Feb. 23, 1937. P. T. FARNSWORTH 2,071,515

ELECTRON MULTIPLYING DEVICE

Filed Oct. 7, 1933 3 Sheets-Sheet 1

Fig. 1.

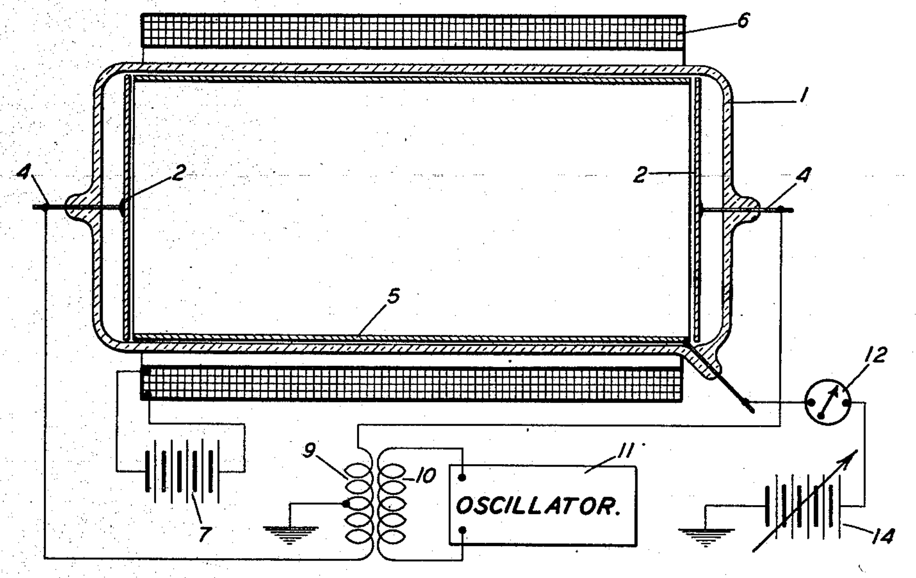

Fig. 2.

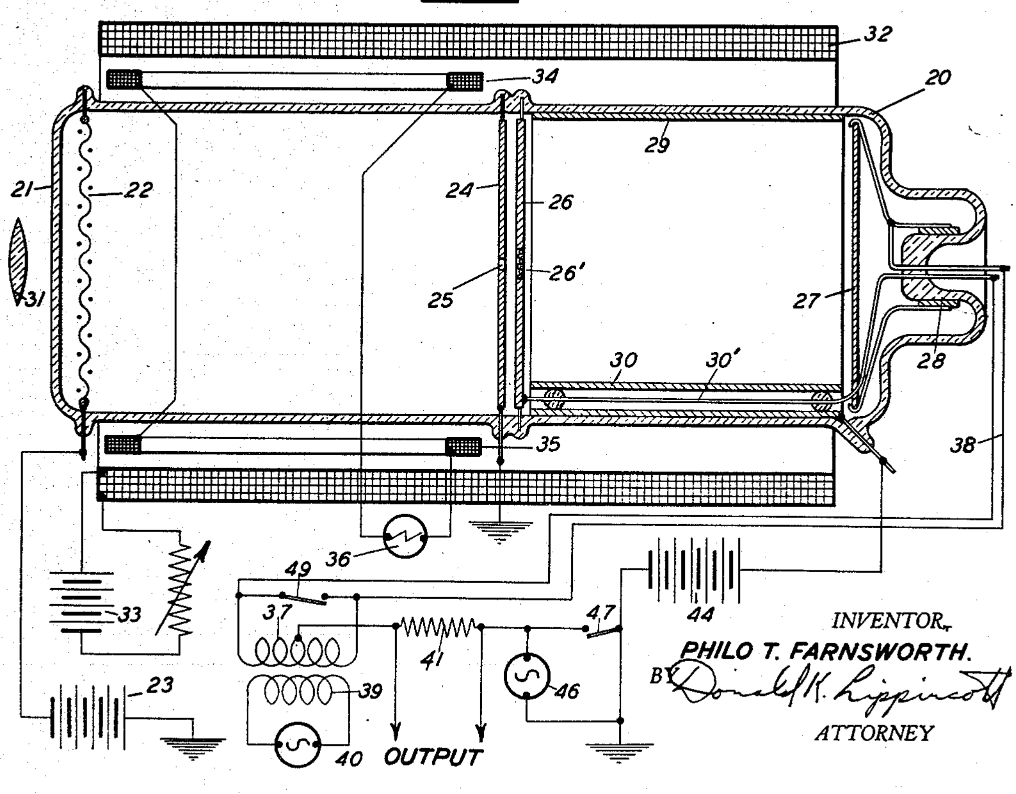

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Fig. 3.

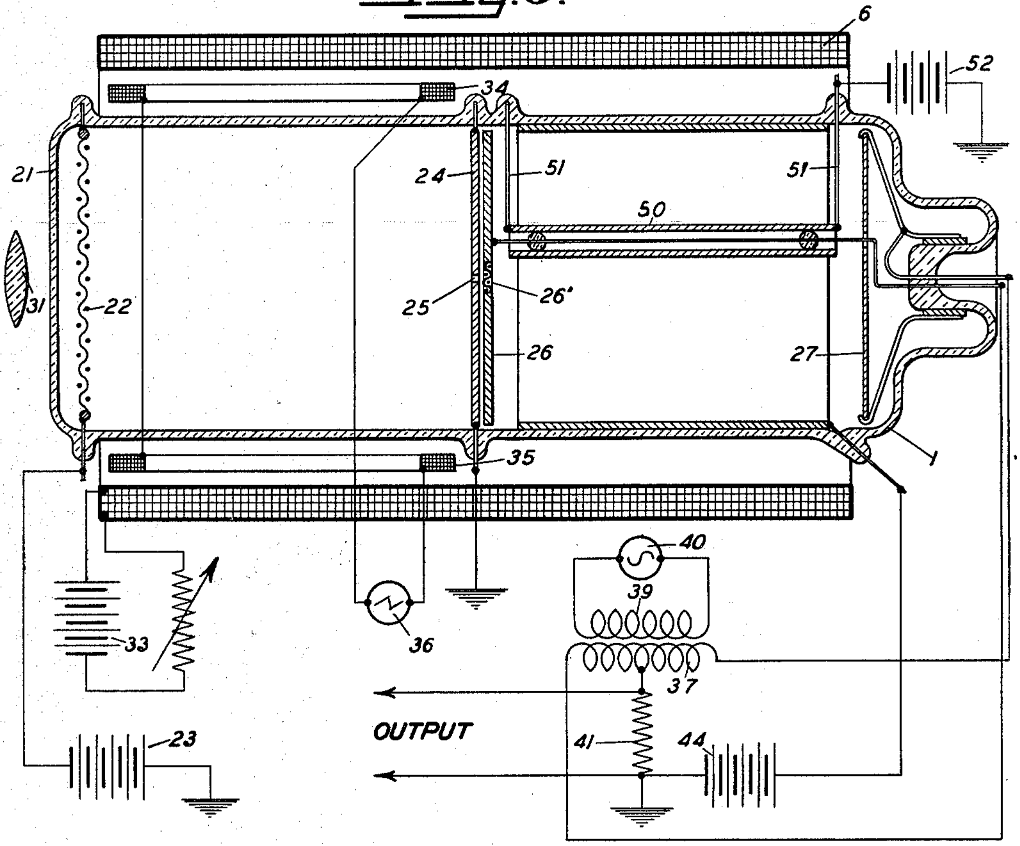

Fig. 4.

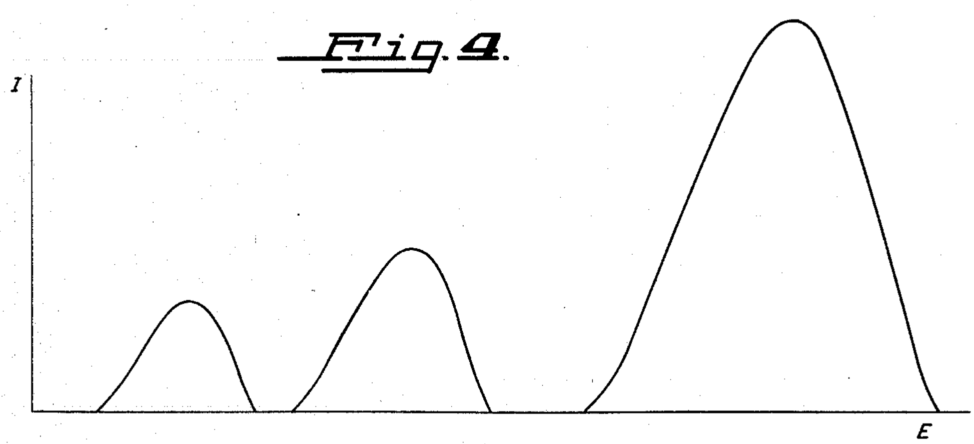

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Fig. 5.

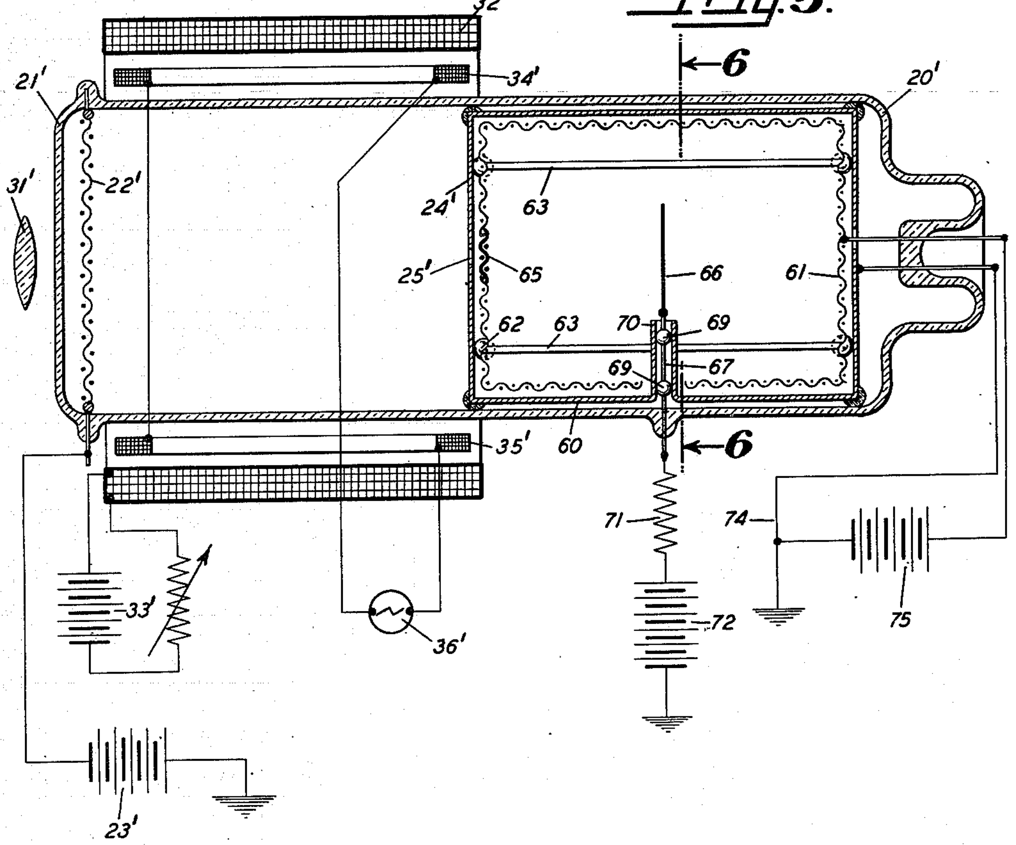
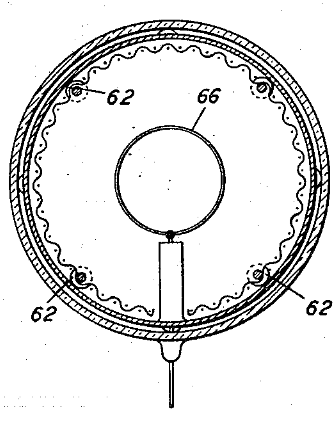


Fig. 6.



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Patented Feb. 23, 1937

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UNITED STATES PATENT OFFICE

2,071,515

ELECTRON MULTIPLYING DEVICE

Philo T. Farnsworth, San Francisco, Calif., assignor to Farnsworth Television Incorporated, a corporation of California

Application October 7, 1933, Serial No. 692,585

60 Claims. (Cl. 178—6)

This invention relates to electron multipliers, i. e., to means for causing small space currents to liberate large numbers of additional electrons to permit relatively large proportional space current to flow, and particularly it relates to means for increasing the sensitivity of television image dissectors by multiplication of the photo-electric picture currents therein.

Among the objects of my invention are: To provide means for causing a small number of electrons to "trigger off" a relatively large proportional electron flow; to provide a television image dissector of greatly increased sensitivity; to provide a space discharge device of novel type having characteristics adapting it for use as a multiplier of electronic currents, an amplifier, an oscillation generator, or a modulator; to provide a device of the class described operative without the use of a thermionic cathode; to provide an electron multiplier which may be used at will either as an ionization device or as a device operative by secondary emission of electrons from solids; and to provide an ionization device of stable characteristics, wherein the ionization produced may be strictly limited, to maintain proportionality with the initiating electron flow.

Other objects of this invention will be apparent or will be specifically pointed out in the description forming a part of this specification, but I do not limit myself to the embodiment of the invention herein described, as various forms may be adopted within the scope of the claims.

Referring to the drawings:

Figure 1 is a longitudinal sectional view of one embodiment of the basic electron multiplier, the operating circuits being shown schematically.

Figure 2 is an axial sectional view of a television image dissector embodying the invention, a schematic diagram showing the circuit arrangements for operation in accordance with two different, but related, modes.

Figure 3 is a view, similar to Figure 2, showing a modified form of image dissector-multiplier apparatus.

Figure 4 is a graph showing a characteristic curve of a multiplier as shown in Figure 1.

Figure 5 is an axial sectional view of another modification of the image dissector-multiplier shown in Figure 2.

Figure 6 is a transverse sectional view of the multiplier tube shown in Figure 5, the plane of section being indicated by the dot-dash line 6—6 in the preceding figure.

Considered broadly the apparatus of my invention comprises a chamber so evacuated that the mean free path of electrons therewithin is at least several times the dimension of the chamber, so that no appreciable ionization can be produced by electrons making a single traversal thereof. The ends of the chamber are defined by a pair of opposed plates, which may be termed cathodes, since their mean potential is negative, and since they are used under certain conditions of operation for the emission of electrons. Positioned between the cathodes is an anode, which is maintained at a potential positive to the mean potential of the cathodes and which is so shaped, positioned or both that it is improbable that an electron traversing a path between the cathodes will be collected thereby. "Improbable" is here to be understood in its mathematical sense, with the corollary that an electron making a sufficient number of traversals will certainly be thus collected. The improbability of collection may be increased by establishing within the chamber a guiding field which tends to hold electrons in a path which avoids the anode. Where the device is used to multiply a photo-electric current an aperture is provided in one of the cathode plates, and a photo-electric cathode is positioned, externally of the chamber, to direct its discharge through the aperture.

Operation of the device is based upon electrons within the chamber oscillating back and forth between the plates and releasing additional electrons in the chamber by repeated impacts. There are two somewhat different methods by which this may be accomplished, these methods differing somewhat in their circuital requirements.

In the first of these methods, to which this application is specifically directed, the impacts are with the cathode plates, and the multiplication occurs by secondary electron emission therefrom. A high frequency potential, which may be of the order of 50 megacycles, is applied between the cathode plates, this potential being preferably relatively small as compared with the direct potential on the anode Under the influence of this potential, electrons strike one or the other of the cathodes, liberating secondary electrons, which are accelerated toward the opposite cathode by the anode potential. If the potential of the latter be so related to the frequency applied to the cathodes that the released electrons traverse the space in time to be accelerated by the oscillating potential on the opposite cathode, a further impact and release of secondaries will occur, and if the ratio of secondary emission be greater than 1, a multiplication will take place which will increase until the number of electrons released at each impact is equal to the number collected by the anode, or until the process is stopped by changing the anode potential or otherwise.

Two other factors serve to limit the available multiplication. The first of these is the space charge which develops when the number of released electrons becomes very large. This charge tends to drive the peripheral electrons, i. e., the electrons more remote from the center of the cloud traversing the tube, toward the anode, making their collection thereby more probable. The second factor is the transverse component of the electrostatic field within the chamber. Such a component exists due to the curvature of the lines of force at the ends of a tubular anode, or it may be supplied separately by a biasing electrode within the tube.

The second method of operation comprises establishing a constant negative potential on both cathodes. Electrons entering the chamber liberate secondaries as in the preceding case, but these secondaries, although accelerated by the anode, probably fail to strike it, and are then retarded and brought to rest before reaching the other cathode, after which they are accelerated in the opposite direction. This continues until, probably after several traversals of the chamber, the liberated electrons, or some of them, encounter and ionize gas molecules. The positive ion thus released is collected by one of the cathodes, but the liberated electrons join the ionizing electrons in oscillating about the anode but with a narrower orbit, since the probability of the collision occurring at the end of the electron's travel is small.

Successive impacts with gas molecules occur therefore, closer and closer to the anode, until at length all primary and secondary electrons are traveling too slowly to cause further ionization, and are collected.

Figure 1 shows the essential features of the electron multiplier proper, comprising a cylindrical evacuated envelope 1 having a plate-like cathode 2 mounted in each end thereof and provided with lead wires 4 sealed through the ends of the envelope. The plates 2 may be made of nickel and are preferably, although not necessarily, coated with caesium, or other powerful emitter of secondary electrons, on their opposed faces.

A cylindrical anode 5, of nickel, molybdenum, or other readily out-gassed material, either sheet or screen, is positioned between the plates 2. The anode preferably fits quite snugly into the envelope, and is spaced but slightly from the plates, although the device is still operative if the spacing be made much greater and the anode be reduced to a mere central ring.

A solenoid 6 surrounds the envelope and is supplied with direct current from a source 7 for establishing a longitudinal magnetic field in the space between the cathode plates. For low values of this field the output of the device is substantially proportional thereto, although saturation effects appear at higher values as will be explained below.

The plates 2 are connected to the ends of an inductor 9, the center of which is grounded and which forms the secondary of a high frequency transformer, whose primary 10 is excited by an oscillator 11. The anode is connected through a meter 12 to the positive terminal of a variable potential source 14, whose negative terminal is grounded.

This structure is all that is necessary to demonstrate the characteristics of the device, from which its general properties and many of its uses may be deduced. Certain other embodiments adapting these properties to specific uses will be described hereinafter.

Applying say 50 volts at a frequency of 10 to 100 megacycles between the plates 2, and gradually increasing the potential applied to the anode from the source 14, the meter 17 will indicate currents as shown by the graph of Figure 4. Up to a certain minimum voltage, which depends principally on the distance between the plates, no measurable current will flow. Beyond this point the current increases with voltage up to a definite point, while beyond this point it decreases again to zero. Further increase of voltage gives another definite point where current starts to flow, giving a second curve of the same general form as the first, rising to a maximum and again falling to zero, while still further increase will show a second repetition of the effect usually of greater magnitude.

It will be understood that the curves shown are illustrative merely, no numerical values being shown, since these will vary with the magnitudes of the oscillating potential on the cathodes, the frequency of this potential, the focusing current, and the dimensions of the device.

Cutting off the magnetic focusing field stops the flow immediately. Increasing the oscillating potential on the cathodes broadens the range wherein the current flow occurs, eventually causing the curves to merge into a single continuous one having either multiple peaks or mere changes of slope indicating their position. Changing the frequency of the oscillator changes the position of the peaks; i. e., the voltages at which the maxima occur. The same is true as to tubes of different dimensions.

The explanation of these properties is simple in general, although the detailed analysis presents certain obscurities which render its presentation here undesirable. An electron (e. g., a photo electron) liberated at one of the plates 2 is accelerated toward the other plate by the anode voltage, being prevented from striking the anode by the magnetic field which converts the transverse component of its motion into an arcuate one. Its time of flight is determined by the distance between the plates and the velocity imparted to it by the anode potential plus the integrated effect of the potential between the plates 2 during its flight. The latter factor determines whether (1) it will strike the other plate with sufficient velocity to cause emission of secondary electrons, (2) strike with a lesser velocity, or (3) fail to strike at all.

Where the first condition obtains the emitted secondaries are accelerated in the opposite direction to generate new secondaries at the plate where the first electron was emitted, and if the ratio of secondary emission be greater than unity, a multiplication by this ratio will occur at each impact. Under the second and third conditions no multiplication will occur.

It will be noted that the anode potential contributes only to the mean velocity of the electrons through the tube, and has no effect whatever on the velocity of impact, since the acceleration it imparts to an electron leaving one of the cathodes is exactly neutralized by the deceleration imparted to the same electron approaching the other cathode.

Although the collection of any individual electron by the anode is improbable, owing to the shape and position of the latter and to the presence of the guiding field, a certain proportion of the total electrons will be collected. This proportion will depend upon the portion of the cathodes which are emitting secondaries, (i. e., upon whether the electrons are striking near the center or near the periphery), and upon the transverse component of the electrostatic field within the chamber as determined by the space charge, the curvature of the lines of force between cathodes and anode, and upon any bias which may be applied within the tube.

Eventually, however, a point will be reached where the number of new secondaries emitted is equal to the number collected at each impact, and the current through the meter becomes constant. Within certain limits, therefore, the less the probability of any individual electron being collected, the greater the equilibrium current will be, and hence this current will be increased by increasing the guiding field. A limit to this, however, is the space charge developed when the number of electrons in the cloud which travels between the plates becomes very dense, causing the saturation effect above mentioned.

The peaks in the curve occur when the average time of flight or travel of the electrons is an odd number of half-cycles of the oscillating potential on the cathode, the three peaks shown in Figure 4 representing 5, 3 and 1 half-cycles respectively. With a given tube and source of oscillations and range of anode voltage it may only be possible to show one or two of the peaks. Under other circumstances still other peaks might be shown, e. g., the 7 or 9 half-cycle peaks, although these have not yet been demonstrated in the laboratory. The higher the anode potential, the smaller is the time of flight, and hence the peak of output current corresponding to the highest voltage represents a time of flight of 1 half-cycle. This peak is usually materially higher than the others under otherwise similar conditions of operation.

The presence of gas in the tube, if it be so limited that the length of the mean free path is materially greater than the distance between the plates, may be advantageous in that slight stable ionization causes partial neutralization of the space charge, and to this degree it is preferred to have gas present. It is to be emphasized, however, that the phenomenon described is not one of gas ionization, and that successful operation was first obtained with a vacuum so high that no fluorescence could be shown on the walls of the tube, while an ionization gage showed practically zero indication.

Where electrons strike the cathodes without emitting secondaries (condition 2 above), they will subtract from the anode current; where they meet condition 3 they are ineffective except as they increase the density of the electron cloud or plasma and hence the probable number of electrons collected per half-cycle.

From the above the reasons for the performance of the device will be clear. The total output current or equilibrium current varies with the proportionate number of electrons falling under conditions 1, 2 and 3, and this in turn varies with the potentials applied.

The uses of the device may readily be deduced from the characteristic curve, which shows alternate regions of positive and negative resistance. These regions obviously permit the modulation of the output by variation of anode potential. Operation in the negative resistance regions permits use as a generator of oscillations of any frequency, as in the case of any of the well known negative resistance devices. Rectification and frequency doubling both occur in the anode branch of the circuit, and may be put to their usual uses. Self-excited oscillations may be developed if the inductor 9 be tuned to the exciting frequency and coupled to the output. These effects are described in detail and claimed in copending applications.

Current multiplication, which is the particular concern of the present application, may be obtained with this apparatus in at least three distinct ways, all being dependent upon limiting the average number of impacts resulting from a single initial electron so that the total output current remains materially below the equilibrium value.

The first of these modes of operation comprises interrupting the action periodically at such short intervals that the limiting conditions cannot supervene. As these intervals will include the same number of half-cycles, and hence the same number of multiplying impacts, it is clear that the mean output current within the interval will be proportional to the number of initiating electrons liberated in the interval.

The second mode of operation depends upon a "drift" of the electron cloud toward the anode, so that if the first impact occurs on the axis of the tube the succeeding impacts will occur successively nearer and nearer the anode, until the electrons are finally collected, the "descendents" of successive initiating electrons reaching the collection point in their proper order, having accomplished the same number of impacts.

The third mode of operation is effective only if there be enough gas to permit the condition of stable ionization described above, and in this mode the exciting oscillator 11 is not energized, the plates 2 being held at a fixed negative (or zero) potential. The guiding field should also preferably be somewhat stronger in this case.

The discharge may be initiated by photo-emission from one of the cathode plates 2. The electrons are accelerated by the anode potential, but are repelled as they approach the opposite plate, coming to rest and returning along their path just before striking it. They thus oscillate about the center of the tube until they have traversed a distance equal, on the average, to the mean free path corresponding to the gas pressure, then striking gas molecules and ionizing them.

The collisions will probably not occur at the end of the tube, and the electrons released thereby will therefore oscillate through a smaller path than the initial electron, as will the initial electron itself. The resulting positive ion will be collected by one of the cathodes.

Successive collisions will therefore take place, each occurring nearer the center of the tube than the last, until finally the oscillations about the central plane become of too small energy to cause further ionization, and all of the resulting ions and electrons are collected.

Statistically, both the time required for this process and the number of ionizing impacts resulting from an initial electron will be constant, and a multiplication will result which although not as great as that obtainable by the first mode of operation, can quite readily be brought to a factor of 2000 without loss of stability.

In Figure 2 the multiplier is shown embodied in a television image dissector. The evacuated envelope 20 is provided at one end with a plane window 21, immediately behind which is placed a cathode 22 of fine wire gauze (mesh say 200 per inch). This is coated with photo-electrically sensitive material, such as caesium on silver oxide.

Spaced from the cathode 22 is an anode 24, having a scanning aperture 25 therein. Cathode and anode are connected through a high potential source 23, and the anode 24 is preferably grounded.

The electron multiplier lies within the chamber behind the anode. One of the cathode plates, 26, is spaced but slightly from the anode 24 and is itself provided with an aperture, lying immediately behind the aperture 25, and covered with a fine mesh screen 26', this screen being adapted to the secondary emission of electrons. The other cathode plate, 27, is supported by the reentrant stem 28 at the end of the tube opposite the window 21. The cylindrical anode 29 fits snugly within the walls of the tube 20, and surrounds the space between the cathodes.

A tubular conduit 30, preferably integral with or connected to the anode 29, carries the lead 31 which connects to the plate 26, and is brought out through the stem 28, as is the lead from the cathode 27.

Externally of the tube there is mounted a lens 31 for focusing the image to be transmitted upon the cathode 22. A solenoid 32 surrounds the entire tube, and is supplied with direct current from a battery or equivalent source 33. It exercises the dual function of providing a guiding field for the electron-multiplier portion of the device and for focusing the electrical image formed by the emission from the photo-electric cathode, in the plane of the anode 24. A pair of deflecting coils 34, 35, placed on opposite sides of the tube, carry alternating current, preferably of saw-tooth waveform, delivered by a generator 36. These coils serve to deflect the electrical image across the aperture 25. In practice a similar set of coils, displaced 90° about the axis of the tube, and supplied by a generator of different frequency, deflects the image across the aperture in a plane perpendicular to that of the deflection caused by the coils shown. This second set of coils is omitted because it has been shown in numerous previous applications, the method of scansion is well known and well understood, and because the addition of the second set of coils would merely serve to confuse the drawings.

An inductor 37 is connected, through line 38, to the cathode plates 26 and 27. Coil 37 forms the secondary of a transformer whose primary 39 is supplied with current at a frequency of the order of 50 megacycles by the oscillator 40.

The center of the coil 36 is tapped and connected through an output resistor 41, the negative end of a potential source 44. The positive end of this source connects with the anode 29. A generator 46 of alternating current, at a frequency of the order of 1 megacycle, is included in series in this circuit. A switch 47 may be used to short around this generator when not in operation, and a second switch 49 similarly shorts out the inductor 36.

The arrangement may be operated in a number of different ways. Regardless of the mode of operation the image to be transmitted is focused upon the cathode 22, liberating the electrical image which is scanned by deflecting it across the aperture 25, the electrons from successive elementary areas of the image entering the aperture and liberating secondary electrons from the screen 26'.

At this point the differences in mode of operation occur. With the switches 47 and 49, open, as shown, and the oscillation-generators 40 and 46 excited, the electrons entering the aperture are oscillated back and forth within the chamber releasing secondaries at each impact with the end-plates 26 and 27, as in the case of the simple multiplier.

Owing to the fact that the potential on the anode 30 is varied at high frequency, oscillating between a value giving no amplification and one giving very large electron multiplication, each group of electrons, that is, the electrons entering the aperture at any one cycle of the oscillator 46, execute a definite number of impacts and undergoes a definite, and proportionate, multiplication. These electrons are collected by the anode 30, flow through the output resistor 41, and produce across this resistor a potential which is effective across the leads marked "output" and which may be applied to an amplifier of any satisfactory type.

Under this particular set of conditions the output current is prevented from building up to the maximum equilibrium condition of the tube, and the resultant output current is proportional to the electron flow entering the aperture 25, as it would not be were the device permitted to reach equilibrium without being stopped by the change in voltage due to the generator 46.

With a somewhat less powerful focusing field, and with the switch 47 closed, and the generator 46 not operating, a set of conditions may be obtained where the radial component of the field between the plates 24 and 27 and the anode 30 will, of itself, be sufficient to cause a drift of electrons toward the anode, so that each successive impact of any particular group of electrons occurs closer to the outer periphery of the tube. This results in the multiplied electron flow from successive elementary areas of the cathode 22 being picked up in order by the anode 30, so that again the output of the device is prevented from reaching the equilibrium condition.

In the third method of operation the switch 49 is also closed and the oscillator 43 is left inactive. Under this condition of operation the multiplication or ionization as described in connection with the third mode of operation of the tube of Figure 1, becomes effective. The multiplication achieved in this manner is not as great as that which may be obtained with the other methods of operation, but it may still be several thousandfold.

The tube illustrated in Figure 3 is similar to that in Figure 2 with the exception that the conduit shield 50, carrying the lead to the plate 26, is mounted from the sides of the envelope on support wires 51, and a negative bias is applied thereto by a battery 52, whose positive end is grounded. Since the other elements of the drawings all have their counterparts in Figure 2, they are designated by similar reference characters.

The electrode 50 is used to set up a transverse component within the space 26, which serves to accelerate the transverse drift of the electron groups, causing them to be collected by the anode 30 after a limited number of collisions, and thus obviating the necessity for using the oscillator 46 to limit the amount of multiplication. Because the value of the transverse component may, in this instance, be varied independently of the anode potential, the device is less critical in adjustment than where the mere radial component of the cathode-anode field is relied upon to cause the drift toward the anode.

In the form of the device illustrated in Figures 5 and 6, the lens, photo-electric cathode, focusing and deflecting coils, and their circuits, are substantially similar to those illustrated in Figures 2 and 3 and are accordingly designated by similar reference characters distinguished by accents. The anode 24', however, forms a portion of a hollow metal container 60, within which is the multiplying chamber. This chamber is provided with a lining of metal gauze 61, formed with a relatively open mesh of extremely fine wire. Glass or other insulating beads 62, mounted on frame wires 63 to which the lining is secured, serve to hold the lining spaced and insulated from the interior of the container 60.

A small portion 65 of the liner, immediately behind the aperture 25' is formed of heavier mesh gauze, which may be coated with caesium so as to emit secondary electrons more readily.

A filamentary anode 66, preferably of annular form, is mounted approximately in the center of the container, being mounted on a wire support 67 which is insulated by beads 69 from an inwardly extending side tube 70 which projects into the amplifying chamber. The anode 66 connects through an output resistor 71 to the positive end of a battery or other potential source 72, and thence to ground. The body of the container also connects to ground through the lead 74, while the liner 61 is maintained a few volts positive by means of the battery 75.

In the operation of this form of the device, the electrical image is scanned over the aperture as described in connection with the other modifications of the device. Those electrons entering the aperture strike the heavy gauze portion 65 of the screen liner, emitting secondary electrons therefrom. These electrons are attracted toward the collector anode 66, but by reason of its small size and its position the probabilities are against these electrons being collected. After passing the collector anode 66 they are decelerated, and reversed in direction by the field through which they are falling, in general missing the liner and thus making repeated oscillations back and forth through the container past the collecting electrode. After a number of oscillations, depending upon the degree of vacuum within the container, the electrons encounter gas molecules and ionize them in the same manner as was described in the third method of operation of the device shown in Figure 2.

Positive ions liberated by these impacts are attracted to the side walls of the container, in general missing the fine wire mesh of the liner and impinging upon the walls of the container itself. Any secondary electrons liberated by these impacts are, in all probability, picked up by the liner, since their low velocities render them more susceptible of deflection than the high speed electrons traveling in the main chamber. Experiment has shown that this picking up of secondary electrons liberated by the slowly moving positive ions may be accomplished with the liner either positive or negative to the container itself.

Electrons liberated by successive collision within the body of the chamber travel through successively smaller orbits and with lower velocities until they are finally collected by the anode 66. The current formed by these electrons causes the potential drop in the output resistor 71, this drop being amplified in the usual manner.

While each of the methods of operation of the multiplier herein set forth has its particular advantages and field of usefulness, my present preference is for the form of a device illustrated in Figure 2, as operated with the switch 47 closed and the oscillator 46 inactive. When the device is to be operated in this manner, the current through the focusing coil is increased to its maximum value, and the potentials from the oscillator 40 and the battery 44 are varied until a maximum equilibrium current is established. The focusing or guiding field is then weakened until current just ceases to flow in the absence of photo-electrons through the aperture 25. This gives maximum sensitivity without over-regeneration leading to equilibrium conditions. The focus of the electrical image from the cathode 22 may then be brought into the plane of the anode 24 by suitable adjustment of the potential of the battery 23.

Theoretically this method of multiplication should give somewhat lower sensitivity than that wherein the oscillator 46 is used to interrupt the multiplication at short intervals. In practice there appears to be little difference between the sensitivity of the two methods, since instability appears to supervene at about the same multiplying value with either method. Both methods lead to very large amplification; with either system of operation the current through the output resistor can readily be made of the same order of magnitude as the total emission from the photoelectric cathode 22, the area of the aperture 25 being approximately 10^{-5} times that of the cathode.

I claim:

1. A device for causing a relatively small number of primary electrons to establish relatively large space currents which comprises an evacuated envelope, a pair of electrodes spaced within said envelope, means for establishing an oscillating potential between said electrodes sufficient to cause secondary emission of electrons therefrom at a ratio greater than unity, a collecting electrode positioned between said first mentioned electrodes, and means for guiding electrons between said first mentioned electrodes in a path such that the probability of the average individual electron reaching said collecting electrode is small.

2. A device for causing a relatively small number of primary electrons to establish relatively large space currents which comprises an evacuated envelope, a pair of electrodes spaced within said envelope, means for establishing an oscillating potential between said electrodes sufficient to cause secondary emission of electrons therefrom at a ratio greater than unity, a collecting electrode positioned between said first mentioned electrodes, and means for establishing a longitudinal magnetic field between said first mentioned electrodes to guide electrons therebetween into a path such that the probability of the average individual electron reaching said collecting electrode is small.

3. A device for causing a relatively small number of primary electrons to establish relatively large space currents which comprises an evacuated envelope, a pair of electrodes spaced within said envelope, means for establishing an oscillating potential between said electrodes sufficient

to cause secondary emission of electrons therefrom at a ratio greater than unity, a collecting electrode positioned between said first mentioned electrodes, means for applying an accelerating potential to said collecting electrode to control the velocity of electrons between said first mentioned electrodes to a value giving a time of travel therebetween having a predetermined ratio to the half period of said oscillating potential, and means for guiding said electrons in a path such that the probability of the average individual electron reaching said collecting electrode is small.

4. An electron discharge device comprising a chamber dimensioned and evacuated so that an electron liberated therein will probably make a plurality of traversals thereof before colliding with a gas molecule, a pair of cathode plates positioned at opposite ends of said chamber, an anode positioned between said plates, and means for establishing fields within said chamber capable of affecting the motions of electrons therein along a line between said pair of cathode plates said means being so constructed that the probability of any individual electron being collected by either said anode or the side walls of the chamber is relatively small during traversal of the space between said cathodes and the probability of its releasing another electron by impact with one cathode or the other before being so collected is relatively large.

5. An electron discharge device comprising a chamber dimensioned and evacuated so that an electron liberated therein will probably make a plurality of traversals thereof before colliding with a gas molecule, a pair of cathode plates positioned at opposite ends of said chamber, an anode positioned between said plates, means for establishing fields within said chamber capable of affecting the motions of electrons therein along a line between said pair of cathode plates said means being so constructed that the probability of any individual electron being collected by either said anode or the side walls of the chamber is relatively small during traversal of the space between said cathode and the probability of its releasing another electron by impact with one cathode or the other before being so collected is relatively large, and means for introducing electrons into said chamber for multiplication.

6. An electron discharge device comprising a chamber dimensioned and evacuated so that an electron liberated therein will probably make a plurality of traversals thereof before colliding with a gas molecule, a pair of cathode plates positioned at opposite ends of said chamber, an anode positioned between said plates, means for establishing fields within said chamber capable of affecting the motions of electrons therein so that the probability of any individual electron being collected by either said anode or the side walls of the chamber is relatively small and the probability of its releasing another electron by impact before being so collected is relatively large, means for introducing electrons into said chamber for multiplication, and means for limiting the amount of multiplication produced by the primary electrons introduced.

7. An electron discharge device comprising a chamber dimensioned and evacuated so that an electron liberated therein will probably make a plurality of traversals thereof before colliding with a gas molecule, a pair of cathode plates positioned at opposite ends of said chamber, an anode positioned between said plates, means for establishing fields within said chamber capable of affecting the motions of electrons therein so that the probability of any individual electron being collected by either said anode or the side walls of the chamber is relatively small and the probability of its releasing another electron by impact before being so collected is relatively large, means for introducing electrons into said chamber for multiplication, and means for periodically interrupting the multiplying process.

8. A television image dissector comprising an envelope, a photo-electrically sensitive cathode within said envelope, a pair of plates within the envelope forming a chamber therein, one of said plates facing said cathode being provided with an aperture, means for directing electrons from said cathode through said aperture, an anode positioned between said plates, and means for applying potentials to said anode and plates to cause electrons within said chamber to oscillate between said plates, whereby electrons entering said aperture may cause, by impact, the liberation of relatively large numbers of additional electrons.

9. A television image dissector comprising an evacuated envelope, a photo-electrically sensitive cathode within said envelope, an auxiliary chamber within the envelope apertured to receive electrons from said cathode, means for directing electrons from a selected portion of said cathode through said aperture, and means for oscillating electrons within said chamber to cause additional electron flow by repeated impacts therein.

10. A television image dissector comprising an evacuated envelope, a photo-electrically sensitive cathode within said envelope, an auxiliary chamber within the envelope apertured to receive electrons from said cathode, means for directing electrons from a selected portion of said cathode through said aperture, and means for oscillating electrons along predetermined paths within said chamber to cause additional electron flow by repeated impacts therein.

11. A television image dissector comprising an evacuated envelope, a photo-electric cathode within the envelope, a plate having a scanning aperture therein positioned to receive electrons from said cathode and dividing said envelope to form a separate chamber therebehind, a second plate opposing said apertured plate within said chamber, an anode between said plates, means for establishing a magnetic field longitudinally of the space between said plates, means for establishing an oscillating potential between said plates, and means for establishing a potential on said anode positive to the mean potential on said plates.

12. A television image dissector comprising an evacuated envelope, a photo-electric cathode within the envelope, a plate having a scanning aperture therein positioned to receive electrons from said cathode and dividing said envelope to form a separate chamber therebehind, a second plate opposing said apertured plate within said chamber, an anode surrounding the space between said plates, means for establishing a magnetic field longitudinally of the space between said plates, means for establishing an oscillating potential between said plates, and means for establishing a potential on said anode positive to the mean potential on said plates.

13. A television image dissector comprising an evacuated envelope, a photo-electric cathode within the envelope, a plate having a scanning aperture therein positioned to receive electrons

from said cathode and dividing said envelope to form a separate chamber therebehind, a second plate opposing said apertured plate within said chamber, an anode between said plates, means for establishing a magnetic field longitudinally of the space between said plates, means for establishing an oscillating potential between said plates, and means for periodically establishing on said anode a potential positive to the mean potential of said plates, the period of said potential being sufficiently long to include a plurality of cycles of said oscillating potential.

14. A device for causing a relatively small number of primary electrons to establish relatively large space currents which comprises an evacuated envelope, a pair of electrodes spaced within said envelope and having surfaces adapted readily to emit secondary electrons, means for establishing an oscillating potential between said electrodes sufficient to cause secondary emission of electrons therefrom at a ratio greater than unity, a collecting electrode positioned between said first mentioned electrodes, and means for guiding electrons between said first mentioned electrodes in a path such that the probability of the average individual electron reaching said collecting electrode is small.

15. An electron discharge tube comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, means for energizing said electrodes to cause an electron therebetween to make repeated and successive impacts therewith, and means for collecting the resultant electrons.

16. An electron discharge tube comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, means for energizing said electrodes to cause an electron therebetween to make repeated and successive impacts therewith, means for collecting the resultant electrons, and means for introducing electrons between said electrodes.

17. An electron discharge tube comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, means for energizing said electrodes to cause an electron therebetween to make repeated and successive impacts therewith, means for collecting the resultant electrons, and means for introducing a varying number of electrons between said electrodes.

18. An electron multiplying apparatus comprising an evacuated envelope, a cathode within said envelope having an extended active surface capable of emitting secondary electrons at a ratio greater than unity, an anode opposed to said cathode and presenting thereto an aspect whose area as projected on said active surface is relatively small, means for applying a substantially constant positive potential on said anode with respect to said cathode, means for guiding an electron cloud from the active surface of said cathode past said anode, means for reversing the direction of flight of the electron cloud passing said anode and returning said cloud toward said cathode, and means for imposing between said cathode and anode an oscillating potential of a frequency whose period is approximately equal to the time required by the electron cloud to leave said cathode and return thereto under the influence of said constant potential and reversing means, said oscillating potential being of such magnitude as to impart to said cloud during its time of flight a velocity sufficient to cause secondary emission of electrons from said active surface at greater than unity ratio.

19. An electron multiplying apparatus comprising an evacuated envelope, a cathode within said envelope having an extended active surface capable of emitting secondary electrons at a ratio greater than unity, an anode opposed to said cathode and presenting thereto an aspect whose area as projected on said active surface is relatively small, means for applying a substantially constant positive potential on said anode with respect to said cathode, means for guiding an electron cloud from the active surface of said cathode past said anode, means for reversing the direction of flight of the electron cloud passing said anode and returning said cloud toward said cathode, and means for imposing between said cathode and anode an oscillating potential of a frequency an integral multiple of whose period is approximately equal to the time required by the electron cloud to leave said cathode and return thereto under the influence of said constant potential and reversing means, said oscillating potential being of such magnitude as to impart to said cloud during its time of flight a velocity sufficient to cause secondary emission of electrons from said active surface at greater than unity ratio.

20. An electron multiplying apparatus comprising an evacuated envelope, a cathode within said envelope having an extended active surface capable of emitting secondary electrons at a ratio greater than unity, an annular anode opposed to said cathode and presenting to the active surface thereof a negligible projected area, means for applying a substantially constant positive potential on said anode with respect to said cathode, means for guiding an electron cloud from the active surface of said cathode past said anode, means for reversing the direction of flight of the electron cloud passing said anode and returning said cloud toward said cathode, and means for imposing between said cathode and anode an oscillating potential of a frequency an integral multiple whose period is approximately equal to the time required by the electron cloud to leave said cathode and return thereto under the influence of said constant potential and reversing means, said oscillating potential being of such magnitude as to impart to said cloud during its time of flight a velocity sufficient to cause secondary emission of electrons from said active surface at greater than unity ratio.

21. The method of obtaining relatively large space currents from a relatively small number of initial electrons which comprises the steps of subjecting said initial electrons to an oscillating electrostatic field, guiding said electrons within said field along substantially predetermined paths, controlling the velocity of said electrons along said paths to cause them to reach the ends thereof with a material velocity component derived from said oscillating field, causing said electrons to initiate an increased number of secondary electrons by impact at the end of said paths, and repeating said steps with said secondary electrons to cause a further increase in number.

22. The method of obtaining relatively large space currents from a relatively small number of initial electrons which comprises the steps of subjecting said initial electrons to an oscillating electrostatic field, guiding said electrons within said field along substantially predetermined paths, controlling the velocity of said electrons along said paths to cause them to reach the ends

thereof with a material velocity component derived from said oscillating field, causing said electrons to initiate an increased number of secondary electrons by impact at the end of said paths, repeating said steps with said secondary electrons to cause a further increase in number, progressively varying the paths followed by each successive generation of secondary electrons, and eventually collecting the electrons liberated at the final generation.

23. The method of obtaining relatively large space currents from a relatively small number of initial electrons which comprises the steps of subjecting said initial electrons to an oscillating electrostatic field, guiding said electrons within said field along substantially predetermined paths, controlling the velocity of said electrons along said paths to cause them to reach the ends thereof with a material velocity component derived from said oscillating field, causing said electrons to initiate an increased number of secondary electrons by impact at the end of said paths, repeating said steps with said secondary electrons to cause a further increase in number, progressively varying the paths followed by each successive generation of secondary electrons, and eventually collecting the electrons liberated at the final generation at a time when the electrons collected at each cycle of said oscillating field are the resultant of substantially the same average number of secondary electron generating impacts.

24. The method of obtaining relatively large space currents from a relatively small number of initial electrons which comprises the steps of establishing an oscillating field of predetermined frequency, subjecting said initial electrons to said field for acceleration thereby, applying additional accelerations to said electrons to cause them to traverse a predetermined path within approximately one-half cycle of said oscillating field, causing said initial electrons to initiate secondaries by impact at the end of said path, and repeating said steps with the secondaries thus liberated.

25. A device for causing a relatively small number of primary electrons to establish relatively large space currents which comprises an evacuated envelope, a pair of electrodes spaced within said envelope, an oscillator connected to energize said electrodes and capable of supplying potentials sufficient to cause secondary emission of electrons therefrom at a ratio greater than unity, a collecting electrode positioned between said first mentioned electrodes, and means for guiding electrons between said first mentioned electrodes in a path such that the probability of the average individual electron reaching said collecting electrode is small.

26. A device for causing a relatively small number of primary electrons to establish relatively large space currents which comprises an evacuated envelope, a pair of electrodes spaced within said envelope, an oscillator connected to energize said electrodes and capable of supplying potentials sufficient to cause secondary emission of electrons therefrom at a ratio greater than unity, a collecting electrode positioned between said first mentioned electrodes, and means for establishing a longitudinal magnetic field between said first mentioned electrodes to guide electrons therebetween into a path such that the probability of the average individual electron reaching said collecting electrode is small.

27. A device for causing a relatively small number of primary electrons to establish relatively large space currents which comprises an evacuated envelope, a pair of electrodes spaced within said envelope and having surfaces adapted readily to emit secondary electrons, an oscillator connected to energize said electrodes and capable of supplying potentials sufficient to cause secondary emission of electrons therefrom at a ratio greater than unity, a collecting electrode positioned between said first mentioned electrodes, and means for guiding electrons between said first mentioned electrodes in a path such that the probability of the average individual electron reaching said collecting electrode is small.

28. An electron multiplying apparatus comprising an evacuated envelope, a cathode within said envelope having an extended active surface capable of emitting secondary electrons at a ratio greater than unity, an anode opposed to said cathode and presenting thereto an aspect whose area as projected on said active surface is relatively small, means for applying a substantially constant positive potential on said anode with respect to said cathode, means for guiding an electron cloud from the active surface of said cathode past said anode, means for reversing the direction of flight of the electron cloud passing said anode and returning said cloud toward said cathode, and an external source of electrical oscillations connected to impose between said cathode and anode an oscillating potential of a frequency whose period is approximately equal to the time required by the electron cloud to leave said cathode and return thereto under the influence of said constant potential and reversing means, said oscillating potential being of such magnitude as to impart to said cloud during its time of flight a velocity sufficient to cause secondary emission of electrons from said active surface at greater than unity ratio.

29. An electron multiplier comprising an evacuated envelope, a pair of opposed cathodes therein having surfaces capable of emitting secondary electrons at a ratio to impacting primary electrons greater than unity, an anode interposed between said cathodes whose area as projected thereon is relatively small, a source of oscillating potentials connected between said cathodes capable of developing potentials sufficient to accelerate electrons therebetween to velocities causing emission of secondary electrons from said surfaces at greater than unity ratio, and a source of constant potential connected between said cathodes and said anode.

30. An electron multiplier comprising an evacuated envelope, cathode structure therein including a pair of opposed surfaces capable of emitting secondary electrons at a ratio to impacting primary electrons greater than unity, an anode interposed between said surfaces whose area as projected on said surfaces is relatively small, a source of potential connected to apply a positive potential to said anode, and a source of oscillating potentials connected to apply said potentials between said anode, said potentials between said anode and said cathode structure in such time and magnitude as will cause electrons traveling between said surfaces to impact said surfaces and release secondary electrons therefrom.

31. An electron multiplier comprising an evacuated envelope, a pair of opposed cathode plates having a coating of photo-electrically emissive material on the surfaces thereof within said envelope, an anode positioned between said cathode

plates whose area as projected on said plates is relatively small, a source of substantially constant potential connected between said cathode plates and said anode, and an external source of oscillating electrical potential whose quarter period is of the order of the time of flight of an electron moving between one of said cathodes and said anode under the influence of said constant potential connected to apply said oscillating potential between said cathode and anode.

32. An electron multiplier comprising an evacuated envelope, a pair of opposed cathode plates having a coating of photo-electrically emissive material on the surfaces thereof within said envelope, an anode positioned between said cathode plates whose area as projected on said plates is relatively small, a source of substantially constant potential connected between said cathode plates and said anode, and an external source of oscillating electrical potential, an odd integral number of whose quarter periods embraces a time approximately equal to the time of flight of an electron moving between one of said cathodes and said anode under the influence of said constant potential connected to apply said oscillating potential between said cathode and anode.

33. An electron multiplier comprising an evacuated envelope, a pair of opposed cathodes within said envelope, an anode between said cathodes whose area as projected thereon is relatively small, a circuit connecting said cathodes, an external source of oscillating potentials coupled to said circuit to impose said potentials between said cathodes, and a work circuit including a source of substantially constant potential connecting said anode and said first mentioned circuit.

34. An electron multiplier comprising an evacuated envelope, cathode structure within said envelope comprising opposed secondary-electron emissive surfaces, an anode positioned between said surfaces, whose area as projected thereon is relatively small, a circuit connecting said anode and said cathode structure including a source of substantially constant potential and an output impedance, an external source of oscillating potential, and means for applying said oscillating potential between said anode and cathode structure.

35. An electron multiplier comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, an oscillatory circuit connecting said electrodes, and means for supplying alternating current to said oscillatory circuit to cause electrons between said electrodes to make repeated and successive secondary electron generating impacts therewith.

36. An electron multiplier comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, an oscillatory circuit connecting said electrodes, means for supplying alternating current to said oscillatory circuit to cause electrons between said electrodes to make repeated and successive secondary electron generating impacts therewith, and means for introducing electrons between said electrodes.

37. An electron multiplier comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, an oscillatory circuit connecting said electrodes, means for supplying alternating current to said oscillatory circuit to cause electrons between said electrodes to make repeated and successive secondary electron generating impacts therewith, and means for collecting the resultant electrons.

38. An electron multiplier comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, an oscillatory circuit connecting said electrodes, means for supplying alternating current to said oscillatory circuit to cause electrons between said electrodes to make repeated and successive secondary electron generating impacts therewith, a collecting electrode positioned to collect the resultant electrons, and an electrical connection including a potential source between said oscillatory circuit and said collecting electrode.

39. An electron multiplier comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, an oscillatory circuit connecting said electrodes, an oscillator driving said oscillatory circuit, a collecting electrode, an electrical connection including a potential source between said oscillatory circuit and said collecting electrode, and means for adjusting the time of flight of electrons between said electrodes to substantially coincide with the period of said oscillator.

40. An electron multiplier comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, an oscillatory circuit connecting said electrodes, means for supplying alternating current to said oscillatory circuit to cause electrons between said electrodes to make repeated and successive secondary electron generating impacts therewith, an accelerating electrode positioned and energized to collect the resultant electrons, after a plurality of impacts, and an electrical connection between said accelerating electrode and a point intermediate the ends of said oscillatory circuit.

41. An electron multiplier comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, means for energizing said electrodes with an alternating potential to cause electrons therebetween to make repeated and successive impacts therewith, and means for controlling the time of electron flight between impacts.

42. An electron multiplier comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, means for energizing said electrodes with an alternating potential to cause electrons therebetween to make repeated and successive impacts therewith, an accelerating electrode positioned and energized to regulate the speed of electron travel between said electrodes, and means for varying the potential on said accelerating electrode to vary the time of electron flight between electrodes.

43. An electron multiplier comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, means for energizing said electrodes with an alternating potential to cause electrons therebetween to make repeated and successive impacts therewith, an accelerating electrode positioned and energized to regulate the speed of electron travel between said electrodes, and means for varying the potential on said accelerating electrode to produce a time of electron flight substantially equal to the period of said oscillating potential.

44. An electron multiplier comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, means for energizing said electrodes with an alternating potential to cause electrons therebetween to make repeated and successive impacts therewith, and means for regulating the time of flight substan-

tially equal to the period of said oscillating potential.

45. The method of amplifying an electron flow, which comprises creating a stream of electrons in the space between two opposed surfaces capable of emitting secondary electrons, accelerating said stream against one of said surfaces to create a new increased stream of secondary electrons in a different direction, accelerating the new stream against the opposing surface to form a still further increased stream again changed in direction, and repeating the cycle between said two opposing surfaces until the desired degree of amplification is obtained.

46. The method of increasing the number of electrons in an electron stream, which comprises intersecting said stream by a surface capable of emitting secondary electrons on impact, accelerating the electrons thus created toward a similar surface to again increase the stream by impact with said surface, and repeating the cycle between said two surfaces until the desired number of electrons is obtained.

47. The method of exciting electron emission from a cathode which comprises withdrawing from said cathode the electrons emitted thereby due to photoelectric emission and thermal emission at room temperature, reversing the direction of said electrons and accelerating them against said cathode with sufficient velocity to cause the emission of additional electrons by impact, and repeating said operation upon all of the emitted electrons to build up the emission in geometric ratio.

48. The method of generating an electronic space charge between a pair of electrodes which comprises introducing an electron between said electrodes and applying a high frequency alternating potential between said electrodes, said potential being adapted in magnitude and period to cause said electron to impact one of said electrodes with sufficient velocity to cause secondary emission therefrom, and to cause the emitted electron to impact the other electrode at a like velocity to cause further secondary emission.

49. The method of maintaining a substantially pure electronic discharge between a pair of electrodes which comprises introducing a cloud of electrons therebetween and cyclically varying the potential between said electrodes to cause electrons component of said cloud to impact one of said electrodes with sufficient velocity to cause secondary emission therefrom at a ratio greater than unity, and to withdraw the emitted electrons into said cloud.

50. The method of generating a substantially pure electron discharge between a cathode and an anode which comprises causing said cathode to emit a relatively small number of electrons, applying a potential to said anode to withdraw the emitted electrons from said cathode, guiding at least a portion of said electrons past said anode in consequence of which passage their direction of motion is reversed so that they again approach said cathode, and varying the relative potentials of said cathode and anode during the time of flight of said electrons to cause them to impact said cathode with a velocity greater than their initial velocity of emission to cause secondary emission at a ratio greater than unity.

51. The method of electron multiplication which comprises causing electron emission from a substantially equipotential surface, withdrawing the emitted electrons into the space bounded by said surface, and reaccelerating electrons from said space against said surface to cause secondary emission therefrom at a ratio greater than unity.

52. The method of electron multiplication which comprises causing electron emission from a substantially equipotential surface, withdrawing the emitted electrons into the space bounded by said surface, reaccelerating electrons from said space against said surface to cause secondary emission therefrom at a ratio greater than unity, again withdrawing the emitted electrons into said space, and causing a systematic drift of the electron flow transverse to said surface to cause successive descendent electrons from the same initial emission to impact different portions of the surface.

53. The method of electron multiplication which comprises causing electron emission from a substantially equipotential surface, withdrawing the emitted electrons into the space bounded by said surface, reaccelerating electrons from said space against said surface to cause secondary emission therefrom at a ratio greater than unity, and collecting electrons forced outwardly in said space by the space charge developed.

54. The method of electron multiplication which comprises causing electron emission from a substantially equipotential surface, withdrawing the emitted electrons into the space bounded by said surface, reaccelerating electrons from said space against said surface to cause secondary emission therefrom at a ratio greater than unity, and collecting electrons in excess of the number required to maintain steady state conditions.

55. The method of electron multiplication which comprises causing electron emission from a substantially equipotential surface, withdrawing the emitted electrons into the space bounded by said surface, reaccelerating electrons from said space against said surface to cause secondary emission therefrom at a ratio greater than unity, and creating a steady state condition by withdrawal of electrons from said space.

56. The method of electron multiplication which comprises causing electron emission from a substantially equipotential surface, withdrawing the emitted electrons into the space bounded by said surface, reaccelerating electrons from said space against said surface to cause secondary emission therefrom at a ratio greater than unity, and collecting electrons forced from said space by the space charge developed.

57. The method of amplifying an electronic flow by means of surfaces capable of emitting secondary electrons at a ratio to impacting primary electrons greater than unity which comprises the steps of causing an initial flow in a space bounded by such surfaces, subjecting the electrons component thereof to a field to cause them to impact with said surfaces, and establishing a separate guiding field which directs the initial electrons and the secondary electrons liberated thereby into different predetermined paths to cause successive impacts with said surfaces and to cause the descendents of substantially all of the initial electrons to accomplish substantially the same number of impacts.

58. The method of amplifying an electronic current by repeated impacts between a pair of opposed surfaces which comprises introducing said current at a predetermined position between said surfaces, applying to said current fields to cause the component electrons to impact said surfaces, and causing the descendent electrons liberated by such impacts to progress systematically across said surfaces from the position of

introduction to a position of collection while accomplishing a substantially uniform number of impacts.

59. The method of amplifying an electronic current by repeated impacts between a pair of opposed surfaces which comprises establishing an electrostatic field directed toward a position intermediate said surfaces so that an electron liberated from either surface will be immediately withdrawn therefrom and be carried by its own momentum nearly if not quite to the opposing surface, and establishing an additional electrostatic field of smaller magnitude in the space between said surfaces to impart an additional velocity to such electrons to cause them to strike the opposing surface with sufficient velocity to cause secondary emission therefrom, and introducing electrons at a position subject to the effect of both of said fields.

60. The method of amplifying an electronic current by repeated impacts between a pair of opposed surfaces which comprises establishing an electrostatic field directed toward a position intermediate said surfaces so that an electron liberated from either surface will be immediately withdrawn therefrom and be carried by its own momentum nearly if not quite to the opposing surface, introducing electrons for amplification into said field, and subjecting said electrons to additional accelerations to cause a regular oscillatory progression of the electric charge whereof such electrons are constituents between said surfaces with repeated impacts at each surface.

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