

# **SECTION I**

## **INTRODUCTION**

This handbook analyzes the operation of EIMAC power grid tubes and provides design and application information to assist the user of these tubes to achieve long tube life, maximum operating efficiency and circuit stability consistent with the full tube capacity.

THE CARE AND FEEDING OF POWER GRID TUBES has been prepared in answer to thousands of questions asked of the EIMAC engineering and laboratory staff over a period of years. Data contained in this volume represents the combined efforts of these staff members to provide meaningful information on all phases of the design of equipment using power grid tubes, and the techniques recommended for the application of power grid tubes in modern circuits.

EIMAC transmitting tubes are recommended for new equipment design and for replacement of older triode, tetrode and pentode tubes in the redesign of older equipment. Compact EIMAC tubes feature reduced internal coupling between input and output circuits, low internal inductance and capacitance, improved linearity and high operating efficiency. EIMAC tubes are built for long operating life and are rated for use well into the VHF region (and in the case of the external anode tetrodes and pentodes, well into the UHF region). EIMAC tubes are designed to withstand electrical and physical abuse and can operate under extreme environmental conditions. The high power gain and excellent efficiency of EIMAC tubes permits design of equipment that operate with a minimum of drive power, allowing a minimum number of stages to achieve the desired power level.

Circuit design and application information in this book are applicable to all EIMAC power grid tubes. For specific ratings, operating parameters and information dealing with particular tube types, refer to the technical data sheet and the Product

Test Specification sheet for the tube in question. The data sheet is generally supplied with the tube. Designers of new equipment are urged to use the Test Specification as well as the data sheet. The Test Specification sheet shows the limits on the range of the more important tube characteristics. Free copies of the data sheet or the Test Specification may be obtained upon request to: Power Grid Product Manager, CPI, EIMAC Division, 301 Industrial Road, San Carlos, CA, USA, 94070 or CPI A. G., Steinhauserstrasse, CH-6300 Zug, Switzerland.

For further technical information, contact EIMAC or your nearest CPI field sales office, listed on the inside rear cover of this publication.

## **SECTION 2**

### **WHAT IS A POWER GRID TUBE?**

A power grid tube is a device utilizing the flow of free electrons in a vacuum. It has an emitting surface called the cathode, and one or more grids controlling the flow of electrons. An element called the anode<sup>1</sup> collects the electrons. EIMAC manufactures gridded tubes which handle large amounts of power, as contrasted to receiving type tubes; hence, the term "Power Grid Tubes."

All gridded tubes must have a cathode and an anode. The general class of tube as described by the terms "triode," "tetrode," and "pentode" is determined by the total number of elements within the tube envelope. Therefore, these terms also indicate the number of grids. A triode has one grid, a tetrode has two grids, and a pentode has three grids.

### **2.1 TRIODES**

The total current flow from the cathode of a three-electrode tube is determined by the electrostatic field near the cathode. The electrostatic field is a function of  $E_c$ , the grid to cathode potential, and  $E_b/\mu$ , the potential due to the plate voltage electrostatic flux penetrating between the grid wires. The " $\mu$ ", or amplification factor, is a characteristic of a triode which in turn is a function of the physical size and location of the grid structure.

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<sup>1</sup> For the purpose of this book, the words 'anode' and 'plate' are used interchangeably. Some specialized tubes do not have plates (see IOT, Section 2.4). However, triodes, tetrodes and pentodes all have plates (or anodes).

The total cathode current of an ideal triode can be determined by the equation:

$$I_k = K \left( E_c + \frac{E_b}{\mu} \right)^{3/2}$$

$I_k$  = cathode current

$K$  = a constant determined by tube dimensions

$E_c$  = grid voltage

$E_b$  = plate voltage

$\mu$  = amplification factor of tube

One of the more important parameters of a triode is the amplification factor or “ $\mu$ ”. The  $\mu$  of a triode can be determined from the equation:

$$\mu = \frac{\Delta E_b}{\Delta E_c} \quad \text{with the plate current held constant}$$

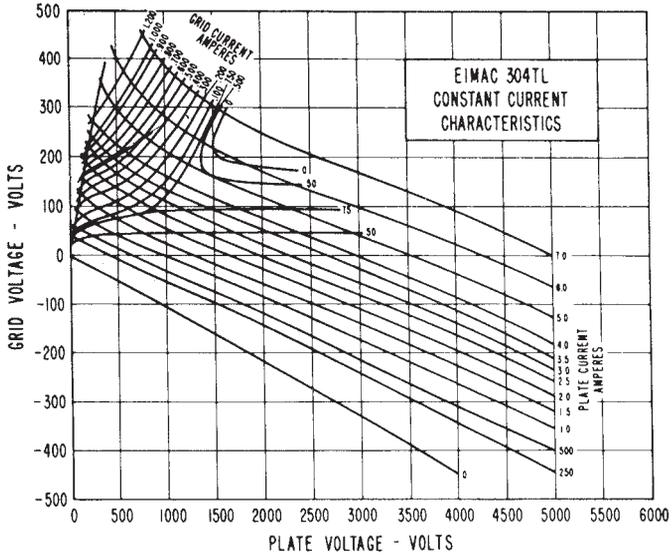
$\Delta E_b$  = change in plate voltage

$\Delta E_c$  = change in grid voltage

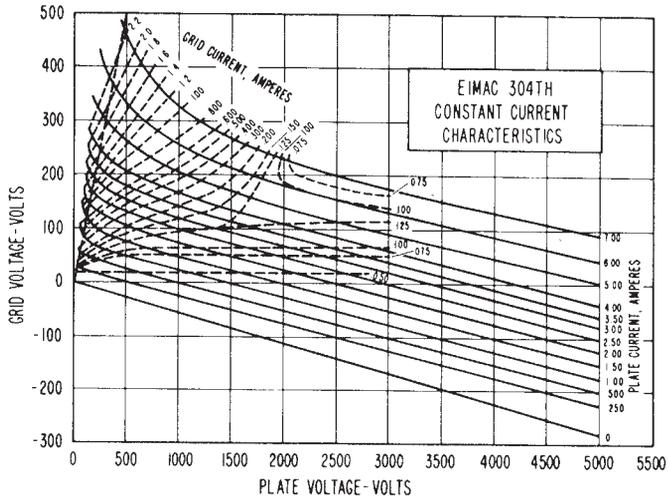
EIMAC manufactures triodes with  $\mu$  values ranging from 5 to 200. The low  $\mu$  tubes are generally used in audio service or any application which requires a large change in plate current without driving the tube into the positive grid region. The difference between a tube with a  $\mu$  of 12 and one with a  $\mu$  of 20 can be seen by comparing Figure 1 to Figure 2.

Observe how much more plate current at a given plate voltage can be obtained from the 304TL without driving the grid into the positive grid region. Note how much more bias voltage is required for the 304TL to cut the plate current off at some given plate voltage. With this increased bias there is a corresponding increase in grid voltage swing to drive up to the zero grid voltage point on the curve. Low  $\mu$  tubes have lower voltage gain by definition, and this fact can be seen by comparing Figure 1 and Figure 2.

Low  $\mu$  tubes also are an excellent choice for series pass tubes in a voltage regulator. They operate over a wide range of load current (pass tube plate current) with low plate voltage drop.



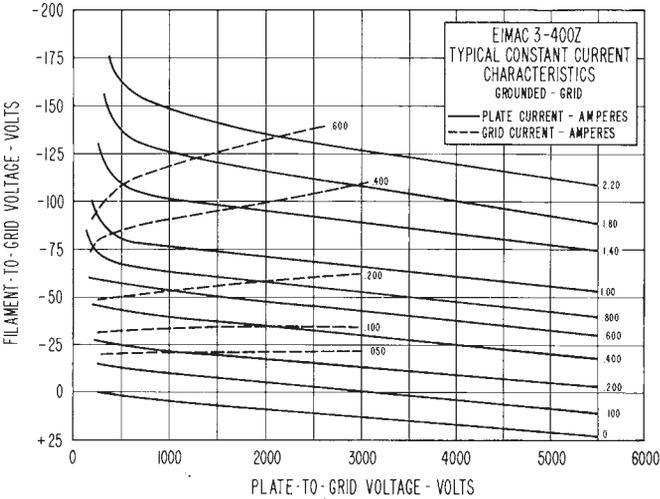
**Figure 1:** Constant current characteristics of a triode with a  $\mu$  of 12.



**Figure 2:** Constant current characteristics of a triode with a  $\mu$  of 20.

The medium  $\mu$ , (20-50) triodes are generally used in radio frequency amplifiers and oscillators. They are also good audio amplifiers and modulators.

The high  $\mu$  (200) triodes have been designed so that the operating bias is zero (See Figure 3). EIMAC has developed a line of zero-bias triodes with plate dissipation ratings of from 400 to 10,000 watts. The zero-bias triode is an excellent choice for grounded-grid radio frequency and audio frequency amplifiers. The main advantages are power gain and circuit simplicity. No bias supply is required. No protection circuits for loss of bias or drive are required.

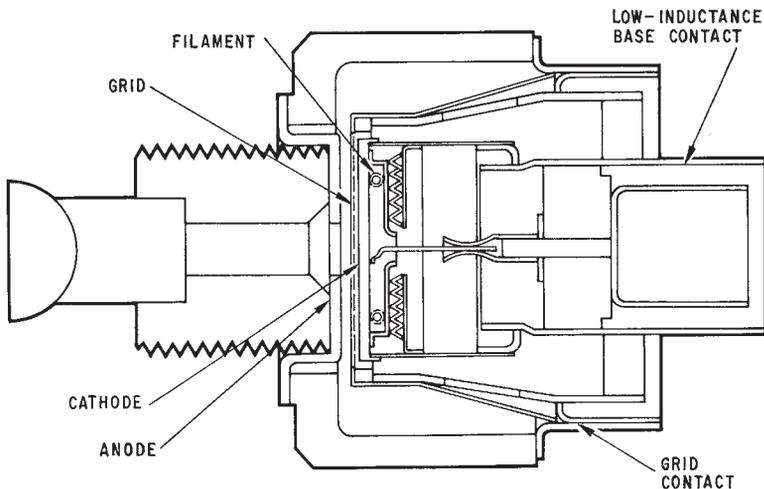


**Figure 3: A typical set of grounded-grid constant current curves for a zero-bias triode with a  $\mu$  of 200.**

Low and medium  $\mu$  rather than high  $\mu$  tubes are usually preferred for industrial heating applications, such as simple oscillators constructed for induction and dielectric heating. The low-to-medium  $\mu$  tubes are preferred because of the wide variation in load that an industrial heating oscillator normally works into. Low and medium  $\mu$  triodes have a much lower grid current variation with the changing load. The grid current of a triode with a  $\mu$  of 20 will rise far less than the grid current of a triode with a  $\mu$  of 40 under no load conditions. Very high  $\mu$  triode oscillators can be designed but extra consideration must be given to the grid current rise under the no load condition. EIMAC has developed a line of triodes specifically for industrial heating applications. These tubes have rugged mounting flanges and flexible filament leads for ease of mounting.

in the cooling or forced air cooling. The filament structures are large with adequate cathode emission. The grid structures are ruggedly constructed with ample dissipation capability. The grid must be rugged for industrial heating triodes because of the wide variations in load. As the load decreases the grid dissipation increases. A good industrial triode must therefore be capable of operating with a reasonably wide range of load variations.

Most of the triodes manufactured by EIMAC are cylindrically symmetrical. That is, the filament or cathode structure, the grid, and the anode are all cylindrical in shape and are mounted with the axis of each cylinder along the center line of the tube. Some triodes are manufactured with the cathode, grid and anode in the shape of a flat surface. The triodes so constructed are called "Planar" triodes (see Figure 4). This construction technique is necessary to provide very small spacings between the elements, and to achieve very short lead lengths within the tube. The very close spacings are necessary to reduce electron transit time\* and therefore allow the tube to be used at frequencies up to 3 GHz and higher. The short leads also increase the operating frequency by reducing lead inductance. Planar triodes are normally used in radio frequency amplifiers in both the continuous wave and pulse modes. The 3CX10OA5 and 8755 series triodes are representative of this type of tube. The contacting surfaces of the planar triode tubes are arranged for ease of design into coaxial and waveguide resonators.



**Figure 4: Internal configuration of a planar triode.**

\* See Section 6.8 (d)

## 2.2 BEAM TETRODE

The tetrode is a four-element tube with two grids. The control grid serves the same purpose as the grid in a triode while a second grid with the same number of bars as the control grid is mounted between the control grid and the anode. The grid bars of the second grid are mounted behind the control grid bars as observed from the cathode surface. Careful alignment of the grids is necessary to assure beam tetrode performance. The additional grid serves as a shield, or screen, between the input circuit and the output circuits of the tetrode, and is called a "screen grid." In addition to serving as a shield, the screen is the accelerating element attracting the electrons from the cathode. The total current from the cathode of a four-element tube is determined by the electrostatic field near the cathode, just as in the triode. The electrostatic field is a function of  $E_{c1}$ , the grid to cathode potential, and  $E_{c2}/\mu_s$ , the potential due to the screen voltage electrostatic flux penetrating through the control grid wires. The plate voltage also contributes a small amount in the ratio of  $E_b/\mu_p$ ;  $\mu_p$  is usually so large in value that the plate voltage contribution is negligible. In an ideal tetrode there will be no plate current change with a change in plate voltage. A tetrode is therefore a constant current device. The screen voltage and control grid voltage determine the amount of plate current that will flow.

The total cathode current of an ideal tetrode can be obtained by the equation:

$$I_k = K \left( E_{c1} + \frac{E_{c2}}{\mu_s} + \frac{E_b}{\mu_p} \right)^{3/2}$$

$I_k$  = cathode current

$K$  = a constant determined by tube dimensions

$E_{c1}$  = control grid voltage

$E_{c2}$  = screen grid voltage

$\mu_s$  = screen amplification factor

$\mu_p$  = plate amplification factor

$E_b$  = plate voltage

The arithmetic value of the screen  $\mu$  is generally not used in the design of radio frequency and audio frequency amplifiers.

In most tetrode applications the screen amplification factor is useful to roughly categorize the performance to be expected.

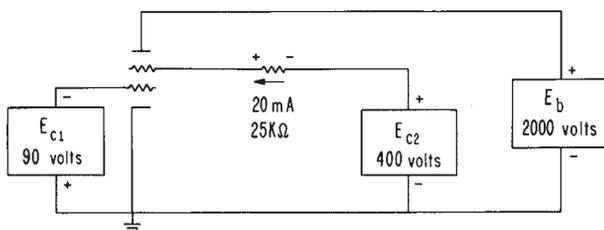
The main advantages of a tetrode over a triode are:

- a. Internal plate-to-grid feedback is much lower due to the shielding effect of the screen grid.
- b. Tetrodes permit the design of amplifier stages which can operate with driving power less than one per cent of the output power in most cases, and with negligible driving power in many audio applications.
- c. Tetrodes operate efficiently and with good life at audio and radio frequencies, including the VHF region (30 to 300 MHz) and in some cases into the UHF region (300 to 3000 MHz).
- d. Tetrodes allow designers to build compact, simple, flexible equipment with little spurious radiation.
- e. Tetrodes permit the designer to build linear amplifiers with low inter-modulation distortion products. (See Section 4.)

In designing equipment using power grid tubes, consideration must be given to unwanted electron emission from the control and screen grids. The grid materials will emit electrons as a primary emitter if the work function of the grid surface material is low enough. The grid must be at a sufficiently high temperature to emit electrons. Primary grid emission is usually quite low in a thoriated tungsten filament type tube, because grid materials can be used which have high work functions. Also, the work function normally does not change significantly during the life of the tube. In the case of the oxide cathode emitter, the grid materials find themselves in a totally different environment. During the life of the tube, free barium evaporates from the cathode coating material. The rate of evaporation is a function of time and cathode temperature. Some of the free barium finds its way to the control and screen grids, and thus the grid can then become another emitting surface. The hotter the grid, the more emission. Grids are often gold plated to reduce the amount of primary emission.

Another type of grid emission is secondary emission from the screen grid. The screen grid is operated at a relatively low potential, which is necessary to accelerate the electrons emitted from the cathode. Not all of the electrons pass through the screen grid on the way to the plate: some electrons are intercepted by the screen grid. In the process of striking the screen grid, other low energy electrons are emitted, and are called "secondary electrons." If these secondary electrons feel a stronger attraction by the screen, they will fall back into the screen. If, however, they find themselves out in the region between the screen grid and the plate, there is a very good chance

that the much higher plate potential will attract them. The result is an electron flow from screen to anode. The control grid is not in this region and so has virtually no control over the number of secondary electrons flowing. During any part of the operating cycle of the tube it is possible that more electrons will leave the screen grid than will arrive. If this occurs, a d-c current meter will indicate a reverse electron flow. On the other hand, if more electrons on the average are arriving than are leaving the screen grid, then the d-c screen meter will indicate a forward electron flow. Reverse screen electron flow is quite normal for high power tetrodes. The circuit designer must provide a low impedance path for the reverse electron flow. EIMAC normally states on the data sheet the amount of bleeding current that must be provided from the screen power supply to counteract the emission current (see Figures 5, 6 and 7). If the screen power supply impedance is too high in the reverse electron flow direction, the screen voltage will attempt to rise to the plate voltage. Note the emphasis on low impedance in the reverse electron flow direction. Most regulated power supplies are low-impedance in the forward electron flow direction only. If the supply is not well bled, the reverse electrons will try to flow from anode to cathode in the regulator series pass tube. As the screen voltage rises, the secondary and plate currents increase, and the tube is in a runaway condition.



**Figure 5:** Incorrect screen circuit for tube requiring low impedance screen supply.

### OBSERVATION

Assume that at some time during the tube's operating cycle, the reverse electron flow is 20 mA. The voltage drop across the 25 K resistor will be 500 volts. Note the polarities. The effective screen-to-cathode voltage will be 900 volts. The increased screen voltage will increase the secondary emission.

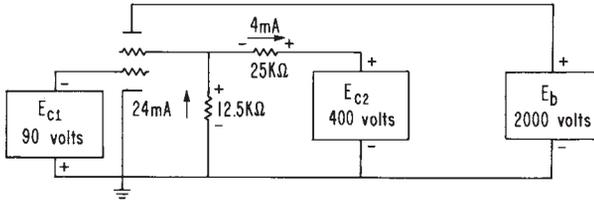


Figure 6: A correct screen circuit for tube requiring low impedance screen supply.

**OBSERVATION**

By the addition of a 12.5 K resistor from screen to ground, there will be a path for the grid emission 20 mA electron flow.

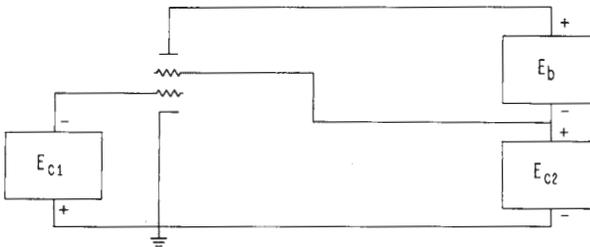


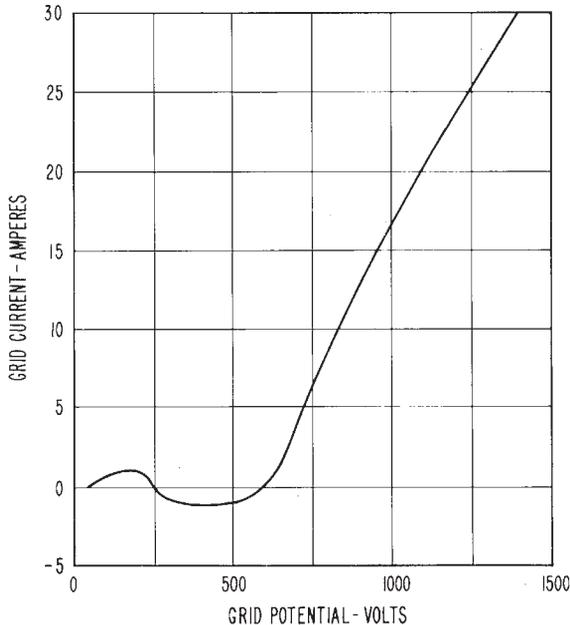
Figure 7: Another approach to swamping the screen circuit.

**OBSERVATION**

In the circuit of Figure 7, the plate current flows through the screen power supply, swamping the screen power supply. The screen power supply must carry the normal screen and plate current. This scheme is used quite extensively in circuits where the screen is operated at d-c ground. The plate to cathode voltage is the sum of the  $E_b$  and  $E_{c2}$  power supplies.

The circuit designer must also consider the impedance of the control grid circuit. Primary grid emission can cause trouble if the grid circuit has too high an impedance. Primary grid emission, in the case of oxide cathode tubes, will increase with tube life.

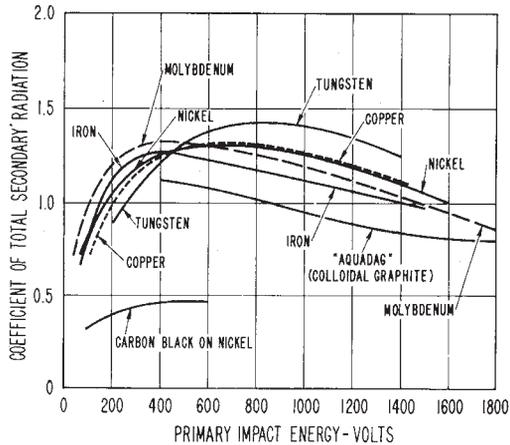
The size and power of gridded tubes dictate certain characteristics of electrical potential. As this geometry increases in electrical terms, secondary electron emission from the control grid can occur. The control grid secondary emission can be present whether the cathode is a thoriated tungsten or an oxide emitter, and can occur in a triode, tetrode or pentode. A typical curve of grid current as a function of grid voltage for a high power thoriated tungsten filament tetrode is shown in Figure 8.



**Figure 8.** Typical curve of grid current as a function of control grid voltage for a high power thoriated tungsten filament tetrode.

### **OBSERVATION**

In Figure 8, grid current decreases and eventually takes a reverse direction as the grid voltage increases. This reduction and reversal of grid current can be explained by the normal secondary emission characteristics of the metals used in the grid structure. In Figure 9 we see the secondary characteristics of the common metals presented in curve form, giving the ratio of secondary-to-primary electron current as a function of the primary electron potential.



**Figure 9.** Secondary-emission characteristics of the metals under ordinary conditions. The curve shows the ratio of the number of secondary to primary electrons for various primary-electron impact velocities expressed in volts. (After Harries.)

### OBSERVATION

A study of Figure 9 shows the region between 200 and 600 volts to be a rather critical one as far as secondary emission is concerned. Any power grid tube which normally operates with 200 to 600 volts on the grid can exhibit the negative resistance characteristic of decreasing grid current with increasing grid voltage when another electrode, such as the anode in a triode or the screen grid in a tetrode, is at a sufficiently high potential to attract the emitted electrons. A driver stage which works into such a non-linear load normally must be designed in such a manner as to tolerate this condition. One technique would be to swamp the driver so that the change in load due to secondary grid emission is a small percentage of the total load the driver works into.

### 2.3 PENTODES

The pentode is a five-electrode tube; it has three grids. The control grid and screen grids perform the same function as that in the tetrode. The third grid, the suppressor grid, is mounted in the region between the screen grid and the anode. The suppressor grid produces a potential minimum in the plate-screen space. This potential minimum prevents secondary electrons from being interchanged between screen and plate.

Following the analogy with the tetrode tube, the electrostatic field at the surface of the cathode is proportional to the plate voltage in a pentode.

The plate voltage in a pentode has even less effect on the total space current than in the tetrode. The same total space current equation holds:

$$I_k = K \left( E_{c1} + \frac{E_{c2}}{\mu_s} \right)^{3/2}$$

The suppressor grid may be operated negative or positive with respect to the cathode, and may be operated at cathode potential. It is possible to control the plate current by means of adjusting the suppressor grid potential. Because of this characteristic, it is possible to amplitude modulate an amplifier by applying the modulating voltage to the suppressor grid. The modulating power will be quite low because of the very low electron interception of the typical suppressor grid.

The main advantages of a pentode are:

- a. Secondary emission effects reduced.
- b. An approach to better linearity when used in linear amplifier service.
- c. It is possible to swing the plate voltage below the screen voltage without exceeding screen dissipation. This characteristic sometimes allows slightly higher power output for a given plate voltage.

Since the suppressor grid reduces the effects of secondary emission, screen grid power supply requirement to provide a reverse electron flow path may be reduced. The screen current requirement for a pentode may be somewhat higher than that for a tetrode of the same general characteristics; control grid power supply requirements will be the same as outlined for tetrodes.

## **2.4 INDUCTIVE OUTPUT TUBE (IOT)**

The Eimac Division of CPI, Inc. invented and pioneered the introduction of the one of the most significant energy efficient tubes, the IOT. Originally it was used mainly in UHF TV broadcasting, but has since then found applications in industrial and scientific markets.

### **2.4.1 The History of the IOT**

During the 1930's, the state of the art in transmitting and receiving tubes had attained a maturity and cost-effectiveness that served

most needs of contemporary radio communications. Thus, research attention turned to higher frequencies, which offered advantages that later culminated in the development of the now common place applications such as television and radar.

With the move to higher frequencies, conventional transmitting tubes decreased in size. Power densities rose and materials technology became the limiting factor in generating high output powers. As a consequence of this limitation, most designers began to look for newer approaches and turned away from the classical gridded density modulated tubes. However, two innovators continued to do research on gridded tubes. They were A. V. Haeff and L. Nergaard, who were then working for RCA in Harrison, NJ.

What Haeff and Nergaard observed was that a major power output limitation was due to wasted power dissipation by the grids and anodes of then present-day tubes. They perceived that if non-intercepting electrodes (apertures, for example) could replace wire grids, and the electron beam could be contained by a coaxial magnetic field, more efficient, and higher power levels could be produced.

Similar to the developers of the klystron, they saw that power could be removed from a bunched electron beam as it passed through a resonant cavity in which the kinetic energy of the high velocity electron beam could then be transformed to electromagnetic energy. This had the benefit of eliminating the need to collect the electrons on the walls of the cavity and generate wasted heat

Invented by Haeff, the inductive output tube (IOT) - precursor of the current day IOT- was first described by him in 1939 (*Electronics*) and again, with Nergaard, in 1940 (*Proceedings IRE*). When built, the tube delivered 100W CW at 450 MHz, with a 10 dB power gain and 35% efficiency - remarkable performance for its time! Unfortunately for the IOT, in W.W.II, VHF triodes and magnetrons became popular. These developments were followed by increased interest in velocity modulation tubes like the klystron. The IOT concept was not implemented until the 1970's when Eimac engineers M. B. Shrader and D. H. Preist, in the search for new ways to improve Television transmission devices, independently resurrected the tube.

In the early 1980's Shrader and Preist presented the first experimental results for the IOT. Eimac named the device the Klystrode® IOT - a name coined by realizing the device had the properties of a **klystron** as well as a **tetrode**. Eimac received several patents on the device in 1982 and 1984. With these promising

successful experiments the development of broadcast television Klystrode IOTs began. By the late 1980's, Varian's Eimac Division had developed a full line of Klystrode IOT amplifiers in 15, 40, and 60 kW peak power output versions for UHF broadcast and 250 kW CW and 500 kW peak power devices for scientific applications. Present day UHF-TV IOT amplifiers are capable of up to 130 kW peak power for both digital and NTSC television service.

Present day IOT amplifiers consist of both the Inductive Output Tube (IOT) and cavity hardware (see figure 10). The hardware has an input cavity that is usually driven by a wide-band solid-state driver. The input is tuned by varying the input cavity dimensions and is matched to the driver with a stub tuner. The IOT forms a density modulated linear beam that traverses a short drift tube and is coupled to the output cavities at the tube's output gap. The kinetic energy of the high-velocity beam at the output gap is transformed to electromagnetic energy in the primary output cavity. A secondary cavity creates an over-coupled double-tuned response to obtain the 7 to 9 MHz bandwidth needed for UHF-TV application. The amplified RF signal is then coupled to the antenna system by a probe in the secondary cavity. The spent beam is intercepted by the water-cooled collector and is dissipated as heat.

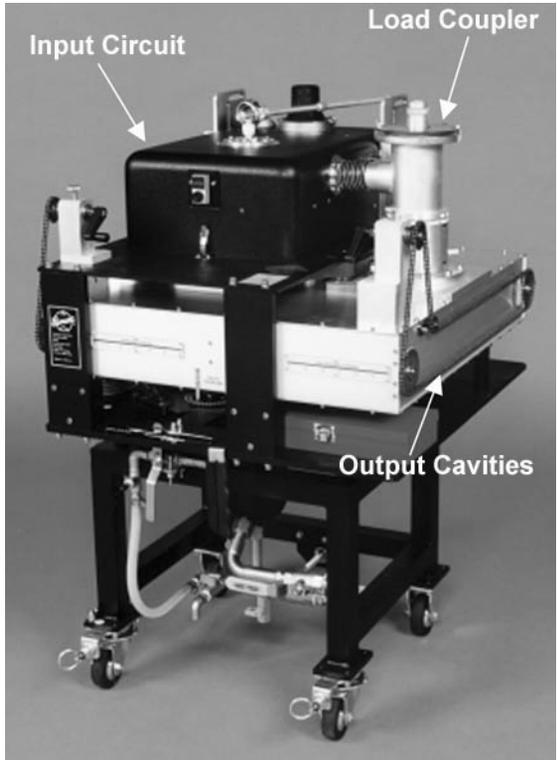
## 2.4.2 IOT System Considerations

UHF-TV IOT systems operate at between 27 kV and 38 kV anode accelerating voltage. The anode and collector are at ground potential with the cathode operated at - 27 to -38 kV with respect to the anode. With these potential levels, consideration has to be given to high voltage arcing . The small interior volume of the IOT requires that the tube be protected from internal arcs. This arc protection is accomplished by crowbar circuitry, which monitors any sharply increased cathode current and causes either a thyatron or spark gap to conduct the arc energy directly to ground, diverting an arcing event from being absorbed by tube components.

Early IOT amplifiers were completely air-cooled. However, with the trend to higher power, a combination of air and water cooling is used. Generally, the cathode, grid, input cavity and output cavities are air-cooled. The collector is usually water-cooled (or a 50% water/glycol mixture). Higher power amplifiers may also require water cooling of the IOT anode and/or output cavity assemblies. New developments in multi-staged, depressed collector IOTs may require oil, deionized water or other collector cooling schemes.

## 2.4.3 IOT System Description

The major assemblies of an IOT are the gun, anode, output gap and collector assemblies (see Figure 11). The gun assembly includes the source for the electron beam and the control grid. The geometry of these components starts shaping the electron beam. A major component of the anode assembly is the drift tube through which the modulated, laminar beam is directed. Ideally, the anode intercepts none of the beam current.



**Figure 10: Eimac K2 IOT Amplifier**

IOT electron emission starts with an indirectly heated dispenser cathode. The cathode is concave, which in conjunction with the corresponding anode and focus electrode geometry starts shaping and focusing the electron beam to pass through the drift tube in the anode on its way to the output gap. An applied magnetic field aids in keeping the beam coherent through the drift tube and output gap.

A pyrolytic graphite control grid is mounted in very close proximity

to the cathode. This grid must conform to the cathode radius with a very high degree of accuracy. Pyrolytic graphite is used for the grid because it is a rugged material that can handle high operating temperatures while retaining its shape. Pyrolytic graphite grids are formed by depositing a graphite cup on a mandrel in a high-vacuum, high-temperature furnace. The graphite cups are then cut with a laser beam to form the final grid.

The cathode is operated at  $-27$  kV to  $-38$  kV with respect to the anode. The grid is biased from  $-45$  to  $-80$  Volts with respect to the cathode. The level of grid bias determines the operating mode of the IOT amplifier.



**Figure 11: Eimac K2 Inductive Output Tube**

An RF signal is coupled between the cathode and grid, causing the electron beam to be density modulated. The focused and modulated beam then goes through the drift tube in the anode to the output gap where the kinetic energy of the beam is converted into electromagnetic energy in the output cavities.

Typical IOT conversion efficiencies at peak power can be in the range of 30 -55%, depending upon the type signal. This means that the remaining 70-45% power in the lower power, spent beam will be dissipated as heat in the collector. This heat is carried away by water cooling the collector.

The IOT hardware consists of three basic active parts, the input tuning section, the output cavities and the output load coupler. The hardware also provides for air and water cooling of the IOT and cavity systems. Additionally, the hardware frame is part of the IOT focus magnet frame.

The input circuit is designed to cover the full UHF (470-860 MHz) frequency band. It forms a resonator, which imparts a RF field between the cathode and grid of the IOT. A paddle inside the cavity and a shorting stub on the top portion of the input circuit are adjusted for resonance and impedance matching at the desired frequency. Shorting pins are used in the input resonator to determine the range covered by the paddle tuner. DC electrical connections for the heater, cathode, grid and vac-ion pump are located in the input circuit assembly.

The output cavity assembly has a primary and secondary cavity. An adjustable iris opening capacitively couples these cavities. Both the primary and secondary cavity walls are movable to make the output circuit resonant at a selected frequency within the UHF TV band. The bandwidth of the system is adjusted by the position of the iris paddle.

Energy in the secondary output cavity is extracted through a coaxial probe located in the secondary cavity. Adjustment of the output probe depth controls the secondary cavity loading.

#### 2.4.4 IOT Tuning

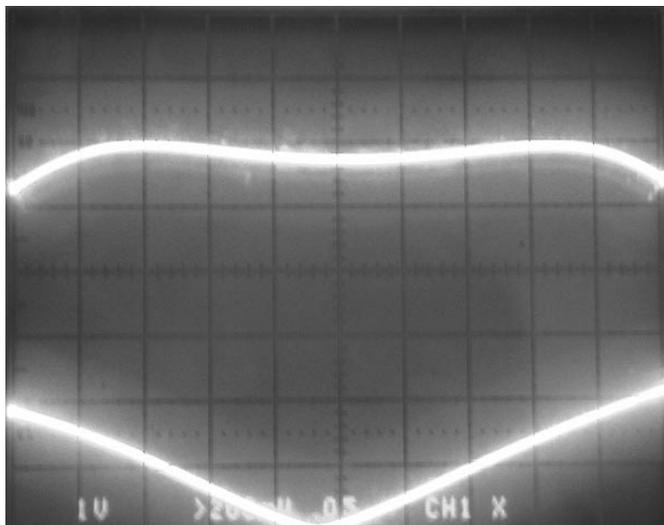
Eimac Inductive Output Tubes use dispenser type cathodes that are indirectly heated. This requires a warm-up period for the cathode heater before high voltage is applied to the IOT. When the cathode heater is first switched on, the heater current must be limited to 15 Amps maximum. As the heater warms up, the heater current will stabilize at approximately 8.0 to 9.0 amps. The heater power should be nominally 80 Watts at normal operating temperatures. Once the heater current is stabilized, the high voltage may be applied between the cathode and anode.

Grid bias should be adjusted to obtain a quiescent (no RF) grid current of 400 to 800 mA. The quiescent grid current will determine the basic operating mode of the IOT amplifier (class A, B, AB, C). Class AB is the usual TV mode of operation.

It is important to remember that input RF power should be limited until coarse tuning of both the input and output cavities is finished.

This prevents trying to dissipate too much power in the collector.

Input tuning of the IOT amplifier is best accomplished using a sweep generator and spectrum analyzer as instrumentation. The sweep generator is set at the center frequency of the channel being tuned. The sweep width is adjusted between 10 MHz to 25 MHz. The wider bandwidth is used for rough tuning, with the narrower bandwidth being used for final adjustments.



**Figure 12:** Typical tuning curves for UHF TV IOT. The lower curve is the reflected drive signal. The upper curve shows the output tuning.

The frequency range of the input cavity is determined by shorting pins in the cavity. Normally, this range is set at the factory and requires change only if the TV channel will be changed. Fine tuning of the input frequency is accomplished by a ten-turn adjusting knob on the front of the input circuit assembly. The input is matched to the drive with a stub tuner (see figure 12 for an example of input tuning using the reflected drive signal. The lowest part of the reflected signal is generally set at the center frequency of the channel. The stub tuner is set to obtain the deepest response of the reflected signal. )

For output tuning, the spectrum analyzer is connected to the sampled output power of the transmitter. Basically, the primary output cavity tuning controls low frequency side of the pass band and the secondary cavity tuning controls the high frequency side of

the bandpass signal. The iris coupler between the cavities controls the bandwidth and the load coupler adjustment controls the dip in the middle of the signal (see figures and ).

## **2.5 MULTISTAGE DEPRESSED COLLECTOR IOT (MSDC IOT)**

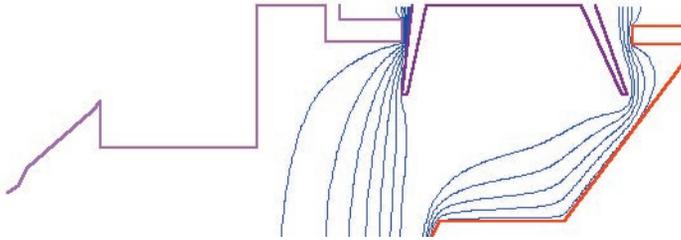
Because of significantly higher efficiency, i.e., the ratio of RF power out to total input power is higher than other amplifier types, standard IOT amplifiers have almost completely replaced previous types of power amplifiers for high power UHF broadcast transmitters. Higher efficiencies result in lower electricity usage. One way of further increasing the efficiency of IOT amplifiers is multistage depressed collector technology.

A portion of the IOT's electron beam is not converted to RF energy at the output gap of the tube. This portion is called the spent beam. The spent beam can be between 50% to 70% of the total beam power.

This spent beam is directed to a collector, where most of the electron energy is dissipated as heat. This heat is wasted power, which can be partially recovered.

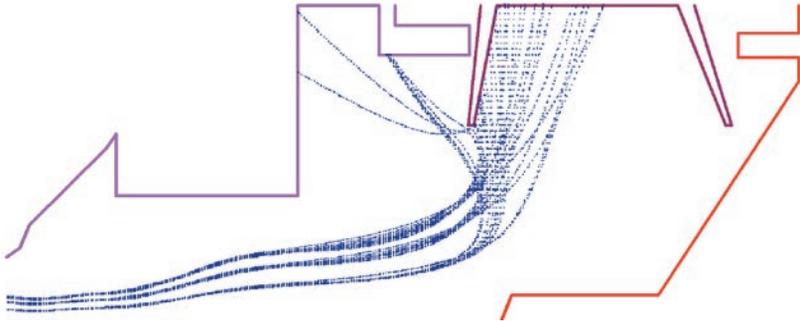
Multistage depressed collector Inductive Output Tubes slow down electrons before they strike the surface of the collector, thereby, allowing recovery of electrical power from the spent beam instead of generating heat. Basically, the collector is divided into one or more stages that are biased at increasing percentages of the cathode to anode potential. All of these stages are at a lower voltages than the cathode to anode voltage. Therefore, they are called depressed voltages or depressed collectors. These depressed voltages set up equipotential fields in the collector that slow down electrons in the spent beam (see figure 13). Ideally, the electrons are nearly stopped when they strike the collector (see figures 14 & 15).

The number of depressed collectors and the voltages on the collectors is highly dependent upon the distribution of electron velocities in the spent electron beam. IOTs have a very uniform electron energy distribution in their spent beam. This is largely because of the more efficient density modulation (as opposed to bunching ) used for IOTs. The result is that excellent power recovery can be accomplished with few depressed collector stages.



**Figure 13: Equipotential Lines in a three stage collector. The potentials are determined by collector geometry and collector voltages.**

Ultimately, the number of collector stages used is a trade-off between the efficiency gained and the complexity of the power supply and tube fabrication. Multistage depressed collector

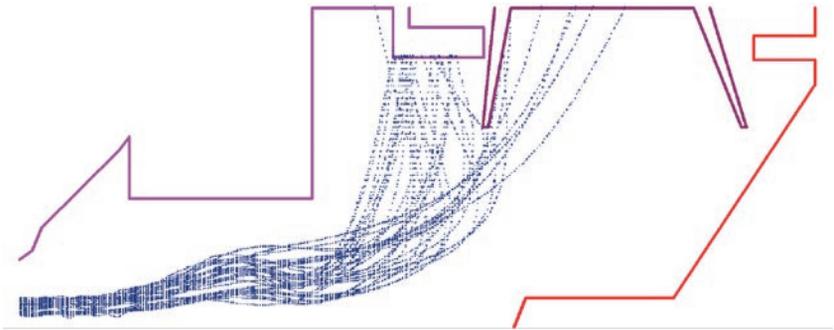


**Figure 14: Electron trajectories at near to ideal power. The tube gap is at the left side of the image, which is only half the collector. The right collector element is at cathode to anode potential. The middle section is approximately half the cathode voltage. The left side collector element could be at ground potential.**

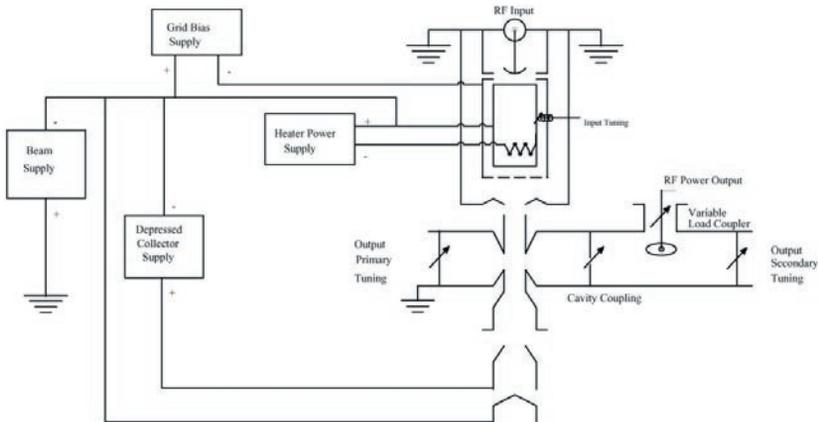
Inductive Output Tubes have been demonstrated with three to five stages. Adding additional stages brings very little more efficiency gain.

One of the consequences of depressed collector design is more complex collector cooling considerations. Standard IOTs have a single collector at ground potential. This type of collector can be directly cooled by water or a water/glycol mixture. The MSDC IOT has several collector stages at differing voltages ranging from ground to cathode potential. Cooling these collector stages requires some dielectric material to carry the heat away from the

collector. MSDC collectors are commonly cooled by using air, deionized water or dielectric oil.



**Figure 15:** Electron trajectories at higher than ideal power. Less power is recovered in the middle, depressed collector segment.



**Figure 16:** Typical MSDC IOT power supply schematic

## 2.6 CATHODE EMITTERS

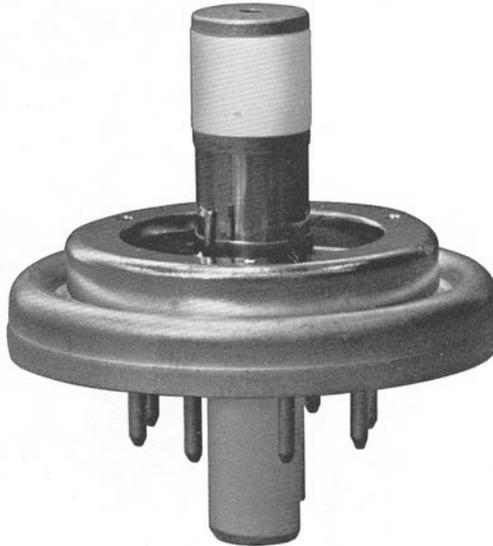
### 2.6.1 Oxide Cathodes

The typical production-type oxide cathode is a coating of barium and strontium oxides on a base metal such as nickel. The oxide layer is formed by first coating a nickel can or disc with a mixture of barium and strontium carbonates, suspended in a binder material. The mixture is approximately 60 per cent barium carbonate and 40 per cent strontium carbonate. During vacuum processing of the tubes, they are baked out at high temperature. The binder is burned

away, and the carbonates are subsequently reduced to oxides. The cathode is now “activated” and will emit electrons. The typical oxide cathode operates at 1000° Kelvin and is capable of roughly 200 to 300 mA per cm<sup>2</sup> at a typical emission efficiency of 200 to 300 mA per watt of heater power. The high emission current capability for each watt of heating power is one of the main advantages of the oxide cathode. Other advantages are high peak emission capability for short pulses and a low operating temperature.

Oxide cathodes are susceptible to deterioration due to ion bombardment; oxide-cathode tubes are usually limited in plate voltage because of this characteristic. Fortunately, high voltage is very seldom needed because of the high currents available at low voltage.

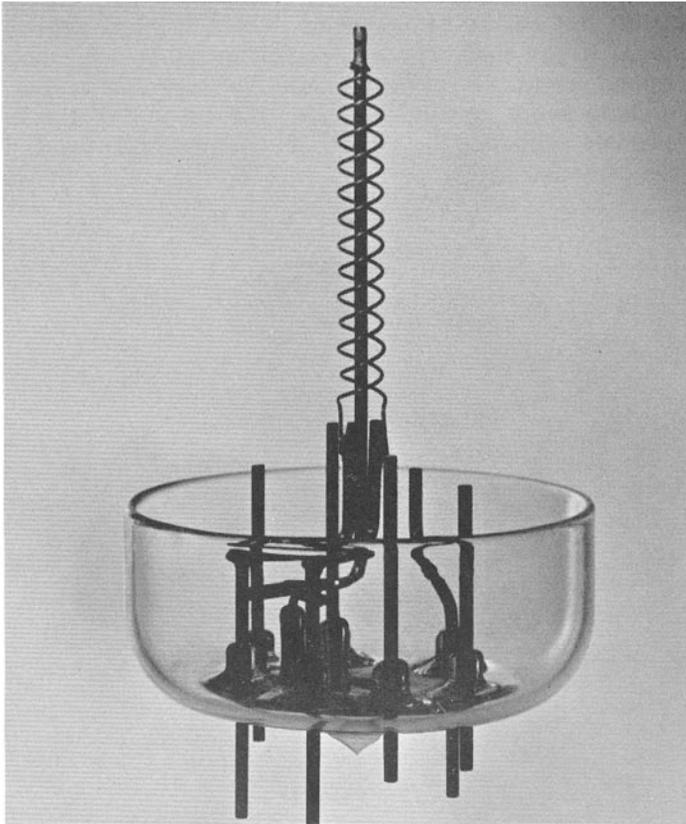
The oxide cathode material will evaporate during the life of the tube, causing free barium to migrate to other areas within the tube. The evaporation can be minimized in the design by means of a high efficiency cathode which runs as cool as possible but still is not emission-limited at the desired heater voltage. In the field, the heater voltage must not exceed the designed value. An oxide cathode which is overheated gives very little more useful emission, but the life of the tube is shortened significantly. Figure 17 is representative of an oxide cathode.



**Figure 17:** Typical oxide cathode.

## 2.6.2 Thoriated Tungsten Filaments

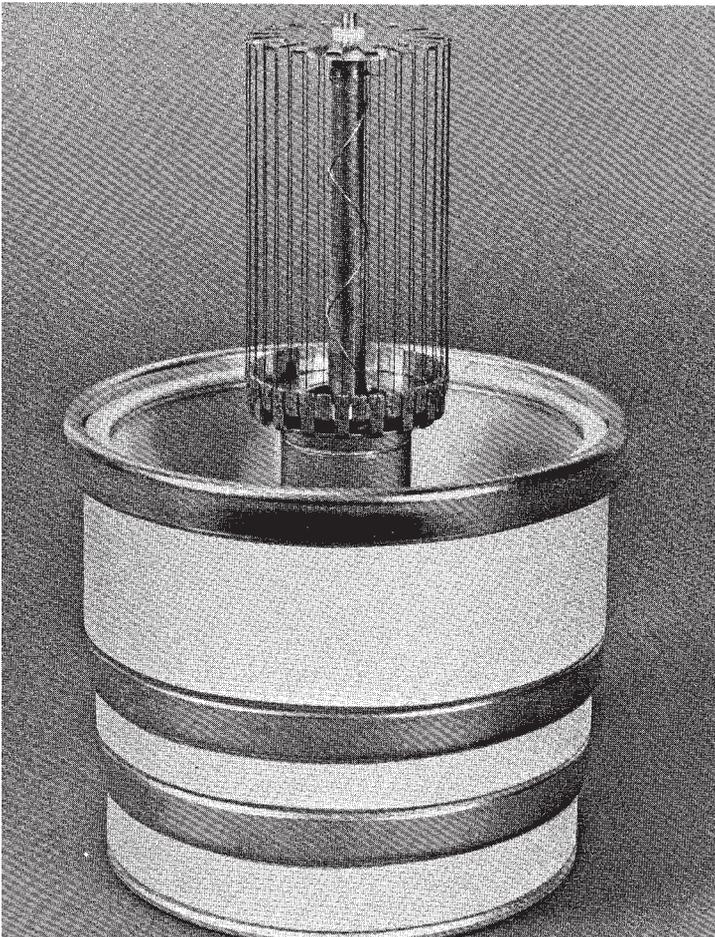
A thoriated tungsten filament is one form of an atomic-film emitter. Thorium is added to the tungsten in the process of making tungsten wire. Typically, about 1.5 per cent of thorium in the form of thoria (thorium oxide,  $\text{ThO}_2$ ) is added. By proper processing during vacuum pumping of the tube envelope, the metallic thorium is brought to the surface of the filament wire, and emission increases approximately 1000 times. The thoriated tungsten filament is also carburized. The small amount of tungsten carbide formed in the carburizing process reduces the evaporation rate of the thorium and thus increases the life of the filament. At a typical operating temperature of approximately  $1900^\circ \text{K}$ , a thoriated tungsten filament will produce a specific peak emission of about 70 to 100 mA per watt of filament heating power. This is normally



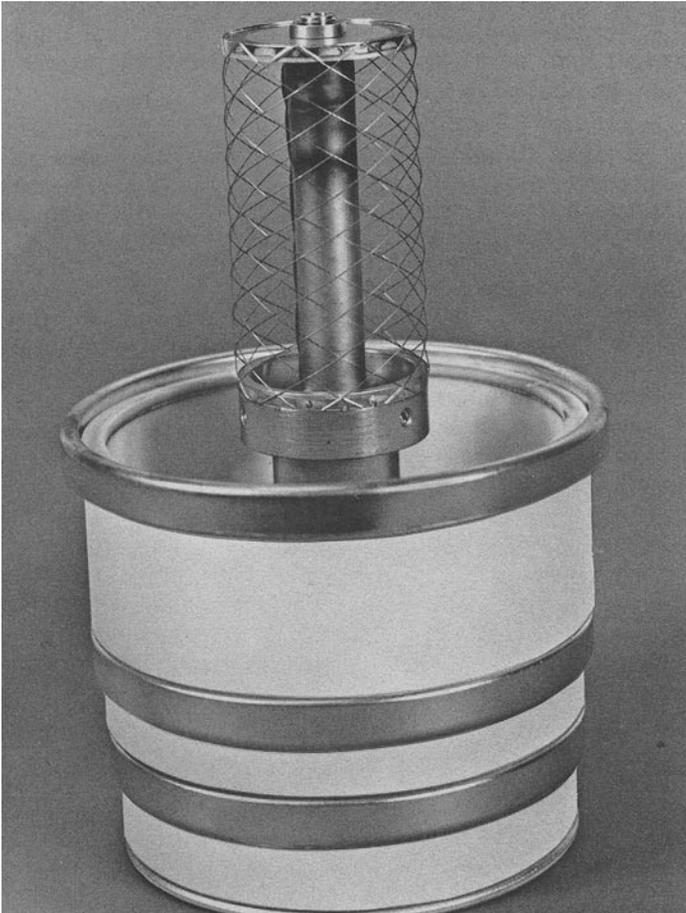
**Figure 18:** Typical spiral tungsten filament.

5 to 10 mA of CW plate current per watt of filament power. A thoriated tungsten filament is more tolerant of ion bombardment than an oxide cathode, and, therefore, higher voltages can be applied to the tube.

Thoriated tungsten filaments can be assembled in several different configurations. Figures 18, 19 and 20 show typical spiral, bar and mesh filament construction techniques. The spiral filament is used quite extensively in the lower power tubes. As the size of the tube increases, mechanical considerations dictate the bar filament construction technique with spring loading to compensate for thermal expansion. The mesh filament can be used on both small and larger tubes, and is more rugged, therefore, less subject to damage from shock and vibration.



**Figure 19: Typical bar tungsten filament**



**Figure 20.** Typical mesh tungsten filament.

### 2.6.3 Gun Type Emitters

Some power grid tubes are designed as a series of electron gun structures arranged in a cylinder around a center line. This type of construction allows large amounts of plate current to flow and be controlled with a minimum amount of grid interception. With reduced grid interception, less power is dissipated in the grid structures. In the case of the control grid, less driving power is required.