Dec. 20, 1938. P. T. FARNSWORTH 2,140,832

MEANS AND METHOD OF CONTROLLING ELECTRON MULTIPLIERS

Filed May 16, 1936 2 Sheets-Sheet 1

Fig. 1.

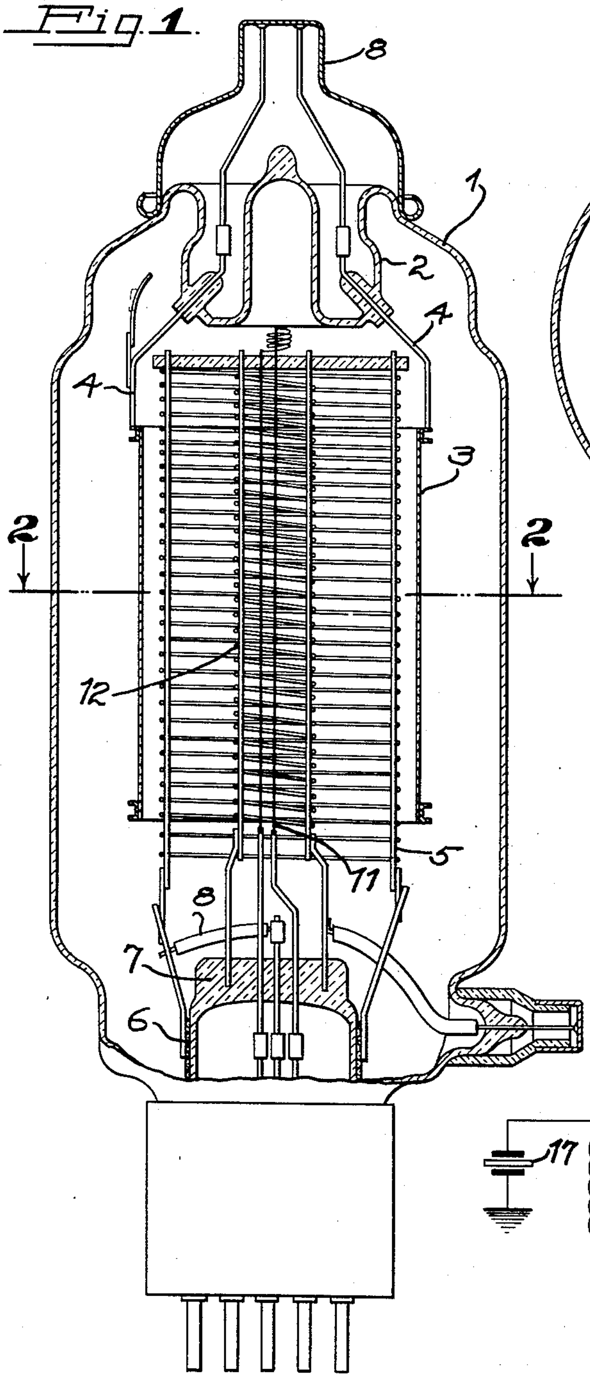


Fig. 2.

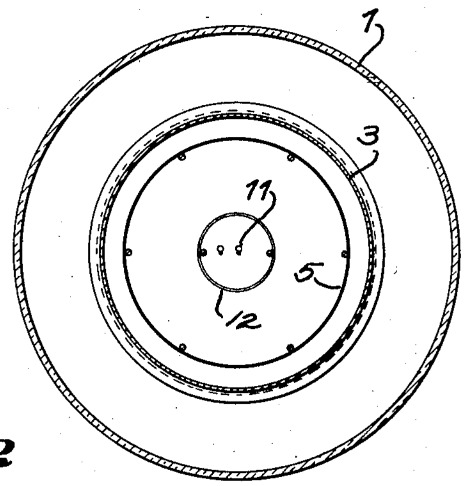
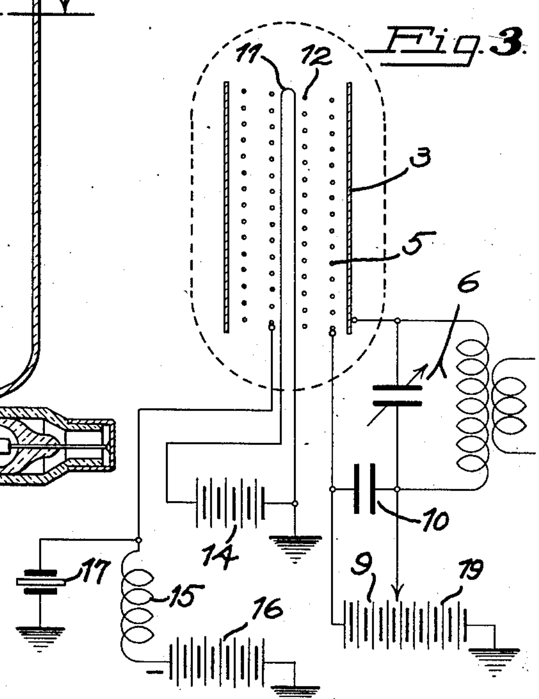


Fig. 3.



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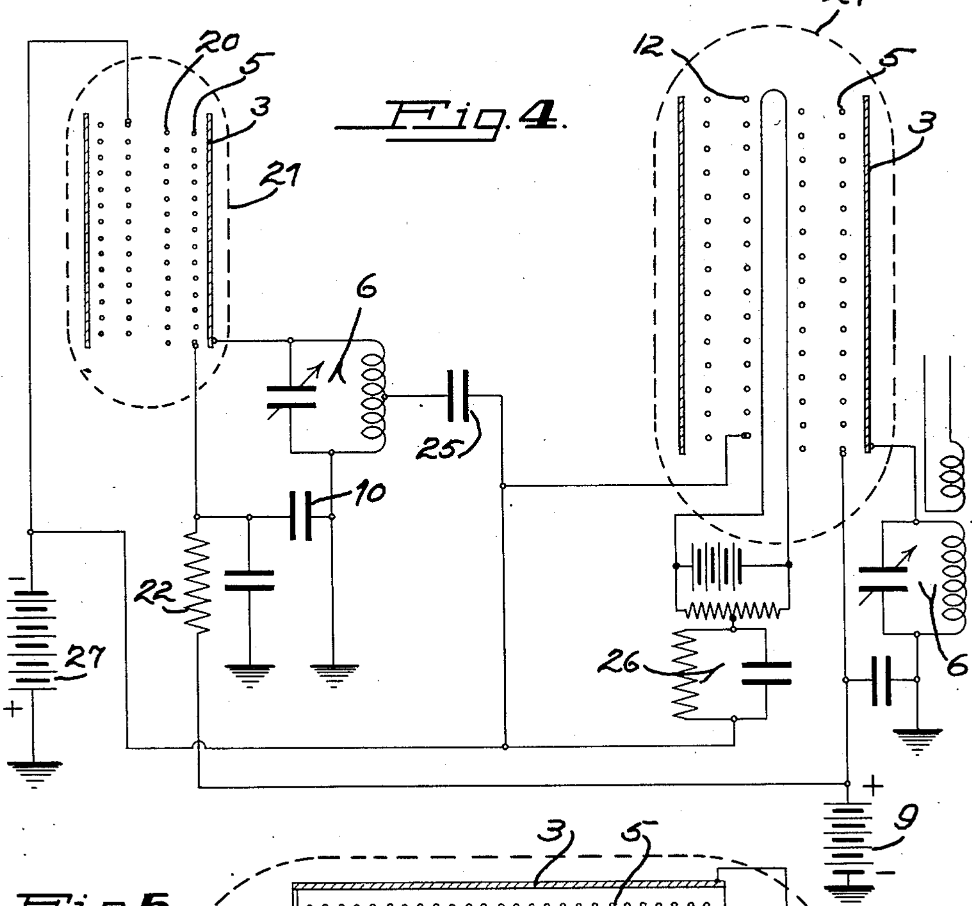

Fig. 4.

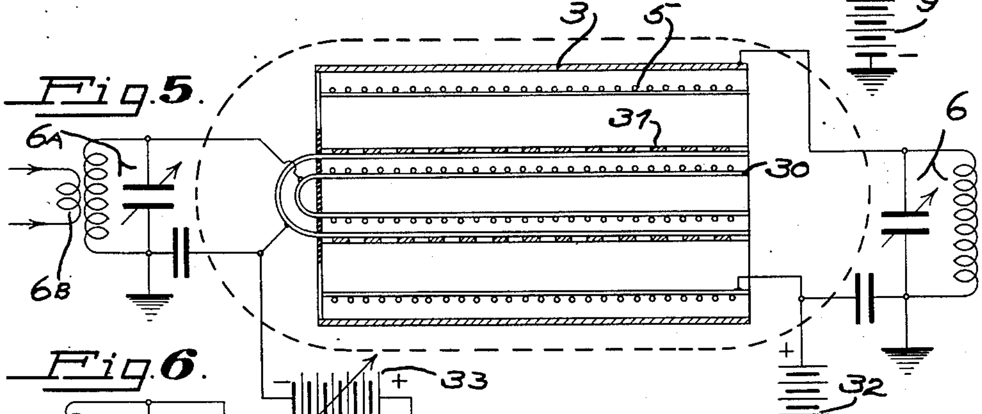

Fig. 5.

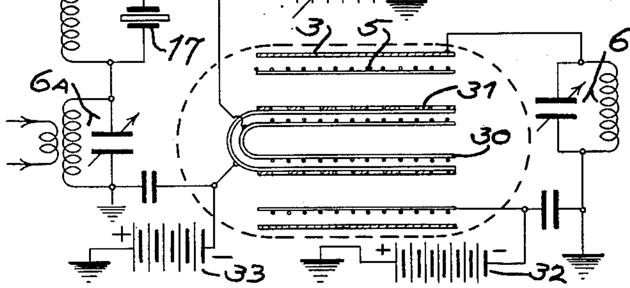

Fig. 6.

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MEANS AND METHOD OF CONTROLLING ELECTRON MULTIPLIERS

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Application May 16, 1936, Serial No. 80,193

3 Claims. (Cl. 250—36)

My invention relates to electron multipliers, and more particularly to electron multipliers wherein frequency and output may be controlled.

In my prior application, Serial No. 67,890 filed March 9, 1936, I have described a type of electron multiplier or multipactor having a unipotential surface adapted to emit secondary electrons upon impact, and an anode, the two being connected by a resonant circuit. This tube, when the anode is supplied with potential, is a self-oscillator. The same structure, when operated with an input stream of electrons under control, may also be used as a class C amplifier, and the output modulated by modulation of the input; in other words, the multiplier structure becomes a radio frequency amplifier.

The present application deals with a multipactor system having various input circuits, and also deals with the problem of removing positive ions from the neighborhood of the oscillating electron stream. I may desire to utilize a single simple electrode for removing the positive ions. In other cases, however, I may desire to utilize an entire complex input structure to remove these electrons. In all cases I have provided a system where large power outputs may be taken from a multipactor.

It is therefore the main object of my invention to provide a power multipactor capable of being used for the generation of high frequency currents in large amounts, although it is to be understood that the present invention is in no way limited to use with high power tubes, the same principles involved being fully applicable to tubes of any power.

Among other objects of my invention are: To provide a means and method of abstracting positive ions from an electron multiplier; to provide a means and method of controlling the input to an electron multiplier acting as a radio frequency amplifier; to provide a multi-stage electron multiplier; to provide a means and method of frequency stabilization in an electron multiplier; and to provide a simple and efficient electron multiplier and circuit therefor.

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 longitudinal sectional view, partly in elevation, of one preferred form of a controlled input multipactor.

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

Figure 3 is a circuit diagram, reduced to lowest terms, showing how the tube of Figure 1 may be connected as a frequency-stabilized device.

Figure 4 is a circuit diagram showing how a pair of multipactors may be utilized for the production of high frequency.

Figure 5 is a circuit diagram of a two-stage multipactor and circuit therefor.

Figure 6 is a circuit similar to Figure 5, the input stage in this circuit being crystal controlled.

In the following discussion the term "piezo electric crystal" shall be deemed a term including all other devices capable of controlling frequency by reason of their physical reaction to electricity, and include as full equivalents, magneto-strictors.

The feature common to all of the structures and circuits herein to be described is an element or assembly of elements, positioned with respect to the stream of electrons, in an electron multiplier which is, when properly energized, able to remove ions from the electron stream.

The fundamental structure of a two-electrode multipactor has been described by me before in the application referred to above, and referring directly to the drawings, Figure 1 shows a typical example of the two-electrode multiplier structure, with the addition of other elements.

An envelope 1 is provided at one end with a reentrant stem 2 to which a cylindrical element 3 is attached by supports 4. Element 3 will be hereafter called a cathode because it is so formed that it will emit secondary electrons at a ratio greater than unity when impacted with electrons traveling at proper velocities. The nature of this electrode may be varied considerably, and I have found, for example, that when the inside surface thereof is coated with any of the alkali metals, such as sodium, potassium or caesium, secondary electrons can be produced therefrom at a 1–1 ratio by electron velocities of around twenty volts.

I have further found that coatings of barium, strontium and thorium produce substantially the same results, and I prefer, for ease of manufacture, in many cases to utilize for the entire electrode an alloy of nickel and barium which, when processed by heating to a bright red heat in vacuo, becomes sensitized for secondary emission, probably through the distillation out of the interior, of barium, either with or without a surface coating of oxide. The process of sensitizing nickel-barium alloys has been described by me in my prior application, Serial No. 70,714, filed March 24, 1936.

Concentrically arranged within the cylindrical cathode is an accelerating electrode or anode 5. This anode is usually built in the form of a grid but its exact construction is not important except that it should be apertured to allow electrons to pass therethrough, and preferably should be, for high power tubes, either of tantalum or tungsten to withstand electron impact.

The anode is supported by a band 6 on an opposing stem 7 and a lead 8 brought out to the outside of the tube. The cathode leads 4 are in like manner brought out and attached to a cap 8 at the other end of the tube. These two structures alone, namely, cathode 3 and anode 5, constitute a multipactor oscillator and may be hooked up as shown in Figure 3, where the cathode 3 is connected to anode 5 by a resonant circuit 6, the anode being energized by anode source 9, the latter being by-passed by a condenser 10.

The device may be operated in two ways, either in a manner where the time of flight of the electron coincides with the frequency of resonant circuit 6, or where the time of flight of the electron is short with respect to the frequency of resonant circuit 6. This is controlled by the adjustment of source 9, and it is possible to make the electrons themselves make numerous trips to and from cathode 3 during a single change in maximum potential between electrodes 3 and 5. In this case I prefer the latter method, as a greater output current is built up per cycle. These two modes of operation will be more fully discussed in a copending application.

If, however, the number of multiplying impacts is limited so that current within the multipactor cannot build up to space charge equilibrium, the output current will be linearly proportional to an initial electron current. This fact enables the multipactor to be used as a linear radio frequency amplifier, and in the tube shown in Figure 1 I have disclosed, axially located within the anode 5, a thermionic filament 11 surrounded by a control grid 12, the latter being of a mesh commensurate with the control desired. The filament need not be capable of supplying more than a few milliamperes, and it is desirable in many cases that the grid be biased for class C operation so that current pulses of short duration are supplied to the multipactor.

Referring again to Figure 3, the filament 11 is energized by a battery 14, one end of which is grounded, and the grid is energized with radio frequency through input impedance 15 and biased by battery 16.

In case it is desired that the output be stabilized in frequency, I prefer to use a frequency stabilizing element 17 connected in the grid circuit, and tune the input circuit to the frequency of the output resonant circuit 6. As stated above, frequency stabilizing element 17 may be a piezoelectric crystal, a magneto strictor, or equivalent device.

Examining the circuit of Figure 3 more fully, it will be seen that there is a portion 19 of anode source 9 between the anode-cathode combination and ground, and that the entire combination of filament 11 and grid 12 is negative to all portions of the anode-cathode combination. This is done for the purpose of positive ion control.

Examining more fully the simple multipactor comprising the combination of cathode 3 and anode 5, together with their operating circuits, it will be seen that there are several limitations in the creation of high power outputs: First, the cathode is at all times during operation, subject to severe positive ion bombardment which would tend to disintegrate or harm the secondary emission surface if power were to be raised above a certain level; second, since in this particular structure the cathode completely incloses the anode, all energy dissipated in the anode must be radiated by the cathode. While these types of tubes have an extremely high anode conversion efficiency, nevertheless if they are designed for high power output, heat presents a problem.

The first problem, that of ionic bombardment, has been substantially reduced by the use of the higher melting point secondary emitters, such as barium and thorium, and by the use of the additional structure energized negatively with respect to the other structures so that most of the ions within the multipactor travel toward and are collected by the central structure. The cathode surface is therefore protected from positive ion bombardment and high power outputs may be obtained. Furthermore, reverse currents are removed from the oscillating structure, giving rise to a greater efficiency, because positive ions are slow and when they arrive on the cathode there is no assurance that they will arrive in any synchronism with the multiplying electrons. They will usually strike with sufficient energy to create secondaries themselves, which become electron currents of random phase, at least for a time until they are collected. The use of the ion control structure, therefore, not only prevents cathode bombardment but reduces anode heating and out-of-phase components.

While I have described the ion control structure as being, in the above case, a composite structure comprising filament and grid, the multipactor may be used as a primary oscillator, not as an amplifier, and the ion collector in this case may be any conveniently located electrode, such as indicated diagrammatically by ion electrode 20, shown in tube 21 in Figure 4. Here, the same output circuit 6 is used as in Figure 3 with the exception that the anode 5 is energized through a resistor 22 from anode source 9, which in this case also energizes anode 5 of tube 24, which is similar in all respects to the tube described in Figure 5. In this case, however, the output of the oscillator tube 21 is led to grid 12 of tube 24 through a blocking condenser 25. Grid 12 is also provided with its operating bias through biasing assembly 26 and grid 12; and tube 24, and ion electrode 20 in tube 21, are both supplied with negative potential for ion collection from collection source 27, preferably made variable. The circuit in Figure 4, therefore, as it stands, amounts to a master oscillator multipactor tube 21, connected to energize and control the input of multipactor tube 25 acting as a radio frequency amplifier, the output of which may be utilized from circuit 6 attached to tube 24.

In Figures 5 and 6, I have shown another embodiment where the input to the final multipactor is a multipactor itself embodied within the same tube. The tube therefore becomes a multistage multipactor.

Referring directly then to Figure 5, the innermost electrode in this particular electrode setup is an open mesh input multipactor anode 30, surrounded by a perforated secondary emission input cathode 31. This multipactor is provided with a multipactor input circuit 6A which may be driven by radio frequency through coil 6B, or the multipactor may be a self-oscillator. In either case the input multipactor builds up a current from zero once each radio frequency period, and current flows through the meshes of input cathode 31 into the second multiplier stage comprising the cathode 3 and anode 5, which are supplied with their usual output circuit 6. Anode source for the input multipactor, added to input anode source 33, maintains the input structure at a negative potential to the output structure, thus resulting in ion collection.

Operating in this manner, the current flowing in the input multipactor will have appreciable value only for a very small portion of the frequency period. Passed into the output multipactor, it may be there multiplied as many times as desired up to the point where power dissipation limits the output. The input impedance of the first multipactor may have any desired value from a fairly low positive resistance through infinity to a fairly low negative resistance. Therefore, the first multipactor may be used as an oscillator or may be crystal controlled, as shown in Figure 6, by the addition of the control circuit including stabilizing element 17, so that the tube will serve as a complete transmitter, if required.

Tubes such as have been described produce a power amplification which is very high, and all of them have the common advantage that a large power output may be varied by the application of a relatively small amount of energy at the input. This also is of great advantage in crystal control because the crystal has to handle very little power.

I have therefore provided means and a method of greatly increasing the effective power output of electron multipliers, placing their advantages in such relationship that they may be used in practical operation of radio frequency transmitters requiring high power outputs. The simplicity of the circuits and tubes I have described is obvious. For example, a tube, such as shown in Figures 1 and 5, may be operated to produce 600 watts as an oscillator and 1000 watts as an amplifier, where the outside cathode 3 is not over three inches in diameter and five inches long. With full power operation the individual wires of anode 5 operate with not greater than at a dull red glow, which in no way interferes with the operation of the tube, particularly if high melting point surfaces, such as barium surfaces, are used on the cathodes.

Furthermore, there is an additional advantage inherent in the use of an ion control electrode per se, irrespective of whether or not it is accompanied by auxiliary structures ancillary to the operation of the device as a whole, and that is that by varying the negative potential on the ion collector structure, the path of the electrons in the output multipactor may be changed. In other words, if the negative potential is low, electrons will leave the cathode 3, pass through the apertures in anode 5, approach the ion collector and return to the cathode through the meshes of the anode. If the ion collector were not present, electrons would pass either directly or tangentially across the tube to impact the cathode at an opposing point. However, the ion control electrode causes them to return to the cathode near the point where they were emitted, and furthermore, the distance toward the center that the electrons may penetrate may be changed by changing the potential on the ion control electrode to give any desired length of path, and any desired transit time. In other words, any desired number of impacts per cycle can be obtained within the voltage limits utilized.

I claim:

1. In a medium containing positive ions, the method of electron multiplication which comprises causing electron emission from a substantially equipotential surface, withdrawing the emitted electrons into the space bounded by said surface, re-accelerating electrons from said space against said surface to cause secondary emission therefrom at a ratio greater than unity, collecting at least a portion of the secondaries produced, and meanwhile abstracting positive ions from the space bounded by said surface.

2. In a medium containing positive ions, the method of electron multiplication which comprises causing electron emission from a substantially equipotential surface, withdrawing the emitted electrons into the space bounded by said surface, re-accelerating electrons from said space against said surface to cause secondary emission therefrom at a ratio greater than unity, collecting at least a portion of the secondaries produced, and absorbing positive ions from the path of said electrons during the interval between impacts with said surface.

3. An electrical discharge tube comprising an envelope containing a cylindrical cathode having its inner surface sensitized to produce secondary electrons at a ratio greater than unity upon electron impact therewith, an apertured anode positioned within and concentric with said cathode, an oscillatory circuit connecting said anode and cathode including means for energizing said anode to a positive potential with respect to said cathode, an apertured cylindrical electrode positioned within said anode and co-axial therewith, a thermionic emitter positioned within said apertured cylindrical electrode, a piezoelectric frequency stabilizing circuit including a source of negative potential for said cylindrical electrode connecting said thermionic emitter and said cylindrical electrode, and means for maintaining both anode and cathode at a positive potential with respect to said emitter.

PHILO T. FARNSWORTH.