

March 14, 1939.

V. K. ZWORYKIN ET AL

2,150,573

ELECTRIC DISCHARGE DEVICE

Filed Jan. 31, 1936

3 Sheets-Sheet 1

Fig. I.

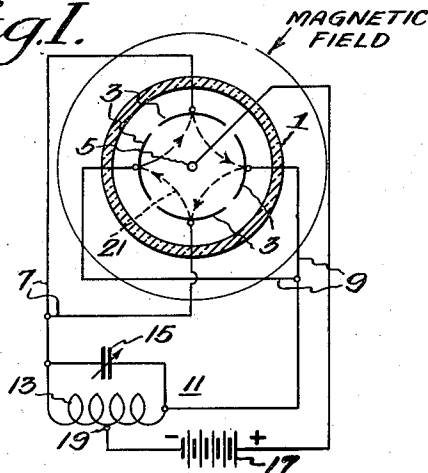


Fig. II.

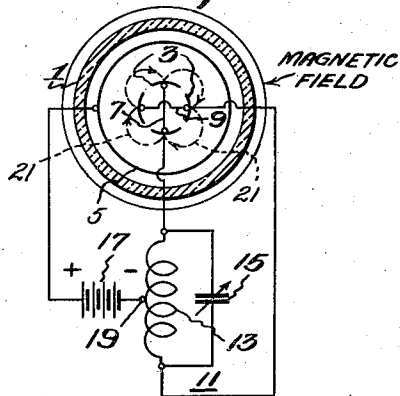


Fig. III.

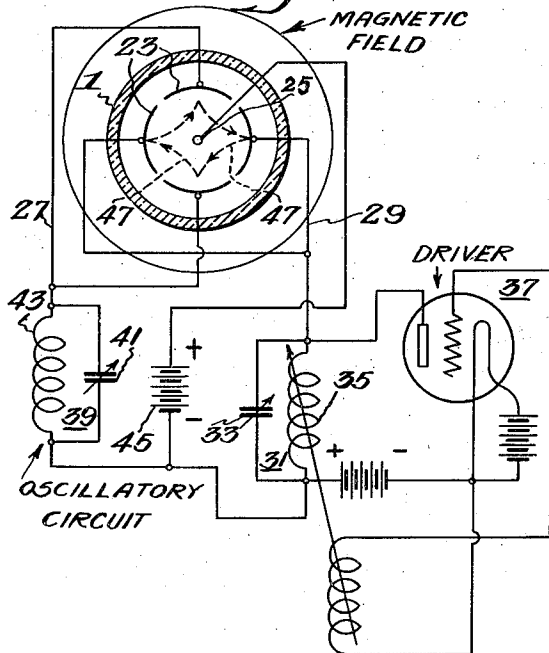
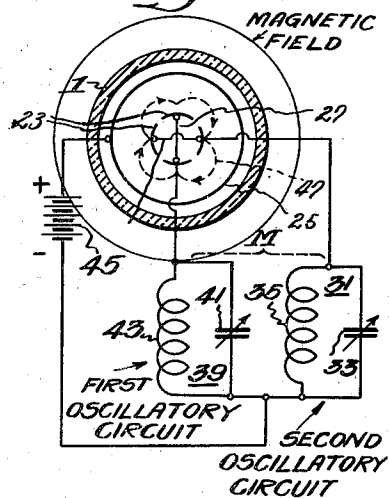


Fig. IV.



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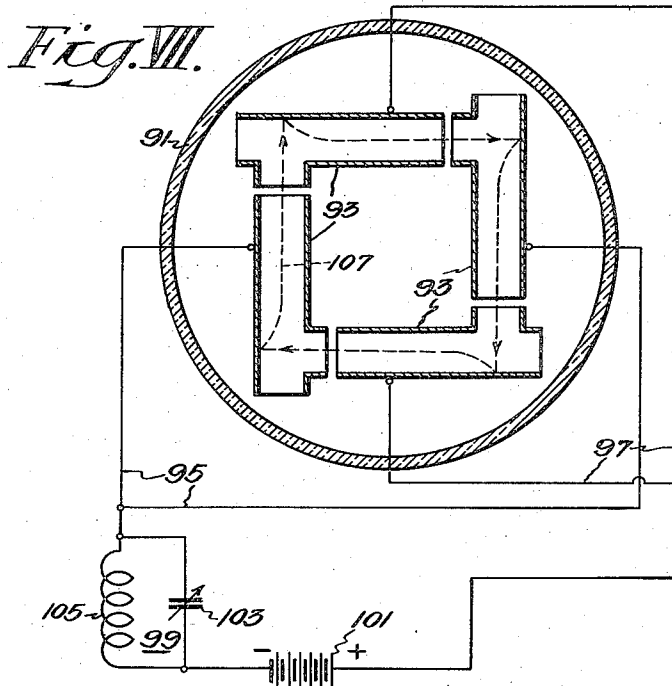
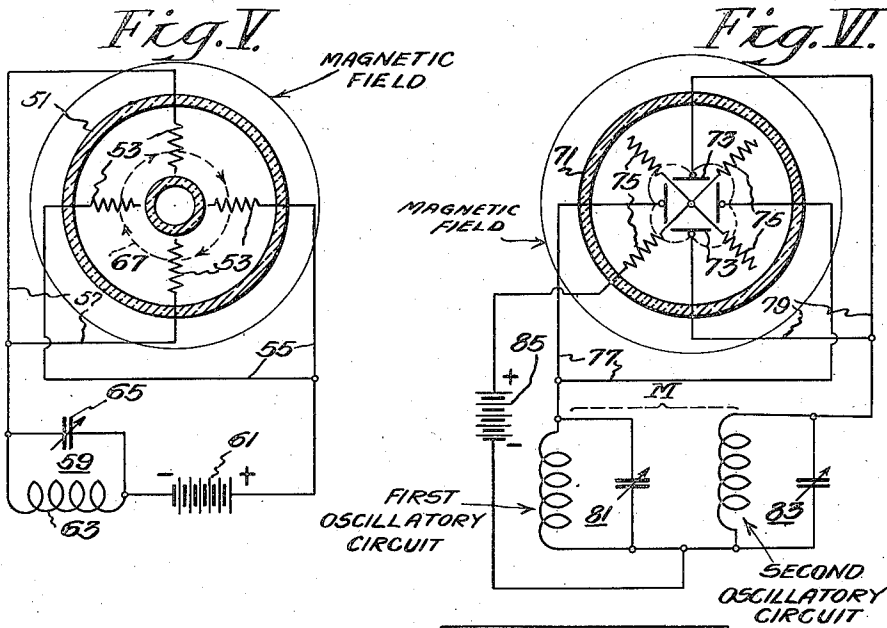
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3 Sheets-Sheet 2



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ELECTRIC DISCHARGE DEVICE

Filed Jan. 31, 1936

3 Sheets-Sheet 3

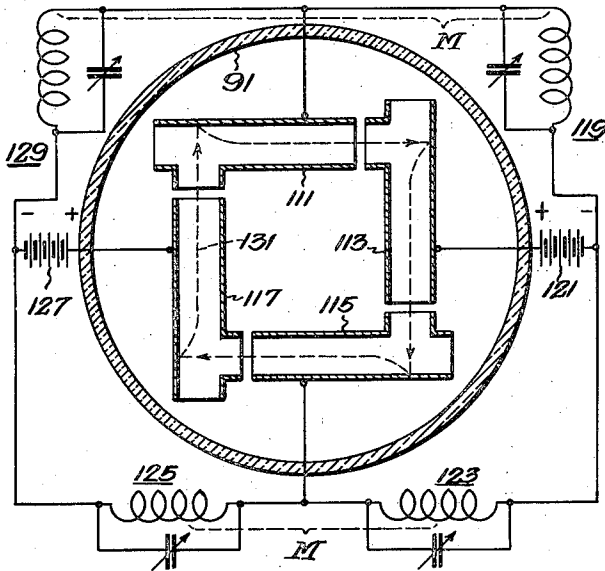


Fig. VIII.

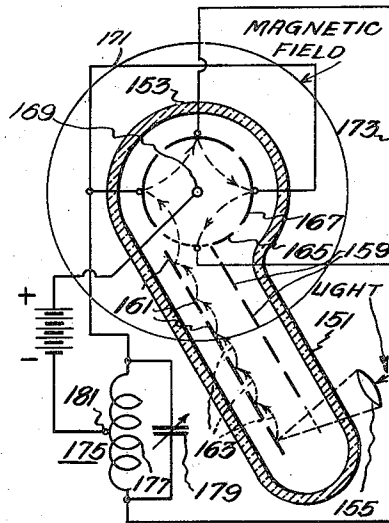


Fig. IX.

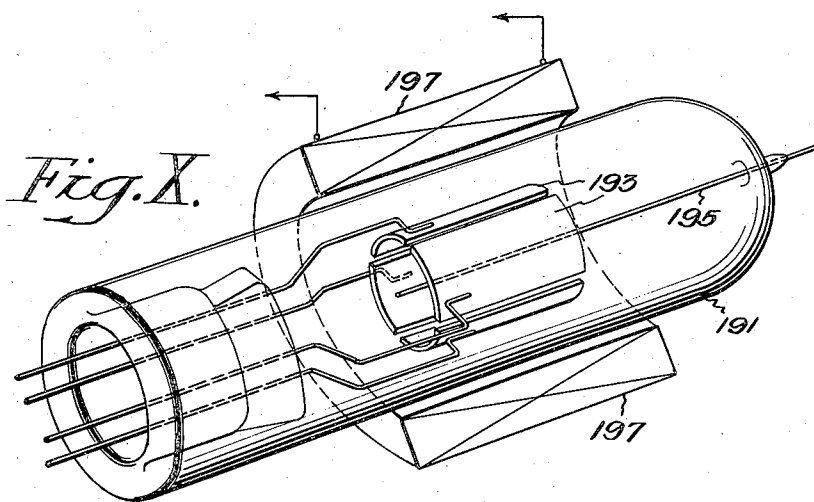


Fig. X.

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UNITED STATES PATENT OFFICE

2,150,573

ELECTRIC DISCHARGE DEVICE

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Application January 31, 1936, Serial No. 61,680

10 Claims. (Cl. 250—36)

Our invention relates to electronic oscillators and multipliers. More specifically, our invention is an electronic oscillator or amplifier in which the number of electrons is multiplied by secondary emission.

We are aware of numerous ultra high frequency oscillators which operate as electronic oscillators. Oscillators of this type are broadly known as magnetrons, or Barkhausen-Kurz oscillators. We are also aware of electronic multiplication devices in which secondary emission increases the total number of electrons flowing in a given circuit. Among the objects of the present invention is to combine the operating characteristics of a magnetron oscillator or amplifier and an electron multiplier.

Another object is to generate ultra high frequency oscillations in a vacuum tube employing cold electrodes which are secondarily emissive. Another object of our invention is to combine a thermionic driver oscillator and an electronic oscillator-multiplier. An additional object is to couple a driver circuit which is energized by the emission of secondary electrons to an oscillatory circuit whereby sustained oscillations are established. A still further object is to devise an electronic oscillator-multiplier device employing electrostatic fields only. A still further object is to establish a source of electrons by means of an electron multiplier and to create ultra high frequency oscillations by feeding electrons from such source into an electronic oscillator-multiplier. Additional objects will appear in the accompanying specification and appended claims.

In the accompanying drawings, Figure I is a schematic diagram of an electronic oscillator-multiplier device.

Fig. II is a modified arrangement embodying the features of Fig. I.

Fig. III is an electronic oscillator-multiplier in which a thermionic oscillator is employed as a driver circuit.

Fig. IV is an electronic oscillator-multiplier in which the driven circuit is mutually coupled to the oscillator circuit.

Fig. V is another embodiment of our invention employing grid shaped electrodes which are secondary electron emitters.

Fig. VI is a schematic diagram of a modified embodiment of our invention which is similar to Fig. V.

Figs. VII and VIII are electronic oscillator-multipliers in which electrostatic fields only are employed.

Fig. IX is a schematic illustration of one form

of our invention in which the electronic multiplier provides a source of electrons for a magnetron oscillator which employs secondary emission, and

Fig. X represents one physical embodiment of our invention.

The theory of operation of our invention involves an understanding of electronic oscillators, secondary emission and electronic multipliers. The theory of the operation of these devices is complicated and not thoroughly understood. However, since the theory may be an aid to an understanding of our invention we shall present a tentative theory of operation but do not intend to thereby limit our invention.

In an electronic oscillator of the split anode type, electrons are emitted by a heated cathode. Under the influence of a magnetic field whose lines of force surround the cathode and are substantially parallel thereto the electrons, emitted by the cathode, follow a curved path from the cathode toward the anodes. If the magnetic field is of suitable strength, the transit time of electrons will be such that ultra high frequency oscillations will be established in a tuned circuit connected between the anodes. The frequency of such oscillations depends primarily upon the magnetic field strength. The oscillatory frequency may also depend on the resonant period of the circuit connected to the anodes.

The theory of secondary emission is as follows: If electrons moving at high velocity strike an electrode surface, secondary electrons are emitted. The number of such secondary electrons will depend upon the velocity of impact and the nature of the surface material of the electrode upon which the primary electrons impinge.

The theory of electronic multipliers is based primarily upon the theory of secondary emission. If primary electrons impinge at sufficient velocity on a suitable electrode, this electrode will emit a large number of secondary electrons. These electrons may be accelerated and impinged on a second electrode which in turn will emit still more secondary electrons. In this manner the number of electrons may be increased and multiplied many fold.

We propose to combine several of these effects whereby a single device may be used as an electronic oscillator-multiplier. One device embodying our invention is illustrated in Fig. I. In this figure within an evacuated envelope 1 four electrodes 3 are suitably mounted. These electrodes are preferably cylindrical in shape and are insulated from each other. An accelerating anode

5 is concentrically mounted with respect to the four cylindrical shaped electrodes. Oppositely disposed pairs of the cylindrical electrodes are connected together by wires 7, 9. An oscillatory circuit 11 is connected between these pairs of electrodes. This circuit comprises an inductor 13 and a variable capacitor 15. The accelerating anode electrode is connected to the positive terminal of a battery 17. The negative terminal of this battery is joined to a tap 19 which is intermediate the ends of the inductor 13.

A magnetic field is generated by a suitable magnet which is not shown in this figure. One suitable type of magnet is shown in Fig. X. This magnet is a simple solenoid winding which surrounds the tube envelope. The solenoid creates a magnetic field whose lines of force surround the accelerated electrode 5 and are substantially parallel thereto.

Under the influence of the accelerating electrode, which has been given a suitable positive potential with respect to the four cylindrical electrodes, electrons will be liberated from the surfaces of these electrodes. It should be understood that these electrodes include an inner surface suitably treated with caesium or the like which renders the surface secondarily emissive. Under the influence of the combined electromagnetic and electrostatic forces, the electrons will follow curved paths as represented by the dash lines 21.

Concurrent with the emission of electrons a transient current will flow in the tuned circuit 11. The natural period of the tuned circuit is so chosen that a suitable phasal relation will exist between this period and the time elapsing between the emission of an electron and its impact upon the succeeding target. This phasing of the transient current with respect to the motion of the electron is such as will permit the transient current to deliver energy to the primary electron before its impact. The relative phases of the transient current in the tuned circuit and the motion of the secondary electrons continuously shift so that a sustained oscillation is built up. The energy for such sustained oscillation is, of course, furnished by the battery 17. Thus oscillations are not only created but the proper phase relation between the tuned circuit and the electronic motion permits the number of electrons to be multiplied to a very high degree. The limit of the electronic multiplication is obtained when the space charge becomes sufficiently large to prevent further multiplication.

The embodiment of my invention shown in Fig. II is substantially similar to that of Fig. I. For this reason it is convenient to use the same reference numbers. The essential modification of Fig. II is that the accelerating anode 5 surrounds the secondarily emissive electrodes while in Fig. I the converse is true. The operation of Fig. II is essentially the same as described above in connection with Fig. I. Both of these figures represent a combined electronic oscillator and multiplier.

In Fig. III, an electronic tube is arranged with four electrodes 23, of partially cylindrical shape, concentrically positioned with respect to the accelerating anode 25. Pairs of oppositely disposed electrodes are connected by leads 27 and 29. Thus far the arrangement of Fig. III is similar to Fig. I. The driver circuit 31 consists of a variable capacitor 33 and the inductor 35. The high potential terminal of the driver circuit is connected to the pair of electrodes 23—23 by con-

necting wire 29. The driver circuit is included in the output of a thermionic oscillator 37. This oscillator may be any well known type.

The second pair of oppositely disposed electrodes 23—23, connected by lead 27, are connected through an oscillatory circuit 39 to the lower terminal of the driver circuit 31. The oscillatory circuit is comprised of a variable capacitor 41 and an inductor 43. An anode battery 45 is connected between the junction of the tunable circuits 31—39 and the accelerating anode 25.

In this figure the oscillatory frequency is determined by the driver oscillator. The electron path 47 is represented approaching, but not contacting, the electrodes 23—23 connected to the oscillatory circuit 39. The time periods of the electron paths 47 and the tuned circuits are preferably the same. In this arrangement the oscillatory circuit represents the output of the network. This oscillatory circuit will absorb energy from the electrons. The energy required to produce the secondary emission is supplied by the driver and battery.

The electronic tube and circuit of Fig. IV is substantially the same as Fig. III. Similar parts have been represented by similar reference numerals. One difference between the apparatus of Figs. III and IV is the addition of external accelerating anode 25 in the latter apparatus. Another difference is the omission of the external driver oscillator in the circuit of Fig. IV. The oscillatory circuits are mutually coupled. The coupling is phased to feed oscillatory currents from the first oscillatory circuit to the second oscillatory circuit in the proper phase so as to produce secondary emission from electrodes 23—23 connected to the second oscillatory circuit 31. The operation of this circuit depends upon electronic multiplication. The theory of operation is broadly similar to Fig. III.

In place of mutual magnetic coupling between the tuned circuits, a thermionic amplifier may be used to couple these circuits. This amplifier is not shown but may be a screen grid, pentode, or other suitable thermionic tube. If the amplifier is used to link the tunable circuits, the phasal relations should be determined by establishing that coupling which sustains oscillations.

In Fig. V the evacuated envelope 51 is preferably of annular or toroidal shape. Within the inner and outer circular walls of this envelope are suitably mounted at 90° intervals four grid-like electrodes 53. Each of these electrodes is made secondarily emissive. Oppositely disposed electrodes are connected together by leads 55 and 57. Between these leads is serially connected a tunable circuit 59 and an accelerating voltage source 61. The tunable circuit comprises an inductor 63 and a variable capacitor 65.

The magnetic field is applied so that its lines of force are substantially parallel to the surfaces of the grid-like electrodes. The electron path is substantially circular and is represented by the dash line 67.

The theory of operation of this circuit is somewhat different from the preceding circuits. Under the accelerating influence of the magnetic field and the positively charged electrodes, primary electrons will be emitted from the negative electrodes. These electrons will strike the positively charged grids and will emit secondary electrons. If the tunable circuit is resonant and if its ratio of reactance to resistance is sufficiently high, a transient voltage will be established

whereby an instantaneous positive voltage will be placed on the electrodes which were previously negative.

This instantaneous positive charge will attract the secondary electrons with sufficient velocity to cause increased numbers of secondary electrons to be emitted when they strike the temporarily positive target. The phasal relation between the transient and the electronic motion will be such as to result in the building up of sustained oscillations in the tuned circuit.

A modification of our invention appears in Fig. VI. In this figure, the evacuated envelope is represented by reference numeral 71. Four square or rectangular electrodes 73 are disposed to form a hollow square with open corners. An accelerating grid-like anode 75 has four branches arranged in line with the diagonals of this square and projecting through the open corners. Oppositely disposed pairs of the square or rectangular electrodes 73 are connected together by leads 77, 79.

Tunable oscillatory circuits 81, 83 are connected to each of these leads. The lower terminals of these circuits are joined together and to the negative terminal of a battery 85. The positive terminal of this battery is connected to the accelerating grids 75.

It should be understood that the outer surfaces of the electrodes 73 are made of material which readily emits secondary electrons. A magnetic field is disposed about the electrodes so that its lines of force are substantially parallel to the electrode surfaces. Electrons emitted from the instantaneously negative pairs of electrodes are accelerated in a curved path under the forces established by the magnetic field and accelerating electrodes.

These electrons approach the pairs of electrodes which are instantaneously positive but do not contact the surface of these electrodes. Instead they proceed in a curved path to the target formed by the next succeeding electrode. In this arrangement the second oscillatory circuit 83 is suitably coupled by magnetic coupling to the oscillatory circuit. The theory of operation of Fig. VI is substantially similar to that of Figs. III and IV. It is not essential that the coupling between the driver circuit and oscillatory circuit be arranged as shown. In place of magnetic coupling, an amplifier may be employed to couple these circuits. In any event, the phase of the coupling should be such as will sustain oscillations.

Fig. VII is a schematic illustration of our invention in which electrostatic forces only are employed. In this figure, within a suitable envelope 91 four hollow electrodes, 93, are arranged to form a substantially rectangular path. Each of these electrodes resembles a hollow L or a hollow irregular T. The hollow section of each of these electrodes may be a circular section. It will be observed that the several electrodes have three openings at the ends thereof. Oppositely disposed pairs of these electrodes are joined by connecting wires 95 and 97. Between these wires, 95, 97, are serially connected a tunable circuit 99 and a battery 101. The tunable circuit comprises a variable capacitor 103 and an inductor 105. The ratio of the reactance to the resistance of this circuit should be high.

The theory of operation of this circuit is substantially the same as that of Fig. V. It is assumed that electrons will be emitted from each of the instantaneous negative electrodes and will be accelerated at high velocity toward the in-

stantaneously positive pairs of electrodes. The surfaces of these electrodes, which act as targets, are made secondarily emissive and liberate increased numbers of secondary electrons. These secondary electrons are in turn accelerated at high velocities toward the next succeeding instantaneously positive electrodes. The electron paths are represented by the dash line 107.

It will be apparent that the instantaneous voltage of the tunable circuit 99 must exceed the voltage of the battery 101 if sustained oscillations are to be generated. If this circuit is resonant and has a low resistance in relation to its reactance, the currents flowing in the resonant circuit will be sufficient to establish the required potentials. In this as in the other figures, it is preferable to have the resonant period of the oscillatory circuit suitably related to the time between successive electron movements or multiples thereof.

In Fig. VIII the envelope 91 and the electrodes 111, 113, 115, 117 are similar to those of Fig. VII. The circuit arrangements illustrated by this figure differ from those of Fig. VII. In the present circuit, each of the adjacent electrodes beginning with 111 are connected as follows: An oscillatory circuit 119 is connected to the first electrode 111 and to the negative terminal of a battery 121. The positive terminal of this battery is connected to the second electrode 113. The negative terminal of the battery 121 also is connected to a second oscillatory circuit 123. This oscillatory circuit 123 in turn is connected to the third electrode 115 and to a third oscillatory circuit 125. This oscillatory circuit is connected to the negative terminal of a second battery 127. The positive terminal of battery 127 connects to the fourth electrode 117. The negative terminal of battery 127 is also connected to a fourth oscillatory circuit 129. This oscillatory circuit is connected to the first mentioned electrode 111.

Of these oscillatory circuits, the first and third mentioned 119, 125 are the circuits which deliver energy to the electrons resulting in secondary emission, the second and fourth mentioned circuits 123, 129 are the circuits which abstract energy from the electrons so as to maintain oscillations within these circuits. The circuit 119 and the circuit 129 are suitably coupled by mutual magnetic coupling M or the like. The circuit 123 and the circuit 125 are likewise coupled. No magnetic field is required in this circuit arrangement. The electrostatic field provides the necessary force. In this arrangement, electrons emitted from the instantaneously negative electrodes approach the next adjacent instantaneously positive electrode but do not strike this target as the instantaneous polarity changes during the electron movement so that the next succeeding target is struck by the electrons at high velocities. The impact of these electrons liberates secondary electrons which are in turn carried around the electron path 131. The mutual coupling between the pairs of oscillatory circuits provides the necessary feedback path by means of which sustained continuous oscillations are generated.

A modification of our invention is illustrated in Fig. IX. In this figure an electron multiplier is represented within the lower portion of the envelope 151. In the upper portion of the envelope 153 an electronic oscillator-multiplier is shown. Inasmuch as the present application is not directed to electronic multipliers per se, a detailed description is not included. In applica-

tion Serial No. 4,049 filed on January 30, 1935, and entitled Electric discharge device, by Louis Malter, and assigned to the same assignee as this present application, a complete description of a

5 suitable form of electronic multiplier is contained. It is sufficient for the present application to point out that a source of light is focused by a lens 155 on a photosensitive electrode 157. A series of accelerating anodes 159 and secondary
10 emitter electrodes 161 cause the electrons to follow the paths represented by dash lines 163. The numbers of electrons are multiplied by each successive impact until the final target is reached. This target is adjacent a grid-like electrode 165
15 which is preferably of cylindrical shape. Three additional electrodes 167 are concentrically mounted within the upper envelope section 153. These electrodes are each insulated from each other and are concentrically positioned with respect to an accelerating anode 169.

20 Oppositely disposed pairs of the cylindrical electrodes are joined by connecting leads 171, 173. A resonant circuit 175 is connected between these leads 171, 173. This resonant circuit
25 is composed of an inductor 177 and a variable capacitor 179. A tap 181 is arranged intermediate the ends of the inductor 177. A battery is connected between this tap and the accelerating anode 169. A magnetic field whose lines of force
30 surround the electrodes and are substantially parallel to the accelerating electrode is applied to the electrodes within the upper and lower sections. Excepting the fact that the electron multiplier in the lower section of the envelope 151
35 provides a source of secondary electrons which are projected within the space formed by the cylindrical anodes, this arrangement is essentially the same as Fig. 1. The present embodiment of our invention is used whenever large
40 numbers of electrons are initially required. It should be understood that in place of the light source any suitable means of establishing electrons may be employed.

45 In Fig. X one physical embodiment of our invention has been illustrated. In this figure the evacuated envelope is represented by the reference numeral 191. The four cylindrical shaped electrodes 193 are suitably supported within the envelope. These electrodes 193 are concentrically
50 arranged with respect to the accelerating anode 195. The magnetic field is established by a direct current flowing in the solenoid winding 197, which is cut away for clearness of illustration. A permanent magnet may be substituted for the electro-magnet.

55 It should be understood that various combinations of parts which are represented in the several illustrations of our invention may be combined; for example, the thermionic oscillator
60 which is the driver in Fig. III may be employed in connection with any of the embodiments illustrated in the other figures. Likewise, an amplifier coupling may be employed to couple the oscillatory circuits of any of the several figures.

65 Although we have illustrated electronic devices in which four secondarily emissive electrodes are employed it should be understood that our invention is not limited to this specific arrangement. Any even number of secondarily emissive electrodes may be employed. Likewise, we have described electrodes of cylindrical shape. This particular shape is not essential and plane electrodes may be substituted, as illustrated in Fig. VI. The electron tube of Fig. VI may be employed in a circuit similar to Fig. I. Likewise, a

grid-like electrode may be used, as illustrated in Fig. V.

Other modifications within the scope of our invention will occur to those skilled in the art. The foregoing examples are by way of illustration of our invention and are not to be taken as limitations of form or circuit.

We claim:

1. In an electronic oscillator-multiplier, at least four electrodes having electron emissive surfaces, said emissive surfaces being the principal source of electron emission for said oscillator-multiplier, an accelerating anode, means for supporting said electrodes in substantially uniform relation with respect to said accelerating anode, means electrically connecting alternately disposed electrodes, an oscillatory circuit, means whereby one terminal of the oscillatory circuit is connected to one group of interconnected electrodes and the other terminal connected to the remaining group of 20 interconnected electrodes, a source of polarizing potential effectively connected between said oscillatory circuit and said accelerating anode, and a magnetic field whose lines of force surround said electrodes and are substantially parallel to said
25 accelerating anode.

2. In an electronic oscillator-multiplier, a plurality of at least two pairs of electrodes having electron emissive surfaces, said emissive surfaces being the principal source of electron emission for said oscillator multiplier, an accelerating anode, means for supporting said plurality of electrodes in substantially uniform relation with respect to said accelerating anode, means electrically connecting alternately disposed electrodes of said plurality, an oscillatory circuit, means for impressing oscillating voltages developed across said oscillatory circuit between adjacent electrodes of said plurality of electrodes, a source of polarizing potential effectively connected between said circuit and said accelerating anode, and a magnetic field whose lines of force surround said electrodes and are substantially parallel to said accelerating anode.

3. In an electronic oscillator-multiplier, a plurality of at least two pairs of electrodes having electron emissive surfaces, said emissive surfaces being the sole source of electron emission, an accelerating anode, means for supporting said plurality of electrodes in concentric relation to said accelerating anode, means electrically connecting alternately disposed electrodes of said plurality, at least one oscillatory circuit connected serially between adjacent electrodes of said plurality, a source of polarizing potential effectively connected between said circuit and said accelerating anode, and a magnetic field whose lines of force surround said electrodes and are substantially parallel to said accelerating electrode.

4. In an electric discharge device, a plurality of at least four curve-shaped electrodes having exposed electron emitting surfaces which are the sole electron emitting surfaces for said device, an accelerating anode, means for supporting said electrodes in concentric relation to said anode, means electrically connecting alternately disposed electrodes, means for impressing oscillating potentials between adjacent electrodes, means for maintaining said accelerating anode at a positive potential with respect to said plurality of electrodes, and means for creating a magnetic field whose lines of force are substantially perpendicular to electron paths between said electrodes, whereby electrons traverse curved paths between
75

said electrodes, impinge on said exposed surfaces and thereby cause the emission of electrons from said surfaces.

5 5. In a device of the character of claim 1 in which the accelerating electrode is located at substantially the center of said plurality of electrodes.

10 6. In an electric discharge device, a plurality of pairs of electrodes having electron emissive surfaces, an accelerating anode, means for supporting said electrodes in substantially uniform relation with respect to said anode, means connecting electrically alternately disposed electrodes, a first and a second oscillatory circuit, means mutually
15 coupling said circuits, an anode current source effectively connected between said circuits and said anode, means connecting first oscillatory circuit to one group of interconnected electrodes, and means connecting second oscillatory circuit
20 to the remaining group of interconnected electrodes, whereby secondary electrons are emitted from said electrodes and travel between said pairs of electrodes to maintain continuous oscillatory currents in one of said circuits.

25 7. In an electric discharge device, a plurality of pairs of electrodes having electron emissive surfaces, an accelerating anode, means for supporting said electrodes in substantially uniform relation with respect to said anode, a first and a second oscillatory circuit, an anode current source
30 effectively connected between said circuits and said anode, means connecting each of said circuits to a pair of said electrodes, and a thermionic driver connected to one of said oscillatory circuits

whereby secondary electrons are emitted from said electrodes and travel between said pairs of electrodes to maintain continuous oscillatory currents in one of said circuits.

8. In an electric discharge device, a plurality of 5 pairs of electrodes having electron emissive surfaces, an accelerating anode, means for supporting said electrodes in substantially uniform relation with respect to said anode, means electrically connecting alternately disposed electrodes, a first and a second oscillatory circuit, an anode current
10 source effectively connected between said circuits and said anode, means connecting first of said oscillatory circuits to one group of said interconnected electrodes, means connecting second of 15 said oscillatory circuits to the remaining group of interconnected electrodes, and means for feeding back oscillatory currents in one of said circuits to the other of said circuits whereby secondary electrons are emitted from said electrodes and travel
20 between said pairs of electrodes to maintain continuous oscillatory currents in one of said circuits.

9. In a device of the character of claim 1 an auxiliary source of electrons derived from an electron multiplier, and means for impinging
25 said electrons on one of said plurality of electrodes.

10. In a device of the character of claim 4 an auxiliary source of electrons derived from an electron multiplier, and means for impinging said
30 electrons on one of said plurality of electrodes.

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