Nov. 22, 1938. P. T. FARNSWORTH 2,137,528

MULTIPACTOR OSCILLATOR

Filed Jan. 27, 1936

Fig. 1.

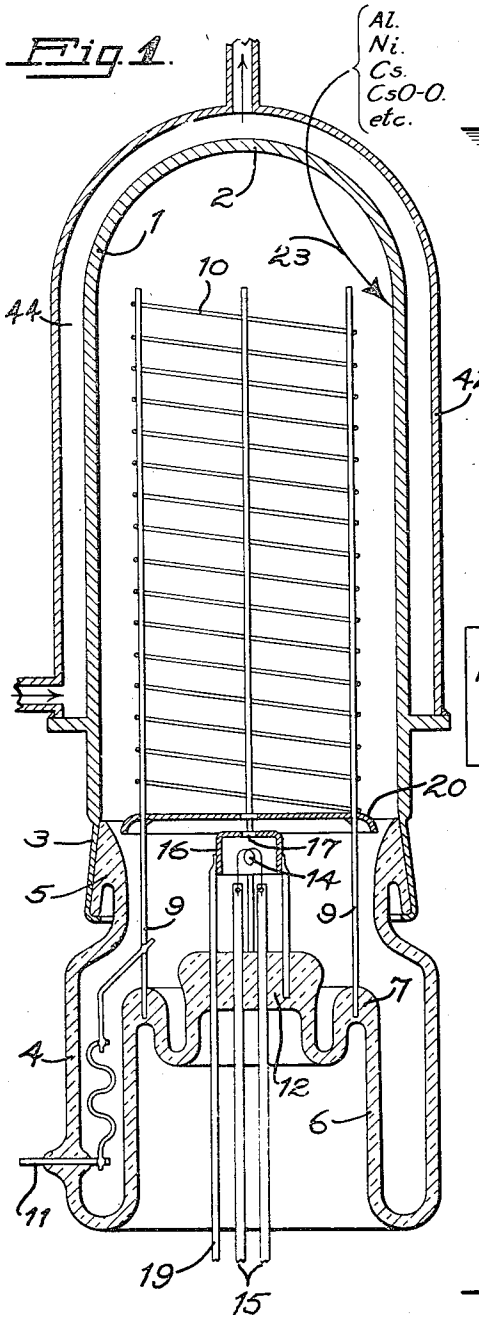


Fig. 4.

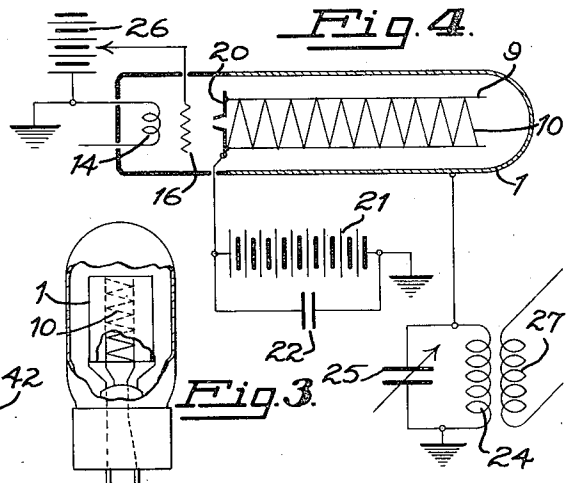


Fig. 3.

Fig. 5.

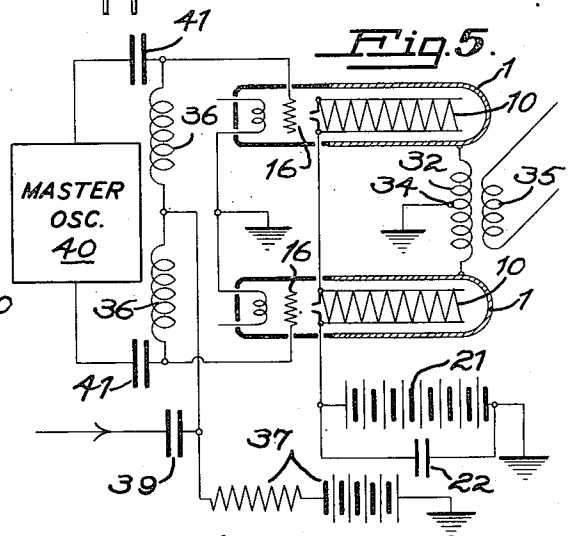
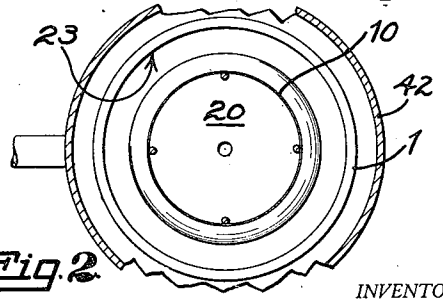


Fig. 2.



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

Patented Nov. 22, 1938

2,137,528

UNITED STATES PATENT OFFICE

2,137,528

MULTIPACTOR OSCILLATOR

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

Application January 27, 1936, Serial No. 61,042

7 Claims. (Cl. 250—36)

My invention relates to a multipactor oscillator, and more particularly to an oscillation generator operating by virtue of electron multiplication.

This application is a continuation in part of my prior application, Serial No. 733,837, filed July 5, 1934, Patent No. 2,071,516, granted Feb. 23, 1937, for an Oscillation generator, and operates broadly on the principles set forth in my prior application, Serial No. 692,585, filed October 7, 1933, for an Electron multiplying device and my prior application Serial No. 706,965, filed January 17, 1934; Patent No. 2,071,515, granted Feb. 23, 1937, for Methods of electron multiplication.

The present application deals with a multiplier structure and method of operation wherein only two electrodes, i. e., an anode and a cathode, are necessary for electron multiplication and self-excited oscillation.

The primary object of this invention is to provide a new type of electronic oscillator wherein the electron flow is derived, substantially in its entirety, from so-called "secondary electrons" liberated from a solid conductor by bombardment.

Among other objects of this invention are: To provide an oscillator which will convert direct current energy to alternating current at extremely high efficiency; to provide an oscillator which is substantially free from frequency limitations; to provide a type of oscillator which is particularly well adapted for the generation of very large amounts of power; to provide an oscillator of high vacuum type which is independent of ionization phenomena and is not subject to the instability and inconsistencies which such phenomena introduce; to provide an oscillator which has no heated electrode of the thermionic type, and which is correspondingly free of the difficulties and complications introduced by cathode-heating circuits; to provide a high power transmitter and modulator as a single unit; to provide a water-cooled multipactor; and to provide an oscillation generator of simple construction, needing only a simple circuit for operation and control and one which may be modulated with a minimum power loss.

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:

Figure 1 is a longitudinal view partly in section and partly in elevation of a high powered, water-cooled, multipactor oscillator.

Figure 2 is a cross-sectional view, taken as indicated by line 2—2 in Figure 1.

Figure 3 is a view in elevation partly cut away of a two-electrode tube.

Figure 4 is a circuit diagram, reduced to lowest terms of an oscillator circuit employing a single tube.

Figure 5 is a circuit diagram, also reduced to lowest terms, of a pair of multipactors connected in push-pull as power amplifies.

In my copending application, Serial No. 692,585 (cited supra), I have described an electron multiplying device, or multipactor, wherein by utilizing the phenomenon of secondary electron emission, extremely small currents may be multiplied to give very large final outputs. The initial current necessary in this apparatus may be so small as to be immeasurable by any ordinary method, e. g., the photoelectric current emitted from nickel by light in the visible spectrum, or that which may exist within the tube in the form of free electrons. I have there pointed out the regenerative nature of the multiplication, stating that by back-coupling the output of this device into its input, self-sustaining oscillations can be produced; and my Patent No. 2,071,516 (also cited supra) describes various modifications of electron multiplier structure capable of producing such self-sustaining oscillations by the method therein indicated.

In my Patent No. 2,071,516 I have shown the use of a pair of opposing cathodes with an anode therebetween as the fundamental structure desirable for the practice of my method of generating self-sustaining oscillations. The present invention, however, specifically relates to the production of self-sustaining oscillations in a tube embodying a multipactor structure having only two electrodes, and it was pointed out in my Patent No. 2,071,516, that the opposed electrodes could be operated at the same potential, and the embodiment shown in Figure 5 of that patent shows such an arrangement. The present application, therefore, is devoted to an oscillation generator of the type shown in Figure 5, with modifications of structure whereby the device can be made more versatile.

Considered in its broad aspect, the essential features of the present invention comprise a tube

having a pair of electrodes, one of which preferably is positioned around the other, and I prefer to form the outer electrode as a cathode having an inner surface capable of emitting secondary electrons at a ratio greater than unity when impacted by primary electrons traveling at the proper velocity. The inner electrode is energized at a positive potential and is therefore an anode. A cloud of electrons is oscillated by the potential applied between the electrodes within the space bounded by them, and strikes the cathode with sufficient velocity to release secondary electrons at a ratio greater than unity, as compared with the impacting primary electrons, thus causing a current flow from a D. C. source of potential included in the circuit connecting the electrodes. A potential drop due to this current is applied in phase to supply the necessary impacting velocity to the oscillating cloud of electrons, and thus the oscillation becomes self-sustaining and relatively large amounts of oscillating power may be withdrawn from the circuit. The energy for maintaining the oscillation is, of course, derived from the D. C. source, which must be sufficiently high in potential to release the secondaries at the required ratio.

For the oscillations to be self-starting as well as self-sustaining, the requirements are somewhat more rigorous, and I have found that in tubes such as will be herein described, it is not necessary for the work function of the cathode surface to be exceptionally low; in fact, I have found that when ordinary metallic copper is used for the cathode, that the surface is sufficiently sensitive for self-starting when the surface is coated with a small amount of sputtered aluminum, for example. There is, of course, no objection, from a theoretical point of view, to decreasing the work function of the cathode surface by coating it with alkali metals, such as caesium, for example, or caesium oxide, but from a practical point of view the surface is much more stable and uniform when metals of higher melting point, such as aluminum, are utilized. The two-electrode structure may be utilized directly as a primary oscillator, or it may be used as a power amplifier and modulated as well.

Considering the invention now in greater detail, Figure 1 shows one preferred tube structure adapted for the production of radio frequency power in large amounts, and I have therefore provided a metal cathode 1 in cylindrical form, having a closed end 2 and an open end 3 to which a glass or quartz extension 4 may be sealed, thus making the cathode itself a portion of the envelope. It is of course to be understood that this construction is used for the purpose of increasing the cooling of the cathode, and in smaller power tubes the cathode would be totally enclosed within the envelope as shown in Figure 3.

Inasmuch as I prefer to form the cathode 1 from copper, the glass extension 4 may be joined to the cathode tube by a copper-to-glass seal 5, as is well known in the art, and the extension is then provided with a double reentrant stem 6. The outer ring 7 of the stem has sealed thereto uprights 9 extending into the cathode cylinder to form supporting uprights for an anode spiral 10 of relatively finer wire, and I prefer that this open spiral be positioned so that it has an axis common with that of the cathode cylinder. The anode thus defined is provided with an exterior connection 11, sealed through the wall of the glass extension 4 in any convenient manner.

The central portion 12 of stem 6 supports a thermionic emitter 14, energized through leads 15, and a control grid 16 which may be positioned in or adjacent the path of the electrons emitted from the emitter 14, in this case being shown as a cup, inverted over the emitter, and having an axial aperture 17 therein for passage of electrons therethrough. This control electrode is also provided with an exterior lead 19.

Mounted on anode supports 9 is an anode disc 20, also apertured in the axis so that the apertures in the anode disc and in the control electrode are in line. The combination of the apertured anode disc 20, the apertured control electrode 16, and the emitter 14, forms an electron gun which is positioned to project electrons into the space bounded by the cathode, and in this particular modification, into the space bounded by the anode spiral as well. It is only necessary that this electron gun furnish a very small current in the beam therefrom. For example, in a 10 kilowatt oscillator or amplifier, a gun supply of 2 to 4 milliamperes is usually sufficient. During exhaust I prefer to sputter aluminum on the inner surface 23 to sensitize the surface so that it will emit secondaries at a ratio greater than unity when bombarded.

Figure 4 shows one form of circuit in which this type of tube may be utilized. The anode 9—10—20 is energized to a high positive potential—for example, 50 thousand volts—from an anode source 21, the negative end of which is grounded. The source may be by-passed for radio frequency by a condenser 22. The cathode 1 is connected to a tuned circuit comprising inductance 24 and variable capacity 25, the opposite side of the resonant circuit thus formed being grounded, thus placing the tuned circuit in series with the anode and cathode 1.

The electron gun cathode 14 is energized in any convenient manner, and the electron gun control electrode is maintained at any desired potential by bias source 26. The tube when energized is self starting and self oscillating and may be used to transmit by coupling a radiator 27 thereto. The output may be keyed in any convenient manner and the gun current insures quick starting characteristics.

A pair of these tubes may be used in push-pull relationship for amplification as shown in Figure 5. In such an arrangement the cathodes 1—1 are connected together by resonant circuit 32, the center point 34 of which is grounded. Circuit 32 may be resonant because of distributed capacity or, as is well known in the art, may be resonated by means of an additional exterior capacity, as described in conjunction with the tuned circuit 24—25 in Figure 4. The term resonant hereafter shall be deemed to include either one of these methods of causing resonance, or any other method which is well known in the art. A radiating circuit 35 is coupled to the resonant circuit. The anodes of each tube are connected together and through the anode source 21 to ground, this source having the usual bypass condenser 22.

Gun control electrodes 16 are connected together through a pair of radio frequency chokes 36, the connection between them being grounded through a bias assembly 37, and the input is given to the grids through blocking condenser 39. The two grids are also supplied with radio frequency excitation from a master oscillator 40 through excitation condensers 41—41. It will thus be seen that energy from the master oscillator 40 is supplied to the two multipactors in

push-pull through condensers 41, whereas the modulation is supplied through condenser 39 to both multipactors in parallel. Gun emitters 14 are heated in any convenient manner, connected together, and their midpoint grounded.

While the multipactors may be excited as amplifiers from any type of master oscillator, it is of course entirely possible and obvious that this master oscillator may be an oscillator of the multipactor type previously described herein.

Considering only the fundamental structure of the multipactor herein described, namely, an axial anode of small diameter, and a cathode surrounding the anode, I have found that such an arrangement alone is an effective oscillator. All that is necessary to cause the tube to break into self-oscillation is to apply the anode potential to the anode and then adjust either the anode potential or the tuning of the resonant circuit connecting anode and cathode, so that the time of flight of an electrode between cathode surface impacts is a complete period, two complete periods, three complete periods, etc., but I usually prefer to adjust the anode potential and the resonant circuit so that the whole period is approximately equal to the time of flight of the electrons between cathode impacts. The tube starts oscillating immediately without the use of the gun described herein, probably because there are sufficient free electrons within the space bounded by the cathode so that multiple impacts may be initiated.

Starting with the cathode surface, therefore, and supposing that a few electrons are released from some point on the cathode surface, perhaps by impact by a free electron, these will be attracted to the anode and will require approximately the time of one half cycle to reach this point, due to the adjustment of the anode potential. If the phase of the potential developed in the oscillating circuit by the electron flow from the cathode is correct, this potential will reverse after the electrons pass through the anode spiral, so that this potential will still be effective to accelerate the electrons during the remainder of the journey across the tube, and they will cause secondary electrons to be emitted by impact with the opposite cathode surface. These electrons, greater in number than the originals, will repeat their flight through the central portion of the tube to again contact the opposite cathode surface.

It will be seen, however, that in the type of structure shown in the illustrations herein, the anode occupies a considerable space within the cathode. Under these circumstances I have found that when the anode encloses a substantial amount of space, such multipactors are relatively inefficient when given the adjustment where the electron flight time equals approximately one period. Since the electrons spend most of their time in an equipotential space, the conditions for efficient energy transfer are poor, only a small amount of energy being transferred at the beginning and end of their trip, when the oscillating voltage is necessarily low.

In the particular type of structure shown it is preferable, therefore, to make the electron time of flight quite short in comparison with the period. The multiplication period then starts when the cathode is at the greatest negative potential, so that for each succeeding trip it becomes less negative. The multiplication period ends when the cathode is at its maximum positive potential, after which the electrons are collected on the anode. The high efficiency obtainable with this mode of operation is due to the fact that the space current across the tube has appreciable value only during the interval when the cathode and anode are nearly at the same voltage. It is therefore to be understood that I may use both modes of operation without departing from the spirit of my invention, depending upon the anode structure utilized in the tube.

With this form of tube and circuit there will therefore be an electron cloud starting all around the inner surface of the cathode cylinder and traveling radial paths in all directions through the space bounded by the anode, passing each other in that space, and continuing through the space to impact a point substantially diametrically opposite that from which it started.

Due to the fact, however, that the anode is not linear, but occupies a substantial space in the center of the cylinder, not all the electrons will travel in paths which are exactly radial or diametrical, but will travel in a path which is tangential to a circle whose radius is equal to the distance of the path from the axis of the tube at that point. The anode, being of open mesh, interferes to a minimum degree with the passage of electrons, and oscillations will build up within the tube until the equilibrium point is reached, where the output is balanced by the multiplication obtained.

The two-electrode type of tube differs from the three-electrode type, as has been described in my prior application and patents, in that it derives energy from the D. C. source but once in each cycle, whereas the three-electrode tubes derive the energy from this source twice in each cycle.

The use of the electron gun in conjunction with this two-electrode oscillator greatly enhances the value of the tube, in that it forms a means whereby the oscillation and multiplication of the tube may be controlled. For example, when used as a straight oscillator, a gun current of 1 or 2 milliamperes greatly improves and stabilizes the operation of the tube, in that it is not necessary for the oscillation to build up from the free electrons in the interior. It will be seen that the gun anode is directly attached to the multipactor anode, and therefore is at the same potential. No extra energization is needed, and the fact that the multipactor portion of the device can be made to operate as a linear multiplier, makes this form of device extremely valuable for power amplification, as has been described with the tube as connected in push-pull operation in Figure 4. It is obvious however that a primary oscillator may be modulated if desired by varying the gun current.

In adjusting the multipactor for use as an amplifier, the frequency of the tuned circuit 32 is adjusted so that the tubes are incapable of sustaining self-oscillations without the use of the gun current; in other words, the multiplication in a one-half period is not sufficient to build up enough current in that time. In this condition the tubes are extremely sensitive electron multipliers, so that the output current of the tube is directly proportional to the gun beam current.

Accordingly, the radio frequency output is also proportional to the beam current, and since the tube current builds up from the beam current to the final value at each period, we have the conditions for an R. F. amplifier. Therefore, if we control the beam current through its control electrode from a master oscillator, we have provided a high efficiency R. F. power amplifier. Furthermore, the output of the amplifier may be further

modulated by simultaneously modulating the average bias on the control electrodes of the guns; thus the tube may be used for the transmission of voice-modulated radio frequency or television signals. Of course, any modulation of a frequency differing from that of the master oscillator may be applied through the grids of the guns.

It will be noted that I have shown means for cooling the cathode, because in this type of tube it is only the cathode which heats, due to the repeated electron impacts, and as most of the surfaces which are capable of emitting secondary electrons at a ratio greater than unity, upon electron impact, are relatively soft materials, it is desirable to keep the temperatures from running too high during operation.

The tube I have described is ideally adapted for such cooling by the placing of a water jacket 42 around it to form a cooling chamber 44 through which a cooling fluid may be circulated during operation. It should be noted that there are considerable advantages, from a construction point of view, to cooling the cathode in a tube of this sort rather than the anode in high powered tubes of the thermionic type, because it is not necessary to insulate for the high positive anode potential; and, in fact, the convolutions of the tuning inductance 32 can be made hollow and utilized for carrying fluid to and from the cathodes, thus eliminating any need for insulation, the fluid entering and leaving at the midpoint 34.

In view of the fact, therefore, as explained above, that the electron gun may be considered as merely an adjunct to increase the usefulness of the two-electrode multipactor, I do not wish to be limited in any way to a combination wherein this electron gun is deemed essential, as there are, in point of fact, many other ways of controlling the output of such an oscillator; and there are, if desired, other ways of supplying, into the space controlled by the cathode, more electrons than would normally be present as free electrons. For example, a simple fundamental anode may be used; light may be introduced through the glass end of the tube, and the active cathode surface be so treated that it is photoelectric, and the photoelectrons utilized for controlling the output of the tube as an amplifier; in this case the light may be modulated.

The broad invention disclosed and claimed herein is a means and method for creating electron multiplication in a tube wherein there are two simple electrodes, neither one of which is thermionically active, namely, a cold anode and a cold cathode; and for controlling the multiplication, either by causing the tube to be self-excited or by causing it to become a linear amplifier of an introduced electron stream, and then controlling the amount of such introduction.

I claim:

1. In combination, a pair of multipactor tubes each having an envelope, anode and a cathode capable of emitting secondary electrons at a ratio greater than unity disposed around said anode, said anodes being connected together and through a power source, a resonant circuit connecting said cathodes, said resonant circuit being centrally connected to the other end of said power source, means associated with each tube for projecting a stream of electrons into the space bounded by said cathodes, and means for varying said stream cyclically in opposite phase.

2. In combination, a pair of multipactor tubes each having an envelope, anode and a cathode capable of emitting secondary electrons at a ratio greater than unity disposed around said anode, said anodes being connected together and through a power source, a resonant circuit connecting said cathodes, said resonant circuit being centrally connected to the other end of said power source, means associated with each tube for projecting a stream of electrons into the space bounded by said cathodes, means for varying said stream cyclically in opposite phase, and additional means for varying both of said streams in phase.

3. In combination, a pair of multipactor tubes each having an envelope, anode and a cathode capable of emitting secondary electrons at a ratio greater than unity disposed around said anode, said anodes being connected together and through a power source, a resonant circuit connecting said cathodes, said resonant circuit being centrally connected to the other end of said power source, an electron gun comprising an anode, cathode and control grid in each tube positioned to project a stream of electrons into the space bounded by said cathodes, means for cyclically varying the potential on the gun grids in opposite phase, and additional means for simultaneously varying the potential on said gun grids in the same phase and in like amount.

4. The method of electron multiplication in a tube containing a single cathode surface capable of emitting secondary electrons at a ratio greater than unity, which comprises initiating a stream of primary electrons, applying a potential to said electrons to cause oscillation of said electrons between various portions of said single surface until impact occurs therewith, producing secondaries, and continuing the application of said potential to the combined and augmented electron cloud.

5. The method of electron multiplication in a tube containing a single cathode surface capable of emitting secondary electrons at a ratio greater than unity, which comprises initiating a stream of primary electrons, applying a potential to said electrons to cause oscillation of said electrons between various portions of said single surface until impact occurs therewith, producing secondaries, continuing the application of said potential to the combined and augmented electron cloud, and withdrawing from said tube a portion of said cloud during each oscillation.

6. The method of electron multiplication in a tube containing a single cathode surface capable of emitting secondary electrons at a ratio greater than unity, which comprises initiating a stream of primary electrons, applying a potential to said electrons to cause oscillation of said electrons between various portions of said single surface until impact occurs therewith, producing secondaries, continuing the application of said potential to the combined and augmented electron cloud, withdrawing from said tube a portion of said cloud during each oscillation, and utilizing energy withdrawn to maintain said oscillation.

7. In combination, an envelope enclosing an anode and a copper cathode disposed around said anode, said cathode having an applied surface of a metal capable of emitting secondry electrons at a ratio greater than unity, said surface being exposed to said anode, and a resonant circuit connecting said anode and cathode, said cathode forming a portion of said envelope.

PHILO T. FARNSWORTH.