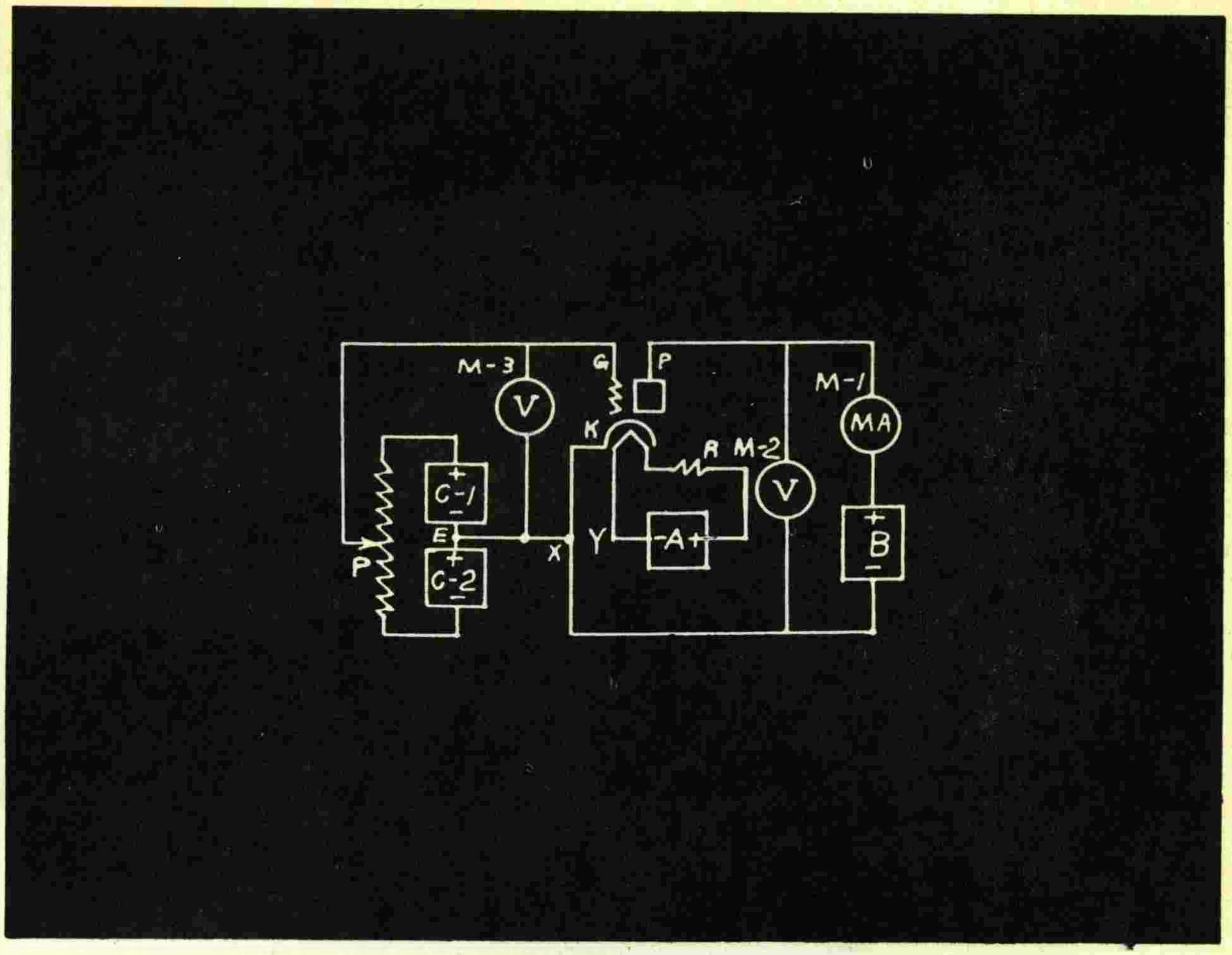


LESSON 15 RA

# ELECTRON TUBES AND THEIR APPLICATIONS

RADIO-TELEVISION TRAINING SCHOOL ESTABLISHED 1922 LOS ANGELES

RADIO-TELEVISION TRAINING SCHOOL, INC.
5100 SOUTH VERMONT AVENUE • LOS ANGELES 37, CALIFORNIA, U. S. A.

# ELECTRON TUBES AND THEIR APPLICATIONS

ONE BASIC OPERATING PRINCIPLE. All the various tubes listed for use in radio receivers employ the same basic operating principle, namely, the emission of electrons from a heated object within a vacuum. Each tube thus contains an electrode built up of a substance rich in electrons and called the cathode. This cathode may be either a directly heated filament as in most of the early tubes, or a cylindrical sleeve that is indirectly heated from a filament passing through its center.

The electrons emitted by the cathode are attracted to a second element called the plate or anode which carries a high positive potential. This migration of electrons from cathode to plate renders the space within the tube conductive, and therefore permits current to flow from the negative cathode to the positive plate. At a constant cathode temperature as determined by the rated filament voltage, the rate of electron movement toward the plate depends upon the plate potential, and increases at higher potentials until all electrons emitted by the cathode reach the plate. At this point a condition of saturation is said to exist. In other words, at a constant cathode temperature the plate current flow increases as the plate potential is increased, but only up to a certain point, and beyond this stage no further increase in plate potential will affect the current flow.

In such a 2-element tube, or diode, current can thus flow from the cathode to the plate but not in the reverse direction; that is, the tube has uni-directional conductivity. It is therefore suited for use as a rectifier of alternating currents and is used as such in the power units of A.C. line operated receivers. The same feature also adapts the diode for use as a detector-rectifier, and it is now employed in that manner in the detector stage of many modern receivers. The diode is further adapted for various automatic control purposes in more complex circuit systems. These different applications will be explained in detail later on.

## THE ELECTRON FLOW IN A VACUUM TUBE

The amount of current flow in a vacuum tube depends upon the positive potential of the plate as an attracting force and the amount of emission from the cathode which is caused by heat. The stronger the plate potential, the more electrons it will attract up until the point of saturation. As stated previously electron emission in a vacuum tube is produced by heat. The higher the cathode temperature the more electrons are emitted, and the greater becomes the plate current. This continues until the electrons leave as rapidly as they become available, and beyond this point no further rise in cathode temperature will increase the plate current. In practice, however, tubes are operated at such a constant temperature that an abundant supply of electrons is constantly available without overtaxing the cathode and shortening its useful life.

The plate current flow also increases at higher plate voltages, for then more electrons reach the plate and the space within the tube becomes more conductive. This continues until the electrons reach the plate as fast as they are released from the cathode, and beyond this point of saturation further changes in plate potential have no effect on the current flow. These several points should be clearly kept in mind, for they will come up again in the discussion on tube characteristics, such as plate impedance, mutual conductance, etc. It should be plainly evident by this time that the electrons are the all-important units and that the operating qualities of a tube can easily be influenced by exerting the proper electrical control on these electrons.

## THE GRID AS AN ELECTRON CONTROL ELEMENT

Since the electrons are merely small parcels of negative electricity emitted by the cathode and attracted to the positive plate, an electrically charged object placed between these electrodes will necessarily influence this electron movement -

a positive charge will aid the movement and increase the number of electrons reaching the plate, while a negative charge will retard the movement and decrease the number reaching the plate.

Such an element is the grid, which is in the form of a wire mesh mounted between the cathode and plate and electrically connected to a pin in the base of the tube or to a metal cap at the top of the tube. Externally the grid is connected (or returned) through the coupling unit to the cathode, the latter always being taken as the starting point or point of zero potential. Therefore, when the grid or plate is referred to as positive or negative, the cathode is always the point of reference.

A positive charge on the grid, it was stated, helps to attract the electrons and increases the number reaching the plate. But if this positive charge on the grid is increased too far, a saturation point is again reached, and beyond this point the plate current remains practically constant. Whenever the grid is at a positive potential, some of the electrons will impinge on the grid, and this is equivalent to current flowing from the cathode to grid. It is commonly referred to as grid current flow, and naturally involves a dissipation or waste of energy in the grid circuit. More will be said about the effects of grid current flow later on.

As the charge on the grid becomes more negative, it repels a larger number of the electrons back to the cathode and the plate current decreases proportionally. Soon a state is reached where as many electrons are repelled back as leave the cathode, and the plate current is reduced to zero. This grid potential is known as the cut-off point, for here the electron flow from cathode to plate is cut off.

## RELAY ACTION OF THE GRID IN A TUBE

It is evident that all the electrons leaving the cathode are not intercepted by the grid, but the greater number pass through and on to the plate. The intensity of the electric charge on the grid, however, regulates the number that can get through, and in this manner the grid acts as a control lever on the plate current.

A positive charge on the grid aids the electron movement and has the same effect on the plate current as increasing the plate potential has. On the other hand, a negative charge on the grid retards the electron movement and has the same effect as decreasing the plate potential. However, since the grid is so very much nearer to the cathode than the plate is, its influence on the electron movement also is much greater. That is, a slight change in grid potential can cause the same change in plate current flow as would result from a large variation in plate potential. In other words, small amounts of energy on the grid can control or release large amounts of energy in the plate circuit.

It is this control or relay action of the grid that makes the 3-element tube or triode so valuable in a radio receiving system. The minute signal voltages picked up by the antenna and brought to the receiver via the lead-in, are impressed on the grid of a tube. Instantly the electrons between the cathode and plato come under the influence of these grid voltages and the plate current is modulated accordingly. The signal thus reappears in the plate circuit as a variable current, the variations corresponding in every detail to the signal voltages impressed upon the grid.

On reviewing the entire action it can be seen how the grid receives the small signal voltages and by virtue of its influence on the electron movement transfers them to the plate circuit where they are imbued with more power supplied by the B-battery or electric B-power unit. The signals are accordingly strengthened or amplified. The grid thus acts as a very delicate relay unit, and enables the tube to amplify the signals.

## TUBE CHARACTERISTICS ILLUSTRATED BY CURVES

The operating characteristics of a vacuum tube as it is subjected to different circuit conditions, are generally illustrated by means of graphs or curves drawn on cross-section paper. Such curves are supplied by the tube manufacturers for every tube produced, and from these curves one can tell at a glance just what circuit conditions are required to obtain certain tube performance, or what tubes best meet the requirements of a particular circuit system.

A frequently used curve is the grid-voltage plate-current characteristic curve which illustrates the variations in plate current flow at a constant plate potential but for different values of grid voltage. Such a typical curve is illustrated in Fig. 1, and the data needed to make the curve can be taken with the circuit arrangement as in Fig. 2. The tube is a typical triode with an indirectly heated cathode such as the type 27, 37, 56, 76 or 6C5. In the case of a filament type cathode the connections shown at "X" are made to point "Y". A high voltage source "B" is connected into the plate circuit, of a value corresponding to the voltage at which the tube is operated in actual practice. In the grid circuit are two 9-volt C-batteries, C-1 and C-2, connected in series and with the common connection between them joined to point "X". Also, a 50,000-ohm potentiometer "P" is connected across the two batteries as illustrated, the slider being brought to the grid of the tube.

Three meters are used, a D.C. milliammeter M-1 in the plate circuit to indicate the plate current flowing, a high-resistance D.C. voltmeter M-2 to indicate the applied plate pressure, and a suitable zero-center D.C. voltmeter M-3 to indicate the voltage on the grid. By moving the potentiometer slider from the upper extremity to the lower, the voltage on the grid can be varied from 9 volts positive through zero to 9 volts negative.

In making the observations the potentiometer is started at maximum negative position and the grid voltage and plate current recorded for successive one-volt settings, until the plate current appears to reach a steady value. The data obtained is then plotted in graphic form as in Fig. 1.

## ANALYSIS OF THE PLATE CURRENT CHARACTERISTIC

The curve illustrated in Fig. 1 is the usual plotted graph of the grid-voltage plate-current characteristic of a tube. The general trend and position of the curve, however, may vary with different tubes due to the design and arrangement of the various electrodes in the tube, as will be discussed later on.

The curve has a sloping straight portion and bends off to the horizontal at each end. As the negative potential on the grid increases, it repels more and more of the electrons and the plate current gradually decreases to zero. The grid potential at which the curve hits the horizontal axis, (point "F" on the curve) is known as the cut-off point, for here all movement of electrons from cathode to plate is cut off.

The lower bend in the curve can be made either very sharp or gradual according to the manner in which the grid is wound. For example, the type 24A tube differs chiefly from the No. 35 in that its curve drops down almost vertically and then bends sharply to the left with a very short cut-off, as in Fig. 3, while that of the No. 35 slopes more and makes a big bend to the left. It approaches the zero axis very gradually and has a long cut-off. In the No. 24A tube the grid is wound over all with a uniform close weave or mesh, but in the No. 35 the grid is wound closely at the upper and lower portions and more and more loosely toward the middle. In other words, the winding of the grid mesh seems to determine the distribution of the charge on the grid and consequently also its influence on the electron movement.

The upper bend of the curve shows how a positive charge on the grid increases the electron movement toward the plate, and how when all the electrons leaving the cathode reach the plate, the plate current gradually becomes constant in value (indicated by the curve becoming horizontal.)

## SHAPE OF CURVE DETERMINES PERFORMANCE OF TUBE

The manner in which a tube operates is determined by both the shape of the curve and the normal location of the operating point, the operating point being the place on the curve where the vertical line representing the no-signal grid potential intercepts the characteristic curve. If in the curve illustrated, the grid is not biased and is at zero potential, that is, at the same potential as the cathode or filament, the normal operating point falls at "A" on the curve, for this is the point of intersection with the zero axis. If the grid is operated at a negative bias of 2 volts, the operating point falls at "B"; and if it is at a 2-volt positive bias, the operating point is at "C".

It is thus evident that the operating point can be shifted to practically any desired position on the curve by regulating the bias on the grid of the tube. It is most economical, of course, to operate the tube at all times as far down on the curve as possible, for this keeps down the steady plate current flow and therefore increases the operating efficiency of the tube.

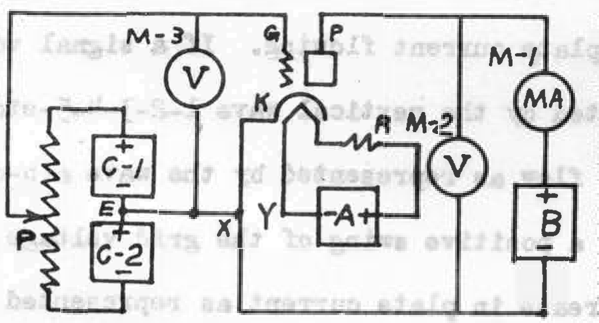


Fig. 2

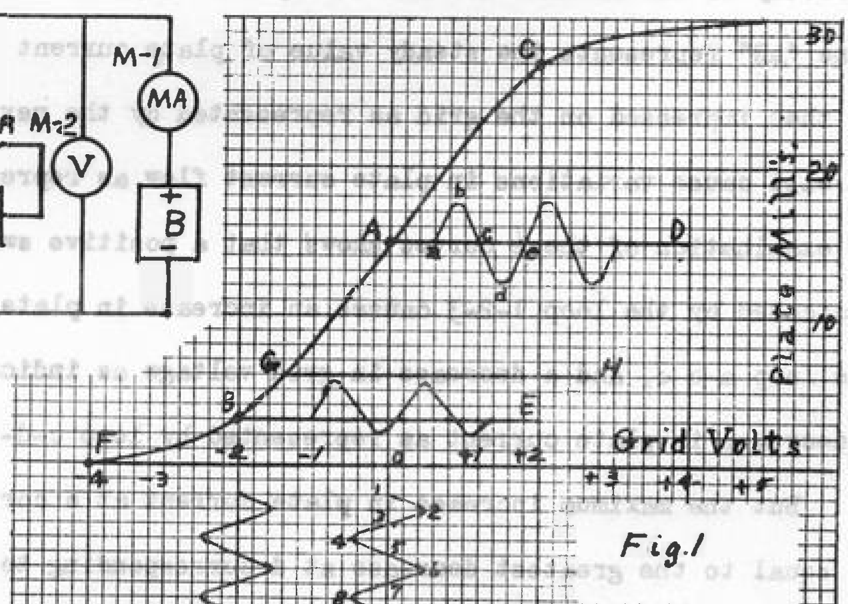


Fig. 1

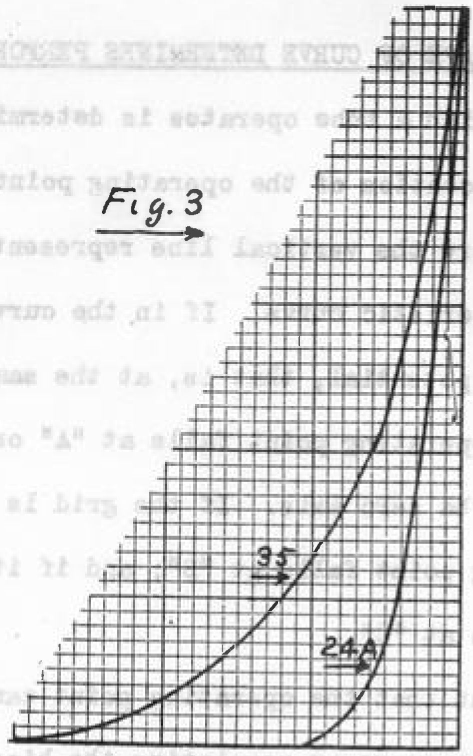


Fig. 3

## HOW SIGNAL VOLTAGES ON THE GRID AFFECT PLATE CURRENT FLOW

If the tube represented by the curve in Fig. 1 has the grid return brought directly to the cathode so that the operating point falls at "A", the horizontal line "AD" represents the steady value of plate current flowing. If a signal voltage is then impressed on the grid as represented by the vertical wave 1-2-3-4-5-etc., it will cause variations in plate current flow as represented by the wave a-b-c-d-e-etc. An examination of these curves shows that a positive swing of the grid voltage as indicated by the loop 1-2-3 causes an increase in plate current as represented by the loop a-b-c, and a decrease in grid voltage as indicated by loop 3-4-5 produces a decrease in plate current as represented by loop c-d-e.

But the maximum increase in plate current at b corresponding to grid potential 2 is equal to the greatest decrease at d corresponding to grid potential 4; that is, equal variations in grid potential bring about equivalent variations in plate current flow. However, since the current change represented by loop a-b-c-d-e involves a reater variation in power than is represented by the grid voltage loop 1-2-3-4-5, the signals have not only been relayed from the grid to the plate circuit, but they have been invested with greater power, or amplified as is commonly stated. As long, then, as the operating point falls on the straight portion of the curve and the grid swing for the received signal does not shift the operating point into either of the curved regions,any signal voltage impressed on the grid will be accurately reproduced in the plate circuit and at the same time be greatly amplified, and the tube is said to operate as an amplifier.

## THE IMPORTANCE OF PROPER GRID BIAS

An important point to observe in connection with the plate current characteristic shown in Fig. 1 is this: It is not the actual value of plate current flowing that determines the degree of amplification available from a tube but it is the variation or change in current flow for each input cycle.

To make this statement more clear - the current in the plate circuit of a tube consists of two components, a steady or constant flow as determined by the B-voltage and resistance of the circuit (corresponding to line "AD" in Fig. 1), and superimposed on this is a pulsating component created by the fluctuating signal voltage impressed on the grid (corresponding to the wave a-b-c-d-etc.). Further, a load impedance of some form is connected into the plate circuit, and the current in flowing through this load impedance creates a voltage drop across it. This voltage inherently also consists of two components, one is a constant drop caused by the normal current flow and the other is a pulsating potential caused by the current fluctuations. The constant potential is of no useful purpose; it merely dissipates part of the plate supply voltage, and the lower it can be kept the greater will be the operating efficiency.

However, the pulsating potential built up across the load resistor is important, and the greater this is, the more amplification is secured from the tube. This involves two important considerations; the first is to maintain the steady plate current component at a low value so that as much as possible of the B-supply voltage is available for circuit operation, and the second is to make the grid very sensitive so that it has maximum influence on the electron movement. Both of these features, of course, are a matter of tube design and therefore a problem of the design engineer.

Keeping the steady plate current down, however, is to a great extent also a matter of operating the grid at the proper bias. The object is always to bring the normal operating point as low down on the curve as possible without drifting into the lower bend. For example, in Fig. 1 with the operating point at "A" (corresponding to zero grid potential) the steady value of plate current is represented by "AD" and has a value of 15 milliamperes. The current fluctuations due to the signal voltage on the grid vary about 3 milliamperes above and below this value. In other words, the total current fluctuation is 6 milliamperes.

If the operating point were shifted to "G" on the curve, corresponding to a negative grid bias of 1.4 volts, the steady plate current flow would be represented by "GH" with a value of only 6 milliamperes and with the same signal voltage on the grid the plate current could still fluctuate 3 milliamperes up and down without getting into the lower bend of the curve. Therefore, it certainly would be more economical to operate at point "G" than point "A", for there would be a saving of 9 milliamperes steady current flow without affecting the signal amplification.

However, there is one precaution that must be taken at this point, for if the signal voltages reaching the grid are strong enough to swing operation into the bend of the curve the plate current fluctuations will not be uniform and symmetrical, and signal distortion will result. This means that the strength of signal voltage that can be applied to the grid is limited by the operating bias. In the operating data supplied by tube manufacturers for their different tubes the indicated grid bias is generally of such a value that the normal operating point is located near the middle of the straight portion of the curve. The maximum signal that can then be applied to the grid without overloading the tube is limited to the bias voltage.

## TUBE CLASSIFICATIONS AND OPERATING CHARACTERISTICS

Although it might appear that there already are more types of tubes available than the Radio Industry can employ to best advantage, tube development still continues to broaden and expand at a rapid pace. New tubes are appearing regularly, with improved structural efficiency or with special operating characteristics to meet the requirements of the new circuit systems that are constantly being evolved.

Tubes can be classified in several ways: (1) according to their electrode structure or number of elements employed; (2) according to mechanical construction or type of housing, and (3) according to the function or class of service for which they are intended. In many cases the same type of tube is available in two or three different forms, but that does not necessarily mean that they are interchangeable, for there may be just enough difference in operating characteristics to prevent substitution.

## TUBES CLASSIFIED BY ELECTRODE STRUCTURE

According to their electrode structure or number of elements they contain, tubes can be classified as follows:

### DIODES

A diode is the simplest form of tube and contains merely two elements, a cathode and a plate. The type 81 and 1223 rectifier tubes are simple diodes.

## TRIODES

A triode is a 3-element tube, and contains a cathode, grid and plate. The No. 27, 76, 45, 2A3, and 6C5 are typical triodes. In the case of indirectly heated cathodes the heater is not considered as a tube element.

## TETRODES

Tetrodes are 4-element tubes containing a cathode, two grids and a plate. They are also called screen grid tubes, among which are the 24A and 35. The beam power tube is also a form of tetrode.

## PENTODES

Pentodes are 5-element tubes, and contain a cathode, three grids and a plate. Among these are the 77,78,6J7, 6K7, 41 and 42.

## HEXODES

Hexodes are 6-element tubes containing a cathode, plate and four other elements.

## HEPTODES

Heptodes are 7-element tubes containing a cathode, plate and five other elements usually grids. The term, pentagrid, (meaning 5 grids) is also commonly applied to this type of tube. The 6A7 and 6L7 are tubes in this group.

## DUO-DIODES

These are two diodes in one composite tube structure. Included in this group are power rectifiers such as the type 80 and 84, and detector rectifiers such as the 6H6.

## DOUBLE-TRIODES

These are composite tube structures containing two triode units. Among these are the 6A6, 6E6, 6F8G, 6N7 and 6Y7G which have a common cathode for the two triodes. Also the 6C8G which has separate plate, grid and cathode terminal connections for each triode section.

## DUO-DIODE TRIODES

These also are composite tube structures containing a double-diode and a triode with a common cathode connection. The double diodes are similar to the 6H6, while the triode can be either the medium-mu or high-mu type. The 85 and 6R7 represent the former type, and the 75 and 6Q7 the latter type.

## DUO-DIODE PENTODES

These are composite tube structures that contain a double-diode and a pentode, all with a common cathode connection. The 6B7 and 6B8 are tubes of this type.

## DIODE-PENTODES

These are composite tube structures containing a diode rectifier and pentode output amplifier. The 12A7 and 25A7G are tubes of this type.

## TRIODE-PENTODES

These also are composite tube structures, but contain a triode and a pentode section with a common cathode terminal. The 6F7 and 6P7G are representatives of these tubes.

In addition to the above general classifications, there are also a number of other composite tubes but of a more specialized nature. Among these is the 6B5, a duo-triode or direct coupled power amplifier, and its metal equivalent, the 6N6 and 6N6G. There is also the 6J8G, a triode-heptode used in superheterodyne receivers as a triode oscillator and pentagrid mixer. All these tubes are taken up in greater detail in later lessons where typical circuit applications are also given.

## TUBES CLASSIFIED AS TO FUNCTION OR CLASS OF SERVICE

As to the class of service for which they are intended, tubes can be arranged into the following groups:

## DETECTORS

The detector serves to separate the voice frequency component of a modulated signal from the high frequency carrier. Diodes, triodes, tetrodes and pentodes are used as detectors.

## VOLTAGE AMPLIFIERS

A voltage amplifier tube serves to step up the potential of a signal so that it can swing the grid of the next tube with greater intensity. Typical voltage-amplifier tubes are the 24A, 35, 77, 78, 6J7 and 6K7.

## SUPER-CONTROL AMPLIFIER

A type of R.F. amplifier that requires a high negative bias to reduce the plate current to zero, and hence large signal voltages can be applied before modulation distortion sets in. They have a variable-mu control grid. The type 35, 78, 6D6 and 6K7 are of the super control type.

## POWER AMPLIFIERS

A power amplifier tube is one designed to develop or release a greater amount of power in the output stage for operating the reproducer system. The 41, 42, 43, 45, 6A3, 6L6 and 6V6 are typical power amplifier tubes.

## RECTIFIERS

Rectifiers are tubes used in A.C. power supply units for converting the A.C. power supply voltage to pulsating D.C. voltage. A half-wave rectifier allows current flow only during every alternate half cycle, and consists of a single diode, such as the type 81 or 12Z3 tube. A full-wave rectifier permits current flow during each half cycle, and consists of a double diode, such as the type 80 and 84 tubes, etc.

## VOLTAGE DOUBLER

A voltage doubler is a twin diode with separate cathode terminals so that the two sections can be connected in series in a voltage doubling circuit. The 25Z5 and 25Z6 tubes are suitable as voltage doublers.

## OSCILLATORS

An oscillator is a tube arranged to convert D.C. power, as from a B-battery, to high frequency A.C. power. Triodes such as the 76 and 6J5G are commonly used as oscillators.

## MIXER TUBES

A mixer tube is one which can accept two voltages of different frequencies, combine the two, and deliver an output frequency which is equal to the sum or difference of the two input frequencies. The 6L7 and 6L7G are such mixer tubes.

## CONVERTERS

A converter is a special form of mixer tube in which one of the two heterodyning frequencies is developed by self-oscillation in a portion of the tube itself. The 6A7, 6A8 and 6D8G are such converter tubes. They all contain five grids and hence are frequently called pentagrid converters.

## TUNING INDICATOR TUBES

Tuning indicator tubes or Electric Eyes as they are frequently called, employ a beam of electrons that produce a luminous area on a fluorescent screen or target, the size of this luminous area depending upon the potential applied to the control grid of the tube. The grid thus serves as a control element to indicate the conditions in the circuit to which it is connected.

## RADIO TUBE MANUALS

Nearly all of the radio tube manufacturers publish manuals containing up-to-date information on the characteristics of their tubes. These manuals can, in many instances, be obtained by all interested without charge. On the other hand, oharges are made by some organizations to cover the cost of printing these manuals. A tube manual may give the following information about tubes:

1. Type number
2. Construction
   a. Style (Glass or metal and so forth)
   b. Class (Diode or triode and so forth)
   c. Basing Diagram (Socket connections and so forth)
3. Emitter
   a. Type (Cathode or filament and so forth)
   b. Volts
   c. Amperes
4. Capacitances in micro micro farads
   a. C-gp (Screen grid to plate capacity)
   b. C-in (Grid to other elements capacity)
   c. C-out (Plate to other elements capacity)
5. Use (Amplifier-rectifier-oscillator and so forth)
6. Plate volts
7. Negative grid volts
8. Screen volts
9. Plate current (milliamperes)
10. Screen current (milliamperes)
11. Plate resistance in ohms
12. Mutual conductance in micromhos
13. Amplification factor
14. Load for rated power output (Ohms)
15. Power output (undistorted-milliwatts)

From the above, it can be seen that the date given about a tube enables the serviceman to determine the relative characteristics of one tube in respect to another. This information is oftentimes helpful when making replacements. Although a set manufacturer may specify one type, several types may actually be used to obtain satisfactory results. It is, however, best to use the type of tube specified by the manufacturer of the set whenever possible.

EXAMINATION QUESTIONS ON FOLLOWING PAGE