Grounded-Grid Power Amplifiers

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Grounded-Grid Power

Radio-frequency power amplifiers using grounded-grid circuits operate at higher frequencies and can handle wider bandwidths than capacitance-neutralized grounded-cathode circuits. These advantages suit the grounded-grid circuit to television, f-m, and industrial uses

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POWER AMPLIFICATION at high frequencies has always been a difficult technical problem. As the frequency is increased, the problems become more difficult. A number of these problems can be alleviated by a novel circuit which, undoubtedly, is destined to be used widely in the high-frequency field. This circuit is often called the grounded-grid circuit, and while it is not new it has not until recently received the attention it deserves. The purpose of this article is to call attention to this circuit, point out its advantages and characteristics, and show how such a circuit is designed.

There are three practical ways of utilizing a triode as an amplifier. The most common way is to apply the input signal between grid and filament terminals and take output from plate and filament. A second way is to apply input to grid and plate and take output from filament and plate. This type of amplifier is known as a cathode follower. The third way is to apply input to grid and filament and take output from plate and grid. There is no generally accepted name for this type of amplifier. It has been variously called grounded-grid amplifier, inverted amplifier, and common grid circuit because the grid is common to the input and output circuits. According to this terminology, the normal amplifier would be called a common cathode circuit, and the cathode follower would be a common plate circuit. In this article, the designation grounded-grid will be employed since it has been used fairly widely.

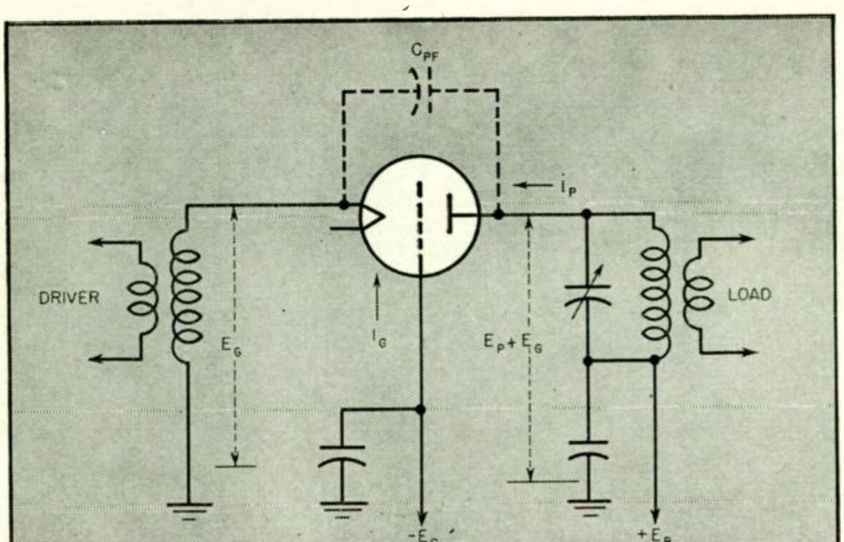

FIG. 1—Circuit and parameters of grounded-grid r-f power amplifier

Problems of Tube Design

Consider a normal triode circuit with input applied between grid and filament and a tuned output circuit between plate and filament. The filament is grounded. It is well known that such an amplifier will oscillate by itself at some undesired frequency because of feedback through the grid-plate capacitance of the tube. The cure for this difficulty is neutralization. However, as the frequency is increased, neutralization becomes increasingly difficult to handle. Because feedback is caused by capacitance between grid and plate and because any external neutralizing circuit is isolated from the internal capacitance by the inductances of grid and plate leads, the frequency band over which the tube can be neutralized becomes narrower and narrower with increasing frequency and finally vanishes altogether. Another undesirable effect is that capacitance neutralization serves to increase the input and output capacitances of the amplifier. For example a push-pull cross-neutralized amplifier has an output capacitance per tube equal to the plate-filament capacitance of the tube plus twice the grid-plate capacitance. This resultant high capacitance narrows the r-f bandwidth that can be handled or it may reduce the efficiency of the amplifier because of excessive circulating kilovoltamperes.

Tetrodes and pentodes were developed to overcome the foregoing

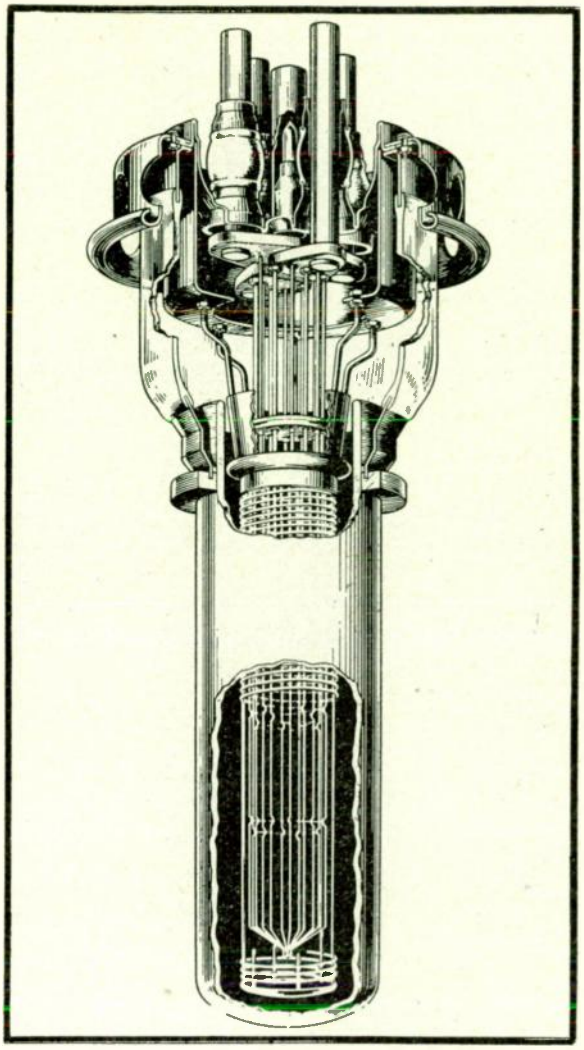

FIG. 2—Cut-away view showing method of extending grid cylinder to complete the shielding between filament and plate circuits in a triode especially designed for grounded-grid circuits

difficulties. In these types of tubes, the screen and suppressor shield the control grid from the plate so that the feedback capacitance is low enough to make neutralization unnecessary. However, as the frequency is increased, self-oscillation may occur if the screen and suppressor leads have appreciable inductance. Then, these grids cannot be held effectively at r-f ground potential and, as a result, feed-through may occur. Twin tubes such as the RCA-829B were designed to overcome this difficulty. In a twin tube designed for push-pull operation, screen grids and cathodes can be intimately connected within the tube so that practically no inductance is present between these electrodes. Tubes of this design give excellent performance. The only difficulty is that tube cost for a twin-pentode tends to be high compared to the cost of triodes or triodes for equivalent power output capability.

Circuit Characteristics

The grounded-grid circuit is a way of using a triode which reduces the possibility of self-oscillation without the need for neutralization. Figure 1 shows a grounded-grid amplifier circuit, in which the control grid acts as shield between plate and cathode to reduce feedback capacitance C_{PF}. Thus, the control grid performs one function of a screen grid in a tetrode.

A second characteristic of the grounded-grid circuit is that the driver tube and output tube act in series to supply the load. In Fig. 1, the driver produces an r-f voltage E_G across the input terminals of the output tube. The latter has an r-f voltage E_P across its plate and cathode. These voltages are 180 degrees out of phase with respect to the cathode so that the r-f voltage from plate to grid and also across the output circuit is $E_P + E_G$. If I_P is the fundamental component of plate current 180 degrees out of phase with E_P, and I_G is the fundamental component of grid current in phase with E_G, the following relations then hold

Power delivered to load circuit = $(E_P + E_G)I_P$

Power delivered by output tube = E_PI_P

Driver power transferred to load circuit = E_GI_P

Power delivered by driver circuit = $E_G(I_P + I_G)$

Power absorbed by output tube = E_GI_G

It is apparent from these relationships that driver tube and output tube act in series to supply the load circuit. Power output, therefore, is higher than would be expected and the conventional efficiency, based on the input to the output tube, is unusually high.

The foregoing discussion brings out a third characteristic. The driving power of a grounded-grid amplifier is higher than when the same tube is used in a normal triode circuit and may be three to ten times greater. However, this increased power is not lost; it is merely transferred to the plate circuit and appears as output, as explained above.

Tubes for Grounded-Grid Circuits

A fourth characteristic is lower output capacitance. In a grounded-grid circuit, output capacitance is approximately C_{GP}, whereas in a normal capacitance-neutralized amplifier the output capacitance is more than twice this value. This fact is most important at high frequencies because lower output capacitance re-

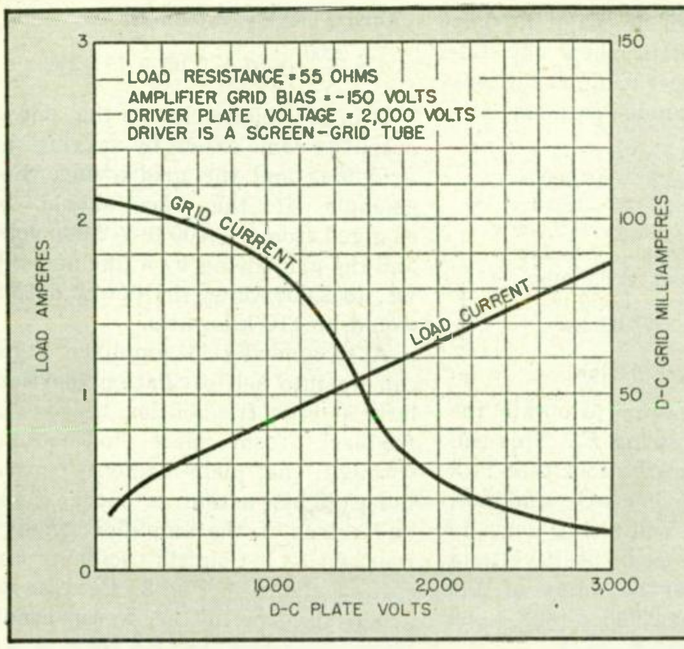

FIG. 4—Plate modulation characteristic of grounded-grid r-f amplifier

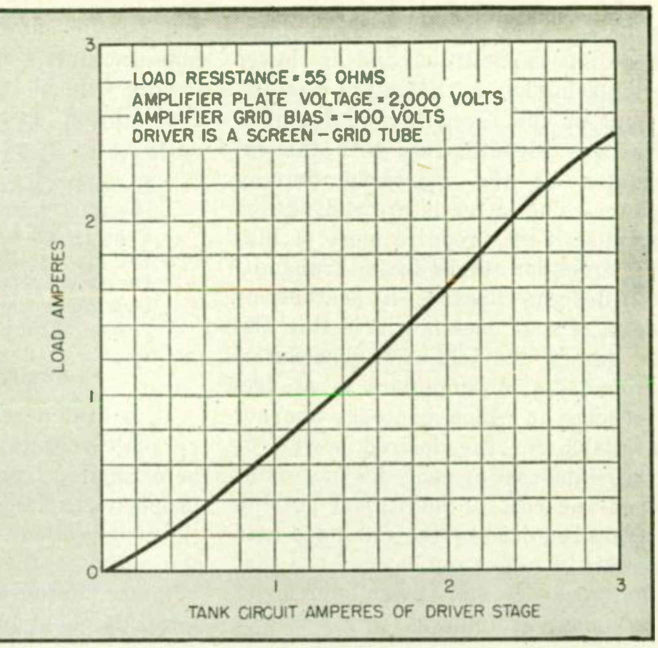

FIG. 5—Class-B power amplification characteristic of grounded-grid circuit

store only appreciable amounts of power at high frequencies. Assume operation at a frequency of 20 mc. The reactance of C_r is then 850 ohms. If the tube is operated at 12 kilovolts with a plate swing of 11.6 kilovolts, the reactive power is $(11{,}600/2)^2/850 = 80$ kilovoltamperes.

We also know that oscillator stability necessitates an operating Q of at least 12. Therefore, in the above case, the circuit could be loaded to 6.7 kw. If all the circuit losses, including driving power and any power delivered to the load, are less than 6.7 kw, the tube will oscillate with certain adjustments of the input and output circuits. If we assume that the normal output circuit loss is five percent of 100 kw, or 5 kw, this value plus the driving power and the normal load coupled to the tube would be sufficient to make the amplifier stable at the assumed frequency.

Modulation Characteristics

When plate modulation of only a grounded-grid amplifier stage is attempted, a characteristic such as illustrated in Fig. 4 is obtained. It will first be noted that grid current varies widely with plate voltage. As the plate voltage increases, the plate current also increases and causes an increasing load on the driver stage. Due to the regulation of the latter, driving voltage decreases and with it grid current. This decrease of grid current is quite large and is characteristic of this type of amplifier.

Over quite a range of plate voltage, the output current is linear with plate voltage as in the case of conventional class C amplifiers. However, at low voltages load current departs from linearity and will not be zero until negative values of plate voltage are reached. This phenomenon is due to the fact that r-f driving voltage and d-c plate supply voltage are in series as shown in Fig. 1. As a result the plate not only has a d-c supply voltage but also simultaneously an r-f supply voltage. Therefore, the plate current and the load current do not drop to zero until a value of negative plate voltage equal to the value of the peak driving voltage is reached. Accordingly, the resultant characteristic of modulating only a grounded-grid stage shows distortion unless one is satisfied with partial modulation. To obtain a modulation characteristic which will permit 100-percent modulation, it would be necessary to modulate simultaneously one or more successive stages.

The above problem is of little practical consequence because amplitude modulation is rarely used at the high frequencies for which the grounded-grid circuit is particularly applicable. The problem does not exist for such services as frequency-modulation, television and industrial power.

When a grounded-grid amplifier is used as a linear, class-B r-f amplifier, quite satisfactory results are obtained, as shown in Fig. 5. Such an amplifier could be used to amplify television signals.

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sults in increased r-f bandwidth-handling capabilities and in lower circulating kva in the output circuits.

All of the foregoing characteristics are advantageous with the exception of the increased driving power. The latter is a disadvantage because it may require more or bigger amplifier stages in the transmitter design. Because a pentode or beam tetrode does not have this disadvantage, the field of application of grounded-grid amplifiers is at frequencies at which pentodes are not available for the desired power, or where the cost of pentodes is greater than the cost of additional driving stages required by the grounded-grid circuit. Present indications are that the frequency and power boundaries are about as follows

Power in Kw	*Frequency in Mc*
0.1	300
25	30
100	10

For the stated power, the grounded-grid circuit becomes desirable at a frequency above that listed.

Most of the characteristics which make a triode desirable in a normal circuit also make it desirable in a grounded-grid circuit. However, there are some additional requirements for a good grounded-grid tube. It has been stated above that the grid and its associated external ground plane should act as a screen between anode and cathode and their respective circuits. Therefore, the tube should be so designed that the anode and cathode connections are on opposite sides of the grid connection. For example, a tube which has an external anode with the grid terminal insulated from one end and the filament terminal insulated from the other end is not at all suited for grounded-grid operation. On the other hand, a tube such as the 9C21 illustrated in Fig. 2 is ideally suited for grounded-grid operation because the grid terminal is a large metal flange which can be connected to a metal shield separating the anode circuit from the cathode circuit. In addition, the grid support of the 9C21 has very low inductance and, therefore, meets the second requirement for a good grounded-grid triode.

Let it be required to design a grounded-grid stage utilizing one 9C21 triode. The tube will be used in the circuit shown in Fig. 1. The manufacturer's data show the following typical operating conditions for normal grounded-cathode circuits

D-c plate voltage = 17,000 v
D-c grid voltage = −1,600 v
Peak r-f grid voltage = 2,200 v
D-c plate current = 7.9 amp
D-c grid current = 0.9 amp
Driving power = 1,800 w
Power output = 100 kw

Amplifier Design

It is first necessary to obtain the r-f plate voltage swing E_p. This can be estimated from the fact that in a properly excited class-C amplifier, the plate voltage will swing down to the value of the peak positive grid voltage. Because the value of the latter is equal to 2,200 minus 1,600 volts, or 600 volts, E_p is $2^{-\frac{1}{2}}(17{,}000-600) = 11{,}600$ volts rms.

Next, the fundamental components of plate current and of grid current must be obtained using the power output and driving power values given above

$$I_p = \frac{100{,}000}{11{,}600} = 8.63 \text{ amperes}$$

and

$$I_g = \frac{1{,}800\sqrt{2}}{2{,}200} = 1.16 \text{ amp.}$$

The output power and the driving power of the grounded-grid stage can now be calculated from the relations given earlier. We obtain

$$\text{Power output} = (E_p + E_g)\, I_p$$
$$= \left(11{,}600 + \frac{2200}{\sqrt{2}}\right) 8.63 = 113 \text{ kw.}$$

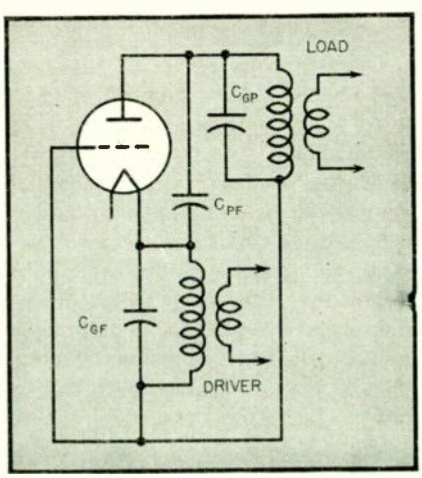

FIG. 3—Rearrangement of circuit of Fig. 1 shows that the grounded-grid amplifier is similar to the Colpitts oscillator

$$\text{Driving power} = E_g(I_p + I_g)$$
$$= \frac{2200}{\sqrt{2}}(8.63 + 1.16) = 15.2 \text{ kw.}$$

It is possible to change the power output to some extent by varying the grid bias and the grid swing. For example, if the bias should be changed from −1,600 to −2,000 volts and the grid swing by a like amount, i.e., to 2,600 volts, the power output would be 116 kilowatts.

A grounded-grid amplifier stage can go into self-oscillation, particularly at high frequencies, because of feedback from plate to cathode through the plate-filament capacitance. This action is more easily understood if the amplifier stage is redrawn as a Colpitts oscillator circuit, as shown in Fig. 3. Because we are dealing with the worst conditions, inductive tuning only is assumed. The output circuit must be inductive at the oscillation frequency, as the following analysis proves.

Conditions for Oscillation

It is well known that circuit reactance between filament and grid must be capacitative and, furthermore, should be at least one-fifth the reactance between plate and filament. This reactance will produce an excitation ratio, that is, a ratio of plate swing to grid swing, of five. In any good grounded-grid tube, the plate-filament capacitance will be so low that its ratio to the grid-filament capacitance will be much less than one-fifth. Thus, to produce oscillation, the input circuit must be inductive so as to reduce the effective capacitance between grid and filament to a value about five times that of the plate-filament capacitance. With tuned input circuits, this condition can easily be fulfilled. Let it be assumed that this condition is exactly fulfilled.

The total tank circuit capacitance is then

$$C_T = C_{PF} + \frac{5\, C_{GP}\, C_{PF}}{C_{GP} + 5\, C_{PF}}$$

In the case of 9C21, this capacitance would be

$$C_T = 1.8 + \frac{48 \times 5 \times 1.8}{48 + 5 \times 1.8} = 9.4\ \mu\mu f$$

Thus for this 100-kw tube, the tank capacitance for parasitic oscillation is only 9.4 $\mu\mu$f, a value which is quite small. This capacitance will