

RCA  
RECEIVING  
TUBE  
MANUAL

# *RCA Receiving Tube* **MANUAL**

THIS MANUAL like its preceding editions has been prepared to assist those who work or experiment with electron tubes and circuits. It will be found valuable by engineers, service technicians, experimenters, students, radio amateurs, and all others technically interested in electron tubes.

The material in this edition has been augmented and revised to keep abreast of the technological advances in electronic fields. Many tube types widely used in the design of new electronic equipment prior to 1950 are now chiefly of renewal interest, in their place, new advanced types are being used. Consequently, in the Tube Types Section, the presentation on the older types has been limited to essential basic data while detailed information has been given on the newer more important types.

In addition to the tube types for home-entertainment use covered in this Manual, the ELECTRON TUBE DIVISION of RADIO CORPORATION OF AMERICA offers other small receiving-type tubes for industrial and specialized applications, such as the "Special Red" tubes, premium tubes, computer tubes, voltage regulators, acorn tubes, and pencil tubes. Other lines of RCA electron devices include:

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## **SPECIAL TYPES**

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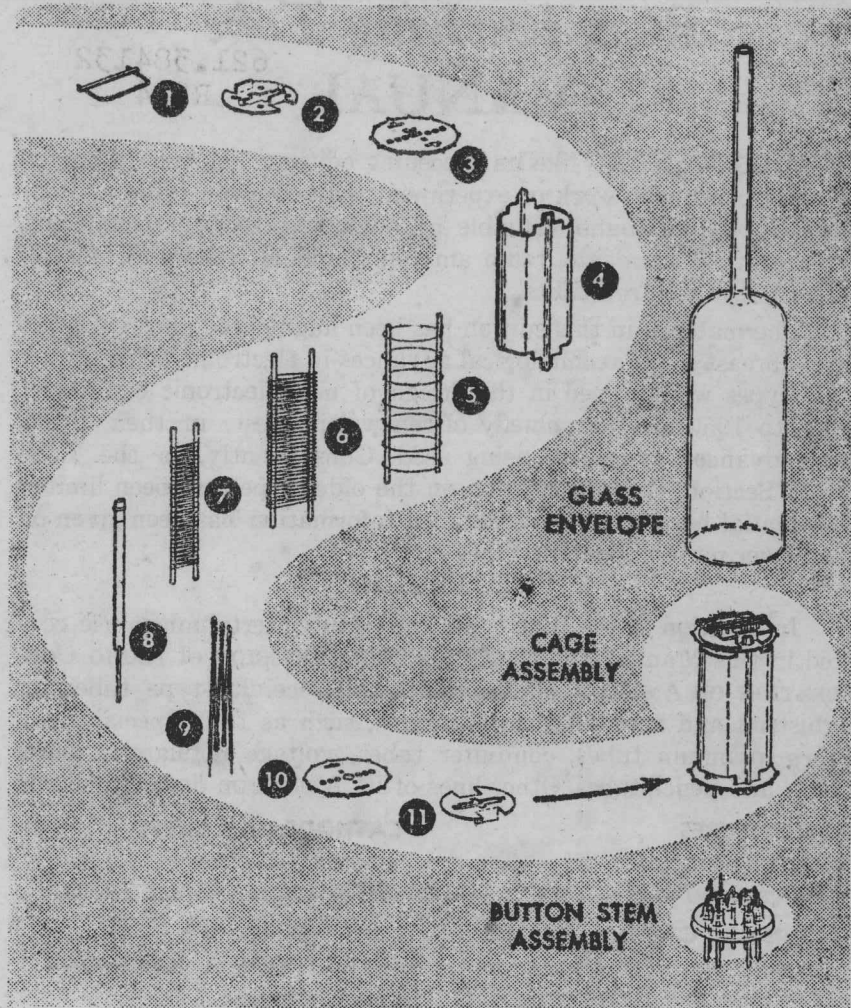
## **SEMICONDUCTOR DEVICES**

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**ELECTRON TUBE DIVISION  
RADIO CORPORATION OF AMERICA  
Harrison, N. J.**



### CAGE PARTS

- |                       |                                    |                          |
|-----------------------|------------------------------------|--------------------------|
| 1. Getter and Support | 5. Grid No. 3<br>(Suppressor Grid) | 8. Cathode               |
| 2. Top Spacer Shield  | 6. Grid No. 2<br>(Screen Grid)     | 9. Heater                |
| 3. Insulating Spacer  | 7. Grid No. 1<br>(Control Grid)    | 10. Insulating Spacer    |
| 4. Plate              |                                    | 11. Bottom Spacer Shield |

## The Parts of a Miniature Pentode

# RCA Receiving Tube MANUAL

## Electrons, Electrodes, and Electron Tubes

The electron tube is a marvelous device. It makes possible the performing of operations, amazing in conception, with a precision and a certainty that are astounding. It is an exceedingly sensitive and accurate instrument—the product of coordinated efforts of engineers and craftsmen. Its construction requires materials from every corner of the earth. Its use is world-wide. Its future possibilities, even in the light of present-day accomplishments, are but dimly foreseen; for each development opens new fields of design and application.

The importance of the electron tube lies in its ability to control almost instantly the flight of the millions of electrons supplied by the cathode. It accomplishes this control with a minimum of energy. Because it is almost instantaneous in its action, the electron tube can operate efficiently and accurately at electrical frequencies much higher than those attainable with rotating machines.

### Electrons

All matter exists in the solid, liquid, or gaseous state. These three forms consist entirely of minute divisions known as molecules, which, in turn, are composed of atoms. Atoms have a nucleus which is a positive charge of electricity, around which revolve tiny charges of negative electricity known as electrons. Scientists have estimated that electrons weigh only 1/30-billion, billion, billion, billionths of an ounce, and that they may travel at speeds of thousands of miles per second.

Electron movement may be accelerated by the addition of energy. Heat is one form of energy which can be conveniently used to speed up the electron. For example, if the temperature of a metal is gradually raised, the electrons

in the metal gain velocity. When the metal becomes hot enough, some electrons may acquire sufficient speed to break away from the surface of the metal. This action, which is accelerated when the metal is heated in a vacuum, is utilized in most electron tubes to produce the necessary electron supply.

An electron tube consists of a cathode, which supplies electrons, and one or more additional electrodes, which control and collect these electrons, mounted in an evacuated envelope. The envelope may be made of glass, metal, ceramic, or a combination of these materials.

### Cathodes

A cathode is an essential part of an electron tube because it supplies the electrons necessary for tube operation. When energy in some form is applied to the cathode, electrons are released. Heat is the form of energy generally used. The method of heating the cathode may be used to distinguish between the different forms of cathodes. For example, a directly heated cathode, or filament-cathode, is a wire heated by the passage of an electric current. An indirectly heated cathode, or heater-cathode, consists of a filament, or heater, enclosed in a metal sleeve. The sleeve carries the electron-emitting material on its outside surface and is heated by radiation and conduction from the heater.

A filament, or directly heated cathode, such as that shown in Fig. 1 may be further classified by identifying the filament or electron-emitting material. The materials in regular use are tungsten, thoriated tungsten, and metals which have been coated with alkaline-earth oxides. Tungsten filaments are made from the pure metal. Because they must operate at high temperatures (a

dazzling white) to emit sufficient electrons, a relatively large amount of filament power is required.

Thoriated-tungsten filaments are made from tungsten impregnated with thorium oxide. Due to the presence of thorium, these filaments liberate electrons at a more moderate temperature of about 1700°C (a bright yellow) and are, therefore, much more economical of filament power than are pure tungsten filaments.

Alkaline earths are usually applied as a coating on a nickel-alloy wire or ribbon. This coating, which is dried in a relatively thick layer on the filament, requires only a relatively low temperature of about 700-750°C (a dull red) to produce a copious supply of electrons. Coated filaments operate very efficiently and require relatively little filament power. However, each of these cathode materials has special advantages which determine the choice for a particular application.

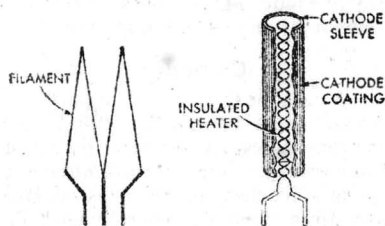


Fig. 1

Fig. 2

Directly heated filament-cathodes require comparatively little heating power. They are used in almost all of the tube types designed for battery operation because it is, of course, desirable to impose as small a drain as possible on the batteries. Examples of battery-operated filament types are the 1R5, 1U4, 1U5, and 3V4. AC-operated types having directly heated filament-cathodes include the 2A3 and 5Y3-GT.

An indirectly heated cathode, or heater-cathode, consists of a thin metal sleeve coated with electron-emitting material such as alkaline-earth oxides. Within the sleeve is a heater which is insulated from the sleeve, as shown in Fig. 2. The heater is made of tungsten or tungsten-alloy wire and is used only for the purpose of heating the cathode sleeve

and sleeve coating to an electron-emitting temperature. Useful emission does not take place from the heater wire.

The heater-cathode construction is well adapted for use in electron tubes intended for operation from ac power lines and from storage batteries. The use of separate parts for emitter and heater functions, the electrical insulation of the heater from the emitter, and the shielding effect of the sleeve may all be utilized in the design of the tube to minimize the introduction of hum from the ac heater supply and to minimize electrical interference which might enter the tube circuit through the heater-supply line. From the viewpoint of circuit design, the heater-cathode construction offers advantages in connection flexibility because of the electrical separation of the heater from the cathode.

Another advantage of the heater-cathode construction is that it makes practical the design of a rectifier tube having close spacing between its cathode and plate, and of an amplifier tube having close spacing between its cathode and grid. In a close-spaced rectifier tube, the voltage drop in the tube is low, and, therefore, the regulation is improved. In an amplifier tube, the close spacing increases the gain obtainable from the tube. Because of the advantages of the heater-cathode construction, almost all present-day receiving tubes designed for ac operation have heater-cathodes.

### Generic Tube Types

Electrons are of no value in an electron tube unless they can be put to work. Therefore, a tube is designed with the parts necessary to utilize electrons as well as those required to produce them. These parts consist of a cathode and one or more supplementary electrodes. The electrodes are enclosed in an evacuated envelope having the necessary connections brought out through air-tight seals. The air is removed from the envelope to allow free movement of the electrons and to prevent injury to the emitting surface of the cathode.

When the cathode is heated, electrons leave the cathode surface and form an invisible cloud in the space around it. Any positive electric potential within the evacuated envelope offers a strong

attraction to the electrons (unlike electric charges attract; like charges repel). Such a positive electric potential can be supplied by an **anode** (positive electrode) located within the tube in proximity to the cathode.

## Diodes

The simplest form of electron tube contains two electrodes, a cathode and an anode (plate), and is often called a diode, the family name for a two-electrode tube. In a diode, the positive potential is supplied by a suitable electrical source connected between the plate terminal and a cathode terminal, as shown in Fig. 3. Under the influence of the positive plate potential, electrons flow from the cathode to the plate and return through the external plate-battery circuit to the cathode, thus completing the circuit. This flow of electrons is known as the **plate current**.

If a negative potential is applied to the plate, the free electrons in the space surrounding the cathode will be forced back to the cathode and no plate current will flow. If an alternating voltage is applied to the plate, the plate is alternately made positive and negative. Because plate current flows only during the time when the plate is positive, current flows through the tube in only one direction and is said to be **rectified**. Fig. 4 shows the rectified output current produced by an alternating input voltage.

Diode rectifiers are used in ac receivers to convert the ac supply voltage to dc voltage for the electrodes of the other tubes in the receiver. Rectifier tubes having only one plate and one

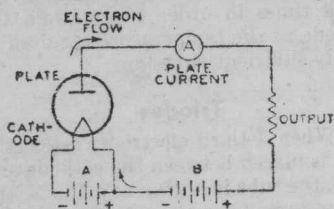


Fig. 3

cathode, such as the 35W4, are called **half-wave rectifiers**, because current can flow only during one-half of the alternating-current cycle. When two plates and one or more cathodes are

used in the same tube, current may be obtained on both halves of the ac cycle. The 6X4, 5Y3-GT, and 5U4-GB are examples of this type and are called **full-wave rectifiers**.

Not all of the electrons emitted by the cathode reach the plate. Some return

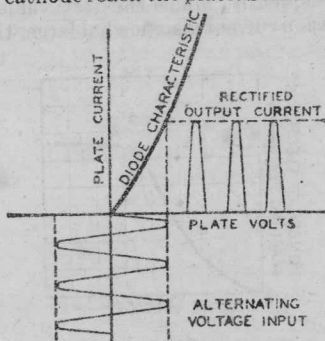


Fig. 4

to the cathode while others remain in the space between the cathode and plate for a brief period to produce an effect known as **space-charge**. This charge has a repelling action on other electrons which leave the cathode surface and impedes their passage to the plate. The extent of this action and the amount of space-charge depend on the cathode temperature, the distance between the cathode and the plate, and the plate potential. The higher the plate potential, the less is the tendency for electrons to remain in the space-charge region and repel other electrons. This effect may be noted by applying increasingly higher plate voltages to a tube operating at a fixed heater or filament voltage. Under these conditions, the maximum number of available electrons is fixed, but increasingly higher plate voltages will succeed in attracting a greater proportion of the free electrons.

Beyond a certain plate voltage, however, additional plate voltage has little effect in increasing the plate current because all of the electrons emitted by the cathode are already being drawn to the plate. This maximum current, illustrated in Fig. 5, is called **saturation current**. Because it is an indication of the total number of electrons emitted, it is also known as **emission current** or simply **emission**.

Although tubes are sometimes tested

by measurement of their emission current, it is generally not advisable to measure the full value of emission because this value would be sufficiently large to cause change in the tube's characteristics or even to damage the tube. Consequently, while the test value of emission current is somewhat larger than

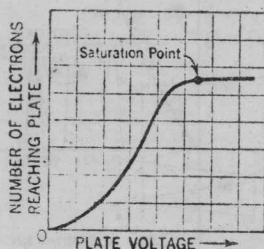


Fig. 5

the maximum current which will be required from the cathode in the use of the tube, it is ordinarily less than the full emission current. The emission test, therefore, is used to indicate whether the cathode can supply a sufficient number of electrons for satisfactory operation of the tube.

If space charge were not present to repel electrons coming from the cathode, the same plate current could be produced at a lower plate voltage. One way to make the effect of space charge small is to make the distance between plate and cathode small. This method is used in rectifier types having heater-cathodes, such as the 5V4-GA and the 6AX5-GT. In these types the radial distance between cathode and plate is only about two hundredths of an inch.

Another method of reducing space-charge effect is utilized in mercury-vapor rectifier tubes. When such tubes are operated, a small amount of mercury contained in the tube is partially vaporized, filling the space inside the bulb with mercury atoms. These atoms are bombarded by electrons on their way to the plate. If the electrons are moving at a sufficiently high speed, the collisions tear off electrons from the mercury atoms. The mercury atom is then said to be "ionized," i.e., it has lost one or more electrons and, therefore, has a positive charge. Ionization is evidenced

by a bluish-green glow between the cathode and plate. When ionization occurs, the space charge is neutralized by the positive mercury atoms so that increased numbers of electrons are made available. Mercury-vapor tubes are used primarily for power rectifiers.

**Ionic-heated-cathode rectifier tubes**, such as the 0Z4 and 0Z4-G, also depend on gas ionization for their operation. These tubes are of the full-wave design and contain two anodes and a coated cathode sealed in a bulb containing a reduced pressure of inert gas. The cathode in each of these types becomes hot during tube operation, but the heating effect is caused by bombardment of the cathode by ions within the tube rather than by heater or filament current from an external source.

The internal structure of an ionic-heated-cathode tube is designed so that when sufficient voltage is applied to the tube, ionization of the gas occurs between the anode which is instantaneously positive and the cathode. Under normal operating voltages, ionization does not take place between the anode that is negative and the cathode so that the requirements for rectification are satisfied. The initial small flow of current through the tube is sufficient to raise the cathode temperature quickly to incandescence whereupon the cathode emits electrons. The voltage drop in such tubes is slightly higher than that of the usual hot-cathode gas rectifiers because energy is taken from the ionization discharge to keep the cathode at operating temperature. Proper operation of these rectifiers requires a minimum flow of load current at all times in order to maintain the cathode at the temperature required to supply sufficient emission.

### Triodes

When a third electrode, called the **grid**, is placed between the cathode and plate, the tube is known as a triode, the family name for a three-electrode tube. The grid usually consists of relatively fine wire wound on two support rods and extending the length of the cathode. The spaces between turns are comparatively large so that the passage of electrons from cathode to plate is practically unobstructed by the grid wires. The pur-

pose of the grid is to control the flow of plate current. When a tube is used as an amplifier, a negative dc voltage is usually applied to the grid. Under this condition the grid does not draw appreciable current.

The number of electrons attracted to the plate depends on the combined effect of the grid and plate polarities, as shown in Fig. 6. When the plate is positive, as is normal, and the dc grid voltage is made more and more negative, the plate is less able to attract electrons to it and plate current decreases. When the grid is made less and less negative (more and more positive), the plate more readily attracts electrons to it and plate current increases. Hence, when the voltage on the grid is varied in accordance with a signal, the plate current varies with the signal. Because a small voltage applied to the grid can control a comparatively large amount of plate current, the signal is amplified by the tube. Typical three-electrode tube types are the 6C4 and 6AF4-A.

The grid, plate, and cathode of a triode form an electrostatic system, each electrode acting as one plate of a small capacitor. The capacitances are those existing between grid and plate, plate and cathode, and grid and cathode

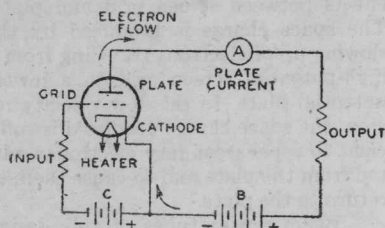


Fig. 6

These capacitances are known as **inter-electrode capacitances**. Generally, the capacitance between grid and plate is of the most importance. In high-gain radio-frequency amplifier circuits, this capacitance may act to produce undesired coupling between the **input circuit**, the circuit between grid and cathode, and the **output circuit**, the circuit between plate and cathode. This coupling is undesirable in an amplifier because it may cause instability and unsatisfactory performance.

## Tetrodes

The capacitance between grid and plate can be made small by mounting an additional electrode, called the **screen grid** (grid No. 2), in the tube. With the addition of the grid No.2, the tube has four electrodes and is, accordingly, called a tetrode. The screen grid or grid No.2 is mounted between the grid No.1 (control grid) and the plate, as shown in Fig. 7, and acts as an electrostatic shield between them, thus reducing the grid-to-plate capacitance. The effectiveness of

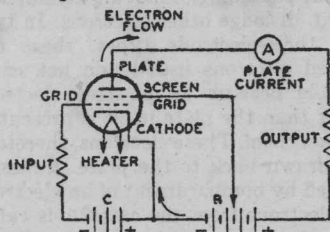


Fig. 7

this shielding action is increased by a bypass capacitor connected between screen grid and cathode. By means of the screen grid and this bypass capacitor, the grid-plate capacitance of a tetrode is made very small. In practice, the grid-plate capacitance is reduced from several micromicrofarads ( $\mu\mu\text{f}$ ) for a triode to  $0.01 \mu\mu\text{f}$  or less for a screen-grid tube.

The screen grid has another desirable effect in that it makes plate current practically independent of plate voltage over a certain range. The screen grid is operated at a positive voltage and, therefore, attracts electrons from the cathode. However, because of the comparatively large space between wires of the screen grid, most of the electrons drawn to the screen grid pass through it to the plate. Hence the screen grid supplies an electrostatic force pulling electrons from the cathode to the plate. At the same time the screen grid shields the electrons between cathode and screen grid from the plate so that the plate exerts very little electrostatic force on electrons near the cathode.

So long as the plate voltage is higher than the screen-grid voltage, plate current in a screen-grid tube depends to a great degree on the screen-grid voltage and very little on the plate voltage. The fact that plate current in a screen-grid

tube is largely independent of plate voltage makes it possible to obtain much higher amplification with a tetrode than with a triode. The low grid-plate capacitance makes it possible to obtain this high amplification without plate-to-grid feedback and resultant instability. In receiving-tube applications, the tetrode has been replaced to a considerable degree by the pentode.

### **Pentodes**

In all electron tubes, electrons striking the plate may, if moving at sufficient speed, dislodge other electrons. In two- and three-electrode types, these dislodged electrons usually do not cause trouble because no positive electrode other than the plate itself is present to attract them. These electrons, therefore, are drawn back to the plate. Emission caused by bombardment of an electrode by electrons from the cathode is called **secondary emission** because the effect is secondary to the original cathode emission.

In the case of screen-grid tubes, the proximity of the positive screen grid to the plate offers a strong attraction to these secondary electrons and particularly so if the plate voltage swings lower than the screen-grid voltage. This effect lowers the plate current and limits the useful plate-voltage swing for tetrodes.

The effects of secondary emission are minimized when a fifth electrode is placed within the tube between the screen grid and plate. This fifth electrode is known as the **suppressor grid** (grid No.3) and is usually connected to the cathode, as shown in Fig. 8. Because of

The family name for a five-electrode tube is "pentode". In power-output pentodes, the suppressor grid makes possible higher power output with lower grid-driving voltage; in radio-frequency amplifier pentodes the suppressor grid makes possible high voltage amplification at moderate values of plate voltage. These desirable features result from the fact that the plate-voltage swing can be made very large. In fact, the plate voltage may be as low as, or lower than, the screen-grid voltage without serious loss in signal-gain capability. Representative pentodes used for power amplification are the 3V4 and 6K6-GT; representative pentodes used for voltage amplification are the 1U4, 6AU6, 12SK7, and 6BA6.

### **Beam Power Tubes**

A beam power tube is a tetrode or pentode in which directed electron beams are used to increase substantially the power-handling capability of the tube. Such a tube contains a cathode, a control grid (grid No.1), a screen grid (grid No.2), a plate, and, optionally, a suppressor grid (grid No.3). When a beam power tube is designed without an actual suppressor grid, the electrodes are so spaced that secondary emission from the plate is suppressed by space-charge effects between screen grid and plate. The space charge is produced by the slowing up of electrons traveling from a high-potential screen grid to a lower-potential plate. In this low-velocity region, the space charge produced is sufficient to repel secondary electrons emitted from the plate and to cause them to return to the plate.

Beam power tubes of this design employ beam-confining electrodes at cathode potential to assist in producing the desired beam effects and to prevent stray electrons from the plate from returning to the screen grid outside of the beam. A feature of a beam power tube is its low screen-grid current. The screen grid and the control grid are spiral wires wound so that each turn of the screen grid is shaded from the cathode by a grid turn. This alignment of the screen grid and control grid causes the electrons to travel in sheets between the turns of the screen grid so that very few of them strike the screen grid. Because of the

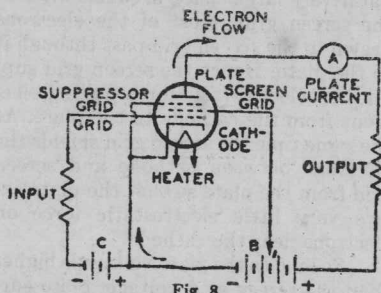


Fig. 8

its negative potential with respect to the plate, the suppressor grid retards the flight of secondary electrons and diverts them back to the plate.

effective suppressor action provided by space charge and because of the low current drawn by the screen grid, the beam power tube has the advantages of high power output, high power sensitivity, and high efficiency.

Fig. 9 shows the structure of a beam power tube employing space-charge suppression and illustrates how the electrons

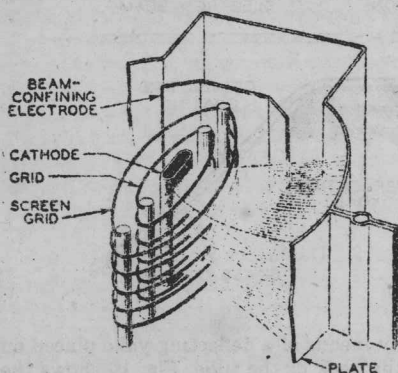


Fig. 9

are confined to beams. The beam condition illustrated is that for a plate potential less than the screen-grid potential. The high-density space-charge region is indicated by the heavily dashed lines in the beam. Note that the edges of the beam-confining electrodes coincide with the dashed portion of the beam. In this way the space-charge potential region is extended beyond the beam boundaries and stray secondary electrons are prevented from returning to the screen grid outside of the beam. The space-charge effect may also be obtained by use of an actual suppressor grid. Examples of beam power tubes are 6AQ5-A, 6L6-GB, 6V6-GT, and 50C5.

### Multi-Electrode and Multi-Unit Tubes

Early in the history of tube development and application, tubes were designed for general service; that is, a single tube type—a triode—was used as a radio-frequency amplifier, an intermediate-frequency amplifier, an audio-frequency amplifier, an oscillator, or a detector. Obviously, with this diversity of application, one tube did not meet all requirements to the best advantage.

Later and present trends of tube design are the development of "specialty" types. These types are intended either to give optimum performance in a particular application or to combine in one bulb functions which formerly required two or more tubes. The first class of tubes includes such examples of specialty types as the 6CB6 and 6BY6. Types of this class generally require more than three electrodes to obtain the desired special characteristics and may be broadly classed as multi-electrode types. The 6BY6 is an especially interesting type in this class. This tube has an unusually large number of electrodes, namely seven, exclusive of the heater. Plate current in the tube is varied at two different frequencies at the same time. The tube is designed primarily for use as a combined sync separator and sync clipper in television receivers.

The second class includes multi-unit tubes such as the twin-diode triodes 6BF6 and 6AV6, as well as triode-pentodes such as the 6U8-A and 6X8. This class also includes class A twin triodes such as the 6CG7 and 12AX7, and types such as the 6CM7 containing dissimilar triode units used primarily as combined vertical oscillators and vertical deflection amplifiers in television receivers. Full-wave rectifiers are also multi-unit types.

A third class of tubes combines features of each of the other two classes. Typical of this third class are the pentagrid-converter types 1R5, 6BE6, and 6SA7. These tubes are similar to the multi-electrode types in that they have seven electrodes, all of which affect the electron stream; and they are similar to the multi-unit tubes in that they perform simultaneously the double function of oscillator and mixer in superheterodyne receivers.

### Television Picture Tubes

The picture tube, or kinescope, is a multi-electrode tube used principally in television receivers for picture display. It consists essentially of an electron gun, a glass or metal-and-glass envelope and face-plate combination, and a fluorescent screen.

The electron gun includes a cathode for the production of free electrons, one

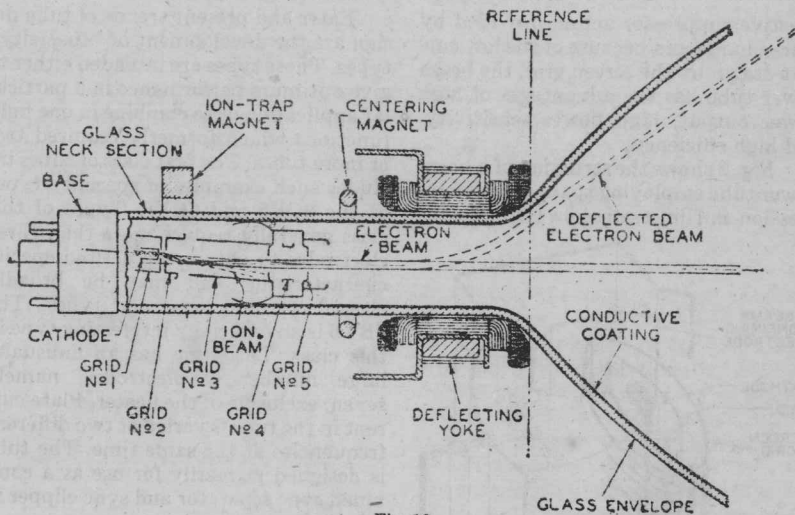


Fig. 10

or more control electrodes for accelerating the electrons in the beam, and, optionally, a device for "trapping" unwanted ions out of the electron beam.

Focusing of the beam is accomplished either electromagnetically by means of a focusing coil placed on the neck of the tube, or electrostatically, as shown in Fig. 10, by means of focusing electrodes (grids No. 4 and No. 5) within the envelope of the tube. The screen is a white-fluorescing phosphor P4 of either the silicate or the sulfide type.

Deflection of the beam is accomplished either electrostatically by means of deflecting electrodes within the envelope of the tube, or electromagnetically

by means of a deflecting yoke placed on the neck of the tube. Fig. 10 shows the structure of the gun section of a picture tube and illustrates how the electron beam is formed, how the ions are separated from the electron beam by means of the tilted-gun and ion-trap-magnet arrangement, and how the beam is deflected by means of an electromagnetic deflecting yoke.

The color kinescope 21CYP22 consists of three electron guns and an aluminized, tricolor, phosphor-dot screen on the inner surface of the spherical filterglass faceplate. It utilizes magnetic convergence, electrostatic focus, and magnetic deflection.

# Electron Tube Characteristics

The term "characteristics" is used to identify the distinguishing electrical features and values of an electron tube. These values may be shown in curve form or they may be tabulated. When the characteristics values are given in curve form, the curves may be used for the determination of tube performance and the calculation of additional tube factors.

Tube characteristics are obtained from electrical measurements of a tube in various circuits under certain definite conditions of voltages. Characteristics may be further described by denoting the conditions of measurements. For example Static Characteristics are the values obtained with different dc potentials applied to the tube electrodes, while Dynamic Characteristics are the values obtained with an ac voltage on a control grid under various conditions of dc potentials on the electrodes. The dynamic characteristics, therefore, are indicative of the performance capabilities of a tube under actual working conditions.

Static characteristics may be shown by plate characteristics curves and transfer (mutual) characteristics curves. These curves present the same information, but in two different forms to increase its usefulness. The plate characteristic curve is obtained by varying plate voltage and measuring plate current for different grid bias voltages, while the transfer-characteristic curve is obtained by varying grid bias voltage and measuring plate current for different plate voltages. A plate-characteristic family of curves is illustrated by Fig. 11. Fig. 12 gives the transfer-characteristic family of curves for the same tube.

Dynamic characteristics include amplification factor, plate resistance, control-grid-plate transconductance, and certain detector characteristics, and may be shown in curve form for variations in tube operating conditions.

The amplification factor, or  $\mu$ , is the ratio of the change in plate voltage to a change in control-electrode voltage in the opposite direction, under the condition that the plate current remains unchanged and that all other electrode

voltages are maintained constant. For example, if, when the plate voltage is made 1 volt more positive, the control-electrode (grid-No.1) voltage must be made 0.1 volt more negative to hold plate current unchanged, the amplification factor is 1 divided by 0.1, or 10. In other words, a small voltage variation in the grid circuit of a tube has the same effect on the plate current as a large

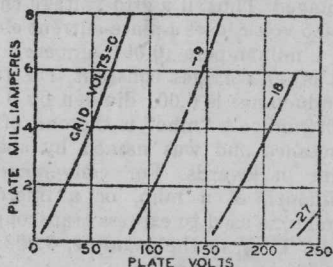


Fig. 11

plate-voltage change—the latter equal to the product of the grid-voltage change and amplification factor. The  $\mu$  of a tube is often useful for calculating stage gain. This use is discussed in the ELECTRON TUBE APPLICATIONS SECTION.

Plate resistance ( $r_p$ ) of an electron tube is the resistance of the path between

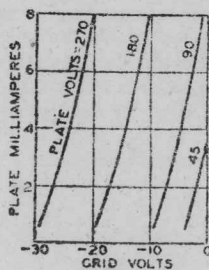


Fig. 12

cathode and plate to the flow of alternating current. It is the quotient of a small change in plate voltage divided by the corresponding change in plate current and is expressed in ohms, the unit of resistance. Thus, if a change of 0.1 milliampere (0.0001 ampere) is produced by a plate voltage variation of 1 volt, the plate resistance is 1 divided by 0.0001, or 10000 ohms.

**Control-grid—plate transconductance**, or simply **transconductance** ( $g_m$ ), is a factor which combines in one term the amplification factor and the plate resistance, and is the quotient of the first divided by the second. This term has also been known as **mutual conductance**. Transconductance may be more strictly defined as the quotient of a small change in plate current (amperes) divided by the small change in the control-grid voltage producing it, under the condition that all other voltages remain unchanged. Thus, if a grid-voltage change of 0.5 volt causes a plate-current change of 1 milliampere (0.001 ampere), with all other voltages constant, the transconductance is 0.001 divided by 0.5, or 0.002 mho. A "mho" is the unit of conductance and was named by spelling ohm backwards. For convenience, a millionth of a mho, or a micromho ( $\mu\text{mho}$ ), is used to express transconductance. Thus, in the example, 0.002 mho is 2000 micromhos.

**Conversion transconductance** ( $g_c$ ) is a characteristic associated with the mixer (first detector) function of tubes

and may be defined as the quotient of the intermediate-frequency (if) current in the primary of the if transformer divided by the applied radio-frequency (rf) voltage producing it; or more precisely, it is the limiting value of this quotient as the rf voltage and if current approach zero. When the performance of a frequency converter is determined, conversion transconductance is used in the same way as control-grid—plate transconductance is used in single-frequency amplifier computations.

The **plate efficiency** of a power amplifier tube is the ratio of the ac power output ( $P_o$ ) to the product of the average dc plate voltage ( $E_b$ ) and dc plate current ( $I_b$ ) at full signal, or

$$\text{Plate efficiency (\%)} = \frac{P_o \text{ watts}}{E_b \text{ volts} \times I_b \text{ amperes}} \times 100$$

The **power sensitivity** of a tube is the ratio of the power output to the square of the input signal voltage ( $E_{in}$ ) and is expressed in mhos as follows:

$$\text{Power sensitivity (mhos)} = \frac{P_o \text{ watts}}{(E_{in}, \text{ rms})^2}$$

# Electron Tube Applications

The diversified applications of an electron receiving tube have, within the scope of this section, been treated under seven headings. These are: Amplification, Rectification, Detection, Automatic Volume or Gain Control, Oscillation, Frequency Conversion, and Automatic Frequency Control. Although these operations may take place at either radio or audio frequencies and may involve the use of different circuits and different supplemental parts, the general considerations of each kind of operation are basic.

## Amplification

The amplifying action of an electron tube was mentioned under Triodes in the section on ELECTRONS, ELECTRODES, and ELECTRON TUBES. This action can be utilized in electronic circuits in a number of ways, depending upon the results desired. Four classes of amplifier service recognized by engineers are covered by definitions standardized by the Institute of Radio Engineers. This classification depends primarily on the fraction of input cycle during which plate current is expected to flow under rated full-load conditions. The classes are class A, class AB, class B, and class C. The term "cutoff bias" used in these definitions is the value of grid bias at which plate current is some very small value.

## Classes of Service

A class A amplifier is an amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows at all times.

A class AB amplifier is an amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows for appreciably more than half but less than the entire electrical cycle.

A class B amplifier is an amplifier in which the grid bias is approximately equal to the cutoff value, so that the plate current is approximately zero when no exciting grid voltage is applied, and so that plate current in a specific

tube flows for approximately one-half of each cycle when an alternating grid voltage is applied.

A class C amplifier is an amplifier in which the grid bias is appreciably greater than the cutoff value, so that the plate current in each tube is zero when no alternating grid voltage is applied, and so that plate current flows in a specific tube for appreciably less than one-half of each cycle when an alternating grid voltage is applied.

The suffix 1 may be added to the letter or letters of the class identification to denote that grid current does not flow during any part of the input cycle. The suffix 2 may be used to denote that grid current flows during some part of the cycle.

For radio-frequency (rf) amplifiers which operate into a selective tuned circuit, as in radio transmitter applications, or under requirements where distortion is not an important factor, any of the above classes of amplifiers may be used, either with a single tube or a push-pull stage. For audio-frequency (af) amplifiers in which distortion is an important factor, only class A amplifiers permit single-tube operation. In this case, operating conditions are usually chosen so that distortion is kept below the conventional 5 per cent for triodes and the conventional 7 to 10 per cent for tetrodes or pentodes. Distortion can be reduced below these figures by means of special circuit arrangements such as that discussed under inverse feedback. With class A amplifiers, reduced distortion with improved power performance can be obtained by using a push-pull stage for audio service. With class AB and class B amplifiers, a balanced amplifier stage using two tubes is required for audio service.

## Class A Voltage Amplifiers

As a class A voltage amplifier, an electron tube is used to reproduce grid-voltage variations across an impedance or a resistance in the plate circuit. These variations are essentially of the same form as the input signal voltage impressed on the grid, but their amplitude

is increased. This increase is accomplished by operation of the tube at a suitable grid bias so that the applied grid input voltage produces plate-current variations proportional to the signal swings. Because the voltage variation obtained in the plate circuit is much larger than that required to swing the grid, amplification of the signal is obtained.

Fig. 13 gives a graphical illustration of this method of amplification and

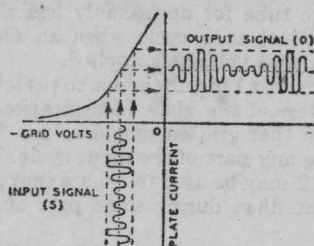


Fig. 13

shows, by means of the grid-voltage vs. plate-current characteristics curve, the effect of an input signal (S) applied to the grid of a tube. The output signal (O) is the resulting amplified plate-current variation.

The plate current flowing through the load resistance (R) of Fig. 14 causes a voltage drop which varies directly with the plate current. The ratio of this voltage variation produced in the load

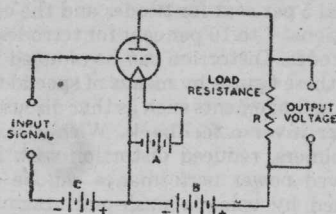


Fig. 14

resistance to the input signal voltage is the voltage amplification, or gain, provided by the tube. The voltage amplification due to the tube is expressed by the following convenient formulas:

$$\text{Voltage amplification} = \frac{\mu \times R_L}{R_L + r_p}$$

$$\text{or } \frac{g_m \times r_p \times R_L}{1000000 \times (r_p + R_L)}$$

where  $\mu$  is the amplification factor of the tube,  $R_L$  is the load resistance in

ohms,  $r_p$  is the plate resistance in ohms, and  $g_m$  is the transconductance in micromhos.

From the first formula, it can be seen that the gain actually obtainable from the tube is less than the tube's amplification factor but that the gain approaches the amplification factor when the load resistance is large compared to the tube's plate resistance. Fig. 15 shows graphically how the gain approaches the amplification factor of the tube as the load resistance is increased. From the curve it can be seen that a high value of load resistance should be used to obtain high gain in a voltage amplifier.

In a resistance-coupled amplifier, the load resistance of the tube is approximately equal to the resistance of the plate resistor in parallel with the grid resistor of the following stage. Hence, to obtain a large value of load resistance, it is necessary to use a plate resistor and a grid resistor of large resistance. However, the plate resistor should not be too large because the flow of plate current through the plate resistor produces a voltage drop which reduces the plate voltage applied to the tube. If the plate resistor is too large, this drop will be too large, the plate voltage on the tube will be too small, and the voltage output of the tube will be too small. Also, the grid resistor of the following stage should not be too large; the actual maximum value being dependent on the particular tube type. This precaution is necessary because all tubes contain minute amounts of residual gas which cause a minute flow of current through the grid resistor. If the grid resistor is too large, the positive bias developed by the flow of this current through the resistor decreases the normal negative bias and produces an increase in the plate current. This increased current may overheat the tube and cause liberation of more gas which, in turn, will cause further decrease in bias. The action is cumulative and results in a runaway condition which can destroy the tube.

A higher value of grid resistance is permissible when cathode-resistor bias is used than when fixed bias is used. When cathode-resistor bias is used, a loss in bias due to gas or grid-emission

effects is almost completely offset by an increase in bias due to the voltage drop across the cathode resistor. Typical values of plate resistor and grid resistor for tube types used in resistance-coupled circuits, and the values of gain obtainable, are shown in the **RESISTANCE-COUPLED AMPLIFIER SECTION**.

The input impedance of an electron tube (that is, the impedance between grid and cathode) consists of (1) a reactive component due to the capacitance

frequencies to affect appreciably the gain and selectivity of a preceding stage. Tubes such as the "acorn" and "pencil" types and the high-frequency miniatures have been developed to have low input capacitances, low electron-transit time, and low lead inductance so that their input impedance is high even at the ultra-high radio frequencies. Input admittance is the reciprocal of input impedance.

A remote-cutoff amplifier tube is

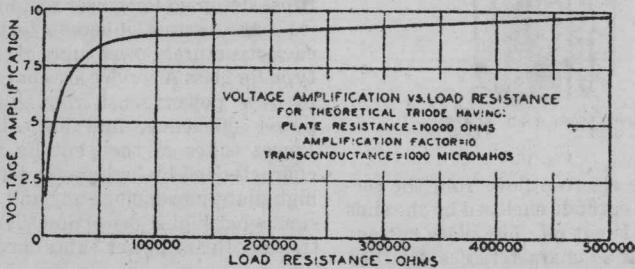


Fig. 15

between grid and cathode, (2) a resistive component resulting from the time of transit of electrons between cathode and grid, and (3) a resistive component developed by the part of the cathode lead inductance which is common to both the input and output circuits. Components (2) and (3) are dependent on the frequency of the incoming signal. The input impedance is very high at audio frequencies when a tube is operated with its grid biased negative. In a class A<sub>1</sub> or AB<sub>1</sub> transformer-coupled audio amplifier, therefore, the loading imposed by the grid on the input transformer is negligible. As a result, the secondary impedance of a class A<sub>1</sub> or class AB<sub>1</sub> input transformer can be made very high because the choice is not limited by the input impedance of the tube; however, transformer design considerations may limit the choice.

At the higher radio frequencies, the input impedance may become very low even when the grid is negative, due to the finite time of passage of electrons between cathode and grid and to the appreciable lead reactance. This impedance drops very rapidly as the frequency is raised, and increases input-circuit loading. In fact, the input impedance may become low enough at very high radio

a modified construction of a pentode or a tetrode type designed to reduce modulation-distortion and cross-modulation in radio-frequency stages. **Cross-modulation** is the effect produced in a radio or television receiver by an interfering station "riding through" on the carrier of the station to which the receiver is tuned. **Modulation-distortion** is a distortion of the modulated carrier and appears as audio-frequency distortion in the output. This effect is produced by a radio-frequency amplifier stage operating on an excessively curved characteristic when the grid bias has been increased to reduce volume. The offending stage for cross-modulation is usually the first radio-frequency amplifier, while for modulation-distortion the cause is usually the last intermediate-frequency stage. The characteristics of remote-cutoff types are such as to enable them to handle both large and small input signals with minimum distortion over a wide range of signal strength.

Fig. 16 illustrates the construction of the grid No.1 (control grid) in a remote-cutoff tube. The remote-cutoff action is due to the structure of the grid which provides a variation in amplification factor with change in grid bias. The grid No.1 is wound with open spacing at

the middle and with close spacing at the ends. When weak signals and low grid bias are applied to the tube, the effect of the non-uniform turn spacing of the grid on cathode emission and tube characteristics is essentially the same as for uniform spacing. As the grid bias is made more negative to handle larger input

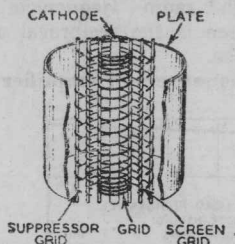


Fig. 16

signals, the electron flow from the sections of the cathode enclosed by the ends of the grid is cut off. The plate current and other tube characteristics are then dependent on the electron flow through the open section of the grid. This action changes the gain of the tube so that large signals may be handled with minimum distortion due to cross-modulation and modulation-distortion.

Fig. 17 shows a typical plate-current vs. grid-voltage curve for a remote-cutoff type compared with the curve for a type having a uniformly spaced grid. It will be noted that while the curves are similar at small grid-bias voltages, the plate current of the remote-cutoff tube drops quite slowly with large values of bias voltage. This slow change makes it

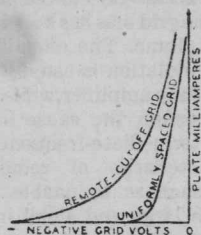


Fig. 17

possible for the tube to handle large signals satisfactorily. Because remote-cutoff types can accommodate large and small signals, they are particularly suitable for use in sets having automatic volume control. Remote-cutoff tubes also are known as variable- $\mu$  types.

### Class A Power Amplifiers

As a class A power amplifier, an electron tube is used in the output stage of a radio or television receiver to supply a relatively large amount of power to the loudspeaker. For this application, large power output is of more importance than high voltage amplification, therefore, gain possibilities are sacrificed in the design of power tubes to obtain power-handling capability.

Triodes, pentodes, and beam power tubes designed for power amplifier service have certain inherent features for each structure. Power tubes of the triode type for class A service are characterized by low power sensitivity, low plate-power efficiency, and low distortion. Power tubes of the pentode type are characterized by high power sensitivity, high plate-power efficiency and, usually, somewhat higher distortion than class A triodes. Beam power tubes have higher

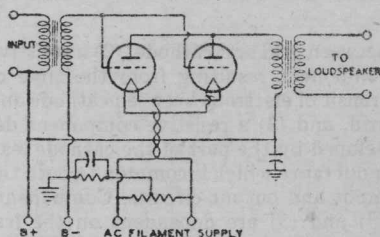


Fig. 18

power sensitivity and efficiency than triode or conventional pentode types.

A class A power amplifier is also used as a driver to supply power to a class AB<sub>2</sub> or a class B stage. It is usually advisable to use a triode, rather than a pentode, in a driver stage because of the lower plate impedance of the triode.

Power tubes connected in either parallel or push-pull may be employed as class A amplifiers to obtain increased output. The parallel connection (Fig. 18) provides twice the output of a single tube with the same value of grid-signal voltage. With this connection, the effective transconductance of the stage is doubled, and the effective plate resistance and the load resistance required are halved as compared with single-tube values.

The push-pull connection (Fig. 19), although it requires twice the grid-signal