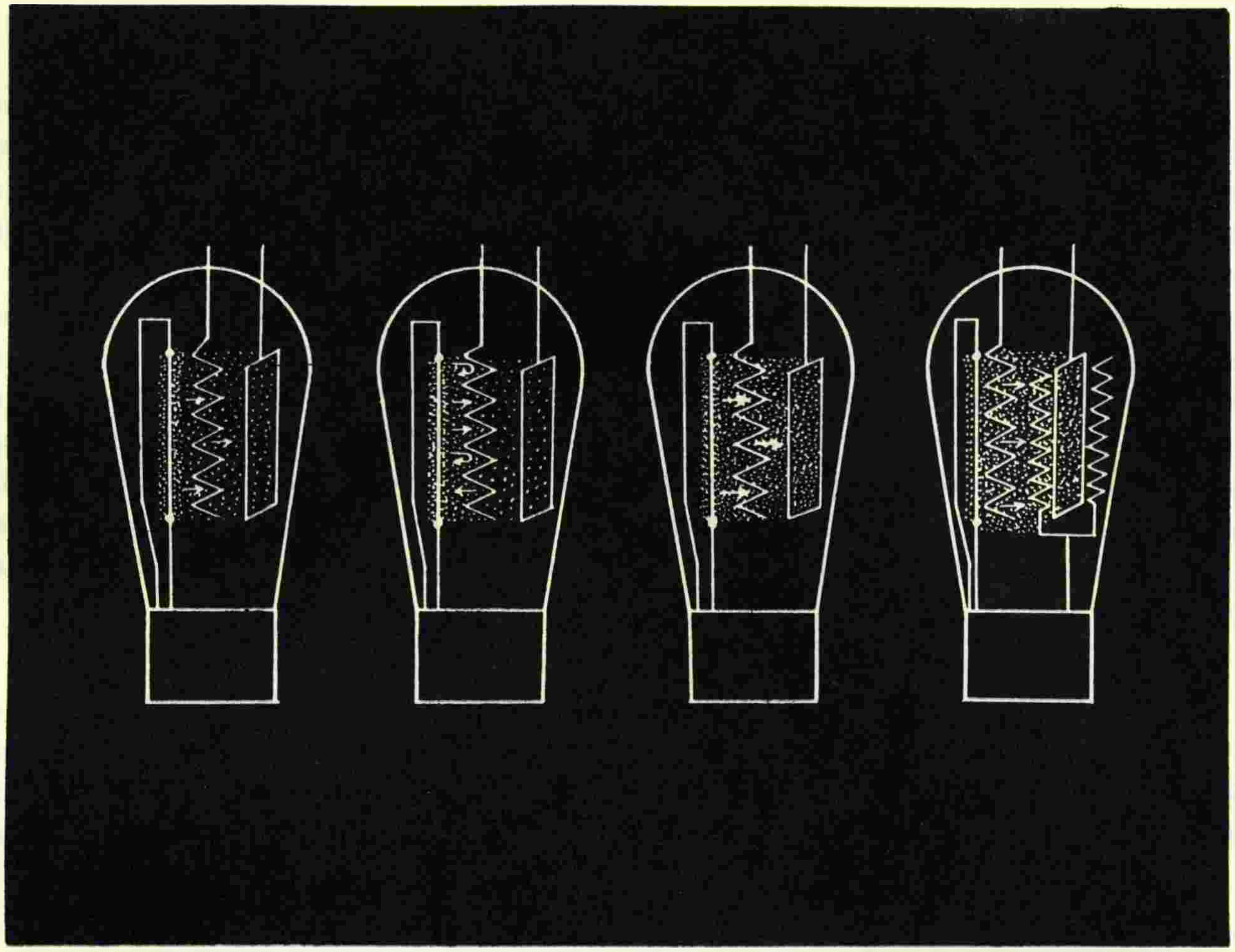

LESSON
19 RA

THE DEVELOPMENT OF TUBES WITH SPECIAL CHARACTERISTICS

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Introduction

The vacuum tubes used in radio and television sets as well as other electronic equipment are selected from the various types made available by tube manufacturers. These tubes are selected by radio and television set design engineers for their special operating and performance characteristics. The radio engineer, in designing a set, selects a tube for a given circuit to obtain reliable and stable operation as well as efficient operation. Then too, the tubes he selects must be of a type that can be manufactured and tested economically. In other words, radio and television tubes are selected for their individual characteristics. Tubes are, therefore, given type numbers and these type numbers are used by the radio and television serviceman when replacing tubes. You, as a serviceman, may refer to a radio tube manual and thus determine the type of socket as well as other details such as the overall size of the tube, and also the total number of the electrodes within a tube of a given type as well as its electrode voltages and currents.

Knowing that tubes are designed by tube engineers and then selected by radio and television engineers for their individual characteristics, let us see how some of these characteristics were developed so that a better understanding of their application may be made when encountered in certain specific circuits of radio and television sets.

THE SCREEN GRID TUBE AND WHY IT WAS DEVELOPED

The screen grid tube has, in addition to its cathode, plate and control grid electrodes, a fourth electrode known as a screen grid. This screen grid, as its name suggests, is in the form of a protecting screen going around, but separated from the plate. In this manner the screen shields the plate from the control grid. This shielding is called electrostatic shielding because it does not allow capacity coupling between the control grid and plate electrodes. By placing an external circuit capacitor of low reactance, such as a .1 mfd. capacitor, between the screen grid electrode and the cathode of a screen grid tube, we can prevent any undesirable capacity coupling between the control grid and plate electrodes of the tube.

The screen grid tube was primarily and originally designed to be used as a radio frequency amplifier and later was used for a number of years as an i-f amplifier in superheterodyne radio sets. It replaced the original three-electrode tube having a cathode, control grid and plate. When this tube was originally introduced, it caused a reduction in the total number of tubes used in a set and also caused the introduction of new circuit arrangements. A review of some of the original problems in radio reception will be made.

In the early days of radio, receiving sets employed three-electrode tubes, such types as the 26, 27, and the X99. Oftentimes these tube type numbers were preceeded by a manufacturer's number such as the number 2, 3 or 4. With these tubes, oscillations were encountered that caused squeals and howls to be heard in the headphones and loudspeakers, along with the desired signal. Most of these oscillations in multi-tube sets were the result of feed-back action occurring between the grid and plate circuits of the three-electrode tubes. Even though all precautions were taken to prevent any external feed-back such as the use of metal shielding, there was still sufficient undesirable coupling between the grid and plate circuits. This coupling occurred within the tube itself. This type of coupling was due to electrostatic coupling, the physical capacity between these electrodes.

Various methods were devised to prevent the effects of this coupling and prevent unwanted oscillations in r-f and i-f amplifiers. One system involved the use of a resistor connected in series with the grid electrode of the tube. The resistor value extended from several hundred ohms to 100,000 ohms. These resistors were known as grid suppressors and always caused considerable loss of signal amplification.

Another method of reducing oscillations in the r-f amplifier stages of radio receiving sets employing three-electrode tubes was used. The method consisted of balancing the circuit, whereby the effects of the unwanted signal voltage which was conveyed between the grid and plate circuits, due to inter-electrode capacity coupling, was cancelled out by a feed-back circuit. This circuit was referred to as the neutrodyne circuit. This circuit essentially employed a small adjustable capacitor connected between the plate and in series with a few turns wound around the bottom end of the r-f transformer coil in the grid circuit of the tube. The undesired signal voltage, due to inter-electrode coupling, was fed back to the grid circuit of the tube. It was an opposing voltage but of equal value to that which was introduced into the plate circuit by the unwanted capacity coupling between the grid and plate electrodes of the tube. This circuit operated satisfactorily over a limited frequency range but became very difficult to adjust or neutralize over wide or many frequency ranges. Furthermore, the overall voltage amplification which was obtainable with the use of the conventional three-electrode tube was low. Greater signal amplification was necessary in not only the r-f but also in the i-f stages of superheterodyne receivers. To overcome the undesirable effects received when using three-electrode tubes, the tube engineer developed the screen grid tube. This screen grid tube actually eliminated the undesirable coupling between the grid and plate elements of a tube. With this undesirable coupling removed, no feed-back could occur within the tube, and consequently there was nothing in the set to cause oscillations other than undesired coupling between unshielded coils, unshielded leads to them and the supply voltage leads within a set which were not properly bypassed.

With the removal of the undesirable feed-back, or oscillation, it was possible to obtain high signal amplification because the screen grid tube had a higher amplification factor. The screen grid tube, therefore, filled a very important need and had a basic reason for its existence. Practically every set, whether it be one of the a-m, f-m or television type, employs at least two or more tubes with screen grids. It solved a problem that for a long time was very troublesome to the radio industry.

HOW THE SCREEN GRID TUBE DIFFERS

To understand clearly the basic principles involved in the operation of the screen grid tube, let us review the action of the three-electrode tube. The heated filament or cathode emits electrons and is often called an emitter. These electrons are attracted by the positively charged plate. This circuit, therefore, becomes a path for the flow of electrons provided, of course, there are no obstructions between the cathode and plate electrodes.

Not all of the electrons emitted reach the plate. Some of them form a cloud that seems to gather around the emitter. These electrons repel or prevent other electrons leaving the emitter from reaching the plate. Those electrons which do not succeed in passing through the openings in the grid electrode also join this cloud of electrons. This cloud of electrons is commonly referred to as a space charge. It is this space charge that greatly hinders the effectiveness of a vacuum tube. For example, when we increase the plate voltage we may find that some of this increase is nullified by this space charge effect and consequently the total number of electrons reaching the plate is lower than it should have been. Since the grid is closer to the emitter than the plate, it, therefore, has a proportionately greater effect on this space charge. Small changes in grid voltage can cause the same change in plate current as a much higher change in plate voltage. This is another way of saying that the grid electrode has the greatest control over the flow of electrons leaving the emitter of the tube.

If this space charge around the emitter was reduced, then a smaller change in grid potential would be more effective in causing a greater change in plate current and consequently, greater amplification would be obtained from a tube. Since there would be no limiting action on the control that is being exercised by the grid, the tube would become more efficient as an amplifier. Naturally, when there is no space charge to contend with, a lower plate voltage may also be applied to obtain the desired amplification of the signal voltage applied to the grid of a tube. At A in Fig. 1 is shown the cloud of electrons leaving the emitter (the filament or cathode) of a three-electrode tube. This cloud is known as the space charge which hovers around the emitter. This space charge repels many of the electrons that have been emitted by the emitter and consequently reduces the number that can reach the plate. At B in Fig. 1, a negative charge on the grid repels some of the electrons approaching it and hence, it decreases the number that reach the plate electrode. The plate current, which is the flow of electrons, is further reduced. The grid being closer to the emitter than the plate has more effect upon the flow of electrons than the plate. Now at C in Fig. 1, a positive charge on the grid increases the total flow of electrons to the plate. The grid being nearer the cathode than the plate, again it has a greater effect on the flow of

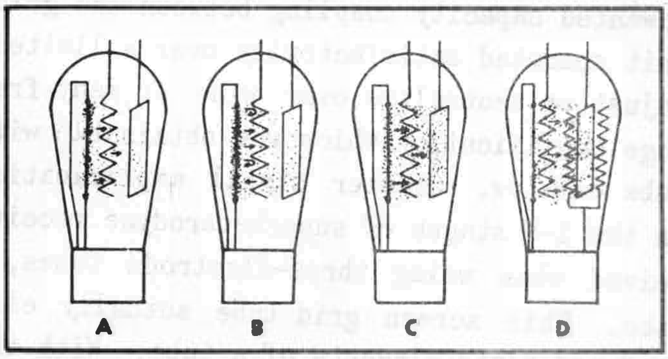

Fig. 1. Electron emission is illustrated here.

electrons than a similar positive potential on the plate. This accounts for the amplifying action of the tube. At D in Fig. 1, the presence of the screen grid with its positive charge aids in breaking up this space charge around the cathode and, consequently, increases the control range of the control grid. The soreen grid also eliminates the troublesome effect on the grid to plate capacity by its complete electrostatic shielding action.

It is the screen grid electrode which does away with most of the space charge and, consequently, enables greater signal amplification. This results in greater receiver sensitivity when this type of tube is employed instead of a three-element tube. The early screen grid tubes had type numbers similar to the following: Type 22, 24A, 35 and 36. Again many tube manufacturers added their own type number, such as the number 2, 3 and 4 ahead of these numbers.

RADIO FREQUENCY PENTODES

The introduction of the screen grid tube was a tremendous step forward in radio tube design. Although the screen grid tube possessed a great many advantages over the triode tube, it had several objectionable features. The most important one was the rapid plate current cut-off. That is, the plate current was cut off very rapidly as the control grid bias voltage applied to the tube was made more negative. This caused, under certain conditions, unlinear amplification of the radio frequency signal voltages as received by an a-m (amplitude-modulated) radio set and, consequently, cross-modulation resulted when the tube was operated near the plate current cut-off region.

The tube also had another objectionable feature, and that was the fact that many of the electrons reaching the plate electrode struck it so hard that they bounced off the plate. These electrons interfered with other electrons coming from the emitter. This condition is called secondary emission. Tube engineers corrected this condition by installing another grid between the screen grid and the plate electrodes. This grid is called the suppressor grid. It suppresses this secondary emission of electrons that bounce off the plate. The electrode is connected to the emitter. In other words, it has zero potential applied to it because the emitter is the starting point for all electrode voltages. This, therefore, was the introduction of the five-electrode tube known as the pentode. These tubes were introduced in radio frequency circuits of receiving sets and gave considerably more amplification and, consequently, greater sensitivity than the four-electrode screen grid tube. With a greater number of electrons reaching the plate, a greater amplification factor was obtained. This meant greater receiver sensitivity for the same number of tubes.

THE POWER OUTPUT PENTODE TUBE

The introduction of the pentode for r-f and i-f amplifier stages of superheterodyne radio receiving sets proved to be very advantageous for the reasons given. Then pentodes with longer cathodes and other electrodes were developed and used in the audio or power amplifier stage of radio sets. Screen grid tubes and pentode tubes used for radio frequency and i-f amplifier purposes employed a screen voltage equal to approximately one-half of the applied plate voltage. The plate voltages were of any value between 120 and 275 volts d-c. Pentode tubes used for audio power output stages had nearly equal screen grid and plate supply (d-c) voltages. These tubes had type numbers known as the types 33, 38, 41, 42 and 43. Again these type numbers were sometimes preceeded by manufacturer's numbers such as the numbers 2, 3 and 4.

The power pentode tube gave sufficient power output with efficient loudspeakers and with but one voltage amplifier tube preceeding it. A reduction in the total number of tubes used in audio amplifiers was possible. This also reduced the size of the filament and plate power units in radio sets. In other words, practically every radio set today employs one or two power output pentode tubes in the last audio amplifier stage.

A CROSS-TALK OR CROSS-MODULATION

In the early days of radio and after the introduction of screen grid and pentode types of tubes, a very disturbing condition existed which was and is called cross-modulation or cross-talk. This condition occurred due to the peculiar manner in which one station signal was heard along with another a-m modulated broadcast station. In other words, even with a very selective receiver tuner tuned to a station of a certain frequency, another station of a different frequency was also heard at the same time. Then, if the receiver was detuned a slight amount from the correct dial setting of the desired station, both of these signals would disappear. This indicated that the unwanted station was received along with the desired station, but not due to poor selectivity of the tuner in the receiver.

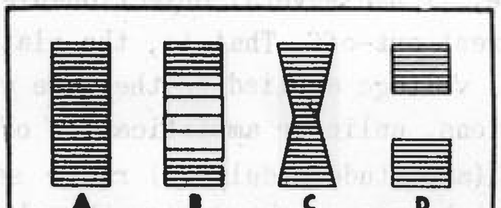

Fig. 2. Control grid designs for uniform and non-uniform electrodes.

A careful study of this situation indicated that the fault was due to the shortcomings of the radio frequency amplifying tubes. These tubes operated as detectors or demodulators instead of linear amplifiers. This type of operation is explained in the following manner. Two things occurred. Insofar as the lower level signal was concerned, this signal operated on the straight part of the plate current curve of the tube, and thus enabled the tube to function normally as a linear radio frequency amplifier. However, the higher level signal would swing the plate current of one or more of the amplifier tubes down on the plate current curve to a point where the plate current was completely cut off for the negative part of the modulated r-f cycle. This caused a tube to function as a detector. The higher level signal then underwent partial detection, and at the same time, modulated the carrier of the lower level signal. This then caused both signals to be heard at the same time. This situation was further aggravated by the fact that most earlier volume control systems, either manual or automatic, varied the grid bias voltage applied to the radio frequency amplifier tubes. Some of the manual circuits changed the screen grid voltage applied to the r-f amplifier tubes. In either case, when a local high level signal was received, it was necessary to reduce the volume materially and this was done by changing the operating point to a low value of plate current.

Then a low signal voltage would cause complete plate current cut-off. This also resulted in distortion that became evident as cross-modulation when the A tube in the set was subjected to more than one incoming signal voltage. This condition was corrected to some extent by the use of a local and long-distance switch on the radio set and connected in the antenna circuit. But even this did not work out in every case. For example, if it was desired to tune in a lowlevelsignal from a distant station with a local-distance switch set in a distance position for maximum sensitivity, cross-modulation was bound to occur if at the same time a powerful broadcast transmitter (high level) signal was received from a nearby station. It, therefore, became evident that with a very selective tuning system and a local distance switch, cross-modulation was still present.

THE VARIABLE MU TUBE

The variable mu tube solves the problem of cross-modulation distortion in an excellent manner in that it has a variable amplification factor. Its amplification factor changes as the negative grid voltage is varied, the amplification factor being controlled automatically by the signal (level) input voltage. A lower grid bias voltage was applied to the grid when high gain was not needed, as on a local (high level) signal from a nearby broadcast station. In effect, the incoming signal selects its own operating region on the characteristic curve of a tube in accordance with the strength of the carrier signal voltage received at the detector tube. The tube can thus function either as a high mu tube or a low mu tube, depending upon the intensity of the input signal and, furthermore, its special characteristics prevent complete plate current cutoff.

STRUCTURE OF THE VARIABLE MU TUBE

The important feature of the variable mu tube lies in the design of construction of its control grid. This grid, it will be remembered, is the controlling element or governor of a tube. Its action regulates the behavior of practically the entire tube. Experimental investigations have shown that many different characteristics can be imparted to a tube by a change in the design of the control grid, and it was these observations that led to the development of the variable mu tube.

In the ordinary triode type tube with a cathode, grid and plate, the control grid is of uniform construction throughout its entire length or mass. The variable amplification characteristic of this variable mu tube is obtained by employing a control grid structure of non-uniform design. Numerous variations have been tried and found capable of producing the desired effect. In Fig. 2 are illustrated three different types of grid construction that can be used to produce the variable mu amplification feature. At A in Fig. 2 is shown the normal uniform control grid winding as it is used in the screen grid tube. It consists of fine wire or ribbon wound around but away from the emitter (cathode) with a uniform spacing from top to bottom, this wire screen being insulated from the emitter and serving as the control grid. As a negative charge accumulates on this grid, the electrons are retarded in their movement from the emitter to the plate, with the result that the plate current falls off rapidly.

In the drawing B of Fig. 2 the grid electrode is again wound around but away from the emitter, but instead of being spaced uniformly, the wires are wound close together at the upper and lower ends and further apart as they approach the middle. With this type of grid, and when the tube is operated with a rather low grid bias, electrons from the cathode are again retarded by the grid, but pass through all the spaces between the grid wires with practically equal ease. Under these conditions the tube functions wit a high amplification factor. However, if the negative grid swing increases considerably,

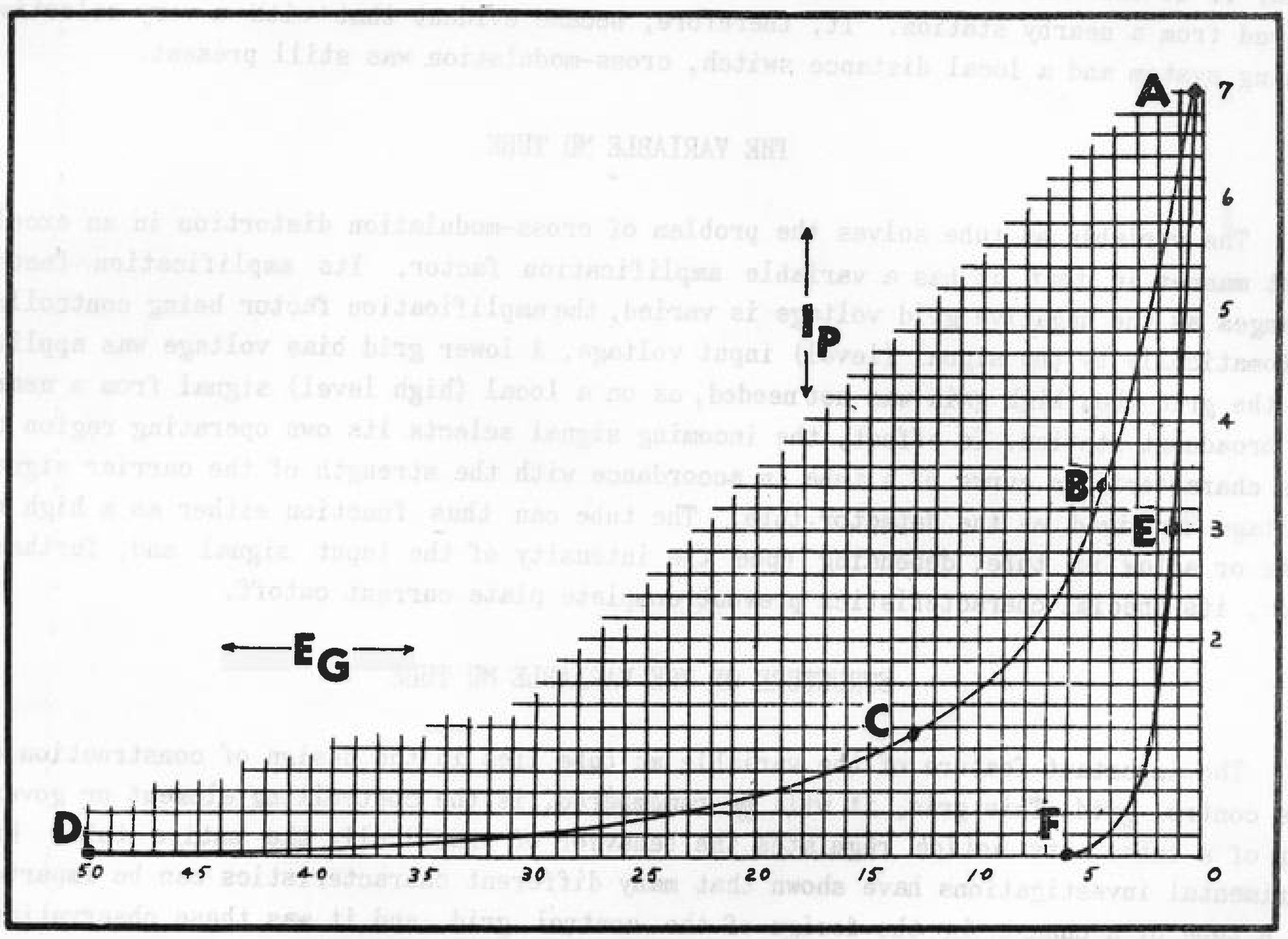

Fig. 3. The Eg-Ip characteristic curves for regular and variable mu tubes.

the action becomes somewhat different. In the regions where the grid wires are close together, the negative bias voltage prevents any electrons from getting through, but in the middle region where the grid windings are separatedfurther, the negative bias voltage is not so concentrated and a limited number of electrons can pass through. The result is that the plate current, and also the amplification factor, are greatly reduced, but on account of the irregular design of the grid winding, this reduction is accomplished in a more gradual and smooth manner in contrast with the abrupt reduction obtained with a uniform grid winding. In other words, with a variable mu tube the plate current does not approach zero as rapidly as the grid bias is increased, and as will be further explained, cross-modulation is eliminated.

Other methods of grid design or construction can also be employed to produce this more gradual reduction of plate current with an increase of negative grid bias or swing. For example, at C in Fig. 2, the grid electrode wires are wound in the form of a double cone. Here again the retarding force, due to the negative bias voltage on the control grid, is very concentrated at the upper and lower ends of the grid electrode, but is much less in the middle region. The same effect is thus produced at B in Fig. 2. At D in Fig. 2 the grid is wound in two rectangular sections with an open space in the middle. Here also the negative bias voltage will be concentrated in two regions, although the electrons can pass with rather free movement through the region between them. Still other designs are possible and used, but the three illustrated at B, C, and D in Fig. 2 are most common.

Graphically we can show the relative difference in the performance characteristics of tubes with uniform and non-uniform control grid electrodes. This is illustrated in Fig. 3. This figure indicates the plate current from zero to seven milliamperes as indicated on the right, vertical side of the graph, while the negative grid bias voltage is indicated from values of zero to 50 volts along the bottom, horizontal side of the drawing. Zero bias voltage is shown in the lower right hand corner. Note that the letters Ip between the vertical arrows indicate the plate current. The letters Eg between the horizontal arrows indicate the control grid bias voltage. In other words, we shall refer to these changes in plate current as changes in Ip. Then the changes in (control) grid voltage shall be indicated as Eg. Radio and television men generally refer to the relative change in plate current with a change in grid voltage as the Eg-Ip characteristic curve of a tube. These characteristic curves indicate the relative change in plate current with a change in grid voltage.

Let us examine Fig. 3 more carefully. This graph shows a change in Ip from zero to 7 milliamperes. The change in Eg is from zero to minus 50 volts. Most graphs showing the characteristic curve for a tube indicate a minus voltage to the left of zero when referring to grid voltages. Having analyzed the graph shown in Fig. 3, let's see the relative difference in the performance characteristics of tubes with uniform and non-uniform control grid electrodes. This will be done by looking at the curves in the graph. The Eg-Ip characteristic curve having the letters A, E and F on it indicates the change in plate current when the grid bias voltage is made more negative from zero to about 6 volts for a tube with a uniformly constructed control grid electrode. The point A indicates the plate current flow of about 7 milliamperes with zero grid voltage. The point E indicates a plate current flow of 3 milliamperes with a grid voltage of 1.5 volts. Then the point F indicates zero plate current flow with a grid voltage of 6 volts. All of these grid voltages are negative with respect to the emitter or the cathode of an indirectly heated tube.

In this graph shown in Fig. 3 the curve formed by the points A, B, C and D indicates the relative change in plate current as the control grid voltage is made more negative for a tube having a control grid of non-uniform design. This curve, as represented by the letters A, B, C and D, therefore is the Eg-Ip characteristic curve for a variable mu tube. In analyzing the curve form by joining points A, B, C, and D note that the plate current at the point A is 7 milliamperes for zero control grid voltage. Then the plate current at the point B is 3.4 milliamperes for 4.5 volts control grid voltage. The plate current at point C is 1.2 milliamperes with a negative control grid voltage of 13 volts. The point D indicates zero plate current flow for a negative control grid voltage of 50 volts. Again all of these control grid electrode voltages are made with respect to the cathode of the tube. Notice that the reduction in plate current from minus 13 volts to minus 50 volts is not very rapid. Radio and television men call this a slow cut-off tube for this very reason.

From the information given above, it therefore is evident that it is possible to obtain a tremendous difference in the number of electrons reaching the plate electrode of a tube by merely changing the construction (the design) of the control grid even though the same screen grid and plate electrode voltages are used. Naturally, when the number of electrons reaching the plate change, there is a change in the signal amplification.

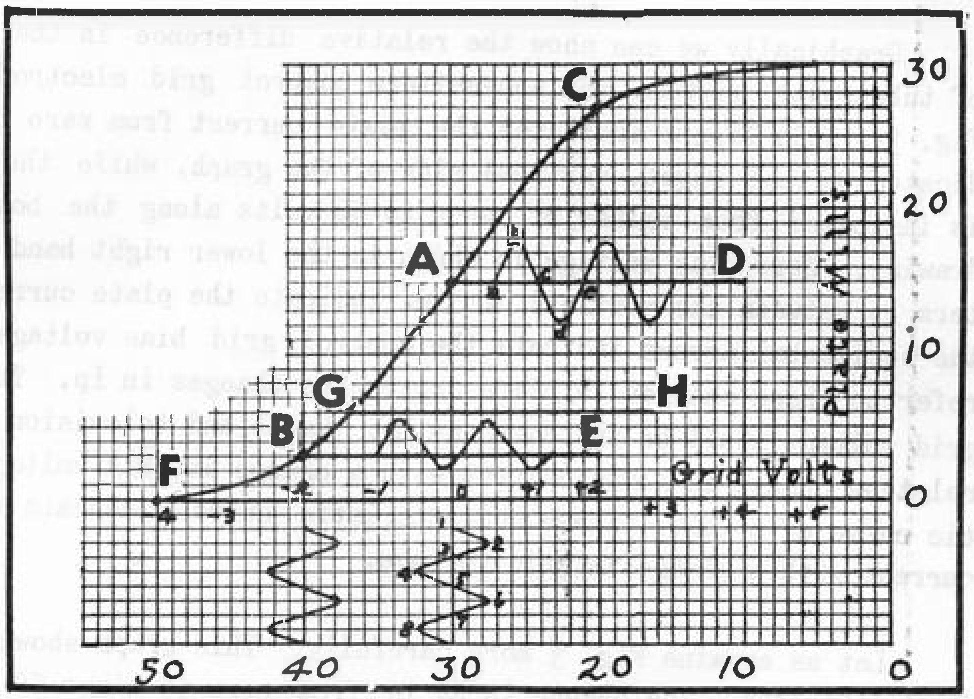

Fig. 4. This Eg-Ip curve will be used to show the operation of Class A, B, and C signal amplifiers.

It is because of this variable mu characteristic that this type tube gives essentially distortionless amplification over a very wide range of signal voltages. For low signal levels, it offers high amplification and for high signal levels it offers less amplification. In other words, the variable mu tube combines the features of high mu and low mu tubes all in one envelope. There are a large number of different types of variable mu tubes made by tube manufacturers. Some of them are known as the type 78, 58, 56, 6SK7, 6AG5 and 6AK5. Practically all r-f amplifier tubes listed in a tube manual are of the variable mu type.

SHARP AND SLOW CUT-OFF AMPLIFIER TUBES

So far in this lesson we have discussed amplifier tubes whose plate current may be cut off completely with a relatively small increase in control grid bias voltage. These tubes are known as the sharp cut-off types. In these types the control grid is of uniform construction. Then we also discussed the types of tubes having very slow plate current cut-off; that is, a large increase in control grid bias voltage is necessary to cut off the flow of plate current. These tubes are known as slow cut-off types and are often called the variable mu or super-control types.

The sharp cut-off type of tube has practically a constant amplification factor regardless of the control grid bias voltage employed. The variable mu type tube has an amplification factor which decreases as the negative bias applied to the control grid is increased.

VOLTAGE AND POWER AMPLIFIER TUBES

Amplifier tubes are further classified. They are referred to as voltage and power amplifier tubes. In voltage amplifiers, the purpose of the tube is to amplify the signal voltage the required amount. In power amplifiers, it is the purpose of the tube to convert the signal voltage into considerable power for the operation of the loudspeaker.

CLASS A - B - C AMPLIFIERS

It is common practice for radio and television men to indicate the region of operation of a tube over its Eg-Ip characteristic curve in addition to its classification as a voltage or power amplifier. Some of these different classes of amplifier operation shall now be explained.

CLASS A AMPLIFIERS

Fig. 4 will be used in explaining the basic classes of amplifier operation. Note that the plate current is indicated vertically and that the grid bias voltage is indicated horizontally. You will also see that the starting point for these values appears in the lower right hand corner of this figure. The Ip values extend from zero to 32 milliamperes and the Eg values extend from zero to minus 50 volts.

A tube operating as a class A amplifier may have its operating point on the Eg-Ip curve at point A. This point shows a plate current of 15 milliamperes. The voltage applied to the grid of the tube for this amount of plate current is indicated as minus 30 volts. This operating point A is on a reasonably straight portion of the Eg-Ip characteristic curve. Let us assume that there is a plate current of 15 milliamperes and a control grid voltage of minus 30 volts applied to an amplifier tube, and that this tube has an Eg-Ip characteristic curve similar to that shown in Fig. 4. When a positive signal voltage is applied to the control grid of this Class A amplifier, then this signal voltage may start from the point 1 and swing to the right, which is in the positive direction, and when the signal voltage reaches the point 2, then the plate current has changed from the point a to the point b along the line A-D. The plate current has increased in proportion to a decrease in the control grid bias voltage. The bias voltage was decreased 2 volts, or from 30 volts to 28 volts. In other words, a 2 volt decrease in bias causes an increase in plate current of 2.5 milliamperes. Then the signal voltage is decreased again and the control grid voltage has changed from point 2 to point 3, the plate current decreases from the point b to the point c. At this point the plate current is the original value of 15 milliamperes and the applied grid voltage is again 30 volts. The grid voltage has now changed from point 1, to point 2, to point 3 which is exactly 180 degrees of the input signal. From point 3 to point 4 the grid input signal swings the control grid voltage more negative and exactly 2 volts. Then from point 4 to point 5 the applied control grid voltage is again 30 volts. The plate current for the corresponding points 3, 4 and 5 are shown as points c, d, and e. The signal voltage applied to the grid has now completed another 180 degrees which made a total change of 360 degrees. This is equal to one complete cycle. You will observe that the input and output signals are identical and furthermore, the grid voltage (the signal voltage) never caused the plate current to swing off the straight region or portion of the Eg-Ip characteristic curve. We, therefore, come to the conclusion that a class A amplifier is an amplifier in which the plate current flows over the entire cycle of its input (control grid) voltage, and that the plate current is directly proportional to the applied signal voltage.

CLASS B AMPLIFIER

The Class B amplifier may operate at the point B on the Eg-Ip curve shown in Fig. 4. Here the grid bias voltage is minus 40 volts, and the no signal plate current flow is equal to 3 milliamperes. When the signal voltage starts in the positive direction and is decreased 2 volts, then the plate current again increases 2 milliamperes. After reaching this maximum value, then the signal voltage goes back to zero again and the plate current again becomes 3 milliamperes. Then the grid signal increases in the negative direction 2 volts, and this causes only a decrease of 1 milliampere in plate current flow. We, therefore, find that the amplified signal is no longer uniform for both halves of the applied signal. The plate current is greater for a decrease in bias than for an increase in bias. This is the typical operation of a Class B amplifier with a low signal level.

CLASS C AMPLIFIER

The Class C amplifier is one in which the control grid bias voltage is two or more times the grid bias voltage required to cut the plate current off completely. For example, the tube shown in Fig. 4 will require a control grid bias voltage of 100 volts for Class C operation. This then means that the applied signal voltage must be more than 50 volts in the positive direction in order to cause the flow of plate current on the positive portion of the a-c signal. When the signal voltage becomes 50 volts or more on the positive peak of the a-c signal, then plate current starts to flow as indicated in Fig. 4. If the signal voltage were 60 volts, then the plate current would increase to the point B on the Eg-Ip characteristic curve. This would be a plate current flow of 3 milliamperes. The Class C amplifier, therefore, operates only on the positive portion of the applied a-c signal voltage.

- END OF LESSON -