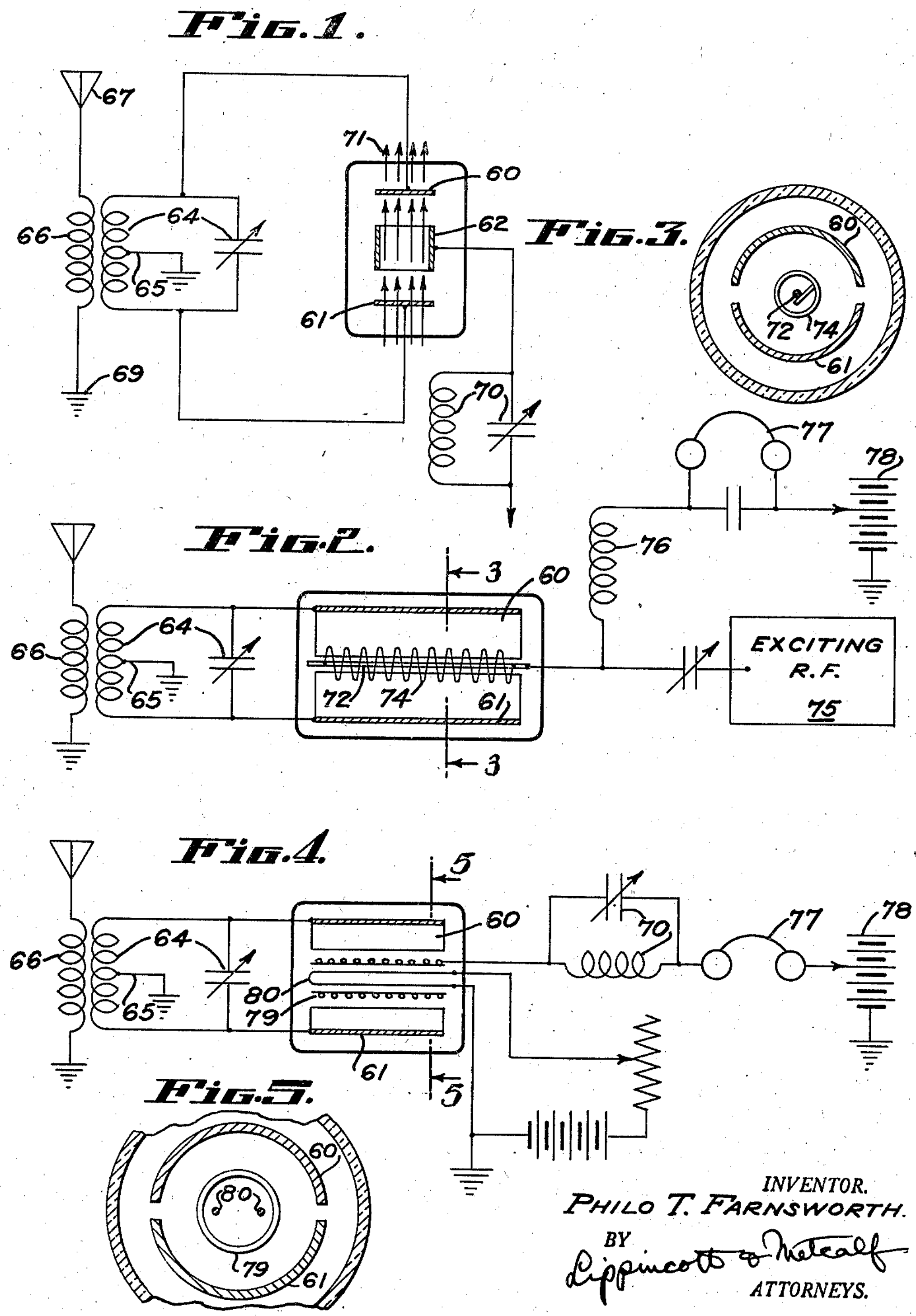
May 2, 1939. P. T. FARNSWORTH 2,156,807

DETECTOR

Original Filed March 12, 1935



INVENTOR.
PHILO T. FARNSWORTH.
BY
Lippincott & Metcalf
ATTORNEYS.

Patented May 2, 1939 2,156,807

UNITED STATES PATENT OFFICE

2,156,807

DETECTOR

Philo T. Farnsworth, Springfield Township, Montgomery County, Pa., assignor to Farnsworth Television & Radio Corporation, Dover, Del., a corporation of Delaware

Original application March 12, 1935, Serial No. 10,604. Divided and this application April 26, 1937, Serial No. 138,924

14 Claims. (Cl. 250—27.1)

This application is a division of my application entitled "Means and method for interrupting electron multiplication", Serial No. 10,604, filed March 12, 1935. The present application is a continuation-in-part of a prior application, Serial No. 692,585, filed October 7, 1933, since matured into U. S. Patent No. 2,071,515, issued February 23, 1937.

My invention relates to electron multipliers, namely, to a means and method 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 a means and method for detecting radio signals.

Among the objects of my invention are: to provide means for causing a small number of electrons to initiate a relatively large proportional electron flow; to provide a space charge device of novel type, energized in part by radio signals derived from energy collected from space; to provide a multiplier operating in part on energy derived from signals collected from space; to provide an electron multiplier and circuit therefor for use in radio receiving; and to provide a new and novel method of utilizing electron multipliers.

My invention possesses numerous other objects and features of advantage, some of which, together with the foregoing, will be set forth in the following description of specific apparatus embodying and utilizing my novel method. It is therefore to be understood that my method is applicable to other apparatus, and that I do not limit myself, in any way, to the apparatus of the present application, as I may adopt various other apparatus embodiments, utilizing the method, within the scope of the appended claims.

Referring to the drawing:

Fig. 1 is a circuit diagram showing an embodiment of my invention in a radio receiving circuit.

Fig. 2 is a radio receiving circuit diagram, wherein the action is periodically interrupted.

Fig. 3 is a sectional view, taken as indicated by the line **3—3** in Fig. 2.

Fig. 4 is a circuit diagram of another embodiment of my invention, as applied to radio receiving.

Fig. 5 is a partial sectional view of the multiplier used in Fig. 4, taken as indicated by the line **5—5** in Fig. 4.

In my prior application, Serial No. 10,604, cited above, I have described the advantages of interrupting the energization of an electron multiplier. Herein I shall describe multipliers wherein the multiplier anode supply may be interrupted, and wherein the electron multiplier may be utilized for the indication of radio frequency signals.

The multiplier broadly 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 will be produced by electrons making a traversal thereof. The cathodes within the chamber are defined by a pair of opposed plates which may, indeed, 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 or collecting electrode 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 sufficient number of traversals will certainly be thus collected. The improbability may be increased by establishing within the chamber a guiding field which tends to hold the electrons in a path which avoids the anode, or decreased by collector electrode construction. In the present method, I may use the mutual fields of the electrodes themselves to create this guiding field, or I may use a field externally applied.

The 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. While there are a number of methods by which this may be accomplished, these methods differing somewhat in their circuital requirements, all of which are explained and set forth in my prior application, which may be referred to for detailed theory, I shall here describe only the first of these methods, as this application more particularly concerns the operation of the device in the following manner, although modifications of the method and apparatus may easily be made by those skilled in the art to encompass operation in other manners within the scope of the appended claims.

Electrons are directed towards the cathode and multiplication occurs by secondary electron emission therefrom. A relatively high frequency potential, which may be of the order of 60 megacycles, is applied between the cathode plates, this potential being preferably relatively small as compared with the collecting potentials on the anode. Under the influence of the cathode energization, electrons strike one or the other of the cathodes and emit secondary electrons which are accelerated towards the opposite cathode by the anode potential. If the potential of the latter be so related to the frequency applied to the cathode that the released electrons travel 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 unity, 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, namely, 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.

When the electrons strike the opposite plate with sufficient velocity to cause emission of secondary electrons, the emitted secondaries are accelerated in the opposite direction to generate new secondaries at the plate or cathode 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. The anode potential contributes only to the mean velocity of the electrons through the tube and has no direct effect whatever on the velocity of impact, since the acceleration it imparts to the electron leaving one of the cathodes is exactly neutralized by the deceleration imparted to the same electron approaching the other cathode. A change in the mean velocity will, of course, vary the multiplication by changing the ratio of the transit time to the period of the oscillation.

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, namely, upon whether the electrons are striking near the center or near the edges of the cathode; upon the transverse component of the electrostatic field within the chamber, as determined by the space charge, the curvature between the lines of force between cathode 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 in the anode circuit will become constant.

Within certain limitation, 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 strengthening the guiding field. A limitation to this is, however, the space charge developed when the number of electrodes in the cloud which travels between the plates becomes very dense, causing saturation.

Up to the point of saturation, the output of the device varies proportionately to either the number of electrons supplied to the chamber when used as a multiplier of electrons supplied from the outside, or to the value of the externally applied alternating voltage on the cathodes when starting from stray electrons. In the latter case, the number of trips is varied, while in the first case, the same number of trips is accomplished but the cloud is initiated by a different number of electrons. In either case, however, the saturation limits are approached when the multiplication is made large.

In the embodiments shown, I prefer to energize the cathodes directly and solely by a modulated signal and interrupt the action to obtain high multiplication. I may also prefer to cause the device to oscillate and to interrupt itself to obtain the same result. Furthermore, I am able to utilize various structural modifications in the device and, for example, by winding a fairly open mesh grid around the collecting anode, to increase the probability of collection. I am also able to operate the device with a guiding field created solely by the relative sizes and shapes of the electrodes of the device. Furthermore, I prefer to make the two cathodes of such shape that they substantially describe a cylinder and by closing the ends of the cylinder, I am able to remove interference with the multiplication due to the ionization of the secondary emitting materials.

Having thus described the general theory of the multiplier in its broad sense, I now wish to describe my present modifications thereof as exemplified by the preferred embodiments illustrated herein.

In the figures, circuits are shown whereby an electron multiplier is used for detection of radio frequency signals. It will be noticed that in all of these three circuits, the radio frequency, presumably modulated or keyed in accordance with signals, is the sole energization of the cathodes. In other words, a multiplier tube such as has been described, is used without any R. F. excitation of the cathodes except the signal. The amount of signal necessary to operate a tube in this manner depends primarily on how sensitive the cathode surfaces are and how efficient the transfer of electron energy through the circuit is. As the efficiency of these two factors is increased, the tube's sensitivity increases until finally it will become a good self-oscillator. Tubes, however, which will not self-oscillate in a circuit as shown, for example, in Figure 1, where the cathodes are energized solely by an incoming R. F. signal train, work well as a detector with a signal of the order of .1 volt or less.

For example, if the device is to be used as a straight multiplier, it may be constructed with a pair of opposing cathodes 60 and 61 with a ring anode 62 positioned between them. A tuned circuit 64, comprising an inductance and capacity has its opposite ends connected to the cathodes and its mid-point 65 grounded. The tuned circuit is fed from a primary inductance 66 which may be in the output of a radio frequency amplifier, or connected directly to an antenna system comprising an aerial 67 and a ground 69 or equivalent collector. If, then, the ring anode 62 were to be energized directly from an anode battery, for example, at a voltage of 70 volts, the

R. F. voltage across the cathodes would be tremendously increased due to the multiplication created by the electrons within the tube, oscillated under the influence of the applied R. F. voltage. The time of flight within the tube may be conveniently adjusted by varying the voltage of the anode battery for the particular wavelength being received, so that the time of flight corresponds at least in some degree to the incoming frequencies. The device operating under these conditions is of course supplied with its original electrons either by beginning the multiplication with a free electron existing in space between the two cathodes or by the release of electrons due to impact upon the cathode of a metallic ion such as caesium ion, providing the cathodes are sensitized with caesium.

When an electron multiplier is utilized in this manner, however, amplification factors of 20 to 100 can be obtained, further gains being terminated by the limiting effects above referred to. I, therefore, prefer to interrupt the anode supply at an intermediate frequency, preferably 2 x 10^6 cycles when 50 to 150 megacycles are being received. The interrupting frequency is controlled by the tuned circuit 70 connected to the anode and fed at the desired frequency by any suitable oscillator. Inasmuch as the multiplier tube illustrated in Figure 1 is provided with parallel planar plates, it is desirable to place the tube under the influence of an external magnetic field as indicated by arrows 71 in order that the multiplying action may be efficient.

By the use of the interrupting intermediate frequency, much larger gains may be obtained in the output of the multiplier and it can be readily seen by those skilled in the art that the receiving circuit of Figure 1 will be suitable for use with a steady anode supply under certain circumstances, and suitable for other uses with an interrupted anode supply as shown in the drawing, the tube operating in both cases in identical manner as regards the energization of the cathodes directly from the incoming signal.

It should also be pointed out that when an interrupted anode supply is used the detected component may be obtained directly from the anode circuit or the output may be taken off at the interrupting frequency if it is desirable to further amplify with an intermediate frequency amplifier.

The same results can be obtained with a detector circuit as shown in Figure 2. Here signal energy contained in the primary 66 of the R. F. transformer is transferred to the tuned circuit 64 having its midpoint 65 grounded, and this energy is then led to the cathodes and is the sole source of potential for these cathodes. The anode in this case is preferably an axial rod 72 having wound around it and connected thereto a fairly wide mesh grid 74. In this case, no external field is necessary for focusing the electrons because the two plates are semi-cylindrical and the static field created by their opposition is sufficient to prevent immediate collection. I use the anode with a grid connected to it in order that the probability of collection may be increased. In other words, electrons entering the space bounded by the grid wires will be more probably collected due to the shielding action of the grid.

It is of course obvious that electrons passing through chords of the grid space will not be collected, while those passing through longer chords approaching the diameter will be collected. By shaping the cathodes, I am able to decrease the probability of collection because of the shaping of the electrostatic field therebetween and by putting a grid around the anode I am able to increase the probability of collection, both the increase and decrease of probability by the two methods being independent of one another. Thus, I am able to regulate the probability, for example, of collection without interfering with the static field and I am able to change the static field and compensate therefor by the use of the grid to obtain certain desired results.

The circuit as shown in Figure 2 is adapted to be used as an oscillating detector and I have therefore shown a source of exciting R. F. 75 for the anode 72—74. This excitation is not necessary, however, in case the multiplier tube associated with the circuit is a self-oscillator. In other words, if the multipler is sufficiently sensitive to generate self-oscillations, the R. F. is unnecessary. Therefore, the multiplier shown in Figure 2 is not only a very good regenerative detector, either with or without an exciting source, according to its sensitivity, but is also capable of being operated as a super-regenerative detector interrupting itself at a frequency which will be determined by an inductance 76 placed in series with an output device 77 and the variable source 78, the latter being variable in order to regulate the time of flight in accordance with the incoming signal. Whether or not there is an exciting R. F. supplied to the tube, I prefer to have the device oscillated at 60 to 100 megacycles for a signal frequency of 30 to 60 megacycles, these adjustments, however, being all within the skill of those familiar with the art.

This particular arrangement is extremely sensitive and a satisfactory detector. Its high sensitivity is obtainable without critical adjustment. Here again, the detected component may be obtained directly from the anode circuit, or the output may be used to supply an intermediate frequency amplifier. The interrupting action produced by the resonant circuit in series with the anode is obtainable either on the portion of the multiplier characteristic showing a negative resistance or at a difference of frequency between the electron period and the signal frequency, or at a difference of frequency between the exciting R. F. and the signal frequency, as may be desired.

It is also possible and sometimes preferable to build the multiplier as a photo-ionic tube duplicating the action of the tube shown in Figure 2. Such a tube and circuit is shown in Figure 4. In this combination the interrupting action is obtained by beat between the signal frequency and the electron frequency. Here, again, the cathodes are supplied solely by the signal circuit 66—64, while the anode in this case is preferably a relatively close meshed grid 79. Inside the grid is positioned a heated filament 80 which is, however, not adapted to provide electrons by emission therefrom, but is purely a source of light so that the photosensitive cathodes may be initially energized to emit photoelectrons. This is operable because practically all surfaces readily emitting secondaries upon impact are also photo-sensitive. In this way, the number of trips necessary to build up the multiplier current is reduced. The tuned circuit 70 is attached as usual in the anode circuit comprising the output device 77 and the anode supply 78, and an oscillator may be coupled thereto to provide interruption.

It will thus be seen that I have provided radio receiving circuits wherein energy derived from the collection of radio signals from space form the sole a.-c. energization thereof, thus saving a local generating unit.

I claim:

1. A signal detector comprising an envelope containing a pair of opposed surfaces capable of emitting secondary electrons upon impact, and an anode positioned between said surfaces and energized to a positive potential, means for collecting a radio signal from space, means for applying a voltage derived from said signal to said surfaces as the sole a.-c. energization thereof, and means for utilizing current flowing in the anode circuit.

2. A signal detector comprising an envelope, a pair of substantially semi-cylindrical surfaces capable of emitting secondary electrons upon impact, and opposed to describe substantially a cylinder, and an anode axially positioned between said surfaces and energized to a positive potential, said anode comprising a central conductor surrounded by an apertured grid connected to said anode, means for collecting a radio signal from space, means for applying a voltage derived from said signal to said surfaces as the sole a.-c. energization thereof, and means for utilizing current flowing in the anode circuit.

3. A multiplier detector comprising an envelope, an electrode therein adapted to emit secondary electrons by electron bombardment, an electron collecting electrode, and means for creating an alternating potential on said electron emitting electrode in accordance with a radio signal collected from space to create successive generations of secondary electrons by repeated electron impact therewith, and a work circuit connected to said collecting electrode.

4. A multiplier detector comprising an envelope, an electrode within said envelope adapted to emit electrons by electron bombardment, means for causing successive bombardments of said surface solely in accordance with a radio frequency signal to create successive generations of secondary electrons before collection, and means for utilizing electrons collected by said collecting electrode in a work circuit.

5. In combination, a detector comprising an electron multiplier having an anode and a pair of opposed cathodes, means for energizing the cathodes of said multiplier solely by a space signal to be detected, and means for utilizing at least a portion of the rectified current in a work circuit.

6. A multiplier detector comprising an envelope, a pair of electrodes spaced within said envelope, means for applying a radio signal to be detected to said electrodes to cause secondary emission of electrons therefrom at a ratio greater than unity, a collecting electrode positioned between said first mentioned electrodes and a work circuit connected to said collecting electrode.

7. A multiplier detector comprising an envelope, a pair of spaced electrodes therein adapted to emit secondary electrons on impact, means for energizing said electrodes solely in accordance with a space signal to be detected to cause an electron therebetween to make repeated and successive impacts therewith, and means for collecting the resultant electrons.

8. The method of detection 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, and energizing said surface solely by a voltage derived from an incoming signal collected from space.

9. The method of detecting a radio signal collected from space which comprises utilizing energy contained in said signal to initiate a stream of secondary electrons, thereafter continuing to apply energy varying in accordance with said signal to create additional generations of secondary electrons until the desired multiplication is reached and collecting at least a portion of said electrons as a unidirectional work current while continuing to create further generations of secondaries from the remainder under the sole control of said signal.

10. In combination, a cathode adapted to emit secondary electrons by electron bombardment, means for applying a radio frequency signal derived from space to said cathode to create successive bombardments thereof of sufficient intensity to release secondaries at a rate greater than unity, and a collecting electrode positioned and energized to withdraw at least a portion of said secondaries as a unidirectional work current.

11. In combination, a detector comprising a pair of opposed cathodes adapted to emit secondary electrons, a collecting anode positioned to collect at least a part of said secondary electrons when emitted, means for energizing said cathodes by a modulated alternating current to cause repeated and successive electron bombardment of said cathodes of sufficient intensity to cause secondary emission therefrom, and a work circuit responding to rectified current connected to said anode.

12. A detector comprising a pair of opposed cathodes adapted to emit electrons by secondary emission, a collecting anode positioned between said cathodes, means for applying a signal to be detected to said surfaces, and a work circuit connected to said anode.

13. A detector comprising a pair of opposed cathodes adapted to emit electrons by secondary emission, a collecting anode positioned between said cathodes, means for applying a signal collected from space to be detected to said surfaces, and a work circuit connected to said anode, said signal being the sole energization of said cathode.

14. A detector comprising a pair of opposed cathodes adapted to emit electrons by secondary emission, a collecting anode energized at a positive potential positioned between said cathodes, means for applying a signal to be detected to said surfaces, and a work circuit connected to said anode.

PHILO T. FARNSWORTH.