Nov. 12, 1940. P. T. FARNSWORTH 2,221,473

AMPLIFIER

Original Filed March 12, 1935 2 Sheets-Sheet 1

Fig. 1.

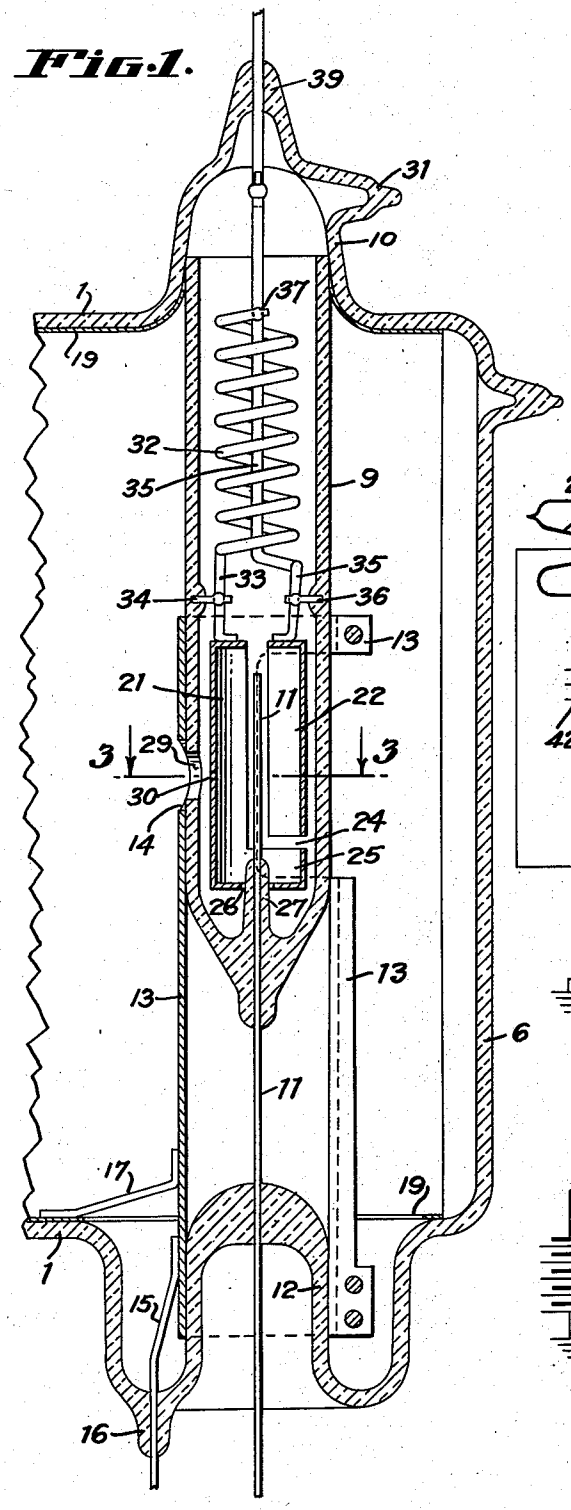
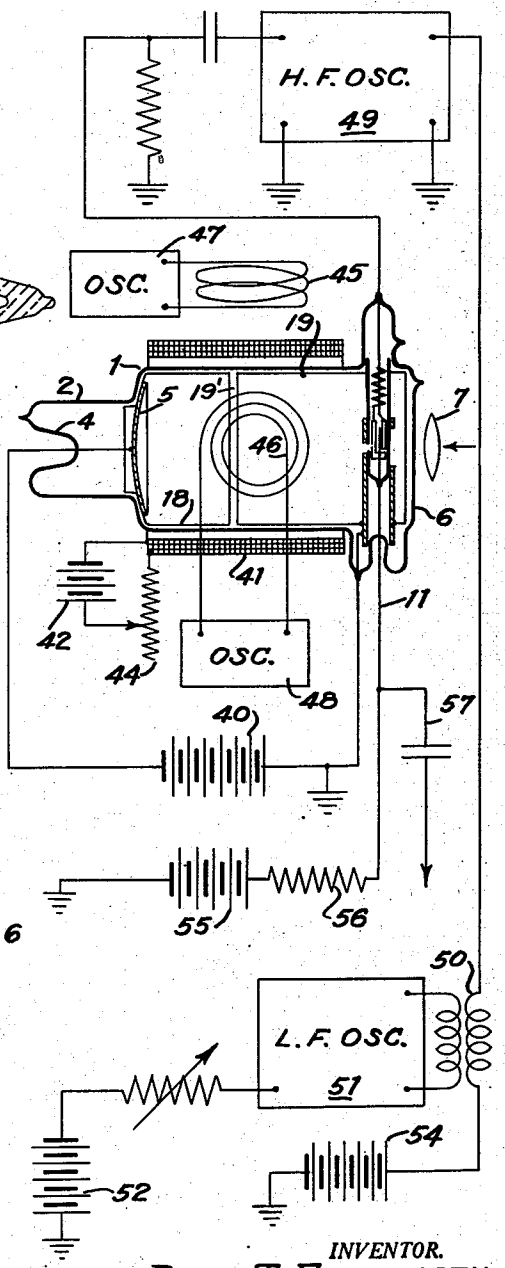


Fig. 2.



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Original Filed March 12, 1935 2 Sheets-Sheet 2

Fig. 3.

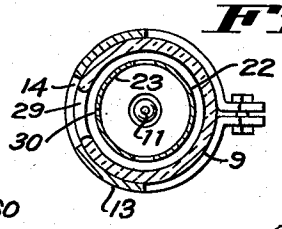


Fig. 4.

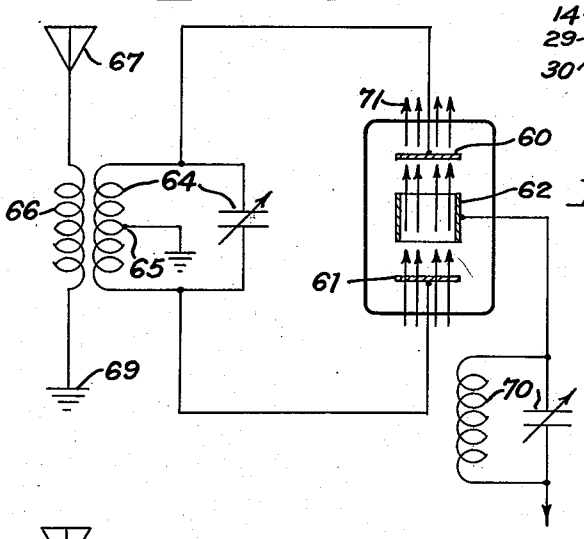


Fig. 6.

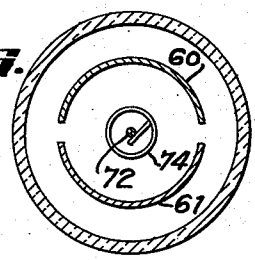


Fig. 5.

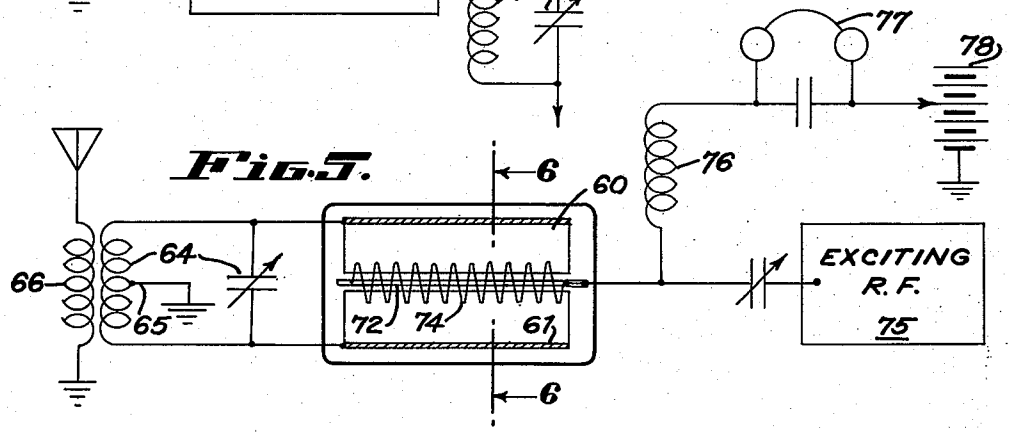


Fig. 7.

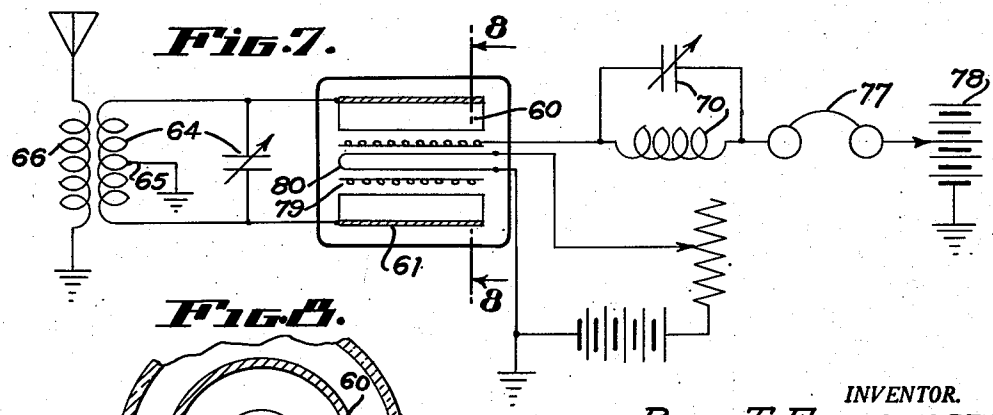
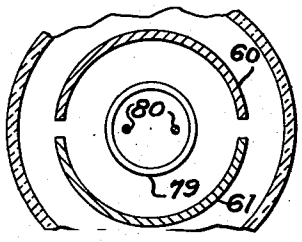


Fig. 8.



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Patented Nov. 12, 1940 2,221,473

UNITED STATES PATENT OFFICE

2,221,473

AMPLIFIER

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Original application March 12, 1935, Serial No. 10,604, now Patent No. 2,143,262, dated January 10, 1939. Divided and this application April 26, 1937, Serial No. 138,923

6 Claims. (Cl. 250—27)

My invention relates to electron multipliers, namely, to 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 removing certain limitations in the operation of electron multipliers, disclosed and claimed in my application, Serial No. 692,585, filed October 7, 1933, since matured into Patent No. 2,071,515, issued February 23, 1937, and the present application is a division of application Serial No. 10,604, filed March 12, 1935, Patent No. 2,143,262, dated Jan. 10, 1939, the latter application being a continuation in part and co-pending with above cited application Serial No. 693,585, now Patent No. 2,071,515.

In the application above cited, the theory and practical aspects of electron multiplication by secondary emission are discussed, pointing out therein that certain limitations in the maximum multiplication obtainable could be overcome by interrupting the action periodically. It is with this phase of electron multiplication that the present application deals, together with the circuits and preferred embodiments of the apparatus for that purpose.

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 television image dissector of greatly increased sensitivity; to provide a space charge device of novel type having characteristics adapted for use as a multiplier of electronic currents and preferred circuits for so operating the device; to provide a simple and efficient radio receiving device; to provide a multiplier operating intermittently; to provide current multiplication of a high degree; to provide an electron multiplier and circuit therefor adapted for high output currents; to provide a means and method of obtaining electron multiplications of exceptionally high values; to provide an electron multiplier of exceptionally small size having high current outputs; to provide an electron multiplier operating without an external focusing field; to provide an electron multiplier which is self-interrupting in its action; to provide a means and method for interrupting the action periodically of an electron multiplier in order to remove factors limiting multiplication; and to provide a new and novel method of operating 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 drawings:

Figure 1 is a view, partly in section and partly in elevation of the mutiplier end of a preferred form of television dissector tube embodying my invention.

Figure 2 is a circuit diagrammatic and reduced to lower terms, showing the multiplier-dissector tube of which a portion was shown in Figure 1, connected for use in television or similar service.

Figure 3 is a sectional view taken through the mulitiplier of the tube of Figure 1, as indicated by the line 3—3 in Figure 1.

Figure 4 is a circuit showing an embodiment of my invention as applied to radio receiving.

Figure 5 is a circuit diagram showing another form of multipler connected in a circuit where the action is periodically interrupted.

Figure 6 is a sectional view taken as indicated by the line 6—6 in Figure 5.

Figure 7 is a circuital diagram of another embodiment of my invention as applied to radio receiving.

Figure 8 is a partial sectional view of the multiplier used in Figure 7, taken as indicated by the line 8—8 in Figure 7.

The present invention, considered broadly, employs certain apparatus of my copending application referred to above, more particularly, an electron multiplier. 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 un-

derstood 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.

Where the device is used to multiply an external photoelectric current, an aperture is preferably provided in one of the cathode plates, and a photoelectric cathode is positioned without the chamber and the discharge is directed through the aperture.

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 mean velocity will, of course, vary the multiplication by changing the ratio of the transit time to the period of 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 cathodes; 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 limitations, 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.

Current multiplication, however, can be obtained with this apparatus by limiting the average number of impacts resulting from a single initial electron so that the total output current remains below the equilibrium value. The mode of operation with which this particular application is in general concerned, comprises broadly, interrupting the multiplier action periodically at such intervals that the limiting conditions cannot supervene. As these intervals preferably will include the same number of half cycles, and hence, the same number of multiplying impacts, it is clear that the main output current between the interval will be proportional to the number of initiating electrons liberated or created in the interval.

The periodical interruption can be obtained in a number of different ways, for example, such as energizing the cathodes from one source of alternating potential at a predetermined frequency and interrupting the action of the tube

at a lower frequency. By using high exciting frequencies, a very small multiplying structure is made possible, small enough, in fact, to be incorporated inside of a photoelectric tube adapted for television or similar apparatus. By such a combination suitable gains of one hundred thousand to one million are easily obtained and experimentally a current input of an interrupted multiplier of 10^{-9} amperes gave a stable and usable output current of from .1 to 1 milliamperes.

In certain other cases, I may 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.

As one of the uses to which my invention is ideally adapted is the multiplication of electrons emitted from a photoelectric or similar source, I prefer to describe one embodiment of my invention as forming a functional part of a television dissector tube such as has been described and claimed by Farnsworth Patent No. 1,773,980, and by Rutherford in his application, Serial No. 696,999, filed November 7, 1933, Patent No. 2,135,149, dated Nov. 1, 1938. Such a structure utilizing my present invention is shown in Figures 1, 2 and 3.

In a preferred embodiment modified to include one use of the present invention, a cylindrical glass blank 1 is provided with mounting arm 2 on which is supported, through the medium of the usual stem 4, a photoelectric cathode 5. While I have shown this cathode being of somewhat concave shape, it may be planar if desired, the shape being merely to reduce distortion in scansion, as will be pointed out later. The cathode itself may well be formed of silver and be photosensitized by the deposit of caesium thereon in ways well known in the art. The opposite end of the blank is closed with preferably a flat glass end wall 6 through which a light beam may be projected by a lens 7 in order that an optical image of an object may be focused on the cathode 5.

Just inside of the end wall 6 is positioned a multiplier assembly which is shown in enlarged detail in Figure 1. The multiplier is composite and comprises a glass tube 9, one end of which engages a tube positioning arm 10 on one side of the blank. The other end of tube 9 is closed, and has an anode 11 sealed therethrough projecting along the axis of the tube, this anode being outwardly extended to pass through an anode stem 12 on the other side of the blank, the tube extending preferably diametrically across the blank. The sealed end of the tube is maintained in place by an anode sleeve 13 which engages the sealed end of the multiplier tube and also engages the end of the anode stem 12. Thus, the multiplier assembly, being engaged with both sides of the blank is maintained in position. I prefer to extend the sleeve along the tube and to provide it with a sleeve aperture 14 opening towards the photosensitive cathode. The anode sleeve 13 has an energizing connection 15 which passes out through a connection seal 16 adjacent the anode 11.

The interior of the cylinder 1 is preferably coated within a thin metallic coat, created by evaporation of a suitable metal within the tube, or by silvering before exhaust, and a film connection 17 is made between the anode sleeve 13 and the film adjacent the multiplier assembly.

I also prefer to so evaporate this film that it will not be present over the front face 6 of the blank so no light will be excluded, but which will extend along the blank to contact the cathode 5. I do not, however, wish to make this coating continuous between the multiplier end of the tube and the cathode end and therefore prefer to shield off a zone around the envelope during evaporation or otherwise remove the coating substantially intermediate the two ends of the blank to form an insulating barrier band 19' so that a cathode film 18 will be separated from the multiplier film 19.

The glass tube 9 contains a complete multiplier assembly. This multiplier comprises a pair of opposed cathodes 21 and 22. These cathodes are preferably separated portions of a cylinder, a space 24 being left between them, and I prefer to form the cathode 21 with a complete cylindrical end portion 25 having an aperture 26 therein through which a glass sleeve 27, which is sealed around the anode 11, extends. This sleeve 27 serves to position the end of the cathode 21 and maintain it in position. The opposite ends of cathodes 21 and 22 are formed to substantially close that end of the cathode assembly so that in effect the combination of the two cathodes describes a cylinder with substantially closed ends. The split in between the two cathodes is preferably at right angles to the longitudinal axis of the blank so that cathode 22 is facing towards the photoelectric cathode 5 and cathode 21 is facing away from photoelectric cathode 5.

A target aperture 29 is provided in the glass tube immediately below sleeve aperture 14, which is directed towards the photoelectric cathode 5 and immediately inside of target aperture 29 is a smaller cathode aperture 30 which acts as the scanning aperture of the multiplier. The two cathodes 21 and 22 are preferably sensitized so that they can readily emit secondary electrons at a rate greater than unity when properly impacted by electrons in motion, sensitization by caesium, for example, being conveniently performed through a sensitizing tubulation, the remains of which are shown as a tubulation seal 31 on the positioning extension 10. For such sensitization, the cathodes are preferably made of silver.

In the modification shown in the drawings, the anode sleeve 13 extends above, and therefore would surround, if completely cylindrical, the multiplier cathodes 21 and 22. These cathodes are designed to carry high frequency, as will be later explained, and the sleeve, if completely around the cathodes, would then form a capacity short between them. I therefore prefer to cut

away the sleeve so that only one of the cathodes, preferably one from the side facing the flat face 6 of the envelope is covered thereby. The capacity between the sleeve 13 and the multiplier cathode 21 is then utilized for purposes later to be explained.

The two cathodes are connected by means of a resonating coil 32 preferably of silver wire positioned inside the glass tube, one end of which is connected to cathode 21 through a coil connection 33 stabilized by cathode insert 34 and an axial connection 35 is connected at one end to the cathode 22 and is stabilized by another cathode insertion 36, this cathode connection 35 extending axially through the silver resonating coil 32 and making a connecting weld 37 therewith at the outer end. The axial connecting wire then extends on out through an end seal 39 so that outside connection may be made to the cathodes and to the resonating coil 32.

It is quite convenient, due to the fact that good secondary emission is obtained by the deposit of caesium, to make not only both cathodes 21 and 22 of solid silver, but also make the resonating coil 32 and the cathode connection 35 of the same material.

Up to a certain point, the operation of the dissector tube is the same as that of the prior dissector tubes referred to above.

An optical image is focused from an object through objective lens 7 onto the photoelectric cathode 5. This cathode will then emit photoelectrons in proportion to the intensity of the light falling on each elementary area. The electrons are accelerated towards the multiplier end of the tube by means of a positive anode potential supplied by an accelerating source 40 of which is connected between the cathode 5 and the associated film 18, and the anode sleeve 13 with its film 19.

A focusing coil 41 surrounds the device, supplied from a D. C. source 42 and regulated by a variable resistor 44, the function of this equipment being to focus the electrons emitted from the cathode into a sharply defined image, in the plane of the scanning aperture 30, of the optical image as projected on the cathode as is described in my United States Patent No. 1,986,330 issued January 1, 1935. The image thus formed is oscillated in two dimensions over the aperture by the magnetic fields developed by suitable scanning coils 45 and 46, excited by oscillators 47 and 48 respectively, which preferably generate scanning waves of saw-tooth form. All of the elementary areas of the electron image are thus successively traversed across the aperture to accomplish the scanning of the image.

It will be seen that the total magnetic field, compounded of the focusing and the two deflecting fields, varies as the image is deflected. Since the distance from the cathode at which the electrons from any given elementary area of the cathode are brought to a focus varies inversely as the total strength of the magnetic field and also inversely as the electron velocity, the focal surface tends to vary from the plane of the aperture as the electron image is deflected, moving closer to the cathode at the instant of maximum deflection and farther away as the deflecting fields approach zero.

The electrode structure, comprising cathode, anode, and the connected films 18 and 19, compensate for this effect. In the first place, the film 19 being in contact with the wall of the tube 1 adjacent the window 6, electrons directed toward the junction of film and window strike the glass with sufficient force to cause it to emit secondaries, leaving a positive charge on the glass, which increases and spreads progressively until the entire window is at the anode-film potential, and the electric field distribution within the structure becomes the equivalent of one due to two cup-shaped electrodes placed mouth to mouth and separated by the gap 19'. In the absence of the magnetic fields, this field distribution would serve to concentrate the cathode discharge in a small circle surrounding the aperture, in accordance with the now well known principles of "electro-static focusing" or "electron-optics."

The magnetic fields overcome this effect, spreading the beam out into an electron image of substantially the same size as the optical image and of high definition, but the non-uniformity of the electrostatic field has another and more important effect which is not affected by the magnetic fields, and that is to vary the mean velocity with which the electrons from the various parts of the cathode traverse the tubes. All of the electrons have the same velocity upon their arrival at the anode, but those traveling from the periphery of the cathode towards the aperture receive more of their acceleration in the first part of their journey than do those leaving from the center of the cathode, and hence their average velocity is higher, and it follows that although they travel a greater distance to the aperture, and through a stronger total magnetic field, they none the less may be brought to a focus at the aperture as accurately as those traveling axially.

The concave cathode has a like effect, tending to equalize the length of path of the electrons to the aperture.

In practice, I prefer to utilize both effects to obtain the optimum correction. The flatter the cathode, the shallower should be the cup formed by cathode film 18, and the deeper the anode cup, and vice-versa. The mathematics of design is tedious rather than difficult, and there are a large number of solutions giving substantially equivalent results. The figure is proportionally correct for one solution, and a small amount of experiment will yield others. A final correction may be obtained by varying the anode voltage.

It will be understood that the actual focal surface where this method is used is not a plane, as it is where planar electrodes are used, but curved and moreover changing in shape with deflection. The important point is that the scanning aperture always lies in the focal surface.

It can be understood that as the number of electrons entering the multiplier aperture 30 at any one time come from relatively small elementary areas of the cathode 5, their actual number is relatively low and the current they represent is relatively small. Thus, if these electrons were to be directly collected, the train of television signals which would ensue would be of relatively small amplitude. As a matter of fact, the average value of such currents without multiplication would be of the order of 10^{-9} amperes or even less, to a minimum of 1 electron. Such small currents normally require a tremendous amount of exterior amplification before they are of sufficient magnitude to be of practical use, and my present invention therefore is of great importance in that these currents may be greatly increased within the dissector tube itself so that

a great reduction in outside amplification can be used.

One of the main objections to such extensive outside amplification is that the noise level becomes excessively high, but by the use of my present invention, the signals alone are multiplied without noise so that the signal-to-noise ratio is maintained at a high value. The remainder of discussion, therefore, will have to do with the action of the multiplier itself and as this action will be the same irrespective of where electrons come from before they enter the space between the cathodes, it should be understood that the particular application of the multiplier is exemplary only. The following description applies equally well to uses of the multiplier entirely different from the combination with a dissector tube.

In the dissector, in order that the light entering the tube from the object be obstructed as little as possible, it will be, of course, desirable to make the complete multiplier assembly as small as possible. I therefore prefer to give specific measurements of one particular multiplier which has been in use for purposes as described above. The space enclosed by the sliver cathods **21** and **22** has a diameter of $\frac{1}{16}$ of an inch. The anode **11** is an axial .010 inch tungsten wire and the silver resonating coil **32** is of a size which will resonate the cathods at approximately 200 megacycles. The resonating coil **32** is excited by the output of an exciting oscillator **49** which of course is tuned to the resonant frequency of about 200 megacycles. Only a single wire is needed to complete the R. F. circuit to the resonating coil because of the capacity between the multiplier cathode **21** and the anode sleeve **13**, the latter being grounded. This 200 megacycle oscillator may conveniently be a vacuum tube oscillator or even in itself a modification of the Farnsworth electron multiplier which is capable of sustaining self oscillations, which is described by me elsewhere.

In the event that a thermionic tube oscillator of the usual type is used, I prefer to supply the oscillator with about $\frac{1}{3}$ or $\frac{1}{2}$ of the necessary anode voltage through an inductance **50** which is coupled to a low frequency interrupting oscillator **51** which may have any frequency up to 30 megacycles and even as low as 60 cycles, if desired for specific purposes.

The adjustment of the amount of multiplication occurring between the two cathodes **21** and **22** may be conveniently made by varying the voltage of the anode source **52** which supplies the low frequency oscillator. The remainder of the voltage for the high frequency oscillator **49** is supplied by a high frequency anode supply source **54**. When the high frequency and low frequency oscillators are both operating, the cathodes **21** and **22** are alternately and intermittently excited and a multiplier anode voltage is supplied to the anode **11** by a steady multiplier anode source **55**. Thus, the combination of the two cathodes **21** and **22** and the central anode **11** constitutes an electron multiplier wherein electrons are repeatedly oscillated between the two cathodes at a velocity sufficient to create secondaries on impact therewith, certain of these electrons being collected by the anode **11**; the low frequency oscillator intermittently and periodically interrupting the energization of the cathodes.

The electrons which initiate the multiplication enter the cathode aperture **30** and the multiplication which takes place within the cathode enclosure is of course dependent, other factors remaining the same, upon the number of electrons entering the chamber. The multiplied electrons collected by anode **11** will be in proportion to the number entering the aperture **30** up to the point where the limiting factors above referred to in the broad discussion would normally supervene. However, due to the fact that the low frequency oscillator interrupts the action of the high frequency oscillator periodically, these limiting factors are not able to persist and the multiplication can be carried on a great deal further. The output is taken from the anode **11** as a potential generated by currents flowing through an output resister **56** and conducted for further use by an output connection **57**.

Certain other factors sometimes enter the picture. It can be seen by an examination of Figure 1 and from the discussion as above, that the secondary emission surfaces are preferably formed by the deposit of caesium thereon. There is a very definite limitation imposed by the presence of caesium ions. The caesium ions will be attracted towards the negative cathode and when they impact the cathode, they too will create secondaries. If these secondaries happen to be in phase with the electrons already oscillating between the two cathodes, the result is not harmful. It is not usual, however, for the phase to be the same because the positive ions have a mobility of almost exactly $\frac{1}{600}$ that of the electron. By closing the end of the multiplier structure as shown, no caesium ion will have to travel more than one-half the diameter of the cylindrical cathodes. Furthermore, any caesium ions which are close to the anode are in a relatively intense field and will therefore make the trip from anode to cathode in no longer than 150 times the time required for an electron to travel between the cathodes. It can be expected, therefore, that the caesium ions can be cleaned out of the tube in a time equal to 150 times the one-half period of the cathode frequency of about 200 megacycles.

In practice, I have found that this time is ample to completely eliminate any holdover action which might be caused by the caesium ions contacting the cathodes.

While I have described the multiplier as being used with a 200 megacycle exciting oscillator, it is manifest that the exciting oscillator can be used to provide a lower frequency and of course if this is done, the interrupting oscillator should be dropped in frequency, accordingly. The use, however, in this particular case, of the 200 megacycle oscillator, makes possible the use of a very small multiplying structure and sufficiently small for incorporation in the dissector tube as shown, without substantial light obstruction.

In this particular case, no external magnetic focusing field is necessary in conjunction with the cathodes as the shape of the cathodes together with the axial position of the collecting anode gives an electrostatic field when energized, within the space enclosed by the cathodes, of the proper shape to permit good multiplication.

With the particular arrangement as shown and described, suitable gains of 100,000 to 1,000,000 are easily obtainable. Experimentally, a current input of 10^{-9} amperes gave an output current of from .1 to 1 milliampere. The multiplier itself passes a very small current, not more than a microampere with no input electrons. The resonating inductance is preferably incorporated inside the dissector close to the cathodes

because this permits more efficient handling of the 200 megacycle frequency.

The use of additional battery voltage to supply the anode of the 200 megacycle oscillator is of course not strictly necessary, but economizes on the power required in the low frequency oscillator. The net result of the incorporation of the multiplier of this type in the dissector tube reduces the amount of gain required outside the dissector tube to a maximum of perhaps 100, greatly reducing the problems of amplification usually associated in amplifying small currents in the manners heretofore known in the art.

The above description applies to a multiplier-dissector tube where the multiplier cathode supply is interrupted to eliminate the effect of limiting factors. Below, I shall describe multipliers where the multiplier anode supply is interrupted, and it is to be distinctly understood that the dissector multiplier may, if desired, be interrupted in the anode circuit as well as in the cathode circuit, as described.

There are a number of other applications of the method of periodically interrupting the action of an electron multiplier, which are shown in Figures 4 to 8 inclusive.

In these 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 4, 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 midpoint **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 $2x10^6$ 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 4 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 3 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 drawings, 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 that 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. Thus, the multiplier device connected as shown in Figure 3 may be used as a primary oscillator, or at least a device acting as a frequency converter, where intermediate frequency amplification might appear desirable.

The same results can be obtained with a detector circuit as shown in Figure 5. 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 short 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 5 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 multiplier is sufficiently sensitive to generate self-oscillations, the R. F. is unnecessary. Therefore, the multiplier shown in Figure 5 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 5. Such a tube and circuit is shown in Figure 7. In this combination the interrupting action is obtained by heat 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.

I have thus provided a means and method whereby the output of a multiplier tube may be greatly increased by the removal of certain limiting factors; principally by interrupting the action of the multiplier. The multiplier may be either an oscillating or a non-oscillating condition. It may be supplied with a varying source of electrons, with a steady source of electrons, or with no source at all, reliance being placed in the latter case on casual electrons present. I may prefer to deliberately interrupt the action or so connect the tube that it will interrupt itself. The latter condition can be accomplished when the tube is sufficiently sensitive to be a self-oscillator. I have shown that either the cathode energization or the anode potential may be interrupted. I have shown that tubes interrupted in this manner may be used to multiply an extraneous source of electrons varying in number, or I may utilize the interrupting action to facilitate the use of the tube as a detector, the output of the detector being available both as a detected component, or as an intermediate frequency carrying the signal impulses. And I have further shown that the multipliers may be used without any external guiding field and when used as a detector may have the cathodes energized solely by a modulated R. F. preferably one which is derived from space.

I have further shown that I may regulate the probability of collection in two manners: (1) by the regulation of the fields through which the electrons travel, due to the arrangement of the cathodes, or an external field; or (2) I may place means around the anode in order to provide a substantially equipotential space of relatively large diameter around the anode without substantial mechanical obstruction to the flight of electrons.

I claim:

1. 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, 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, and means for periodically interrupting the flight of said cloud.

2. 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, 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 in-

fluence 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, and means for periodically varying the oscillating potential to interrupt the flight of said cloud.

3. 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, and periodically interrupting sequence of electron flow.

4. 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, eventually collecting the electrons liberated at the final generation, and cyclically reducing said oscillating field to interrupt the action.

5. 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 after a statistically substantially constant number of repetitions of said steps, and cyclically reducing said oscillating field to interrupt the action.

6. 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 pretedermined 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 secondary electron by impact at the end of said path, and repeating said steps with the secondary electron thus liberated, and cyclically reducing said oscillating field to interrupt the traversals.

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