

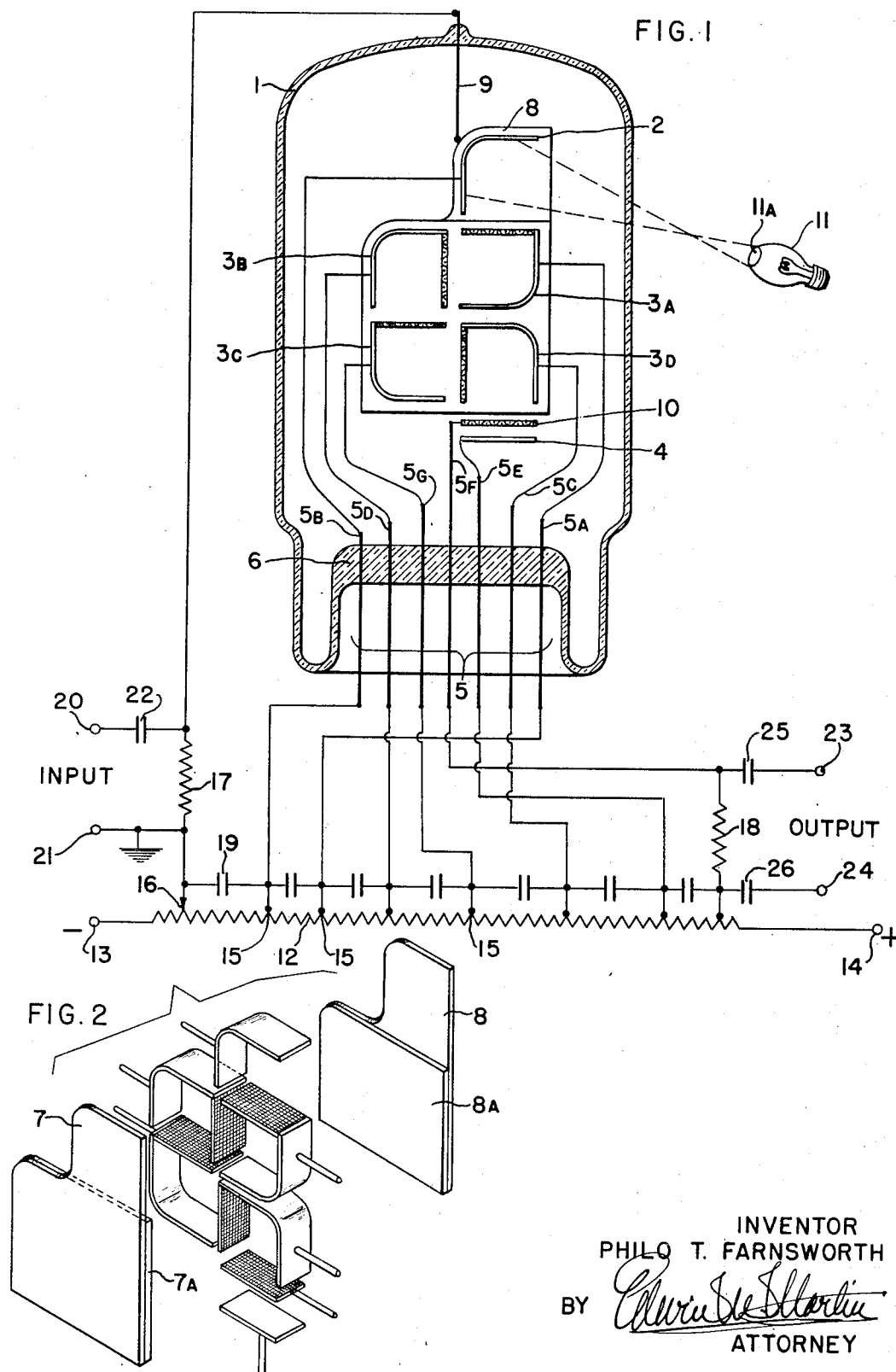
Feb. 23, 1943.

P. T. FARNSWORTH
ELECTRON CONTROL DEVICE

2,311,981

Filed July 25, 1940

2 Sheets-Sheet 1



Feb. 23, 1943.

P. T. FARNSWORTH
ELECTRON CONTROL DEVICE

2,311,981

Filed July 25, 1940

2 Sheets-Sheet 2

FIG. 3

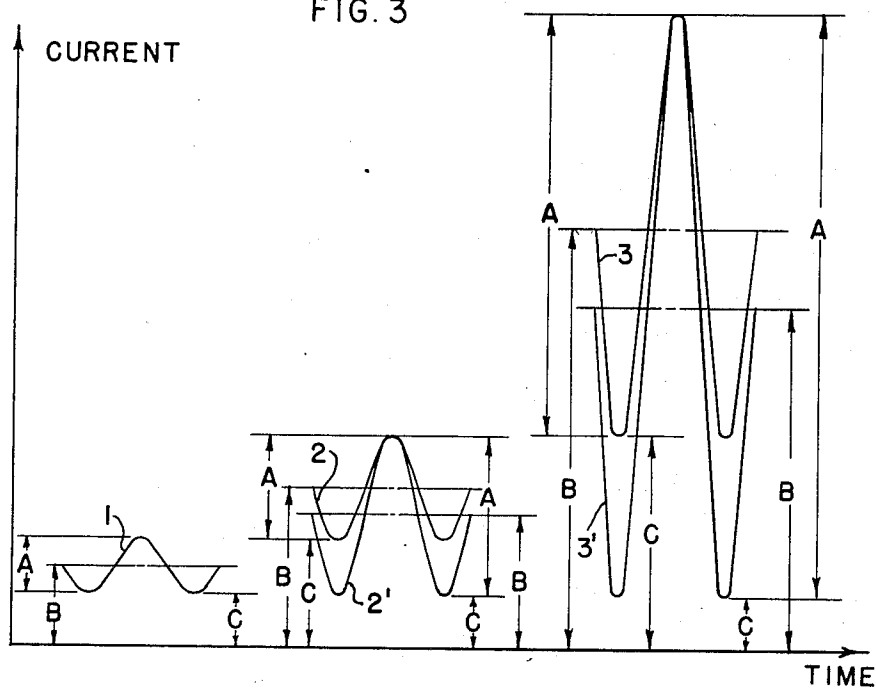
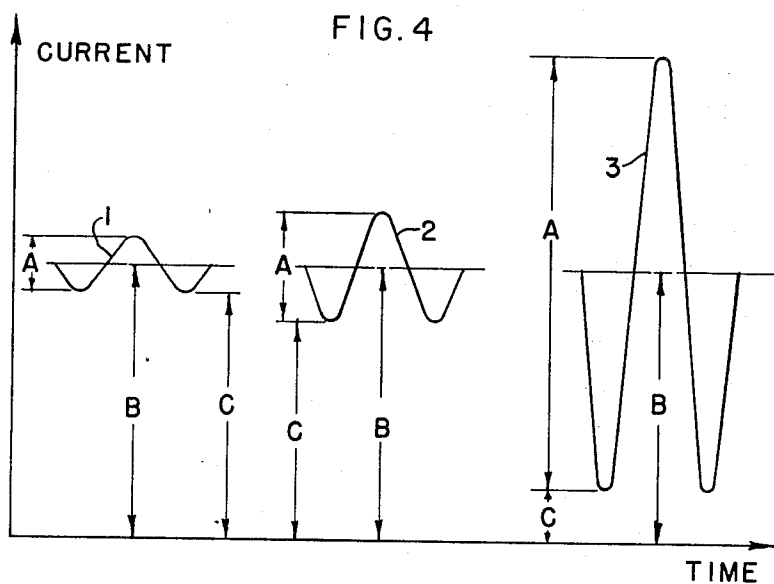


FIG. 4



INVENTOR
PHILO T. FARNSWORTH
BY *Clarence W. Martin*
ATTORNEY

UNITED STATES PATENT OFFICE

2,311,981

ELECTRON CONTROL DEVICE

Philo T. Farnsworth, Fort Wayne, Ind., assignor
to Farnsworth Television and Radio Corpora-
tion, a corporation of Delaware

Application July 25, 1940, Serial No. 347,413

3 Claims. (Cl. 179—171)

This invention relates to electron control devices.

The principle of effecting electron multiplication by causing successive secondary emission by electron impact has proven an effective means for intensifying an electron flow. In tubes of the image dissector and photomultiplier type, this principle has been used most advantageously. In such arrangements, a series of secondary-emissive surfaces is maintained at increasing positive potentials and an electron emitted from one surface is accelerated to strike against a next succeeding surface with a velocity sufficient to eject a plurality of secondary electrons. This action is repeated in succeeding stages, producing increasing intensification of the electron stream. For example, this increase may be at a rate of the order of 3 to 7, depending upon the voltage between stages and, of course, upon the electron-emissive material employed for the electrodes.

Heretofore, this principle of amplification has been useful in the simple form above described only for the purpose of amplifying an electron stream such as, for example, the modulated electron stream produced at the scanning aperture of an image dissector tube or produced from the cathode of a photoelectric cell.

It is desirous to utilize the electron multiplication principle not only for simple arrangements providing current amplification but to provide voltage amplification in various electron control arrangements, such as voltage amplifiers, oscillators, modulators, detectors and the like.

Heretofore, certain electron multiplier arrangements have been utilized wherein the first secondary electron emitting electrode constituted the anode of a conventional thermionic tube. In such arrangements, the electron flow to the first secondary-emissive electrode was varied by impressing a signal voltage upon the control grid disposed between the cathode and this electrode. While this method is both simple and useful for some applications, it is subject to certain serious limitations hereinafter more specifically described.

The total output current of an electron multiplier is limited by the permissible current density in the output stage, or stages previous thereto. An attempt to overcome this limitation leads to electrode structures of undesirably large dimensions and to uneconomical operating conditions. For the purpose of explaining the effects of the current limitation, the electron multiplier can be compared with a direct coupled

thermionic amplifier of the conventional type comprising a plurality of stages. If the current in the first stage of such an amplifier comprises an A. C. component and a D. C. component, whereby a portion of the latter is not modulated by the A. C. signals, both components will be proportionately amplified in subsequent stages. In a resistance capacity coupled thermionic amplifier of the conventional type, it is possible to have a plate current comprising a small A. C. component and a large D. C. component having a large unmodulated portion in the first stage thereof. The current in the following stage, however, can have an increased A. C. component, a D. C. component of the same magnitude and a decreased unmodulated portion thereof. Thus, comparing the two, it will readily be seen that for the same permissible output current, the useful A. C. signal component of the resistance capacity coupled amplifier can obtain higher values than in the direct coupled amplifier. Since substantially the same conditions prevail for an electron multiplier as for a direct coupled thermionic amplifier, the disadvantage of such devices as hitherto constructed and operated for voltage amplification is evident.

In order to reduce the unmodulated portion of the D. C. component in an electron multiplier, it has been proposed to operate the conventional thermionic input electrode structure of the multiplier in the so-called retarding field region, that means, at an extremely low plate current. However, if the total output current is limited to a given value, this measure also has no particular advantage for voltage amplification since it is impractical to utilize a current multiplication ratio of over 20 for a total permissible output current of 5 milliamperes. At 5 milliamperes output current and a multiplication ratio of 20, the input current to the multiplying structure is 250 microamperes. A thermionic input electrode structure having a mutual conductance of 500 micromhos can be readily designed for an anode current of 250 microamperes, and no advantage would be derived from the use of a weaker plate current and a poorer mutual conductance, which would then only necessitate an increase to the above value by means of electron multiplication.

It is an object of the present invention to provide an improved electron control device utilizing the principle of secondary emission electron multiplication and suitable for use as a voltage amplifier, oscillator, modulator, detector or other electron control device.

In accordance with the present invention, there is provided a vacuum tube device comprising a plurality of electrodes disposed in series. Means are further provided for effecting the passage of an electron current successively between the electrodes, which means includes means for applying to successive ones of said electrodes successively higher operating potentials providing predetermined potential gradients therebetween. These means may include, for the purpose of developing an initial electron current, any suitable source of electrons such as, for example, a thermionic cathode or a photoelectric cathode. There is disposed, outside of the path of said current, suitable means for controlling the potential gradients, thereby to control the current as, for example, by applying a signal thereto. An output electrode is provided for utilizing the controlled current.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the accompanying drawings:

Fig. 1 is a schematic diagram illustrating an electron control device, embodying the present invention, utilized as an amplifier;

Fig. 2 is an exploded view of certain elements of the device of Fig. 1;

Fig. 3 is a graph illustrating the operating characteristics of a conventional thermionic grid control type of electron multiplier and of a multiplier in accordance with the present invention; and

Fig. 4 is a graph illustrating the operating characteristics of a resistance capacity coupled amplifier comprising several stages.

Referring now more particularly to the preferred embodiment of the invention which is illustrated in the accompanying drawings, in Fig. 1 there is shown schematically an electron multiplier device embodying an envelope 1 containing a photoelectric cathode 2 and a series of secondary-emitting electrodes 3A, 3B, 3C, and 3D, arranged in juxtaposition, as shown. More particularly, each of these electrodes comprises an L-shaped member having disposed on the inner surface thereof a material, preferably caesium oxide, adapted to emit photoelectrons or secondary electrons. The electrodes 3A—3D are also provided with a screen portion as shown. Adjacent the electrode 3D are positioned an electron collecting screen 10 and a plane secondary-electron emissive electrode 4.

The electrodes 2, 3A, 3B, 3C, 3D, 4 and 10 are held in position by suitable conducting rods 5A, 5B, 5C, 5D, 5E, 5F, and 5G, which extend through a re-entrant stem 6 formed in the envelope 1 as shown. Disposed opposite the open sides of the electrode assembly are control electrodes 7 and 8 (Figure 2), each of which comprises a thin metallic plate provided with an insulating surface 7A and 8A respectively, facing the electrode structure. For the purpose of providing an initial source of electrons, there is disposed outside the tube envelope 1 a source of light in the form of an incandescent lamp 11 having a lens portion 11A fused to its glass bulb. The lamp is so positioned as to direct its light upon the inner photoelectric surface of the electrode 2.

For the purpose of applying operating potentials to the electrodes 2, 3A, 3B, 3C, 3D, 4 and

10, there is provided a voltage divider 12 having its opposite ends connected to a source of unidirectional voltage indicated at 13, 14. Taps 15 are connected at suitable points along the voltage divider by way of suitable leads to the connecting rods 5A, 5B, 5C, 5D, 5E, 5F, and 5G and to the several electrodes, as shown. A slidable tap 16 is provided on the voltage divider 12 in order to apply an adjustable direct-current potential to the control electrodes 7, 8 by way of a resistor 17 whose function will be described shortly. An operating potential is applied to the collector electrode 10 by way of a suitable resistor 18.

By-pass condensers 19 are connected between the taps 15 and 16 in order to provide a low impedance path for the amplified signal currents. The photoelectric electrode 2, acting as the cathode of primary electrons, is connected to the most negative fixed tap 15 on the voltage divider by means of a suitable lead, as indicated.

For the purpose of applying a signal to the control electrodes 7 and 8, an input circuit indicated by the terminals 20 and 21 is provided, the terminal 21 being preferably grounded as shown, and the terminal 20 being connected by way of a suitable coupling condenser 22 to the electrodes 7 and 8.

The electron multiplier device which has been described is suitable for use as an amplifier, particularly an amplifier of radio-frequency signals. In the operation of this device, with sufficient light impinging upon the photoelectric surface of the electrode 2, electrons are emitted therefrom and directed toward the first electrode 3A. These electrons impinge upon the secondary emissive surface of this electrode, thereby causing a plurality of electrons to be emitted therefrom which in turn are directed, by virtue of the higher operating potential applied thereto, to the secondary-emissive electrode 3B where again the impinging electrons effect the emission of secondary electrons, thus effecting a multiplication of the current. This process is repeated throughout the succeeding stages, a final multiplication taking place at the electrode 4. The screens attached to electrodes 3A, 3B, 3C, 3D serve to accelerate the flow of electrons.

The signal to be amplified is applied to the terminals 20 and 21 and hence, by way of condenser 22 and resistor 17, to the control electrodes 7 and 8. This signal effects a variation in the voltage gradient between the successive electrodes, and thereby modulates the stream of electrons with successive multiplication through the path along which these electrons are disposed. The modulated multiplied electron stream is collected by the electrode 10 and produces the amplified output signal across the output resistor 18, to the ends of which the output terminals 23, 24 are coupled by way of blocking condensers 25 and 26, respectively. The advantages obtained by the tube embodying the present invention may be best understood by reference to the curves of Figs. 3 and 4.

In Fig. 3, curve 1 shows the current in the first stage of a three-stage electron multiplier varying in intensity in accordance with a signal voltage in a certain relation determined by the mutual conductance of the input electrode structure, curve 2 shows the current after intensification by electron multiplication in a second multiplier stage, and curve 3 shows the current after intensification in a third multiplier stage. In each case the ordinates have been marked with the

letters A, B and C, designating the alternating component of the current, the direct-current component and the unmodulated portion of the direct-current component respectively. These curves show that the ratio of the alternating component to the direct-current component remains constant throughout the multiplier and, while the absolute value of the mutual conductance increases, the ratio of the mutual conductance to the direct-current component remains constant. Thus, with a limited output current, a large portion of the direct-current component is not utilized for signal amplification due to the low value of the ratio of mutual conductance to direct-current component.

In Fig. 3, curves 1, 2' and 3' show the current in three successive stages of an electron multiplier in accordance with the present invention. From these characteristics it is to be seen that the ratio of the alternating component of the current to its direct-current component increases from stage to stage since, with the particular type of electron control provided by the present invention, the ratio of mutual conductance to direct-current component increases in each successive multiplier stage, as will be shown presently.

In Fig. 4, curves 1, 2 and 3 illustrate the plate current in three successive stages of a conventional resistance capacity coupled thermionic amplifier. It is readily seen, by comparison of the curves 1, 2' and 3' of Fig. 3 with those of Fig. 4, that the operating characteristics of the multiplier, according to the present invention, are similar to those of a conventional thermionic voltage amplifier. However, the use of an electron multiplier for this purpose has the great advantage of being a far simpler means of accomplishing voltage amplification.

In order to point out more specifically the advantage of the electron multiplier of the present invention over multipliers hitherto constructed, it can be shown mathematically that the ratio of the over-all mutual conductance to the direct-current component in the output stage is n times greater than the same ratio for the input electrode structure, whereby n designates the number of stages in which the electron stream has been multiplied. Since this ratio is constant in multipliers in which electron control is effected in one stage only, a tremendous increase in the ratio of mutual conductance to direct-current component is obtained in multipliers in accordance with the present invention.

Considering now the method of electron control utilized in the present invention, it is found that the effect of the potentials applied to the control electrodes 7 and 8 upon the intensity of the electron stream is substantially the same as that produced by potentials applied to a conventional control grid disposed in the path of the electron stream. Thus, for a steady condition, the following laws are valid:

$$E_{eff} = E_g + \frac{1}{u} E_p$$

and

$$i = C \times E_{eff}^{3/2} = C \times \left(\frac{E_g + 1}{u} E_p \right)^{3/2}$$

wherein E_{eff} designates the effective voltage between two successive electrodes, E_g the control electrode potential, E_p the steady potential difference between successive electrodes, u the amplification factor, i the current flowing between successive electrodes, and C a constant.

Considering first the term E_g , it is found that a different steady potential of the control electrode is required for each multiplying stage to obtain the same bias potential, so that substantially the same electrical conditions may prevail throughout the device. In the present embodiment of the invention, the metallic portions of the control electrodes 7 and 8 are held at the proper bias potential for the first multiplier stage, comprising electrodes 2 and 3A, by means of the sliding tap 15 on the voltage divider 12. While the control electrode is shown to be negatively biased with respect to the photoelectric cathode 2, it may conveniently be adjusted to the proper polarity and magnitude of bias by adjusting the sliding tap 15.

While the bias for the first multiplying stage is shown as what is commonly referred to as "battery bias," the following stages are self-biased as will be explained presently. Opposing the open sides of the electrodes 3A, 3B, 3C, 3D, there is disposed the insulated surfaces 7B and 8B of the control electrodes 7 and 8. A number of electrons emitted by the electrode 3A impact the insulated surfaces 7B and 8B and produce secondary emission therefrom which is attracted to the electrode 3B, which is the most positive electrode in the close proximity of the point of impact. According to whether the secondary-emission ratio is greater or smaller than 1, the insulated surfaces become increasingly positive or negative and finally reach an equilibrium potential at which the number of impacting electrons equals the number of emitted secondary electrons. The value of secondary emission just referred to determines whether the equilibrium potential will approach that of the more negative electrode 3A or that of the more positive electrode 3B.

The thickness of the insulation 7B and 8B determines the capacity between its exposed surface and the metallic portion of the control electrodes 7 and 8. This capacity is one of the factors entering into the time constant of the self-biasing arrangement comprising the insulation 7B and 8B and the input resistor 17. Since the capacity is inversely proportional to the thickness of the insulation, thinner insulation is used for tubes to be operated at lower frequencies.

In this manner, the control electrode bias for each multiplying stage automatically adjusts itself to a predetermined value with respect to the direct-current operating potentials of the adjacent electrodes.

Referring now to the second equation above set forth, it may be noted that the current flow throughout the multiplier does not remain constant but is intensified in each successive stage.

The following then holds true for the n^{th} stage, designating any stage in the multiplier tube considered:

$$i_n = i_1 \times K^n = C \times \left(\frac{E_{g_n} + 1}{un} E_{pn} \right)^{3/2}$$

wherein: i_n designates the current in the n^{th} multiplier stage, i_1 the current in the first multiplier stage, K the ratio of output to input current for a multiplier stage, n the number of stages, C a constant, E_{g_n} the steady grid bias of the n^{th} stage, un the amplification factor of the n^{th} stage and E_{pn} the steady voltage applied between the electrodes of the n^{th} multiplier stage.

This shows that with increasing current the term

$$\frac{1}{un} E_{pn}$$

must also increase, since E_g remains constant for each stage, as previously described. This renders three possibilities for operation of the device: First, that the amplification factor remains constant and the voltage between successive electrons is successively increased; second, that the potential between successive electrodes remains constant and the amplification factor for successive stages is decreased; and, third, that both are varied as just described. The proper variations are readily computed from the above equation. However, it is not the object of this description to show the mathematics of such a computation.

It will thus be seen that the present invention provides an electron control device whereby a stream of electrons is repeatedly subjected to the controlling influence of a signal potential in order to obtain a high amplification of signal voltages.

While there has been described what is at present considered the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. A vacuum tube device comprising a plurality of secondary-electron emissive electrodes disposed in series, means for effecting the passage of an electron current successively between said electrodes, including means for applying to successive ones of said electrodes successively higher operating potentials providing electrostatic fields therebetween, control means adja-

cent said electrodes and disposed outside the path of said current for controlling said electrostatic fields to control said current, means for applying an input signal to said control means and an output electrode for utilizing said controlled current.

2. A vacuum tube device comprising a plurality of secondary-electron emissive electrodes disposed in series, means for effecting the passage of an electron current successively between said electrodes, including means for applying to successive ones of said electrodes successively higher operating potentials providing electrostatic fields therebetween, control means adjacent said electrodes and disposed outside and extending at least over a portion of the path of said current for controlling said electrostatic fields to control said current, means for applying an input signal to said control means and an output electrode for utilizing said controlled current.

3. A vacuum tube device comprising a plurality of secondary-electron emissive electrodes disposed in series, means for effecting the passage of an electron current successively between said electrodes, including means for applying to successive ones of said electrodes successively higher operating potentials providing electrostatic fields therebetween, electrode means adjacent said electrodes and disposed outside and extending at least over a portion of the path of said current for controlling said electrostatic fields to control said current, means for applying an input signal to said control means thereby to develop a signal current, and an output electrode for utilizing said signal current.

PHILO T. FARNSWORTH.