

April 29, 1930.

J. C. WARNER

1,756,893

ELECTRON DISCHARGE APPARATUS

Filed July 1, 1925

Fig. 1.

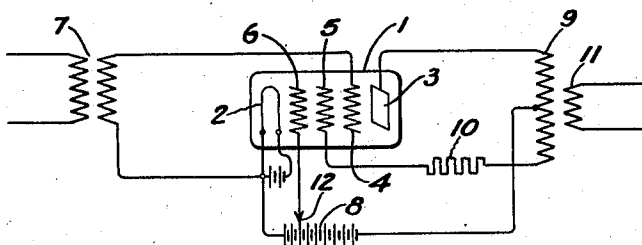
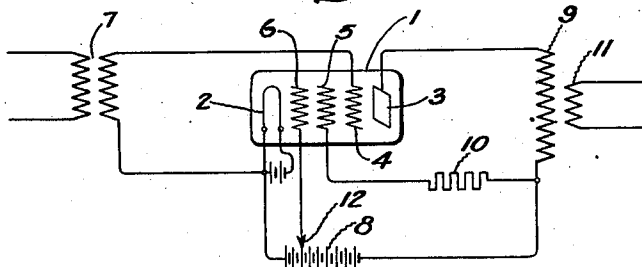


Fig. 2.



Inventor:
John C. Warner,
by *Alexander S. Lunt*
His Attorney.

UNITED STATES PATENT OFFICE

JOHN C. WARNER, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK

ELECTRON-DISCHARGE APPARATUS

Application filed July 1, 1925. Serial No. 40,883.

My present invention relates to electron discharge apparatus, and more particularly to electron discharge devices of the thermionic type, and circuit connections wherein such devices may be utilized to advantage.

It has heretofore been proposed to increase the efficiency of operation of thermionic discharge devices having three electrodes by the provision of a fourth electrode known as a "space charge grid" upon which a constant positive potential is impressed. It has also been proposed to utilize the current variations produced in the circuit of this space charge grid to deliver energy to an output or load circuit in conjunction with the energy delivered by the anode circuit.

By the methods which have heretofore been proposed the amount of energy which can be delivered to the load circuit by the space charge grid is relatively small due to the fact that the internal alternating current resistance of the circuit of the space charge grid is low although the control of the control grid voltage on the space charge grid current may be nearly as large as the control on the plate current.

The object of my invention is to overcome this disadvantage by providing means whereby the internal resistance of the space charge grid circuit is greatly increased and at the same time the effect of the control grid voltage on the space charge grid current is not materially decreased.

I have found that this result may be obtained by the provision of an extra grid located between the space charge grid and the cathode. If a voltage is impressed upon this grid lower than that corresponding to the potential gradient at the point where it is located, the resistance of the path between the cathode and space charge grid may be greatly increased.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims, the invention itself, however, both as to its organization and method of operation will best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 illus-

trates diagrammatically a device and the circuit connections therefor which may be employed in carrying my invention into effect, and Fig. 2 shows a modification in the circuit connections which may be used.

I have indicated in the drawing an electron discharge device 1 comprising an electron emitting cathode 2, an anode 3, and three grids 4, 5 and 6 interposed between cathode and anode. Circuit connections are provided between the cathode and each of the other electrodes. In the arrangements shown, the input circuit of the device is connected to grid 4 nearest the anode. The electrical variations to be amplified may be supplied to this circuit by a transformer 7 in the usual manner. A positive potential is impressed upon the anode 3 by means of a source of potential 8, which is connected to the anode through the upper portion of the primary winding 9 of the transformer. The grid 5 is employed as a space charge grid and a positive potential is applied to this grid from the source 8 through the lower portion of the primary winding 9 and the resistance 10. By proper choice of the value of this resistance the potential impressed upon the grid 5 may be adjusted to a desired value. Since the current variations produced in the circuits of the space charge grid 5 and anode 3 are opposite in direction the currents produced in the two portions of the primary winding 9 combine in their effects upon the secondary winding 11.

The grid 6 is employed for the purpose of increasing the internal resistance of the circuit of the space charge grid 5. This is accomplished by impressing upon the grid 6 a positive potential lower than that corresponding to the potential gradient at the point where it is located due to the positive potential upon the space charge grid 5. The desired potential upon grid 6 may be selected by means of a variable tap 12 connected to the source of potential 8, as indicated, or in some cases, the grid 6 may be connected to the positive terminal of the cathode. I have found that with the arrangement described the control grid may have substantially the same control of the current to the space charge grid

as in the absence of the grid 6 and that the internal resistance of the space charge grid circuit being greatly increased the amount of energy which may be delivered to the load or out circuit from the space charge grid circuit may be greatly increased. If desired, the voltage of the space charge grid may be adjusted in such a way that the direct current field of the lower portion of transformer winding 9 may be made to balance the field of the upper portion so that no direct current magnetization will be produced in the core of the transformer.

The power output of a three-element tube in a simple amplifier circuit may be calculated as follows:

$$I_p = \frac{g_m r_p E_g}{r_p + R_p}$$

$$V_{R_p} = \frac{g_m R_p r_p E_g}{r_p + R_p}$$

$$P = \frac{g_m^2 r_p^2 R_p E_g^2}{(r_p + R_p)^2}$$

Where g_m is the mutual conductance which for the three-element tube is defined as $\frac{di_p}{dE_g}$; i_p is the alternating plate current, r_p is the internal plate resistance; E_g the applied alternating grid voltage, and R_p the load resistance. If we assume that the external resistance is always equal to the internal, i. e. the condition for maximum output for a given applied voltage, the maximum power then becomes

$$P_{max} = \frac{g_m^2 r_p^2 E_g^2}{4}$$

It is then evident that if the plate impedance can be increased without decreasing the mutual conductance the power output will be increased.

Exactly the same reasoning applies to the case of the space charge grid tube when we consider the power output of the space charge grid with a load impedance connected in series with the space charge grid and an alternating voltage applied to the control grid. The maximum output then is proportional to $g_{m_1}^2 r_{s_1}$, where

$$g_{m_1} = \frac{di_{s_1}}{dE_{c_1}}$$

and where g_1 is the space charge grid and g_2 is the control grid. Now, if by some means r_{s_1} can be increased without decreasing g_{m_1} , the power output will increase. This is accomplished by the addition of another grid inside of the space charge grid.

In the tube with two grids the space charge grid impedance is low because this grid is close to the cathode with no electrodes between. Thus with relatively low voltage on the space charge grid the saturation current

of the filament is drawn to or through this grid. A similar case is the two element rectifier in which the plate current reaches the saturation current at relatively low plate voltages. Now if a grid is added to the two electrode tube the plate impedance at once rises and it remains higher than that of the two electrode tube even when the grid is made positive up to the point where the combined field of the plate and positive grid is greater than the field of the plate alone in the two electrode tube. It might be thought that if the grid is positive at all the impedance will be less than that of the two electrode tube, but it must be remembered that when the grid is interposed between filament and plate it screens the filament from the plate, thereby reducing the effect of the plate voltage on the field at the filament.

In a similar manner, the third grid placed between the space charge grid and the filament serves to reduce the effect of the charge on the space charge grid on the field at the filament and the impedance is thereby increased.

In order to obtain maximum control of control grid voltage on plate current and space charge grid current the voltage of the space charge grid can now be increased until the current is, for example, the same as it would have been without the third grid. Thus the supply of electrons outside the space charge grid is approximately the same as before and the control on the current to plate and space charge grid is the same as before. This of course refers to the control as defined by the tube constants only, i. e., without external loads. However since the impedance of the space charge grid circuit has been raised the output from this grid with proper load is increased.

In the arrangement shown in Fig. 2, the output from the space charge grid is utilized to vary the voltage drop across the resistance 10. If the control grid is made more positive with respect to its initial value, the plate circuit current will increase and the current to the space charge grid will decrease. As a result the potential drop across the resistance 10 will decrease and the potential of the space charge grid will increase, thus aiding the control grid in its action, since the space charge grid also controls to a certain extent the plate current. In the same way when the potential of the control grid is made negative with respect to its initial value the plate current will decrease, the current to the space charge grid will increase, and the potential drop across resistance 10 will increase. As a result the potential of the space charge grid will decrease and cause a greater decrease in the plate current than would result from the control of the control grid voltage alone.

In this circuit which involves the indirect effect of the output from the space charge

grid and which takes advantage of the change in voltage across the external resistance in the space charge grid circuit, the third grid, on account of the increased impedance, raises the alternating current voltage across the external resistance. This voltage is equal to

$$\frac{g_m r_{g1} R_{g1} E_{g1}}{r_{g1} + R_{g1}}$$

where R_{g1} is the external resistance.

While I have shown and described certain circuit connections which may be used in connection with a device of the type described, it will be apparent that many modifications in the circuit connections employed may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. An electron discharge device comprising an electron emitting cathode, an anode, a control grid located between cathode and anode, a space charge grid located between the cathode and control grid, and means whereby the efficiency of the device is increased comprising means for increasing the impedance of the electron path between the cathode and the space charge grid.

2. An electron discharge device comprising an electron emitting cathode, an anode, a control grid located between cathode and anode, a space charge grid located between the cathode and control grid and a third grid located between the cathode and space charge grid, means for impressing a positive potential upon the space charge grid and means for impressing upon the third grid a potential lower than that corresponding to the potential gradient at the point where it is located whereby the efficiency of the device is increased.

3. An electron discharge device comprising an electron emitting cathode, an anode and three grid electrodes directly interposed between cathode and anode, means for impressing signaling potentials upon the grid nearest the anode, and means for simultaneously impressing different potentials upon the other two grids whereby the efficiency of the device is increased.

4. An electron discharge device comprising an electron emitting cathode, an anode and three grid electrodes interposed between cathode and anode, means for impressing signaling potentials upon the grid nearest the anode, means for impressing a positive potential upon one of the other grids, and means for impressing upon the third grid a potential lower than that corresponding to the potential gradient at the point where it is located whereby the efficiency of the device is increased.

5. An electron discharge device comprising

an electron emitting cathode, an anode and three grid electrodes interposed between cathode and anode, means for impressing signaling potentials upon the grid nearest the anode, means for impressing upon a second grid a positive potential, and means for impressing upon the third grid a potential lower than that impressed upon the second grid whereby the efficiency of the device is increased.

6. An electron discharge device comprising an electron emitting cathode, an anode and three grid electrodes interposed between cathode and anode, means for impressing a positive potential upon the anode, means for impressing a lower positive potential on one of the grids, means for impressing signaling potentials upon a second grid, and means for impressing upon the third grid a lower potential than that impressed upon the first grid whereby the efficiency of the device is increased.

7. An electron discharge device comprising an electron emitting cathode, an anode and three grid electrodes interposed between cathode and anode, means for impressing signaling potentials upon the grid nearest the anode, means for impressing a positive potential upon the intermediate grid, and means for impressing upon the grid nearest the cathode a potential lower than that impressed upon the intermediate grid whereby the efficiency of the device is increased.

8. An electron discharge device comprising an electron emitting cathode, an anode and three grid electrodes interposed between cathode and anode, means for impressing signaling potentials upon the grid nearest the anode, means for impressing a positive potential upon the intermediate grid, means for impressing upon the grid nearest the cathode a potential lower than that impressed upon the intermediate grid, and an output circuit associated with the anode and intermediate grid whereby the efficiency of the device is increased.

9. An electron discharge device comprising an electron emitting cathode, an anode, a control grid located between the cathode and anode, a space charge grid located between the cathode and control grid, an output circuit associated with the anode and space charge grid, and electrostatic means only for increasing the impedance of the electron path between the cathode and the space charge grid whereby the variations of current in the output circuit in response to variations of the charge on the control grid, are increased.

In witness whereof, I have hereunto set my hand this 30th day of June, 1925.

JOHN C. WARNER.