass under these conditions. The limit of plate direct current voltage is about 10,000 to 20,000. It is evident that the problem of raising the capacity hinges essentially on high filament emission for certain energy input.

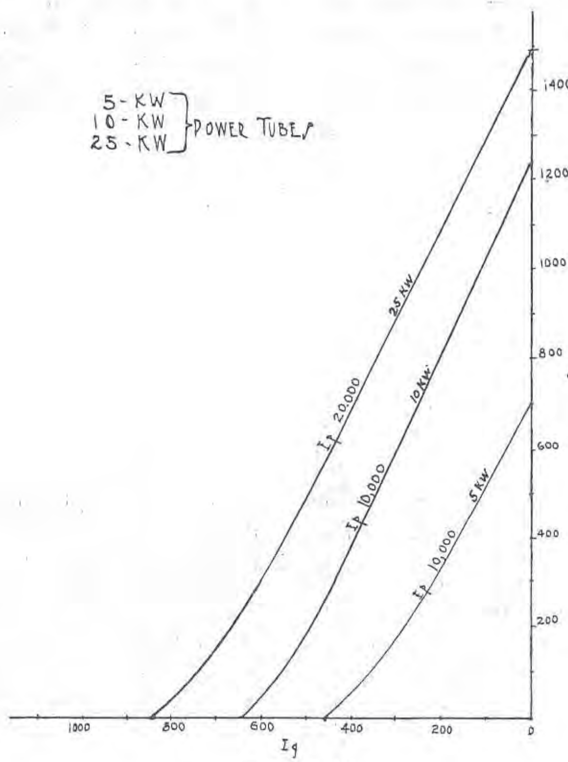


FIGURE 10

* Patent application, serial number 128,375 of October 30, 1916.

To facilitate the electron emission the cathode may be coated with oxides. By this method it is possible to reduce considerably the watts input to cathode and get the same emission. A cathode of this nature has smaller dimensions and therefore the means of support are simpler and the lead-in wires are made smaller. Since the voltage drop thru the cathode is limited, the leads to supply the energy to tungsten cathodes are large and unwieldy. Coated cathodes require either a much smaller lead-in wire or else the same lead-in wire will permit much larger electron emission. The writer will show below how the leads can be omitted altogether. This is accomplished by heating at radio frequency. A compact cylindrical cathode possesses all the advantages and none of the disadvantages of the usual type of cathode.

It is well known that at higher temperatures the escape of occluded gases destroys the vacuum. A coated filament will keep all parts of the tube below a safe temperature, that is, a temperature which will not liberate occluded gases.

A peculiar phenomenon has been observed where the filament supports were not specially treated. It appeared that as soon as heat was applied to the filament a certain amount of gas showed in the tube. This undoubtedly came from the supports. The gas was in only very minute quantities, yet it had a secondary effect on the filament. Hot spots appeared on the plate, presumably due to corresponding high temperature points on the filament. It is conceivable that the filament would undergo a bombardment by positive ions with a consequent volatilization of metal and creation of hot spots.

The presence of volatilization in a device which has a large coated cathode area many times larger than an ordinary tungsten filament would be quite minute. As previously mentioned, the presence of gases or positive ions is indicated by a grid current. To prevent the presence of positive ions and volatilization, it is quite necessary to have the metals free from gases before enclosing them within the vessel. This is accomplished by heating them up to approximately their melting point in a vacuum furnace.

The usual methods of heating the filament have been direct or alternating current. The use of radio frequency permits a number of changes in design, simplifying the structures and increasing the rigidity of filament. In order to obtain a strong filament construction able to withstand the ionizing forces and subsequent handling, a thick rugged filament is always used in high power tubes. This means a large heating current and thick lead-in wires to carry this current. The glass surrounding thick lead-in

wires is subject to severe strains, with liability to fracture. The employment of radio frequency cathode heating makes it unnecessary to carry heavy current thru the glass.

Figures 11 and 12 show two types of construction developed by the author, using radio frequency heating. In Figure 11 the coiled plate carries radio frequency current and induces by transformer action a large current in the centrally located cylindrical cathode. Figure 12 shows a separate inductor located on the outside of the tube and a cylindrical plate split in an axial direction. No lead-in wire is required in Figure 12. In Figure 11 only thin leads are necessary,—sufficient to carry current to induce heating in the cathode. By supplying a sufficient number of convolutions in the inductor the current thru the lead-in wires can be made very small.

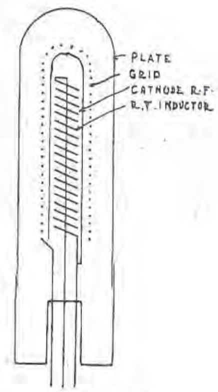


FIGURE 11
Interior of Inductor Heated Cathode Tube

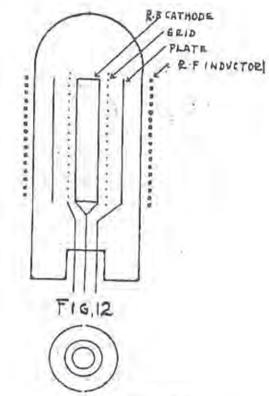


FIGURE 12
Plan of Exterior Inductor Heater Tube

Figure 12 is an example of an equi-potential electrode tube. Such a tube would possess marked advantages when used as an oscillator, power amplifier, or rectifier.

In Figure 13 is shown a rectifier having a plate and a tungsten filament. In this circuit it will be seen that the electron flow is densest towards the negative side of the filament. When the contact R is at the point V on the resistance VZ, the galvanometer G will register a slight thermionic current, but the latter will be very small. As R moved along VZ, this current is rapidly increasing, partly because a greater portion of the filament is coming under the influence of the plate and partly because the attractive force, represented by the plate potential, has also been increased.

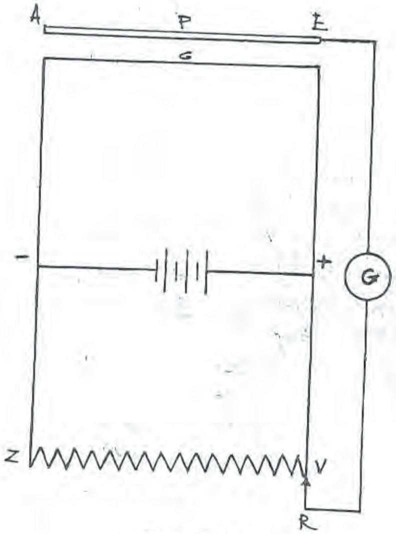


FIGURE 13

From the above consideration we see that:

(1) If an electrode within a vacuum is connected directly to the negative end of the filament, there will be no tendency for an electron flow to be established.

(2) If the electrode is connected directly to the positive end of the filament, electrons will flow from every part of the filament to it, since it is at a higher potential than the filament. Most of the electron current will come from the negative end of the filament since it is there that the potential difference between electrode and filament is greatest. The potential of the electrode will be positive and equal to the emf. across the filament.

(3) If the battery supplying the filament is shunted by a resistance which has a variable contact sliding along it, and the electrode is connected to the sliding contact, the potential of the former may be varied between zero and a positive value equal to the emf. of the battery. The electron flow to the electrode will gradually increase as the sliding contact is moved towards the positive end of the resistance.

The potential gradient along a filament is always a complication, altho practical advantage is often taken of it. It becomes a serious factor when the voltage across the filament is say 30 volts—as may be the case in a large tube. Another important effect is the variation of temperature along filaments.

Normally the temperature along a filament is uniform, except at the ends where cooling takes place. However, when there is a plate current, this current adds itself to the filament current and causes one half of the filament to be hotter than the other. This may be shown by arranging a circuit similar to the one shown in Figure 14. The plate circuit may be completed by closing a switch. Between the negative end *B* of the filament and the battery *A* is connected an ammeter G_1. Between *C* and *A* is another ammeter G_2.

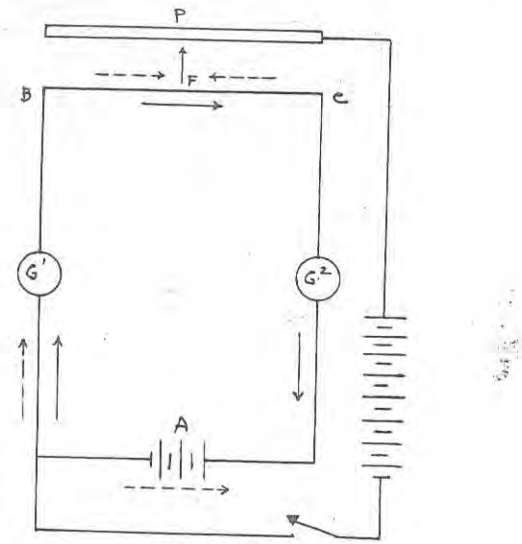


FIGURE 14

If we leave the switch open we will see that the filament current readings G_1 and G_2 are the same. Suppose the filament current flowing in the direction of the arrow-heads is 1 ampere as registered by both ammeters, on closing the switch it will be noticed that the reading in G_1 will increase above 1 ampere, while that of G_2 will decrease below that value.

The phenomenon is explained by the existence of an electron current in the plate circuit which flows round by *H* and the switch and divides at the connection to the filament. Part of the electron current flows via G_1 to the filament and thence to the plate, as shown by the dotted line arrow-heads. It therefore reinforces the filament current from the battery which is flowing in the same direction. Another portion of the thermionic current flows via *A*, G_2, *C*, the filament, and thence to the plate. This current opposes the existing filament current and causes a reduction in the

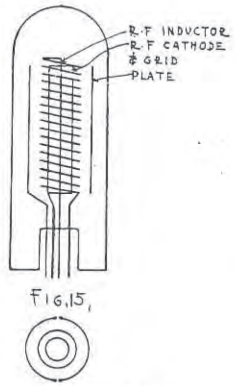


FIGURE 15
Plan of Grid Inductor Heater Tube

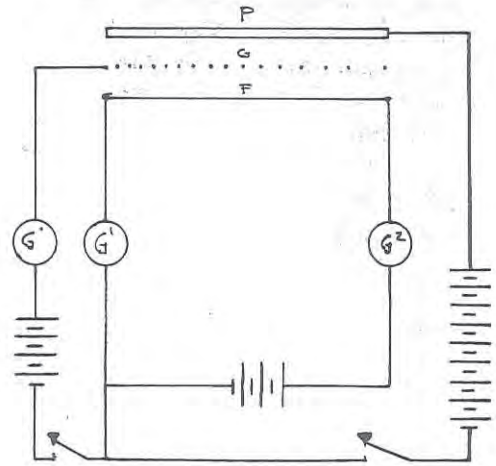
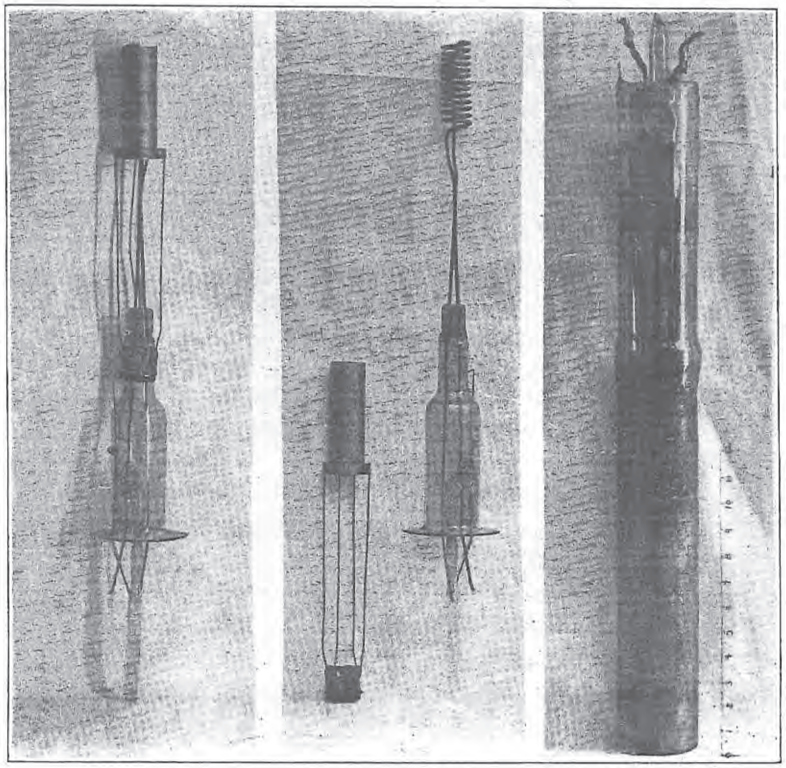


FIGURE 16
A Grid in a Tube which Has Filament Drop Should Be Spaced Accordingly



Radio Frequency Heated Cathode, Assembled — Radio Frequency Cathode — Radio Frequency Inductor — 100 Kilowatt Radio Frequency Heated Cathode Tube

FIGURE 17

current passing thru G_2. The result is that the negative half of a filament is always hotter than the positive half, no matter to which side of the battery the negative of the plate battery may be connected. In practice this peculiar effect is of no importance except when the temperature of the filament is already near melting point and the plate current great. Under such conditions the filament is likely to burn out when the plate circuit is completed.

From the above considerations the advantages of an equipotential emitting surface are evident.

The writer has constructed and operated tubes of this description. They show the possibilities of large electron emission and one line of future progress in high power tubes.

SUMMARY: The general scope of the paper covers the present day commercial tube; states the methods of design; and gives the general dimensions. It later brings forth an entirely new method for obtaining electron emission and control. This new method of heating provides means for heating sheets or discs of tungsten or other high temperature metals to incandescence, which sheets or discs are enclosed in evacuated vessels or ones containing gas.

The tubes in which the grids are made the inductor to heat the cathode provide a radio frequency method for shutting off the current twice per cycle, and gives a double frequency in the output circuit. By these new methods set forth in the paper, it is evident that the tube engineering art will be greatly benefited.