

May 7, 1940.

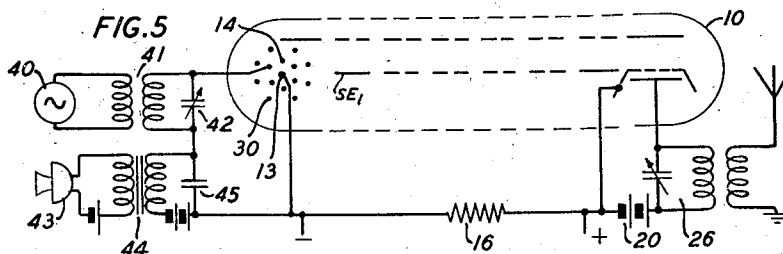
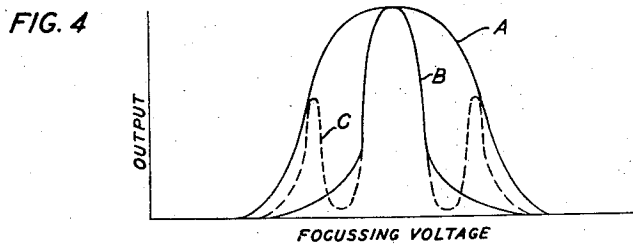
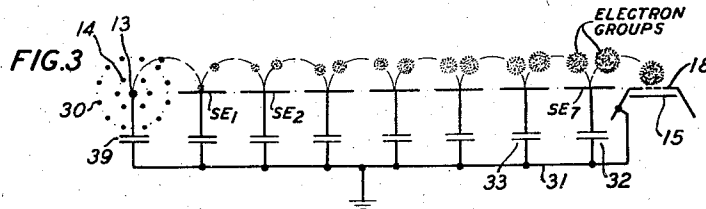
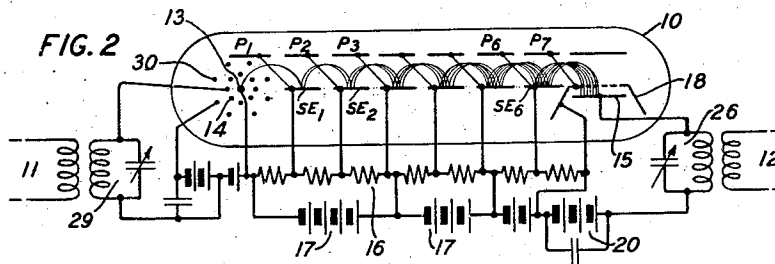
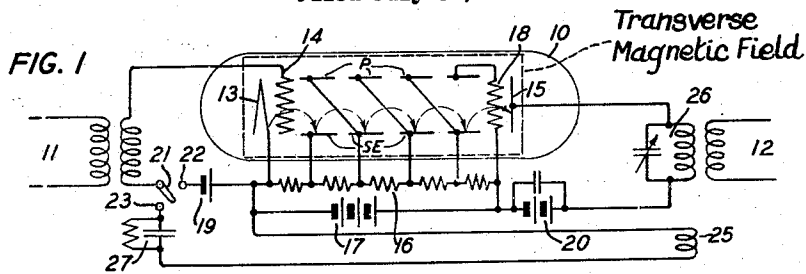
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2,200,063

SPACE DISCHARGE APPARATUS AND CIRCUITS

Filed July 31, 1936

2 Sheets-Sheet 1



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SPACE DISCHARGE APPARATUS AND CIRCUITS

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2 Sheets-Sheet 2

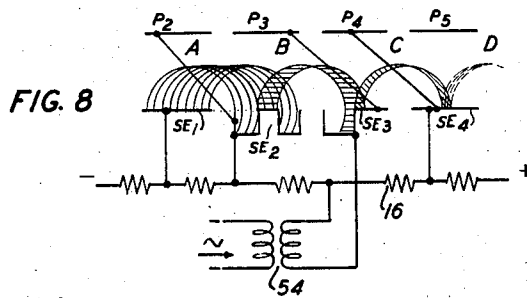
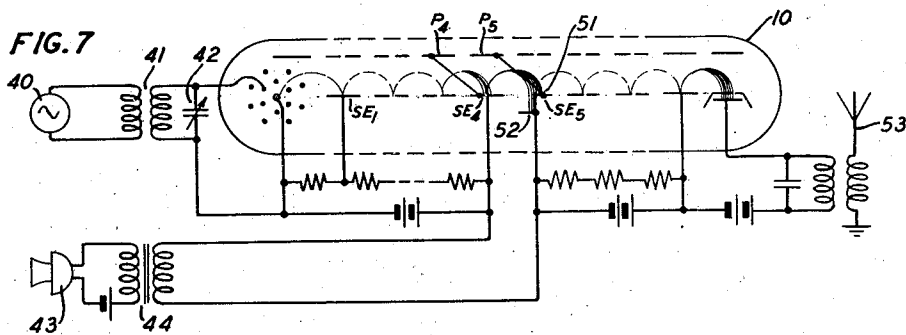
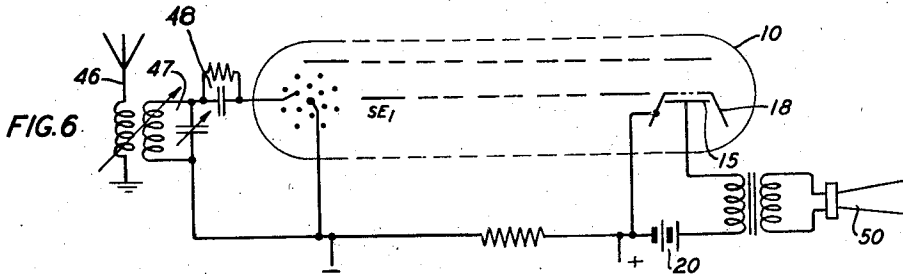
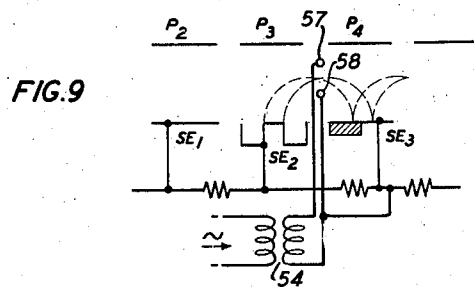
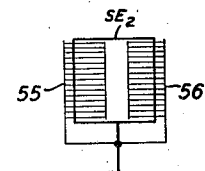


FIG. 8 A



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## UNITED STATES PATENT OFFICE

2,200,063

SPACE DISCHARGE APPARATUS AND  
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Application July 31, 1936, Serial No. 93,546

9 Claims. (Cl. 179-171.5)

The present invention relates to space discharge apparatus involving secondary electron emission, preferably a succession of times to secure large amplification, and to circuits for such apparatus. This general type of apparatus is referred to in the art as an electron multiplier, and will be so termed in this application.

A general object is to improve upon the structure and performance of apparatus or systems using secondary electron emission or systems using electron multipliers.

The invention is particularly, but not exclusively, directed to the use of electron multiplier apparatus at ultra-high frequencies, especially at frequencies so high that at those frequencies it is difficult or impossible for the usual grid-controlled vacuum tube to operate effectively to give high amplification or high output power.

High amplification at very high frequencies is difficult of attainment with the usual type of vacuum tube on account of the inherent capacities between elements of the tube or circuit or capacities to ground from the various elements. A limitation on the output power at very high frequencies is placed by the difficulty that the spacings between grid, filament and plate are so small that the plate itself tends to be small and therefore to have but slight dissipative capacity.

These difficulties are overcome to a considerable extent by the invention, according to which an electron multiplier structure is combined with suitable input and output wave structures to enable high amplification of waves of high frequency and, if desired, at high output power. The input structure may comprise a cathode and grid similar to those used in ordinary vacuum tubes, with the grid preferably located very close to the cathode as in the case of the short wave tube disclosed in my prior application Serial No. 64,697 filed February 19, 1936 and for the same reason as disclosed in that application. In the device of the invention, only a relatively small number of electrons need be passed from the cathode through the grid as compared with grid-controlled vacuum tubes of usual construction, for the electrons instead of constituting the plate current of the tube, enter the electron multiplier structure and produce an eventual output current which may be many times larger than the current passed through the grid. This fact is taken advantage of in the design of the apparatus to secure the necessary control of the initial electron stream by the grid at all frequencies while at the same time keeping the active grid losses small.

Another condition favorable to the use of an electron multiplier in a system of high frequency amplification is that the amplification takes place in the successive stages without the necessity of imposing a high frequency potential between elements of the device or between these elements and ground, there being no coupling impedances between stages as there are in ordinary vacuum tube tandem amplifiers. The capacity to ground or between elements of the device can therefore be relatively large without adversely affecting the operation even at high frequencies.

While the invention, as stated, is especially advantageous at very high frequencies, it is effective at low frequencies also and certain features of the invention comprise methods and means of wave transmission or reception, and of generating, modulating and controlling waves which are capable of general application without regard to frequency range or type of system.

The various features and objects of the invention will be more apparent from the following detailed description of typical embodiments as illustrated in the accompanying drawings.

In the drawings,

Fig. 1 is a schematic sketch of one embodiment;

Fig. 2 shows more in detail a tube construction embodying the features shown schematically in Fig. 1;

Fig. 3 is a functional diagram to illustrate the method of operation of the device of Fig. 2;

Fig. 4 shows curves illustrative of the operation of the apparatus of the invention;

Figs. 5 and 6 show typical circuit applications of the device of Fig. 2;

Fig. 7 is a circuit diagram of one method of modulating or controlling transmission through an electron multiplier;

Figs. 8 and 9 are fragmentary diagrams illustrating modified types of apparatus for modulating or controlling the transmission; and

Fig. 8A is a detail plan view of an alternative construction of emitting plate.

In Fig. 1, an evacuated tube 10 has an input circuit at 11 and an output circuit at 12. The tube includes a hot cathode or other suitable source of electrons 13, and a control grid 14, these two elements being constructed and arranged, for example, as in the case of an ordinary vacuum tube amplifier designed for the same frequency range, in the assumed case, an ultra-high frequency of the order of megacycles per second. From the grid to the anode 15 the structure diagrammatically indicated is an electron multiplier to be more fully described in the succeeding

figures. This multiplier comprises a series of secondary emitter plates SE and an associated system of deflecting plates P, supplied with increasingly positive potential from grid toward anode, as by taps to appropriate points along a potentiometer 16 supplied from battery 17. A screen 18 is interposed between the last emitter and plate and the anode. Bias battery 19 preferably has sufficient voltage to keep the current in the tube at a desired value preferably zero in the absence of input signal waves. The anode 15 is maintained positive with respect to the last emitter and plate in the series by battery 20. A magnetic field produced by a permanent or electromagnet is impressed perpendicular to the plane of the drawings.

In the operation of this circuit, with the switch 21 assumed in contact with terminal 22, the input waves from 11 vary the potential of the grid 14 relative to cathode 13 and control electron flow toward the first emitter and plate, SE and P, which, as stated, are positive toward the cathode. By means of a magnetic field (normal to the plane of the drawings) the electrons are constrained to follow a curved path somewhat as indicated by the arrows and to impinge on the first of the secondary emitters SE, from which they drive out a much larger number of secondary electrons. It is assumed that the plates SE are each coated with a suitable substance to make them efficient emitters of secondary electrons. The secondary electrons thus liberated from the first emitter are in similar manner caused to strike the second emitter and drive out a still larger number of secondaries and so on, until finally after a sufficient number of multiplier stages have been traversed, the resultant large stream of electrons passes through the screen 18 to the anode 15 and sets up current flow in output circuit 12. This eventual output current, while under control of the grid, is many times larger than the current passed by the grid. This fact makes it possible to secure large outputs by means of an input wave construction (grid and cathode) which at the frequencies utilized might be capable of transmitting only very small current when used in an ordinary type of vacuum tube amplifier.

By throwing switch 21 to connect to terminal 23, feedback coil 25 coupled to the output tuned circuit 26, is included in the grid circuit in series with leak resistor and condenser combination 27. In this condition the circuit is a regenerative amplifier or generator of sustained oscillations for supplying a load connected to circuit 12. In this case no input waves at 11 are necessary.

In this and the subsequent figures, batteries such as 17 and 20 would in many cases be replaced by other voltage sources such as direct current generators or rectifiers with suitable filters as is common in the vacuum tube art. It is preferable to separate the supply sources as at 17 and 20 instead of having one source with potentiometer 16 extending across its terminals, for the reason that the current drawn by the emitters SE increases along the series so that relatively large current needs to be supplied to the anode 15 and somewhat smaller current to the last emitter, etc. Large losses would result in a potentiometer resistor across power source 20, and, moreover, since the current through the potentiometer might vary in large amount during signaling, undesirable voltage variations might be produced on the various plates. The

subdivision of the power supply may be carried further, as indicated for example in Fig. 2.

One form which the physical arrangement of the parts, indicated diagrammatically in Fig. 1, may take is shown in Fig. 2. The cathode 13 is shown as a single straight wire extending perpendicular to the plane of the paper and surrounded by an inner grid 14, which is the control grid, and an outer grid 30 maintained more negative than the control grid. There is a positive field on plate P<sub>1</sub> and secondary emitter SE<sub>1</sub> tending to draw electrons through the two grids. Since no other field exists on other sides of the cathode-grid structure, most of the electrons are directed toward the point where they are to be utilized by the electron multiplier structure. While some such method of focusing the electrons is desired, it is not essential since only a relatively few electrons are needed at the input end of the multiplier. By focusing, however, greater amplification is obtainable. It will be understood that in this figure and each of the other figures a magnetic field is used perpendicular to the plane of the paper to cause the electron path to be curved and directed against the secondary emitters at the proper angle. In Fig. 2 the shield 18 is shown as effectively enclosing the anode 15.

As indicated in connection with Fig. 1, such a high negative grid bias is preferably used as to break up the electron stream into a succession of electron groups or clouds somewhat as shown diagrammatically in Fig. 3. In this figure the groups of electrons are indicated by small dots crowded together and occurring one each cycle, by way of example. The numbers in a group are shown increasing toward the right without attempting to depict the actual rate of increase. The time required for an electron leaving the cathode to reach the anode 15 (or more exactly to cause its corresponding successor electrons to arrive at the anode 15) may be a large number of cycles of the impressed waves. The electrons should arrive at the screen 18 during that part of the alternating cycle at which, after passing through the screen, they will deliver power to the load circuit when they move across to the plate 15. (This feature of my invention is claimed in my copending application Serial No. 280,702, filed June 23, 1939.) Several cycles of time may elapse between the instant when an electron leaves the cathode-grid region and the instant of arrival of the corresponding electron group at the screen-anode region without interfering with the power delivering properties if the time and frequency relations are properly observed. The proper time relations can be determined by trial by varying the voltages applied to the tube elements and observing the maximum output for given input.

The time of travel is of first order importance between cathode and grid 14 and also between screen 18 and anode 15. The grid 14 should be near the cathode to effectively control the electrons without too great an active grid loss. The spacing between screen and anode must not be too large since this part of the electron stream delivers power to the load circuit. However, the spacing of screen and anode need not be as small as in the ordinary three-electrode tube for the reason that in the tube of the invention the electrons enter this space at high velocity in contradistinction to the relatively low velocity with which electrons start from the space charge region in the ordinary vacuum tube where they

utilize a large part of a cycle in attaining their speed in passing the grid.

In Fig. 3, a number of capacities are shown between the various emitter plates and ground. Large capacities at these points are not only tolerated but are desired in order to prevent variations in high frequency potential from occurring between shields, secondary emitters, plates, etc. The only points at which it is desirable to keep the capacity between elements as small as possible is between grid and cathode, and between screen 18 and anode 15. Low capacity between cathode and grid is desirable since potential variations must occur between these elements in order to control the electrons passing to the multiplier. Low capacity between shield and anode is desirable since this part of the circuit acts like the plate impedance of a tube in delivering power to a load, and it is important not to have a material amount of shunting capacity. In Fig. 3 a ground plate 31 is shown extending from the screen 18 in such manner as to shield the secondary emitters SE<sub>1</sub>, etc. and plates P<sub>1</sub>, etc. from the output circuit. This plate 31 may have inherent capacity as indicated at 32, 33—39, with respect to the secondary emitters and plates to prevent potential fluctuations on these elements. These capacities may be partly or wholly inherent or may consist of condensers connected at the points shown. The shield 31 may be tubular and surround the electron multiplier apparatus completely. One such capacity 39 is shown between the cathode and the ground plate. If desired the capacity at this point can be placed between the control grid and the ground plate in which case the signal waves vary the cathode potential with respect to ground, necessitating use in the cathode heating circuit of some suitable direct current filter, (which may be of usual construction) to prevent shunting off the signal through the current supply circuit.

In Fig. 4 the curve A gives the general shape of the characteristic of the device of the previous figures when used as an amplifier. As a generator of ultra-high frequency waves the characteristic has more nearly the shape of curve B or C. With relatively few emitters or multiplier stages, the curve takes the form of characteristic B. As the number of stages is increased the curve has some such form as that of C. The reason for this is that the timing becomes important, as well as the voltage. In order to produce maximum output current not only must the voltage be such as to cause the electrons to travel from emitter to emitter in proper paths but the groups of electrons must eventually arrive at the screen 18 and anode 15 in proper instants of time or, in other words, must have the right phase relation to the oscillations being generated. Where the number of stages is great there may be several values of applied voltage at which the timing is such as to produce a current maximum, as shown by curve C.

The remainder of the figures disclose methods of utilizing the device of the invention in signaling circuits, particularly in modulating and detecting circuits.

In Fig. 5 the tube 10 may have the same construction as in Fig. 2 and this construction is indicated in outline. A radio frequency wave is produced at 40 by suitable means and is applied through the tuned coupling 41, 42 to the grid circuit in series with the speech input coupling shown at 44 leading from microphone 43. Condenser 45 affords a by-pass for the high frequen-

cies. Modulation occurs between the cathode and the first emitter plate SE<sub>1</sub> which acts like the anode of a vacuum tube in drawing electrons through the grid. The modulated current is amplified to the desired extent by the electron multiplier structure as described in connection with Figs. 1 and 2. The output current is shown as being led to tuned output circuit 26 which is coupled to any suitable transmitting circuit such as an antenna or line.

In Fig. 6 a receiving circuit or antenna 46 is coupled through suitable tuned input circuit 47 to the grid of tube 10, the grid circuit of which includes a grid leak and condenser combination 48. Detection occurs as in the ordinary grid leak detector and the resulting detected or low frequency current passes into the electron multiplier apparatus where it is amplified to the desired extent. The output is transmitted through transformer 49 to loud-speaker 50 or other utilization circuit.

In Fig. 7 a high frequency wave from source 40 is applied to the grid of tube 10 through tuned input coupling 41, 42 and the resulting high frequency wave is amplified in the electron multiplier portion of the tube. Modulation is effected by applying the speech or other low frequency waves originating in microphone 43 through transformer 44, between two of the emitter plates such as SE<sub>4</sub> and SE<sub>5</sub> and their associated deflecting plates P<sub>4</sub> and P<sub>5</sub>. Emitter plate SE<sub>5</sub> is made in two parts 51 and 52, such that only the part 51 is efficient in emitting secondary electrons, the part 52 being coated with carbon or otherwise rendered non-emissive. It may be constructed as a depressed portion into which about half of the electrons from the previous emitter fall when there are no signal voltages applied. The signal voltages vary the focusing voltage which determines the point at which the electrons from plate SE<sub>4</sub> fall on plate SE<sub>5</sub> and cause a variable portion of these to fall on the active part 51 of plate SE<sub>5</sub>. Thus, the quantity of secondaries emitted from plate SE<sub>5</sub> from instant to instant is varied under control of the modulating waves, and a modulated high frequency wave is produced which is amplified in the portion of the multiplier to the right of plate SE<sub>5</sub>. The modulated output is supplied to antenna 53 or other output circuit.

It will be understood that the modulating waves can be applied between any two adjacent emitter plates along the series. It will also be understood from the drawings and from the foregoing description that the voltages between the emitter plates to the left and to the right of the modulating plates remain relatively fixed.

If desired, the low frequency waves can be applied to the grid and the high frequency waves to be modulated can be introduced between a pair of emitter plates, this representing the converse relationship of that shown in Fig. 7.

A modified type of controlling means is shown in Fig. 8 in which the high frequency or low frequency control or modulating wave is impressed on one emitter SE<sub>3</sub> and plate P<sub>3</sub>. (The successive electron streams are differently hatched in the drawings to distinguish them apart.) Emitter SE<sub>3</sub> may be constructed as in Fig. 7. Emitter SE<sub>2</sub> is non-emissive except for a small central strip which may be pictured as extending across the tube in the direction perpendicular to the plane of the paper. The secondaries emitted from this active strip are under normal conditions directed so that half of them fall on the active part of emitter SE<sub>3</sub>, the other half

striking the non-emissive portion. The modulating or controlling waves are applied by means of transformer 54 between a point on potentiometer 16 and the emitter SE<sub>3</sub> and its plate P<sub>3</sub> so that the voltage of these members is varied by these waves. In this method only a portion of the electrons incident upon plate SE<sub>2</sub> are used to drive out secondaries from plate SE<sub>2</sub>, on account of the use of only a central strip of plate SE<sub>2</sub> as the emitting surface. A fairly sharply defined and relatively narrow electron beam is obtained between plates SE<sub>2</sub> and SE<sub>3</sub>. The modulating waves applied to plate SE<sub>3</sub> cause a greater or less portion of this electron beam to impinge on the active portion of plate SE<sub>3</sub>. A modulated electron beam appears therefore from plate SE<sub>3</sub> onward throughout the rest of the multiplier lying to the right in this figure.

This method of modulation is adapted for use where the modulating wave is either of low or high frequency. Examples of use with a high frequency modulating wave would be the case where the source at 54 is a beating oscillator for heterodyning or for modulating, detecting or amplifying purposes.

Instead of rendering parts of a secondary plate non-emissive by coating it with carbon or other suitable substance, the part to be rendered non-emissive can be covered with a screen consisting preferably of wires running parallel to the direction of general electron motion (parallel to the paper in Fig. 8). Such construction is illustrated in Fig. 8A which is a plan view of plate SE<sub>2</sub> of Fig. 8 with the alternative construction just described. The screens are shown at 55 and 56. The portions of the plate covered by the screens need not be depressed as much as in Fig. 8. The potential on the screens 55 and 56 may be the same as that of the emitter plate SE<sub>2</sub> which they shield.

An alternative modulating method is illustrated in Fig. 9 in which a pair of metal electrodes 57 and 58 extend across the path of the electron beam and have impressed between them the modulating potential, from input 54.

These variations in potential applied to electrodes 57 and 58 shift the electron beam back and forth so that a variable part of it strikes the active portion of emitter plate SE<sub>3</sub> producing a modulated beam of secondaries to be emitted from SE<sub>3</sub>. The modulating wave may have low or high frequency.

In each of the Figs. 7 to 9, for ease in illustration the electron current has been represented as substantially continuous, but it will be understood that it could consist of more or less separated groups of electrons as described in connection with Figs. 2 and 3 by giving the grid a sufficiently high negative bias.

Uniform spacing of the emitter plates is indicated in the various figures. This is not a necessary condition, however. The path taken by the electrons from one plate to the next is determined by the voltage difference between adjacent plates and by the magnetic field. It is generally more convenient to make the magnetic field substantially constant and uniform throughout the tube. When this is the case, the spacing between any two emitter plates and the voltage difference between them must correspond with each other so as to make the electrons strike the emitter plates in the most effective manner. In general where large output power is desired, a high voltage must be used on the output anode, in which case the path taken by the electrons from the last

emitter plate to the anode may be of different shape from that taken between two emitter plates. The screen grid prevents the relatively high voltage on the anode from affecting the electron travel between the secondary emitter plates.

The claims are not to be construed as limited to the details of construction that have been disclosed herein as illustrative examples, since many modification and alternative constructions will follow readily from the types that have been disclosed.

What is claimed is:

1. In combination, an electron multiplier comprising an evacuated enclosure containing a succession of secondary electron emitters, means to supply successively higher potentials to said emitters, means to release electrons from the first emitter of the succession for impinging on the next emitter, and so on, an output electrode leading to a utilization circuit and means to control the electron current transmitted through the multiplier comprising a circuit for impressing a variable control voltage between two adjacent emitters in the succession.

2. In combination, an electron multiplier comprising an evacuated enclosure containing a succession of secondary electron emitters, means to supply successively higher potentials to said emitters, means to release electrons from the first emitter of the succession for impinging on the next emitter, and so on, an output electrode leading to a utilization circuit and means to control the electron current transmitted through the multiplier comprising a circuit for impressing a variable control voltage on one of said emitters, the surface of the emitter on which the control voltage is impressed comprising an emissive portion and a non-emissive portion on the side upon which the incident electrons impinge.

3. In an electron discharge device, a member having a surface a portion of which is emissive of secondary electrons and a portion of which is non-emissive, means including a preliminary emitter of secondary electrons for producing a stream of secondary electrons, means to direct said stream of secondary electrons against said surface to cause emission of secondary electrons from the emissive portion, and means adjacent the path of said stream and controlled by a variable voltage for deflecting the stream so that a variable portion of it is caused to strike the emissive portion of said surface.

4. A combination according to claim 3 including means to vary the intensity of said stream of secondary electrons in accordance with an applied wave.

5. In electron discharge apparatus, a plurality of secondary emitter plates, means to cause electrons to impinge on said plates in succession and to emit secondary electrons from each plate, the surface of each of a plurality of said plates having only a restricted area that is emissive of secondary electrons, means directing the electron beam from the first of said last-mentioned plates to fall partly on and partly off the emissive area of another of said last-mentioned plates, and means to vary the portion of said beam falling on the emissive area of said other plate.

6. In an electron multiplying device, a secondary electron emitter, means to direct primary electrons against said emitter to cause secondary electron emission current therefrom, a member having a surface a portion of which is a good emitter of secondary electrons and a portion of

which is substantially non-emitting, means to direct the said secondary emission current against said surface to produce secondary emission from the emissive portion thereof, and means to deflect  
5 variably the secondary emission current incident upon said surface so that a variable portion of it strikes the emitting portion of said surface.

7. An electron multiplying device according to claim 6 in which means are provided to control  
10 the intensity of the primary electron stream in accordance with an impressed wave to, in turn, vary the strength of the secondary emission current given off from said secondary electron emitter and incident upon said surface, and in  
15 which said means to deflect variably the sec-

ondary emission current is under control of another wave.

8. Electron discharge device according to claim 3 in which said means adjacent said path comprises electrodes between which the electron beam  
5 passes, and a circuit for impressing a variable potential thereon.

9. A combination according to claim 1 in which the last means comprises a circuit carrying low frequency modulating currents and in which a  
10 high frequency source is used in combination with means for varying the intensity of the electron current thereby.

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