

March 12, 1940.

E. BRUCE

2,193,579

ELECTRON DISCHARGE APPARATUS

Filed Jan. 26, 1938

3 Sheets-Sheet 1

FIG. 1

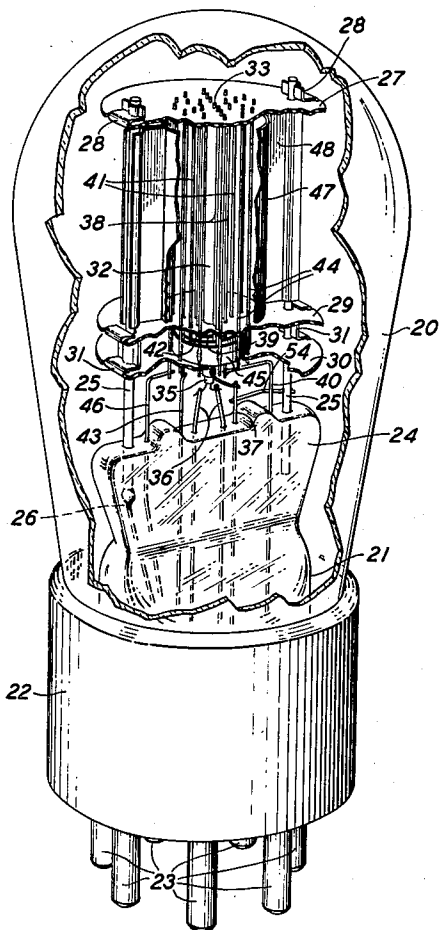


FIG. 2

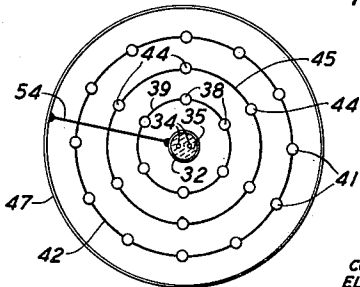


FIG. 6

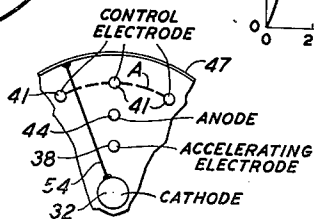
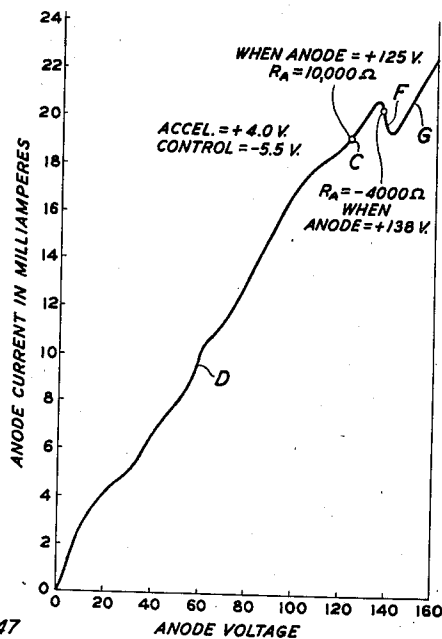
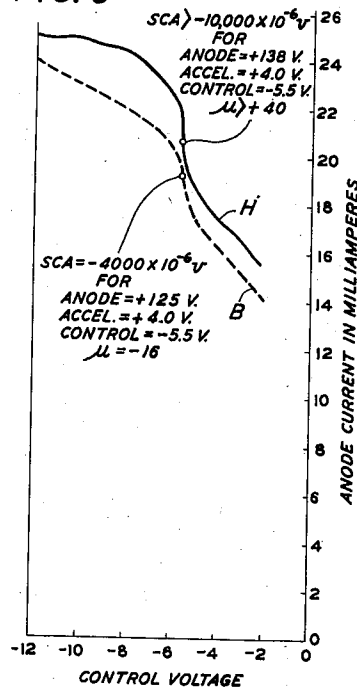


FIG. 3

FIG. 5



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FIG. 11

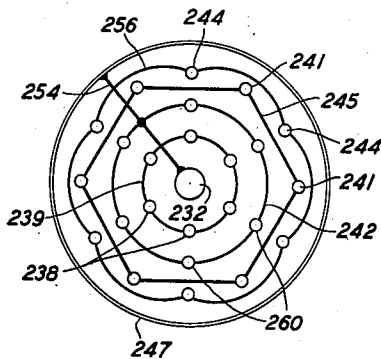


FIG. 12

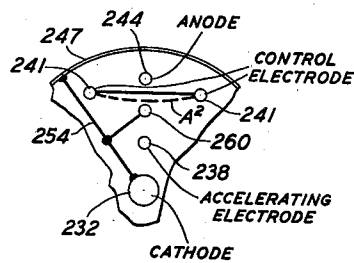


FIG. 13

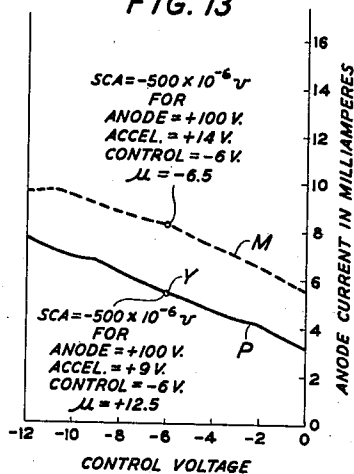


FIG. 14

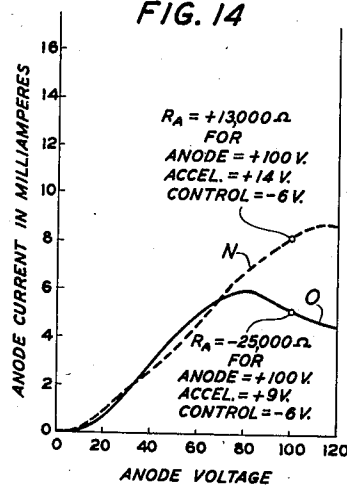
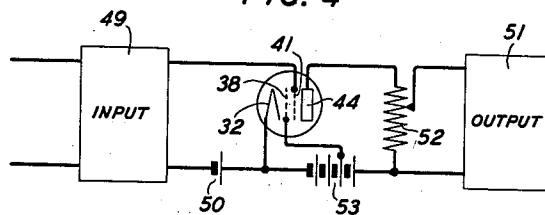


FIG. 4



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FIG. 7

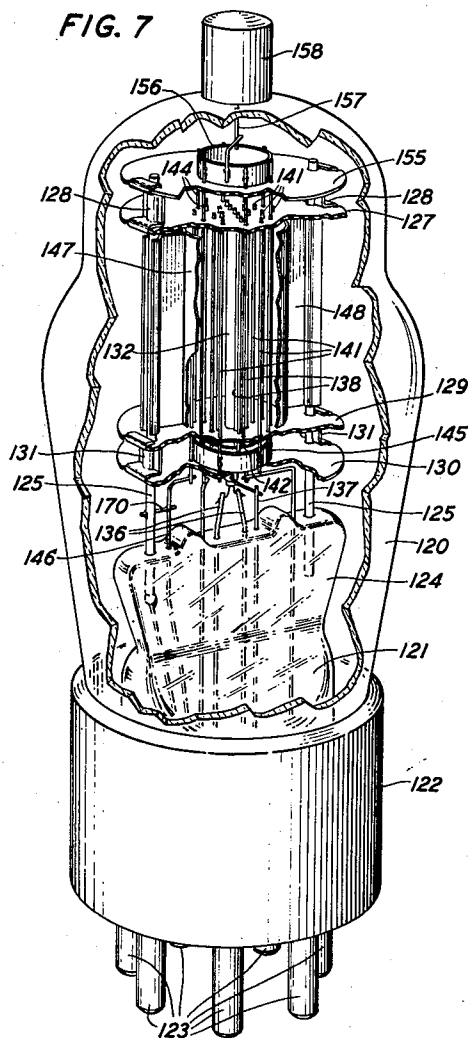


FIG. 8

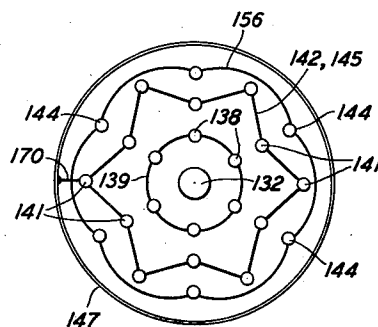


FIG. 9

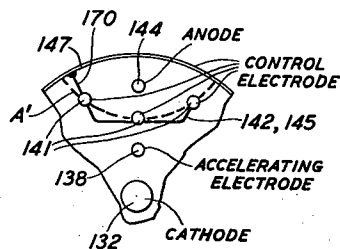
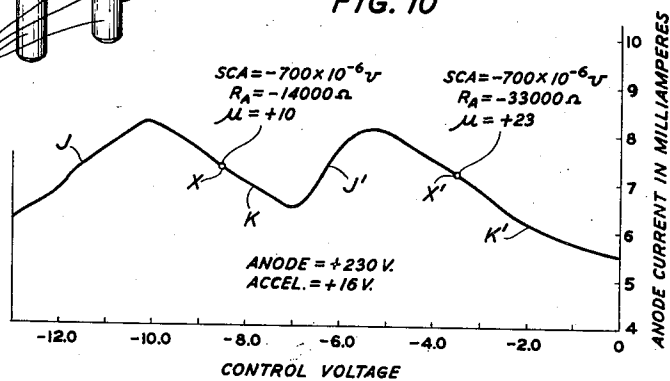


FIG. 10



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ELECTRON DISCHARGE APPARATUS

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Application January 26, 1938, Serial No. 186,950

20 Claims. (Cl. 250—27)

This invention relates to electron discharge apparatus and more particularly to such apparatus as disclosed in my application Serial No. 134,008, filed March 31, 1937, of which this application is in part a continuation, including an electron discharge device of the electron beam type.

In the specific form of electron discharge apparatus disclosed in my prior application above identified, the electron discharge device comprises a cathode, a pair of spaced grid electrodes surrounding the cathode, and an anode outside of the outer grid electrode. Each of the grid electrodes comprises a plurality of spaced linear elements, parallel to each other and to the cathode, the corresponding elements of the two grid electrodes being in radial alignment with one another and with the cathode. The output electrode or anode includes a plurality of linear elements mounted parallel to the cathode, each of these anode elements being in alignment with the cathode along a radius bisecting the space between successive corresponding elements of the grid electrodes.

In such apparatus, it was found that for specified conditions of operation, the control grid potential-anode current characteristic included a region wherein a negative transconductance obtained, that is, a region wherein the anode current decreases as the potential of the control electrode or grid becomes or is made less negative with respect to the cathode.

Control electro-anode transconductance may be defined as the ratio of elementary rates of change of anode current to control electrode potential. This ratio, it will be apparent, may be expressed also as the ratio of the amplification factor to the anode resistance. If the transconductance is to be negative, one of two possibilities must obtain, namely, either a positive amplification factor and a negative anode resistance or a negative amplification factor and a positive anode resistance.

One general object of this invention is to obtain a negative transconductance in electron discharge devices.

More specifically, objects of this invention are:

To increase the magnitude of the negative transconductance in electron discharge devices having a linear anode or output electrode and a multielement control electrode or grid;

To obtain a positive amplification factor and a negative anode resistance in electron discharge devices, without secondary emission from the anode;

To increase the range of grid or control electrode potentials wherein a negative transconductance is exhibited; and

To obtain a plurality of spaced regions in the operating characteristic of electron discharge devices wherein the anode or output current decreases as the control electrode or grid potential becomes less negative.

In one illustrative embodiment of this invention, electron discharge apparatus comprises an electron discharge device having a cathode, a plurality of linear anode elements disposed about the cathode and parallel thereto and to one another, and a control electrode or grid. The control electrode or grid comprises a plurality of linear rods or wires so mounted that each anode element has thereabout a plurality of these rods or wires located in an arcuate boundary at least partially encompassing the corresponding anode element. The constant potentials upon the various electrodes are such that throughout a definite range of grid or control electrode potentials, the output or anode current decreases as the grid or control electrode potential becomes less negative.

The invention and the features thereof will be understood clearly and fully from the following detailed description with reference to the accompanying drawings in which:

Fig. 1 is a perspective view of an electron discharge device illustrative of one embodiment of this invention, a portion of the enclosing vessel and of the electrode structure being broken away to show the inner electrodes more clearly;

Fig. 2 is a view in section, and partly diagrammatic, of the electrodes in the device shown in Fig. 1, illustrating the arrangement and electrical association of the various electrode elements;

Fig. 3 is a diagrammatic fragmentary view of a portion of the electrodes in the device illustrated in Figs. 1 and 2, showing clearly the relative positions of the anode and control electrode or grid elements;

Fig. 4 is a circuit diagram illustrating a typical circuit association of the electrodes of the electron discharge device shown in Fig. 1;

Figs. 5 and 6 are graphs showing the relationship between the control electrode or grid potential and the output or anode current, and between the anode voltage and anode current respectively, of an electron discharge device of the construction illustrated in Fig. 1, connected in circuit as illustrated in Fig. 4;

Fig. 7 is a perspective view of an electron discharge device illustrative of another embodiment of this invention;

Fig. 8 is a view partly diagrammatic and partly sectional illustrating the arrangement and electrical association of the electrode elements in the embodiment of this invention illustrated in Fig. 7;

Fig. 9 is a diagrammatic fragmentary view showing clearly the space relation of the anode and control grid elements in the embodiment of this invention illustrated in Fig. 7;

Fig. 10 is a graph illustrating a typical control electrode potential-anode current characteristic of an electron discharge device of the construction illustrated in Fig. 7;

Fig. 11 is a view partly diagrammatic and partly sectional of the electrodes in an electron discharge device illustrative of still another embodiment of this invention;

Fig. 12 is a diagrammatic fragmentary view showing clearly the relation of the electrode elements in the electron discharge device illustrated in Fig. 11; and

Figs. 13 and 14 are graphs showing typical control electrode potential-anode current and anode voltage-anode current characteristics respectively, of an electron discharge device of the construction illustrated in Fig. 11.

Referring now to the drawings, the electron discharge device shown in Fig. 1 comprises an evacuated enclosing vessel 20 having a stem 21 at one end and having suitably affixed thereto a base 22 carrying terminal prongs 23 through which the electrodes of the device may be associated with external circuits.

Embedded in the press 24 of the stem 21 and arising therefrom are parallel, rigid, metallic supports or uprights 25, one of which is connected electrically to one of the terminal prongs 23 by a leading-in conductor 26. An insulating disc 27, for example, of mica, is affixed to the supports or uprights 25 adjacent the upper end thereof, as by clips 28 which may be welded to the uprights or supports. Similar spaced insulating discs 29 and 30, which also may be of mica or the like, are affixed to the supports or uprights 25 by suitable clips 31, which also may be welded to the uprights or supports.

An elongated linear cathode, which may be either a filament or of the equipotential heater type, is supported between the insulating discs 27, 29 and 30. In the form shown in Figs. 1 and 2, the cathode comprises a cylindrical metallic sleeve 32, coated on its outer surface with a thermionic material, one end of which extends through and is fitted in central apertures in the lower insulating discs 29 and 30 and the other end of which is reduced, as indicated at 33, and fitted in a central aperture in the upper insulating disc 27. The cathode sleeve 32 encloses a heater filament 34 embedded in or threaded through a suitable ceramic or insulating body 35. Heating current may be supplied to the filament 34 through leading-in conductors 36 embedded in the press 24 and connected to corresponding ones of the terminal prongs 23. Electrical connection to the cathode 32 may be established through a leading-in conductor 37 also embedded in the press 24 and connected to one of the terminal prongs 23.

The cathode 32 is surrounded by a cylindrical accelerating electrode or grid coaxial therewith and including a plurality of equally spaced linear conductors or wires 38 mounted parallel to one another and to the cathode. The conductors 38 extend through aligned apertures in the insulating discs 27, 29 and 30 and are electrically connected to one another by a metallic band

or collar 39 seated upon the insulating disc 30. One of the conductors may be connected to one of the terminal prongs 23 through a leading-in conductor 40 embedded in the press 24.

The accelerating electrode or grid 38 is encompassed by a control electrode or grid, preferably coaxial therewith, which comprises a plurality of parallel, linear conductors or wires 41 each of which, as shown clearly in Fig. 2, is in radial alignment with the cathode 32 and alternate of which are in alignment also with a corresponding one of the wires 38 of the inner or accelerating grid. The conductors or wires 41 extend through aligned apertures in the insulating discs 27, 29 and 30 and are connected together electrically by a metallic band or collar 42 seated upon the insulating disc 30. Suitable potentials may be applied to the control electrode through a leading-in conductor 43 connected to one of the conductors or wires 41 and to one of the terminal prongs 23.

The control electrode or grid 41 encompasses an anode, coaxial therewith, which comprises a plurality of equally spaced parallel, linear rods or wires 44. The anode wires or conductors 44 extend through aligned apertures in the insulating discs 27, 29 and 30 and are electrically connected by a metallic band or collar 45 seated upon the disc 30. The anode may be coupled to an external circuit through a leading-in conductor 46 connected to one of the terminal prongs 23 and to one of the conductors or wires 44.

The control electrode or grid may be encompassed in turn by an auxiliary electrode having a cylindrical portion 47 and diametrically opposite flanges 48 which may be secured, as by welding, to the uprights or supports 25. The auxiliary electrode 47 may be connected directly to the cathode by a conductor 54.

As will be seen clearly from Figs. 2 and 3, each of the elements 44 of the anode has cooperatively associated therewith three elements 41 of the control electrode or grid, which lie in an arcuate boundary, indicated by the dotted line A, partially encompassing the corresponding anode element 44 and preferably coaxial with the cathode. The device, then, includes in effect six sections of electrodes electrically connected in parallel.

In a specific embodiment, the grid and anode elements may be rods having a diameter of 0.015", the cathode may have a diameter of 0.067", and the elements may be spaced so that the electrode spacings are as follows:

	Radius, inch
Accelerating electrode to axis.....	0.065
Anode to axis.....	0.125
Control electrode to axis.....	0.185
Cylindrical plate to axis.....	0.250

During operation of the electron discharge device illustrated in Figs. 1 to 3, inclusive, as shown in Fig. 4, an input circuit including a network 49 and a source, such as a battery 50, for applying a negative bias to the control electrode 41, is connected between the cathode 32 and the control electrode. An output circuit 51 may be connected across a suitable resistance 52 connected between the cathode 32 and anode 44 in series with a suitable source, such as a battery 53, for applying a positive potential to the anode. The accelerating electrode 38 may be connected to an intermediate terminal on the battery 51 so that

it is at a positive potential, lower than the anode potential, with respect to the cathode. Preferably, the fixed potentials applied to the several electrodes are such that the electrons emanating from the cathode are concentrated in circular or elliptical paths about the anode wires 44. The auxiliary electrode 47, not shown in Fig. 4, may be connected directly to the cathode as described heretofore and operated at cathode potential.

When the electron discharge device illustrated in Figs. 1 to 3, inclusive, is connected in circuit as shown in Fig. 4, and the anode and accelerating electrode are maintained at positive potentials with respect to the cathode (for example, 125 volts and 4.0 volts, respectively, in the specific embodiment described hereinabove) it has been found that the anode current varies with respect to negative control electrode or grid potential in the manner shown by curve B in Fig. 5. From this curve it will be seen that as the potential upon the control electrode or grid is made less negative, the anode current decreases. This effect obtains throughout a relatively wide range of control electrode or grid potentials.

At the value of anode potentials given, as indicated by the point C on the anode current-anode voltage characteristic D in Fig. 6 (the control electrode being biased at 5.5 volts negative with respect to the cathode), the anode resistance (R_a) is positive. Hence, there being a negative transconductance (S_{ca}) as indicated by the slope of the curve B in Fig. 5, the amplification factor (μ) necessarily is negative. Specifically, it may be noted that for the potentials and parameters given hereinabove, at an anode potential indicated by point C (125 volts), the anode resistance is approximately 10,000 ohms, positive, and the amplification factor is substantially 16, negative. Hence, the mutual conductance is substantially 4000×10^{-6} mhos, negative.

If the anode potential is increased and the grid and accelerating electrode potentials are held constant, it has been found that, as indicated by the portion F of curve D, the anode resistance becomes negative for a range of anode potentials and then becomes positive again as indicated by the portion G of the curve D. Inasmuch as the anode is highly positive with respect to the other electrodes of the device, it may be pointed out that this negative resistance is not attributable to secondary electron emission from the anode.

If the anode is held at a constant potential in the range wherein a negative anode resistance obtains, the anode current varies with the potential of the control electrode or grid as indicated by the curve H in Fig. 5, from which it will be seen that the transconductance is negative. Hence, the amplification factor is positive. Specifically, for an anode potential of 138 volts, a negative control electrode potential of 5.5 volts, and a positive accelerating electrode potential of 4 volts, the anode resistance of the device described above is about 4,000 ohms negative and the amplification factor is substantially 40, positive. Hence, the transconductance is approximately $10,000 \times 10^{-6}$ mhos, negative.

It may be pointed out that when the potentials upon the electrodes of the electron discharge device are such that the anode resistance is positive, the load resistance may be selected in the usual manner to attain a desired efficiency. However, when the potentials are such that the anode resistance is negative, the insertion of a small positive resistance in the load or output circuit, in series with the negative anode resist-

ance, reduces the resultant negative resistance and increases the apparent negative transconductance of the device. Hence, special determination of the load resistance for the particular operating potentials may be necessary.

In the embodiment of this invention illustrated in Figs. 7, 8 and 9, the form, number and arrangement of the cathode, auxiliary electrode, and the various linear electrode elements are the same as that in the embodiment shown in Fig. 1. Certain of the elements, however, are associated differently electrically. In Figs. 7, 8 and 9, the elements of the electrode structure corresponding mechanically or electrically to those in the embodiment shown in Fig. 1 are designated by the corresponding reference numeral increased by 100.

As shown in Fig. 7, the electrode structure includes an additional insulating spacer 155, such as a mica disc, maintained in parallel relation to the insulating spacer 127 by metallic clips 128 affixed to the uprights 125. Mounted upon the insulating spacer 155 is a metallic collar or band 156 which connects electrically alternate of the outermost linear rod members, the other of these members being connected electrically by the collar or band 145. Electrical connection to the band 156 may be established through a leading-in conductor 157 connected to a terminal cap 158 affixed to the enclosing vessel 120.

The outermost rod or wire members connected by the collar or band 156 constitute the anode elements 144 of the device, as illustrated in Figs. 8 and 9. The other of these members are connected, either internally or externally of the enclosing vessel, to the next inner members, as indicated by the connection 142, 145 in Fig. 8, and constitute the elements 141 of the control electrode or grid, mounted at the apices of the angles of a six-pointed star-shaped boundary. The auxiliary electrode 147 is connected to the elements 141 by a tie wire 170 and constitutes a part of the control electrode of the device. Each of the anode elements 144 has cooperatively associated therewith three of the elements 141 of the control electrode or grid, which lie in an arcuate boundary, indicated by the dotted line A¹ in Fig. 9, partially encompassing the corresponding anode element 144. The radius of the boundary A¹ may be approximately equal to the distance between the centers of the cathode 132 and anode elements 144.

The electron discharge device illustrated in Figs. 7, 8 and 9 may be connected in circuit as shown in Fig. 4. The electrode parameters may be substantially the same as those given hereinabove for the specific embodiment of the device illustrated in Fig. 1. When thus connected, and with the anode and acceleration electrode maintained at constant positive potentials, for example, the anode at a potential of 230 volts and the acceleration electrode at a potential of 16 volts, the anode current varies with the control electrode or grid voltage as indicated by the illustrative curve in Fig. 10. As will be apparent from this curve, the transconductance of the electron discharge device is alternately positive and negative as indicated by the portions J and J¹ and K and K¹ respectively. At points X and X¹, corresponding respectively to negative control electrode potentials of 8.5 and 3.5 volts, the transconductance may be of the order of 700×10^{-6} mhos, negative, and the anode resistance may be negative and 1,400 ohms and 33,000 ohms, respectively. The amplification factor, then is 10, posi-

tive, at the point X and 23, positive, at the point X¹.

From Fig. 10 it will be apparent that if the variable potentials impressed upon the control electrode or grid by the input circuit 49 are of sufficient magnitude to embrace the region including J, X and X¹, each pulse or swing of the input potential will produce at least four pulses in the output current so that in effect a frequency quadrupling is obtained. The magnitude and frequency of the output current will be dependent, of course, upon the electrical and mechanical parameters of the electron discharge device.

The negative transconductance, with either positive or negative anode resistance, may be obtained also by connecting the various elements of the electron discharge device shown in Fig. 7 in the manner illustrated in Figs. 11 and 12. In these figures the elements corresponding mechanically or electrically to those of the embodiment illustrated in Figs. 7, 8 and 9 are designated by the same characters as in the latter, increased by 100.

As shown in Figs. 11 and 12, the anode comprises alternate of the outermost linear members 244 electrically connected by the collar or band 256 and the control electrode or grid comprises the other outermost linear members 241 electrically connected by the collar or band 245. The grid composed of the intermediate linear members 260, connected by the collar or band 242, is connected directly to the cathode 232 by the conductor 254.

The elements 241 lie at the corners of a regular hexagon and each successive two of them lie in an arcuate boundary, indicated by the dotted line A² in Fig. 12, partially encompassing the corresponding anode element 244, are equally spaced from such anode element, and are spaced the same distance from the cathode 232 as the anode elements.

The device illustrated in Figs. 11 and 12 may be connected in circuit as shown in Fig. 4 and the parameters thereof may be the same as those given heretofore for the specific embodiment of the device illustrated in Fig. 1. When thus operated and with constant positive potentials upon the anode and accelerating electrode, for example, 100 volts and 14 volts, respectively, the anode current varies with the negative control electrode voltage as indicated by the curve M in Fig. 13, from which it will be apparent that a negative transconductance obtains throughout a relatively wide range of control electrode potentials. If the control electrode is maintained at a fixed negative potential, for example 6 volts, and the accelerating electrode is maintained positive, for example 14 volts, the anode current varies with anode potential as indicated by the curve N in Fig. 14, from which it will be seen that the anode resistance is positive. Hence, the amplification factor is negative; for example, at the values of potential given, that is if anode voltage equals 100 volts, control electrode potential equals -6 volts and accelerating electrode potential equals 14 volts, the amplification factor may be 6.5 negative, and the transconductance 500×10^{-6} mhos, negative.

If the control electrode is maintained at a fixed potential, for example 6 volts negative, and the accelerating electrode is made less positive, for example 9 volts, the anode current varies with anode voltage as indicated by the curve O in Fig. 14, from which it will be seen that for a range of anode voltages, the anode resistance is nega-

tive. If the anode potential is maintained at a fixed value in this range, for example 100 volts, the anode current varies with control electrode potential as indicated by the curve P in Fig. 13. At the point Y on this curve, corresponding to a negative control electrode potential of 6 volts and a negative anode resistance of 25,000 ohms, the transconductance is about 500×10^{-6} mhos, negative, and the amplification factor is approximately 12.5 positive.

It will be apparent from Figs. 13 and 14 that in the device illustrated in Figs. 11 and 12, a negative transconductance, with either a positive anode resistance and negative amplification factor or a negative anode resistance and positive amplification factor, may be obtained throughout a fairly wide range of control electrode potentials.

The novel characteristics attainable with apparatus constructed in accordance with this invention may be utilized advantageously in a variety of applications. In addition to the application in frequency multiplying systems mentioned heretofore, the invention may be utilized, for example, in amplifiers, with or without negative feedback, in detectors or in oscillators.

Although specific embodiments of this invention have been shown and described, it will be understood, of course, that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. Electron discharge apparatus comprising a cathode, a control electrode, an accelerating electrode between said cathode and said control electrode, an anode including a linear electron receiving element, said control electrode including spaced linear elements mounted about said electron receiving element, an input circuit connected to said cathode and said control electrode, and an output circuit connected to said cathode and said anode including means applying such positive potentials to said anode and said accelerating electrode that the anode current varies inversely with increments in the anode potential in the absence of secondary emission from said anode.

2. Electron discharge apparatus comprising a cathode, a linear anode parallel to said cathode, an accelerating electrode between said cathode and said anode, a control electrode including a pair of linear elements on opposite sides of said anode, an input circuit connected to said cathode and said control electrode including means for applying a negative bias to said control electrode, means for applying a positive potential to said accelerating electrode, and an output circuit connected to said cathode and said anode including means for maintaining said anode at a positive potential higher than the potential of said accelerating electrode, said bias and said anode and accelerating electrode potentials being such that the anode current varies inversely with increments in either said bias or anode potential.

3. Electron discharge apparatus in accordance with claim 2 wherein said linear control electrode elements are mounted parallel to said anode, and said elements and said anode are spaced substantially equal distances from said cathode.

4. Electron discharge apparatus comprising a cathode, an accelerating electrode encompassing said cathode, an anode disposed about said accelerating electrode and including a plurality of linear electron receiving elements, a control elec-

trode including a plurality of linear elements disposed about said accelerating electrode and in cooperative relation with said electron receiving elements, an input circuit connected between said cathode and said control electrode, means applying a positive potential to said accelerating electrode, and an output circuit connected between said cathode and said anode including means maintaining said anode at a positive potential higher than the accelerating electrode potential, said positive potentials being such that throughout a range of increments in the anode potential the current in said output circuit varies inversely with anode potential.

5. Electron discharge apparatus in accordance with claim 4 wherein said anode and control electrode elements are mounted parallel to one another and said cathode and are substantially equally spaced from said cathode.

6. Electron discharge apparatus comprising a cathode, an anode, and a control electrode including a plurality of linear elements mounted in an arcuate boundary partially encompassing said anode, certain of said elements being spaced from said cathode a distance substantially equal to the cathode-anode spacing.

7. An electron discharge device comprising a linear cathode, a linear rod anode parallel to said cathode, and a control electrode comprising a plurality of rod members parallel to said cathode and anode, said rod members being mounted in an arcuate boundary about said anode and one of said rod members being in alignment with said cathode and anode.

8. Electron discharge apparatus comprising a cathode, a linear anode in alignment with said cathode, an accelerating electrode including a linear member between said cathode and said anode and in alignment therewith, and a control electrode including linear members on opposite sides of said anode.

9. An electron discharge device comprising a linear cathode, a linear anode in alignment with said cathode, an accelerating electrode including a linear member between said cathode and said anode and in alignment therewith, and a control electrode including a member between said accelerating electrode and said anode and in alignment therewith and other members on opposite sides of said anode.

10. An electron discharge device comprising a cathode, a rod anode in alignment with said cathode, and a control electrode including a plurality of linear elements parallel to said cathode, at least two of said elements being spaced from said cathode a distance substantially equal to the spacing between said cathode and said anode and disposed on opposite sides of said anode.

11. Electron discharge apparatus comprising a cathode, an anode in alignment with said cathode, and a control electrode including a linear member in alignment with said cathode and said anode and other members equally spaced from and on opposite sides of a line passing through said cathode and the center of said anode.

12. Electron discharge apparatus comprising a cathode, an anode including a plurality of linear electron receiving elements mounted about said cathode, and a control electrode including a plurality of linear members between said cathode and said anode and other members mounted between said electron receiving elements.

13. Electron discharge apparatus comprising a cathode, an anode including a plurality of linear elements mounted in a cylindrical boundary about said cathode, and a control electrode including a plurality of linear elements mounted in a cylindrical boundary between said cathode and said first boundary, each of said second elements being in alignment with a corresponding one of said first elements, said control electrode including also other elements mounted between successive anode elements.

14. Electron discharge apparatus in accordance with claim 13 wherein said other elements and said anode elements are spaced substantially equal distances from said cathode.

15. Electron discharge apparatus comprising a cathode, a plurality of electrode elements mounted in a cylindrical boundary about said cathode, a plurality of electrode elements mounted in a cylindrical boundary about said first boundary, means electrically connecting one group of alternate of said second elements to said first electrode elements, means electrically connecting the other alternate of said second elements, an input circuit connected to said cathode and said first electrode elements and said group of second elements, and an output circuit connected to said cathode and said other alternate second elements.

16. Electron discharge apparatus in accordance with claim 15 comprising means included in said output circuit for maintaining said other elements at a positive potential, and means in said input circuit applying such negative potentials to said first electrode elements and the group of said second elements connected thereto that the current in said output circuit increases as said negative potential increases.

17. Electron discharge apparatus in accordance with claim 15 comprising an accelerating electrode between said cathode and said first boundary, means maintaining said accelerating electrode at a positive potential, and means included in said output circuit for maintaining said other second elements at a higher positive potential than said accelerating electrode potential, said potentials being such that the current in said output circuit decreases with increases in said higher positive potential.

18. Electron discharge apparatus comprising a cathode, a linear anode in alignment with said cathode, and a control electrode beyond said anode and including spaced elements in an arcuate boundary about said anode.

19. Electron discharge apparatus comprising a cathode, an anode comprising a plurality of linear elements mounted in a cylindrical boundary about said cathode, a control electrode comprising a plurality of linear elements mounted in a cylindrical boundary about said first boundary, said first and second elements being substantially parallel to one another and to said cathode, an input circuit connected to said cathode and said control electrode, and an output circuit connected to said cathode and said anode.

20. Electron discharge apparatus comprising a cathode, a linear anode in alignment with said cathode, and a control electrode including linear elements mounted in an arcuate boundary passing between said cathode and said anode and an element mounted outside of said anode and electrically connected to said linear elements.

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