SPECIALIZED
TELEVISION ENGINEERING

TELEVISION TECHNICAL ASSIGNMENT

SCREEN-GRID TUBES

733E

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SCREEN-GRID TUBES

SCOPE OF ASSIGNMENT

This assignment will deal with the screen-grid type of tube. First, the disadvantage of triodes for certain applications are discussed. Then, the means of overcoming those disadvantages by the use of a four-element tube or tetrode are described.

However, the four-element tube also has its disadvantages, and has been largely superseded by the pentode (a five-element tube), and the beam power tube, which is regarded as a special kind of tetrode, although its beam-forming plates might legitimately be considered a fifth element.

The assignment concludes with a discussion of miniature-type screen-grid tubes that are today being employed in f-m and television, as well as in other u.h.f. applications.

GENERAL CONSIDERATIONS

In analyzing the need for special types of tubes it is well to first consider the advantages and disadvantages of the simple triode. It must not be thought that because a screen-grid tube, for example, has certain advantages over a triode for certain types of operation, that it is more suitable for all purposes.

On the contrary, in cases where a simple oscillator or multivibrator is involved, the triode is used in preference to the tetrode or pentode. The additional elements introduced as a result of using a screen-grid tube are not only unnecessary in such equipment, but also add complications.

In r-f amplifiers for use at high frequencies, triodes are preferred to pentodes due to the decrease in tube noise afforded when triodes are utilized. For high-power transmitter applications, triodes have the advantage over screen-grid tubes of being more easily cooled. Of course, pentodes do not require neutralization, whereas triodes do.

For certain purposes, however, the triode has two very serious limitations: First, the internal capacity between elements, principally between grid and plate. In order to prevent reverse transfer of power through the tube due to the capacity effect, a somewhat elaborate capacity neutralizing circuit is required, the adjustment of which is critical. If it is attempted to use the triode as a radio-frequency amplifier without a capacity neutralizing circuit, energy will be transferred from the tuned plate circuit back into the grid circuit in such phase and amplitude that the circuit will oscillate.

Second, the voltage amplification that it is possible to obtain with a triode is quite limited. This limitation is not particularly serious in the case of transmitting tubes where the major considerations usually are efficient operation and large power amplification rather than large voltage gain.

It will be recalled from the assignment on vacuum tube amplification that the major requirement of a tube to be used for voltage amplification is that it have a high mu. Thus, in audio amplifier work, it is desirable to use a tube which has a higher μ than that of the ordinary triode. For such purposes, the pentode is preferred. Of course, the actual gain of a pentode will not equal the μ of the tube, but it can be quite high provided sufficient load impedance is used.

For example, suppose an r-f gain of 600,000 is required and triodes (with associated circuits) developing gain of 15 per stage are used; a total of five consecutive stages will be required. An r-f amplifier consisting of five triode stages would require extremely effective shielding, exact capacity neutralization, and then would tend to be unstable. Such a circuit would not be at all practical for quantity receiver production. On the other hand, one stage of r.f., first detector and two stages of i-f gain, all stages using screen-grid tubes, can easily deliver the necessary gain. Such an amplifier is stable and not at all difficult to design or produce.

The two limitations of the triode, excessive plate-grid capacity and insufficient amplification factor, are not present in the screen-grid tube, so that in ordinary receiver r-f and i-f amplifiers the screen-grid type of tube is universally employed. The high R_p of the screen-grid tube gives low damping and a high Q.

The principal constructional difference between the triode and the screen-grid tube consists, in the latter, of a second wire grid which is placed between the plate and the control grid to form an electrostatic screen between those two elements. The screen grid is made positive with respect to the cathode by an amount usually between one-third and one-half of the plate potential.

The screen voltage may be obtained from a tap on the plate power supply. However, a large by-pass capacitor is always connected directly between the screen grid and the cathode, so that, so far as the radio-frequency voltage is concerned, the screen grid is connected directly to the cathode.

The screen grid performs two very important functions: First, it reduces the grid-plate capacity to a usually negligible value; second, it makes the internal plate-cathode resistance R_p very high, usually in the order of several hundred thousand ohms. How these are accomplished will be explained later. It must not be thought that C_{g-p} is reduced to zero; it is not. However, in the case of the pentode type 6AU6 (miniature), the grid-to-plate capacity is .0035 μμF maximum. This may be compared with C_{g-p} of 3.4 μμF for the metal triode type 6J5.

It should be emphasized at this point that while the small grid-plate capacity of the screen-grid tube normally reduces the feedback through the tube to a negligible value, the large voltage gain of the tube *accentuates the effect of stray circuit coupling, so that much more effective interstage circuit shielding is required than when a triode is used.* This point can hardly be overemphasized as failure to properly arrange and shield the grid and plate tuned circuits will nullify the benefits gained by tube design.

THEORY OF THE SCREEN-GRID TUBE.—Strictly speaking (i.e., considering the screen-grid tube as having only four elements), the screen-grid tube has been almost totally supplanted by other tubes. However, in order to understand the theory of operation of more advanced types of tubes, it is first necessary to understand the principle of operation of the fundamental screen-grid tube. By inserting a wire screen between the control grid and plate and then connecting the screen to the cathode by a large by-pass capacitor, the effect is to electrostatically shield the plate from the control grid and from the cathode. The actual construction of the tube is shown in Fig. 1, the circuit connection in Fig. 2. (Note in Fig. 1 that in this tube an outer screen, connected to the inner screen grid,

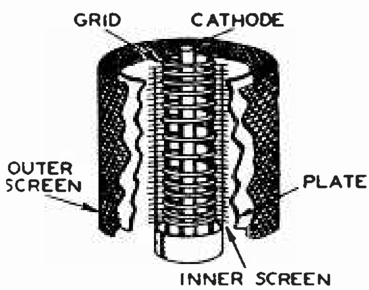


Fig. 1.—Construction of a screen-grid tube.

is placed around the plate. This helped to further shield the plate from any capacity effect to the control grid or its connections.) This practice is not followed to any extent now; however, a type 24-A screen-grid tube is being used as an illustration at this point since it exhibits certain undesirable effects (such as secondary emission) which have been overcome in present-day tubes, but which nevertheless are necessary to consider in order to obtain a thorough understanding of screen-grid tubes.

Consider Fig. 2. The electrons proceeding outward from the indirectly heated cathode come under the influence of the control grid just as in a triode. Consider for an instant that the positive potential is removed from the plate and the regu-

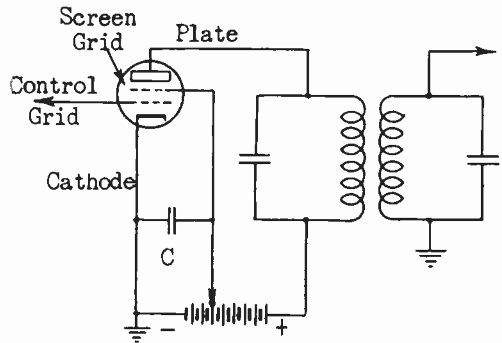


Fig. 2.—Circuit connections for a screen-grid tube.

lar positive potential of about one-half the normal plate voltage is applied to the screen grid. The electrons leaving the cathode are drawn to the positive screen, the number that reach the screen being determined by the voltage on the control grid, just as is the plate current in a triode. Most of the electrons pass through the screen toward the plate, but since the screen is positive and the plate voltage is zero, the electrons passing through the screen are quickly stopped and drawn back to the screen.

Now apply a small positive potential to the plate and increase the plate voltage slowly, observing both plate current and screen current. The results are clearly shown in Fig. 3.

Examine the two curves, I_{c2} which represents the screen-grid current, and I_b for -3 volts on the control grid, I_b representing the plate current. At zero plate voltage I_{c2} is about 4.5 mils and I_b is zero, as explained above. As a *small* positive potential is applied to the plate I_b rises sharply from zero and I_{c2} *falls in the same proportion.* As the plate voltage is slowly increased, a point is soon reached where *a further increase of E_b causes a decrease in I_b and an increase in I_{c2}.* This phenomenon must be further explained.

It has been shown in an earlier assignment that when electrons strike the plate with any appreciable velocity, secondary electrons are emitted from the plate. In the case of the triode this effect is unnoticed because the secondary electrons are drawn right back to the positive plate. However in the screen-grid tube the screen potential is fixed—in Fig. 3 at 90 volts—and for small values of E_b, the positive screen voltage exceeds E_b. With the first very small values of E_b, the electrons arrive at the plate with low velocity and very few secondary

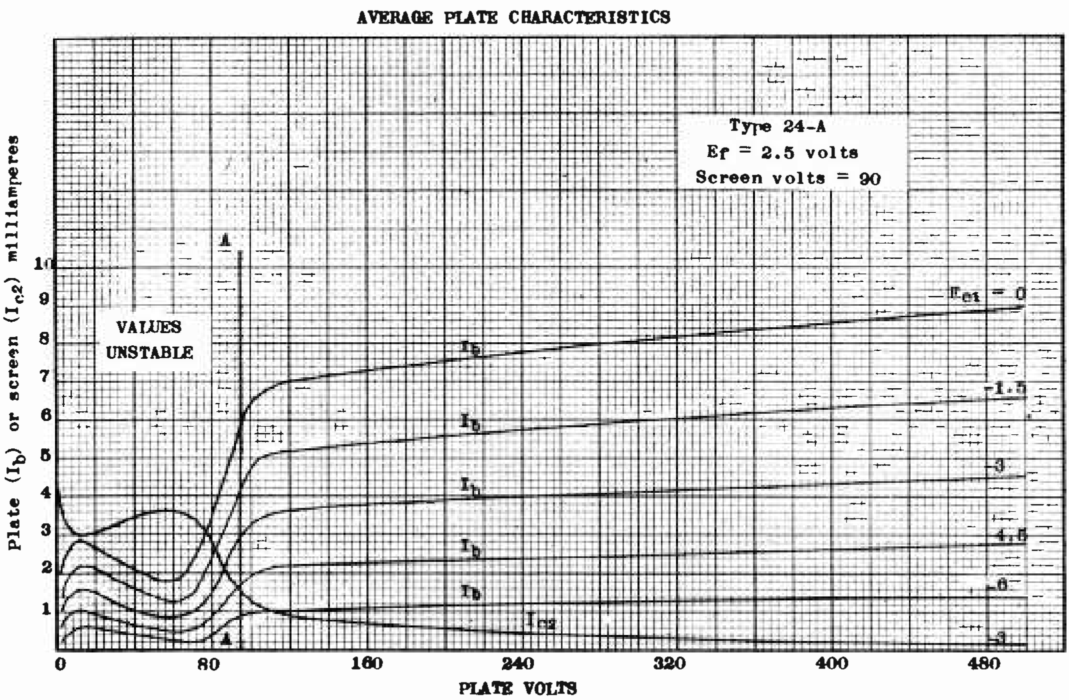


Fig. 3.—Characteristic curves of a screen-grid tube (Type 24-A).

electrons are emitted. As E_b is increased the velocity of the electrons is increased and more and more secondary electrons are emitted. At some certain plate potential the number of secondary electrons emitted and going to the screen grid exceeds the increase of primary electrons reaching the plate due to the increased plate potential, and further increase of E_b continues to aggravate this situation. further increase of E_b *decreasing* I_b and *increasing* I_{c2}. In the region where this occurs the plate resistance is said to be negative.

As E_b is further increased a point is reached where the trend as explained above reverses sharply. This occurs just before E_b equals the screen voltage. As the point $E_b = E_{c2}$ is approached, the secondary electrons are drawn back to the plate because they are closer to the plate than to the screen, and with E_b about equal to E_{c2} the stronger attraction is at the plate. At $E_b = E_{c2} = 90$, I_b is just about equal to the value of I_{c2} before the negative resistance effect occurred and I_{c2} is reduced to about one-third of its original value.

At about $E_b = 100$, the sharp rise in I_b and the sharp drop in I_{c2} cease and for further increases of E_b—even quite large increases—I_b increases very slowly and I_{c2} decreases slowly in about the same proportion. It should be noted that over the entire range of E_b, the total space current ($I_b + I_{c2}$) is essentially constant.

The fact that the plate current increases very little for a large increase of E_b shows that R_p is very large. The fact that the space current is essentially constant regardless of the value of E_b demonstrates that the positive plate charge ends at the screen grid and does not extend beyond the screen toward the space charge around the cathode. If the positive plate potential extended appreciably beyond the screen toward the cathode, an increase of E_b would cause an appreciable increase in the total space current, which actually is not the case. This indicates that the shielding effect of the screen between the control grid and plate is very effective, because if essentially all of the electrostatic lines of force from the plate end at the screen, they cannot extend to the control grid, and the capacity effect between plate and control grid is thus reduced to almost zero.

GAIN CONSIDERATIONS.—An examination of Fig. 3 will also make apparent the large amplification factor of the screen-grid tube. If the tube is operated at $E_b = 240$ and E_{c1} (control-grid bias) $= -3$, E_b must be increased by 240 volts or to 480 volts to increase I_b by .5 mil. On the other hand a decrease of negative control-grid bias from -3 to -1.5 volts with $E_b = 240$ increases I_b by 1.75 mils. To increase I_b one mil requires a change in E_{c1} of approximately .8 volt. A similar change in I_b could be obtained by increasing E_b by 480 volts. Thus under these given conditions for the curve of Fig. 3 with the control grid biased to -3 volts, $\mu = dE_b/dE_{c1} = 480/.8 = 600$. This is a much higher amplification factor than can be obtained with a triode.

Operated as explained in the preceding paragraph, the internal plate-filament resistance R_p is very high. $R_p = dE_b/dI_b$. If $dE_p = 240$ volts and $dI_b = .5$ milliampere, then $R_p = 240/(5 \times 10^{-4}) = 480{,}000$ ohms.

The mutual conductance, $G_m = \mu/R_p = 600/480,000 = 1,250$ μmhos.

To obtain actual gain approaching the μ of the tube, it is necessary that the load impedance Z_L be much greater than R_p. This is not practical and in practice the actual gain goes not approach μ.

$$\text{Gain} = \frac{\mu Z_L}{R_p + Z_L}$$

In screen-grid tube calculations it is customary to write equations in terms of G_m rather than μ. In terms of G_m,

$$\text{Gain} = \frac{G_m R_p Z_L}{R_p + Z_L}$$

If R_p is very large compared with Z_L then the latter may be neglected in the denominator, and

$$\text{Gain} = G_m Z_L$$

From this equation it is seen that *until Z_L is made very large, the actual gain per stage obtained with a screen-grid amplifier is proportional to the load impedance.*

In ordinary i-f amplifiers of receivers the tube ordinarily operates into a tuned circuit as shown in Fig. 2. Since, as shown in the equations above, the gain actually obtained with a given screen-grid tube is a function of the load impedance, it will be seen that to take proper advantage of the voltage amplifying capabilities of the tube, the plate load circuit must be carefully designed.

The parallel resonant impedance of a circuit as shown in Fig. 2, if the secondary circuit is neglected, is equal to L/CR. From this it is apparent that L should be as large as practical and C correspondingly small. The circuit resistance R should be kept to a minimum. For reasons which will be explained later in the study of receivers, it is ordinarily not practical in an i-f amplifier to make L very large and C very small, one reason being that if C is very small, a slight variation in the capacitor setting will result in a large variation of capacity.

However, in the case of intermediate-frequency amplifiers in superheterodynes, tuning over a wide range is not necessary and the load circuit can be designed for gain several times greater than that obtained in the r-f stage or stages, where the plate circuit is not usually tuned.

It will be seen that the matter of reducing circuit losses, R, is as necessary as obtaining a large L/C ratio. In a well designed i-f circuit practically all the loss may be ordinarily assumed to be in the coil. Thus it is necessary to employ a coil design that will allow R to be kept to a minimum. One method of accomplishing this which is used extensively, is to wind the coil with Litz wire. At the intermediate frequencies good Litz wire may cut the radio-frequency resistance to one-half or less than that of a coil wound with an equivalent size of solid wire. The development of very low-loss iron cores for both r-f and i-f coils has allowed further reduction in coil resistance, the added losses in the iron core being less than the resistance taken out of the circuit by the reduction in the number of turns made possible by the greater magnetic permeability of the iron core.

Tetrodes have been developed

having the inner surface of the plate ribbed to form pockets from which secondary electrons are not easily drawn by the positive charge of the screen grid. However, in general it may be said, that the conventional screen-grid receiver-type tube is not suitable as a power amplifier.

PENTODES

The pentode or five-element tube was developed originally as a receiver power amplifier to remove the plate voltage swing limitation as explained above and to permit the benefits of high μ operation to be combined with large audio power output. In audio amplifiers, of course, the grid-plate capacity is usually of little consequence, but the factor of high voltage gain is extremely desirable in many cases.

By placing a screen grid between the plate and control grid, the effect of plate voltage variations on all electrons between the cathode and screen grid is made essentially negligible because the electrostatic field of the plate ends at the screen. By similar reasoning, if a second screen is placed between the plate and screen grid, the second screen being held at cathode potential by actually connecting it to the cathode, the electrostatic fields of both plate and screen grid will terminate near this zero potential screen and neither voltage will have any appreciable effect on the other. This second screen is called the *suppressor grid* and the arrangement is shown in Fig. 4. It should be observed that the plate and screen grid in power pentodes may ordinarily be operated at the same d-c potential.

The principle of operation of the pentode is quite simple. The total space current, $I_b + I_{c2}$, is controlled by the combination of control and screen-grid potentials just as in the tetrode. (The ratio of the effect on the space current of the control grid over that of the screen grid is sometimes referred to as μ_{sg}, this factor comparing with the amplification factor of a triode.) The high velocity electrons under the attraction of the screen

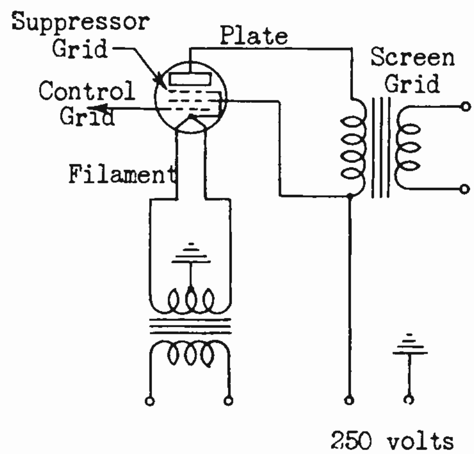


Fig. 4.—Arrangement of grids, and circuit connections for a pentode.

grid pass through the screen-grid wires, through the suppressor grid, and to the plate. Secondary electrons are dislodged from the plate as in the tetrode. However the electrostatic field of the screen grid ends at the suppressor grid; the secondary electrons emitted from the plate are drawn back to the plate, even when the plate voltage is low, because there is no higher positive potential acting on them as in the tetrode. Thus the negative resistance characteristic of the tetrode at low values of E_b is not present in the pentode. This is shown in the curves of Fig. 5 for the 6AK6 miniature-type power pentode.

In ordinary operation with reasonably high plate voltage, the electrons passing through the screen grid are slowed down as they approach the suppressor grid, but most of them come under the influence of the plate voltage and are drawn through the suppressor and hence to the plate. However, as the plate voltage is reduced to very low values its effect on the screen side of the suppressor is also reduced, and below a certain value of plate voltage the electrons passing through the screen are slowed down as they approach the suppressor grid. This space charge is called a *virtual cathode*. After the virtual cathode forms, the control grid has little further effect on the plate current and further decreases of plate voltage result in a considerable decrease in plate current and a sharp increase of screen current. This is shown in Fig. 5 by the gradual bend in the plate current curves for low values of plate voltage.

The screen-grid tube (particularly the pentode) is capable of giving greater power output at a higher efficiency than the triode tube for a given B supply voltage. The reason for this is that the quantity E_{min} in the power output

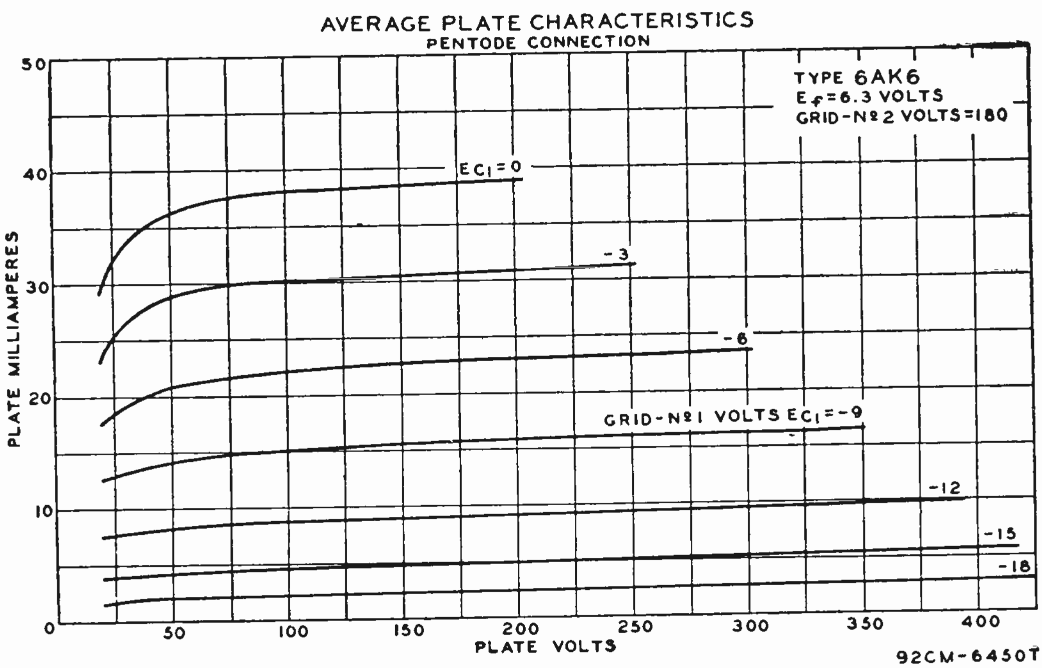


Fig. 5.—Characteristic curves of a miniature power pentode Type 6AK6.

formula, which is

$$P_o = \frac{(E_{max} - E_{min})(I_{max} - I_{min})}{8}$$

can be made less in the case of a pentode and tetrode tube than in the case of a triode tube. Refer to Fig. 6. However, it should be noted that the "knee" of the pentode

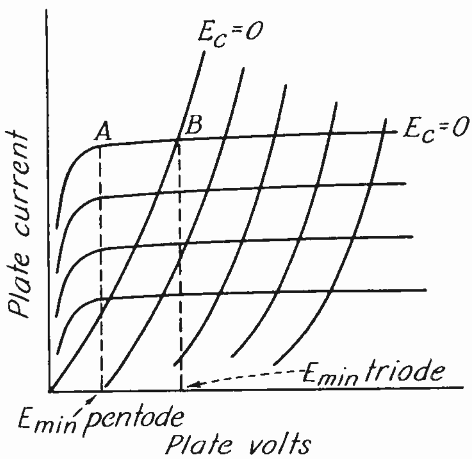


Fig. 6.—**Illustration showing that E_{min} can be made less in the case of a pentode than for a triode.**

characteristic does produce a certain amount of distortion as explained in the assignment on vacuum tube amplifiers; for this reason, the "knee" of the pentode characteristic should be sharpened as much as possible.

Of course, the second-harmonic distortion can be reduced by push-pull operation of the tubes; however, it will be recalled from a previous assignment that under certain operating conditions, the third harmonic may exceed the second harmonic in a pentode, and third-harmonic distortion cannot be balanced out by push-pull operation.

Examination of Fig. 5 will also bring out the fact that even if the distortion factor were neglected a very large value of load resistance, as represented by a load line having a very small slope, would result in lower rather than greater power output due to the shape of the $E_b I_b$ curves. By decreasing the slope of the load line, the same grid voltage swing would of course result in a larger plate voltage variation. However it is plain that the plate current variation would decrease at a more rapid rate than the increase in plate voltage swing. The power output is a function of the product of the a-c components of plate voltage and plate current. Thus from the shape of the $E_b I_b$ curves, it will be seen that the maximum power output from a pentode will be obtained with quite small R_L, much smaller than the R_p of the tube. The operating conditions for *maximum power output* from a pentode audio amplifier should of course not be confused with the conditions for *maximum voltage* gain in a pentode r-f amplifier. For maximum voltage gain R_L should be large. Maximum voltage gain and maximum power output are obtained with quite different load conditions.

The principal advantages of the pentode as a power amplifier are its high plate efficiency and its high power output at low values of plate supply voltage.

The higher μ of the pentode makes it possible in many cases to resistance-couple a single power pentode directly to the detector, thus eliminating a first audio stage entirely and further eliminating one or two transformers. This is a large proportionate saving in the construction cost of an inexpensive receiver. It also allows a space reduction where this is helpful, as in auto receivers.

Due to its several advantages, the pentode is now almost universally used in receiver r-f and i-f amplifiers, the r-f pentode being a better tube for this purpose than the tetrode. In r-f and i-f amplifiers where the plate voltage swings are not great, the principal advantages of the r-f pentode are considerably higher μ and G_m.

HIGH MUTUAL CONDUCTANCE PENTODES.—With the advent of FM and television it has been necessary to develop entirely new types of r-f pentodes. There are three units in a television system where conventional r-f pentodes, due to their comparatively low mutual conductance, are entirely inadequate. These units are the video amplifier, the intermediate-frequency amplifier of the receiver, and the ultra-high frequency r-f amplifier of the receiver. The inadequacy of the ordinary pentode is due to the input and output capacities of the tube and associated wiring, which make it impossible, at the high frequencies involved, to obtain satisfactory gain.

Fig. 7 illustrates the load circuit of an intermediate-frequency amplifier, the load impedance, Z_L, consisting of L-C-R in which L is the tuned circuit inductance, R is the resistance in coil L, and C consists of the sum $C_1 + C_2 + C_3$. In the intermediate-frequency amplifier of a broadcast receiver in which the frequencies range approximately from 175 kc/s to 465 kc/s, L can be made quite large and C_1 is normally large compared with C_2 and C_3. Thus in this range of frequencies Z_L can be maintained in the order of 100,000 to 200,000 ohms. This means that with a tube having a G_m of 1,000

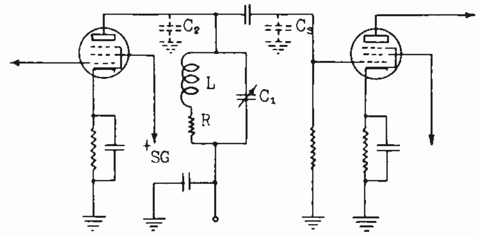


Fig. 7.—I-F amplifier circuit.

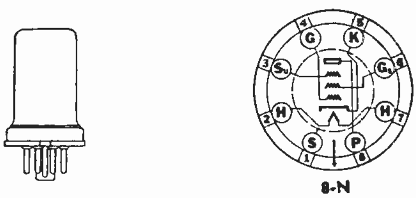
micromhos, gains per stage of 100 to 200 are practical.

When the intermediate frequency is increased to the order of 10,700 kc/s as in an f-m receiver, L becomes extremely small and C_1 approaches the order of $C_2 + C_3$. C cannot possibly be reduced below $C_2 + C_3$, so that in addition to the small value of L made necessary by this capacity limitation, the ratio of L/C is also greatly reduced.

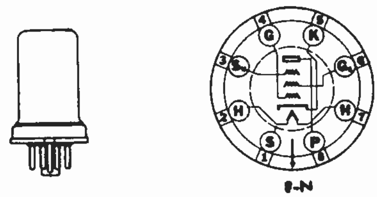
Since Z = L/CR, the fact that the L/C ratio is reduced means that the value of load impedance obtainable is also reduced. Since the gain is equal to $G_m Z_L$, with ordinary tubes designed for low-frequency operation (and having a rather low value of transconductance), if Z_L is quite low owing to high-frequency circuit operation, the gain obtainable will be extremely low. In fact (as will be explained in detail in a later assignment), at very high frequencies the value of gain obtainable may drop to unity or less. Therefore, for satisfactory operation of high-frequency amplifiers, special high-G_m tubes have been developed.

Among the metal-type tubes which meet the necessary requirements for high-frequency circuit operation are the 6AB7, and the 6AC7, photographs and base diagrams of which appear in Fig. 8. grid winding. By the use of flat structures in which the grid winding can be stretched after heating and in which the grid supports can be mounted beyond the ends of the flat surfaced cathode, it has been found practical to reduce the spacing between grid and cathode to .005 inch.

For optimum control the elec-



Type 6AB7/1853 Television Amplifier Pentode



Type 6AC7/1852 Television Amplifier Pentode

Fig. 8.—Photographs and base diagrams of two all-metal high-μ pentodes.

The 6AB7 is particularly applicable to circuits having automatic-gain control. The 6AB7 and the 6AC7 tubes are employed in the video and i-f picture amplifier stages.

The problems encountered in the development of this group of tubes were mostly mechanical. Mutual conductance is increased primarily by two methods: first, by placing the control grid closer to the cathode; second, by increasing the number of turns per inch on the tric field in front of the cathode—and due to the voltage on the grid—should be uniform, even though this field is the result of the combined fields from the individual spaced grid wires.

In conventional tubes this condition is approximated when the distance between the centers of adjacent grid wires is .6 or less of the space from the cathode surface to the plane of the centers of the grid wires. With grid-cathode spacing of .005 inch this would require a grid having 300 turns per inch which is mechanically impractical.

In the 6AC7, the grid is made of .002" wire wound at 142 turns per inch. This results in a mutual conductance at I_b = 10 milliamperes of 9,000 micromhos.

The position of the screen grid is important. For minimum input capacity the screen should be as far from the control grid as practical. However for given plate current, the required screen voltage is almost directly proportional to the spacing between control grid and screen. In the 6AC7 the screen grid is so placed that with normal control-grid bias, 150 volts on the screen will allow maximum g_m and I_b. If a plate potential of 300 volts is used, a dropping resistor of 60,000 ohms will provide the proper screen voltage.

By the use of two flat plates in place of the usual cylindrical plate, the output capacity was reduced from 11 μμF to 5 μμF during development. Due to the focusing effect of the control-grid supports, at normal bias the plate current is confined to a strip only about one-half the width of the plate.

The 6AC7 is similar in appearance to the 6AB7. However, where the 6AC7 has a sharp cutoff characteristic, the 6AB7 is a remote-cutoff type suitable for use with automatic gain control.

MINIATURE-TYPE SCREEN-GRID TUBES.—Miniature-type screen-grid tubes are finding wide application in AM, FM, and television receivers. Some of the most recent tubes of this type are the 6BA6, the 6AU6, and the 6BJ6. The 6BA6, for example is a remote-cutoff pentode of the 7-prong type; it is used as an r-f or an i-f amplifier, or as a mixer in a-m/f-m receivers. Another application of a 6BA6 is as the 1st sound i-f amplifier in a TV set, such as the RCA 721TS, a schematic of the audio section of which is shown in Fig. 9.

The 6BA6 has a grid-to-plate

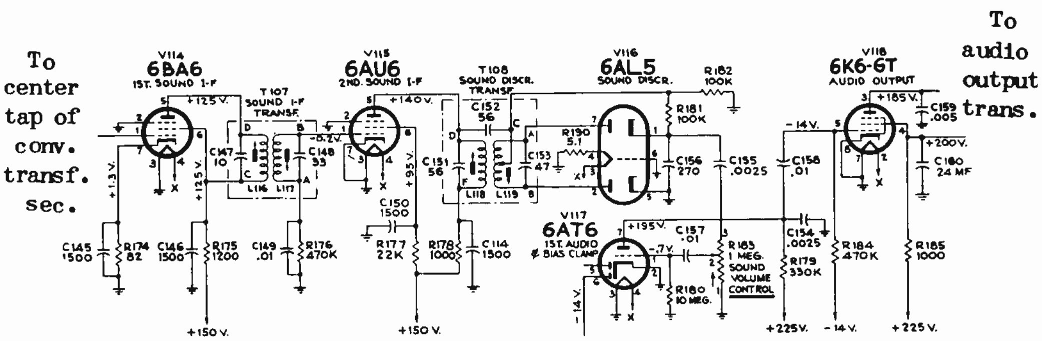


Fig. 9.—Schematic showing the audio section of the RCA 721TS television receiver.

capacitance of .0035 μμF; such a low value of interelectrode capacity helps to minimize the regenerative effects. The tube has a high value of transconductance (in the neighborhood of 4,300 μmhos) which makes possible a high signal-to-noise ratio.

A TV receiver which utilizes a 6BA6 in the sync amplifier portion of the circuit is shown in Fig. 10.

Another 7-prong miniature-type remote cutoff pentode (whose characteristics and applications closely coincide with those of the 6BA6 just described) is the 6BJ6. The transconductance of the 6BJ6 is not quite as high as that of the 6BA6, being in the neighborhood of 3,700 μmhos, instead of 4,300 or so.

Another popular miniature-type tube is shown in Fig. 9; namely, the 6AU6. This tube unlike the 6BA6 is a *sharp*-cutoff pentode. In addition to being used as an r-f amplifier in high-frequency circuits having wide band-pass characteristics, the 6AU6 is used in a limiter stage in f-m receivers. One such receiver is the RCA Model 730TV2 (a simplified schematic of the f-m portion of which is shown in Fig. 11) which covers the broadcast, f-m and TV bands.

In the schematic of the sync portion of the Admiral TV receiver (Fig. 10) a 6AU6 is utilized in the sync separator circuit. Its purpose here is to remove traces of the video signal from the sync circuit; such action is accomplished as a result of the tube being a sharp-cutoff type, and also owing to the fact that the tube is operated with low plate voltage and a rather high biasing voltage. This results in plate clipping of the video portion of the TV signal. This will be explained in detail in a later assignment.

Another 7-prong miniature-type tube which finds wide application in high-frequency equipment is the

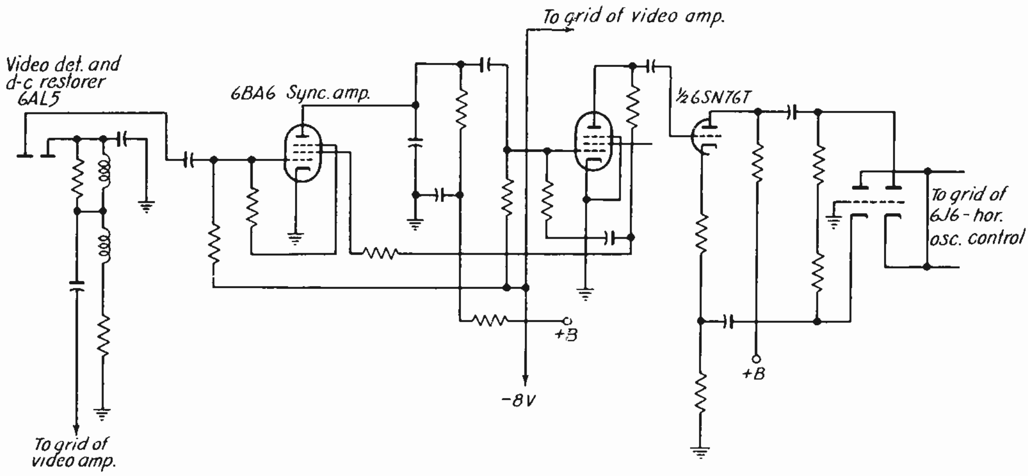


Fig. 10.—Schematic showing the sync portion of the Admiral 301A television receiver.

6AG5. This tube can be used as an r-f or i-f amplifier in circuits proximately 5,000 µmhos. The RCA television receiver (Model 721TS)

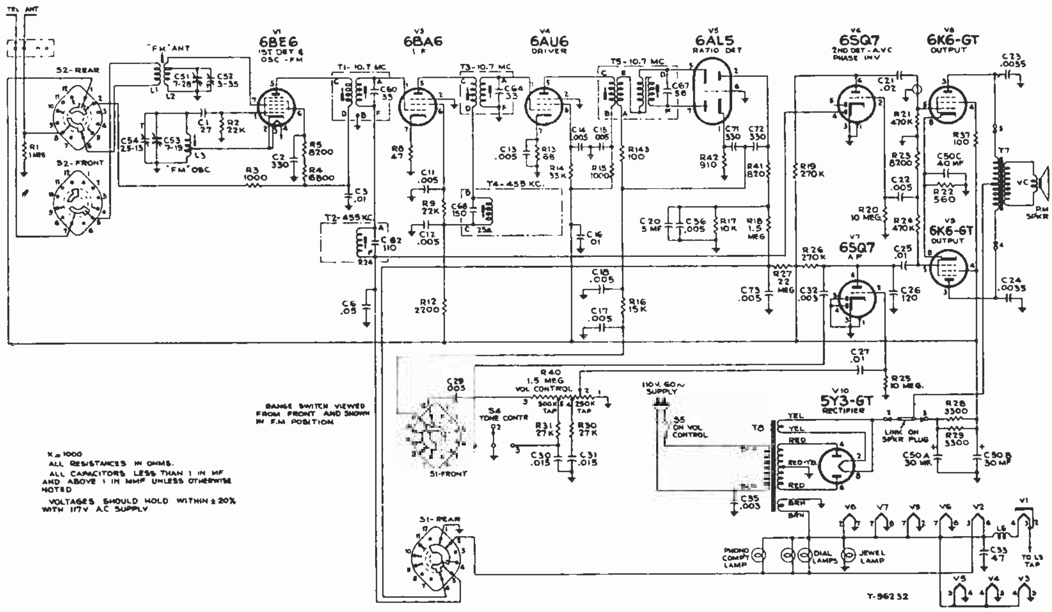


Fig. 11.—Schematic of the f-m section RCA 730TV2 receiver.

operating near 400 megacycles. The 6AG5 has a transconductance of ap— uses 3-6AG5's as picture i-f amplifiers as shown in Fig. 12.

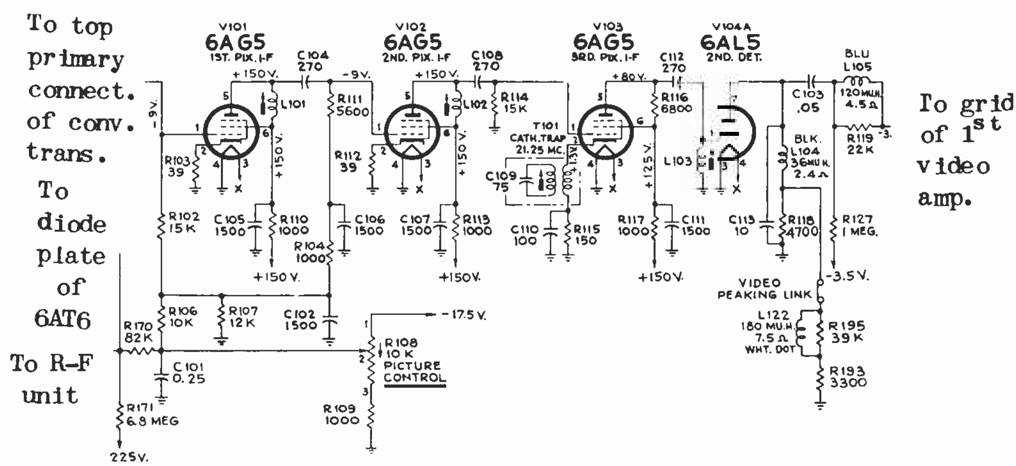


Fig. 12.—A portion of the schematic of the RCA Model 721TS television receiver showing the use of miniature-type tubes as picture i-f amplifiers.

BEAM POWER AMPLIFIERS.—It has been pointed out that the principal weakness of the power pentode lies in the gradual bend of the $E_b I_b$ characteristic at low values of plate voltage which occur when the control grid is made less negative by the signal voltage, with resulting large third-harmonic distortion. It was also shown that the suppressor grid (although it eliminates the fault of the tetrode in the lower operating region due to secondary emission) becomes too effective at low plate voltages and results in formation of a space charge or virtual cathode of electrons just ahead of the suppressor grid, this in turn cutting off the effect of the control grid on the plate current. Actually, what happens in this region is that the suppressor grid acts as a control grid between the virtual cathode and the plate.

The development of the beam power amplifier resulted in a tube which is in effect a "pentode without a suppressor grid" and in which the curved portion of the characteristic is straightened out as shown in Fig. 13.

Since the undesirable effects in the pentode are caused largely by the properties of the actual suppressor grid wires which have a fixed position in the space between screen and plate and which are held at essentially constant potential (that of the cathode), it would seem desirable to eliminate the suppressor grid. However the *suppressor-grid effect*—that of preventing the electrons due to secondary emission from the plate from being attracted to the screen grid—must be maintained.

It was reasoned that the suppressor-grid *effect* would be obtain-

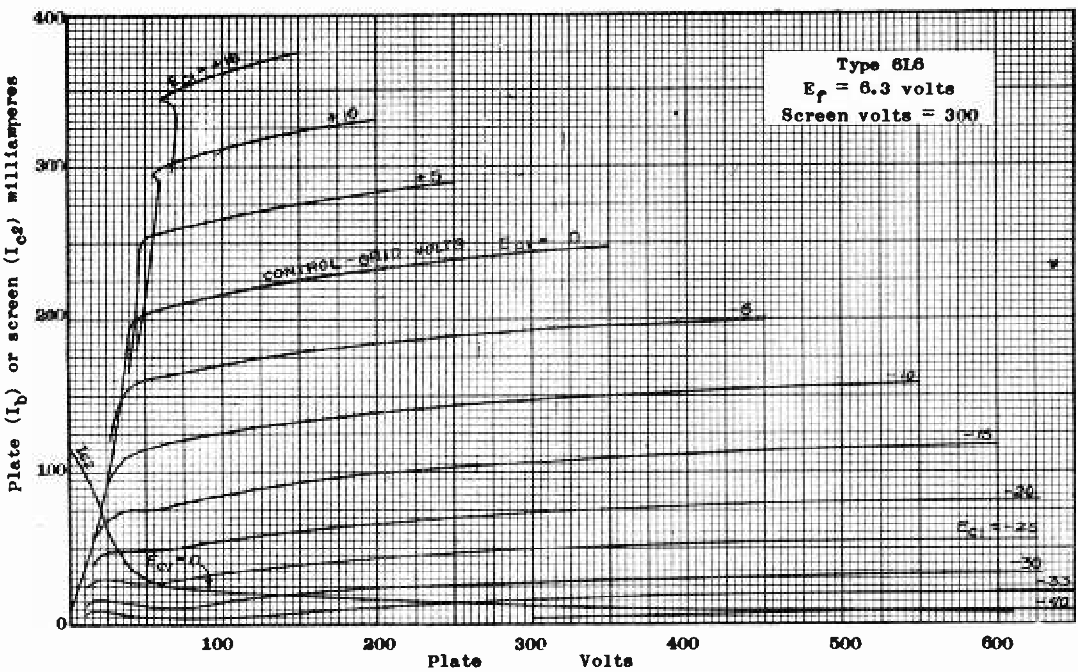


Fig. 13.—Characteristic curves for a beam power amplifier type 6L6.

ed by establishing an equipotential surface of zero gradient in the region between the plate and the screen. The space current in the tube is focused (by means of beam-forming plates) into beams which overlap one another in the region between the plate and the screen, thereby forming a zero-gradient surface having a uniform electron density. The space current (owing to its being focused into beams) passes through the spaces between the wires composing the control grid. The coils of wire making up the screen grid are aligned with those of the control grid; this fact, plus the use of the beam-forming plates (operated at cathode potential) enables the electron stream to be focused away from the screen-grid wires, *even though the value of plate voltage drops below that of the screen-grid voltage.*

By using an equipotential surface as mentioned a more uniform "suppressor-grid action" is obtained than is possible when the suppressor grid is physically present. A further point to note is that the beam-forming plates prevent *plate-emitted secondary electrons* from flowing back to the screen grid.

In the ordinary pentodes, the suppressor-grid action on the electrons between the screen and plate is not uniform. Owing to this factor, as the plate voltage is reduced, the corresponding reduction of plate current is quite gradual.

In the beam power tube, the electrons are more uniform in velocity than in the ordinary pentode; owing to this fact, the point at which the plate current begins to drop, as the plate voltage is reduced, can be more definitely determined for the beam power type tube than for others. The value of E_{min} is lower than in the ordinary pentode, with the result that more power output is obtainable for a given supply voltage when a beam power tube is used. The "knee" of the beam-power characteristic curve is sharper than the "knee" of the pentode characteristic, as can be seen from Fig. 12. The internal arrangement of a beam power amplifier tube such as the 6L6 is shown in Fig. 14, considerably enlarged. The smaller figure shows the arrangement of the entire tube structure; the larger figure demonstrates the operation of one-half of the tube.

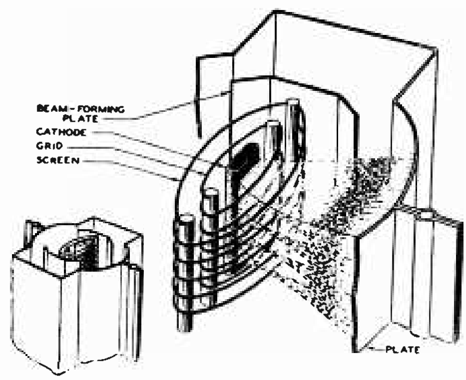


Fig. 14.—Internal structure of beam power tube.

The indirectly heated cathode structure, instead of being cylindrical, is elongated and the emitting coating is placed only on the flat surfaces. Thus the actual electron emission is restricted to the opposite surfaces and the space current is at once concentrated into two beams, the horizontal angles of which add up to a small proportion of the total 360 degrees. To aid in this horizontal concentration, the beam-forming plates, are placed on both sides of the element structure between the screen grid and the plate. Thus any electrons which tend to stray beyond the desired horizontal angle of the beam are shielded from the effect of the plate potential and simply return to the cathode through the shield connection.

In order that there may be no open spaces in the electron field due to shadow effects from the screen-grid wires, the screen-grid wires are placed immediately behind the control-grid wires; as mentioned previously; that is, the screen and control-grid wires are wound so as to have exactly the same pitch. The result of this is clearly shown in Fig. 14. The electrons emitted from all parts of the emitting surface are concentrated vertically into beams by passing through the control-grid wires, the thickness of the beam being small as it passes through the screen wires, and gradually increasing as it approaches the plate due to the mutual repulsion of the electrons. At a certain distance in front of the plate the beams come together and form at that point a quite uniform and highly concentrated electron cloud which, being negative, *repels electrons due to secondary emission back to the plate.*

As a result of placing the screen-grid wires in the shadow of the control-grid wires, a considerable reduction in screen current is obtained; this of course increases the over-all efficiency of the tube. Two of these tubes operated in push-pull Class A, without the grid going positive and self-biased by means of a cathode resistor, have operated at an over-all efficiency as high as 45 per cent, the losses included in the calculation being those due to screens, plates, bias resistors and heaters. This may be compared with plate efficiency of around 20 to 25 per cent, (usually about the maximum), that can be obtained with triode power amplifiers operated Class A.

The harmonic distortion of a beam power amplifier depends upon the value of the load resistance, R_L. If the load resistance is fairly low, the predominating harmonic will be the second; however, if a high value of R_L is used, the third harmonic will predominate. The second-harmonic distortion can, of course, be eliminated by operating two beam power tubes in push-pull. Dist.

For example: A single Type 6L6 operated Class A with fixed bias of -14.0 volts, plate and screen voltage of 250 volts, and load resistance of 2,500 ohms, will develop 6.5 watts power output with second-harmonic distortion of 9.7 per cent and third harmonic of 2.5 per cent. Two such tubes operated in push-pull Class A, with fixed bias of -16 volts, plate and screen voltages both 250, and plate-to-plate load resistance of 5,000 ohms, will develop a power output of 14.5 watts with second and third harmonics of two per cent each. Under suitable operating conditions, two 6L6 tubes operated push-pull Class AB, the grids allowed to swing positive, with a plate-to-plate load resistance of 3,800 ohms, will deliver a power output of 60 watts and a plate-circuit distortion not greatly in excess of two per cent.

The beam power tube, like the pentode, has a large internal resistance, and a high amplification factor. Another point of similarity between the two tubes is that (for proper operation) both require a load resistance, R_L, which is much smaller than their internal resistance, R_p.

The principal difference in operation between the beam power amplifier and the power pentode is the great reduction of third-harmonic distortion in the former. This allows the beam power amplifier to be driven much harder so as to develop much greater power output, because under such conditions the principal increase in distortion is due to the second harmonic which can be balanced out by push-pull operation. In short, the beam power tube is a superior pentode tube; this is due at least in part, to more scientific design, and not only to the elimination of the suppressor grid.

MINIATURE BEAM POWER TUBES.— Miniature-types of beam power amplifiers have also been developed. One of these is the 6AQ5, a base diagram and photograph of which are shown in Fig. 15. Some other miniature-type beam power amplifiers are the 35B5 and the 35C5 (which are equivalent to the 35L6GT), and the 50B5 and 50C5 (which are equivalent to the 50L6GT). The terminal connections and photographs of the 35B5 and of the 35C5 are shown in Figs. 16(A) and (B). The terminal connections of the 50B5 and the 50C5 correspond respectively to those of the 35B5 and the 35C5.

Many other new miniature tubes are being used; these however, will not be described until the assignment on multi-element tubes is studied.

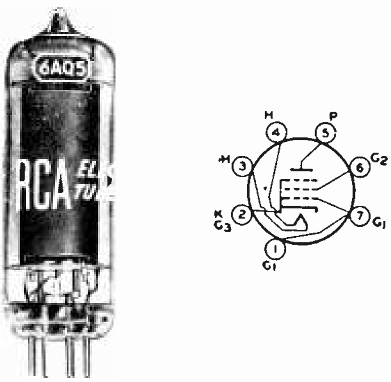
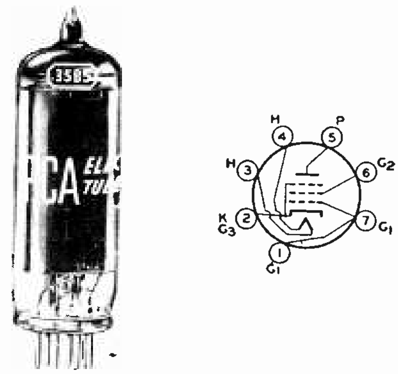
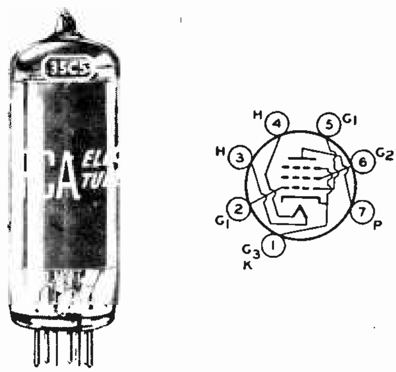


Fig. 15.—Photograph and base diagram of a miniature beam power amplifier tube.



(A)



(B)

Fig. 16.—Photographs and base diagrams of miniature beam power tubes (Types 35B5 and 35C5).

The calculations for power output and distortion have been treated in a previous assignment both with regard to *triode* and *pentode* type tubes. Consequently, no further example will be analyzed here.

RESUME'

This assignment has dealt with the pentode and tetrode tubes. The advantages of these tubes over triodes have been described and are briefly as follows:

1. The introduction of a screen grid between the control grid and the plate eliminates the capacitive coupling between those two elements and consequently obviates the feedback that otherwise may occur, particularly at high frequencies. Although neutralization is possible in the case of a triode tube to eliminate such feedback, the pentode and tetrode tubes do so without any additional circuit and without the difficulty of attempting to make the neutralization operate over a wide range of frequencies.

2. The tetrode and particularly the pentode tube is capable of giving greater power output at a higher efficiency than the triode tube for a given B supply voltage. The reason for this is that the quantity E_{min} in the power output formula, which is

$$P_o = \frac{(E_{max} - E_{min})\ (I_{max} - I_{min})}{8}$$

can be made less in the case of a pentode and tetrode tube than in the case of a triode tube. This is particularly noticeable in the tube characteristic for a beam power tube, since here the so-called "knee" of the characteristic is very close to the current axis.

3. The pentode tube is one having inherently a high R_p and a high μ. The latter enables the pentode tube to function particularly well as a resistance-coupled voltage amplifier, and circuit gains on the order of 20 to 100 are possible. Such amplifications compare more than favorably with transformer-coupled triode amplifiers.

4. A further point of interest in the case of pentode power-amplifier tubes is the fact that the power sensitivity is greater than for a triode tube. This refers to the grid voltage swing required for a given power output. In this respect a pentode tube requires less input signal than the triode and hence less preliminary voltage amplification for a desired power output. Less amplifier stages preceding the power stage, of course, means a greater economy in manufacture and also in operation.

With the advent of TV and FM, a new line of tubes was developed; these tubes are the so-called miniature types and are designed to have high gain at the high frequencies used in TV work.

V-9174-33

SCREEN-GRID TUBES

EXAMINATION

1. Explain briefly the advantages of the tetrode over the triode for certain types of operation.

The inter-element capacity in the tube is decreased, thus making unecessary neutralizing circuits to prevent feedback. The voltage amplification is much higher than that of a triode. ✓

2. How are these advantages obtained?

Above advantages are obtained by placing a second grid between the control grid and the plate of the tube, and connected by a large by-pass condenser to the cathode. This electro-statically shields the plate from the grid and the cathode. ✓

3. Mention at least two instances wherin a triode would be used in preference to a screen-grid type tube.

1. Simple oscillator
2. RF amplifier at high frequencies. ✓

EXAMINATION, Page 2

4. What is the principle advantage of a pentode over a tetrode?

The negative resistance characteristic of the tetrode at low plate voltages is corrected so it is possible to use greater plate voltage swing.

5. How is this advantage obtained?

A suppressor grid is placed between the plate and the screen grid. This grid is at cathode potential, so secondary electrons dislodged from the plate are returned to it even at low plate voltages because there is no other positive potential acting on them.

6. Explain briefly why pentodes are capable of giving greater power output at a higher efficiency than triodes (for a given value of B supply voltage).

The B_{min} value in the power formula can be made much lower in the pentode so the swing from B_{max} to B_{min} is greater, if B_{max}, which is the supply voltage, is the same in both instances.

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7. How does the value of load resistance necessary to obtain maximum power output from a pentode compare to its internal plate resistance R_p? How does it compare with that necessary to obtain the maximum power output from a triode?

For maximum power output from a pentode R_L must be much smaller than R_p. Theoretically for maximum power output from a triode R_L should be twice R_p.

8. Explain briefly why ordinary tubes designed for low-frequency work are not applicable to high-frequency circuit operation.

In high frequency operation the L/C ratio of the load is reduced, thus reducing the value of Z_L. Gain = $G_m Z_L$ so if Z_L is reduced the gain is reduced.

9. What is the principal advantage of a beam power tube over an ordinary pentode?

The knee of the characteristic is sharper than for an ordinary pentode, so E_{min} can be lower resulting in larger power output.

10. Describe briefly the construction of a beam-power amplifier tube.

The cathode, instead of being cylindrical, is elongated with the emitting material on the flat surfaces, thus forming two beams of electrons. To further the beam effect, beam forming plates are placed on both sides of the element structure between the screen grid and the plate. The screen grid is wound with the same pitch as the control grid so that its wires are immediately behind those of the control grid. This reduces screen current.