Sept. 8, 1942. R. H. GEORGE 2,295,396

ELECTRONIC DEVICE

Filed Oct. 7, 1939 2 Sheets-Sheet 1

Fig. 1

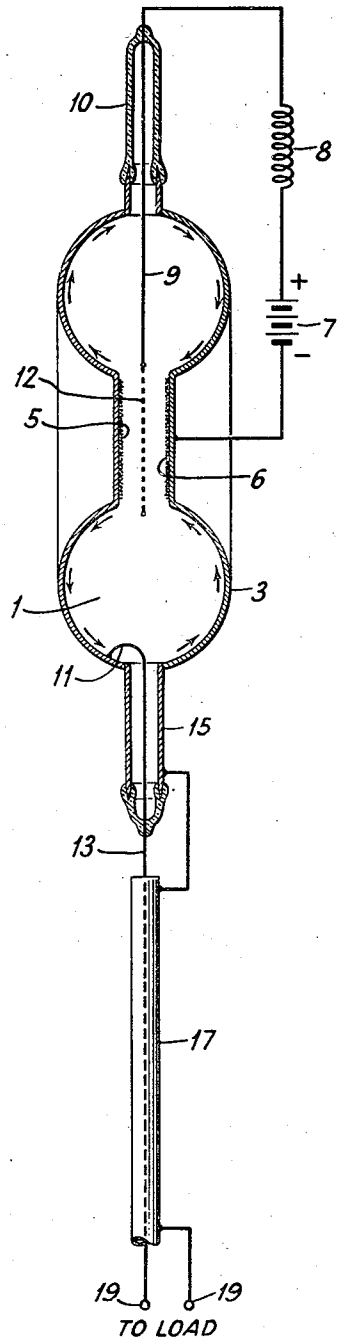
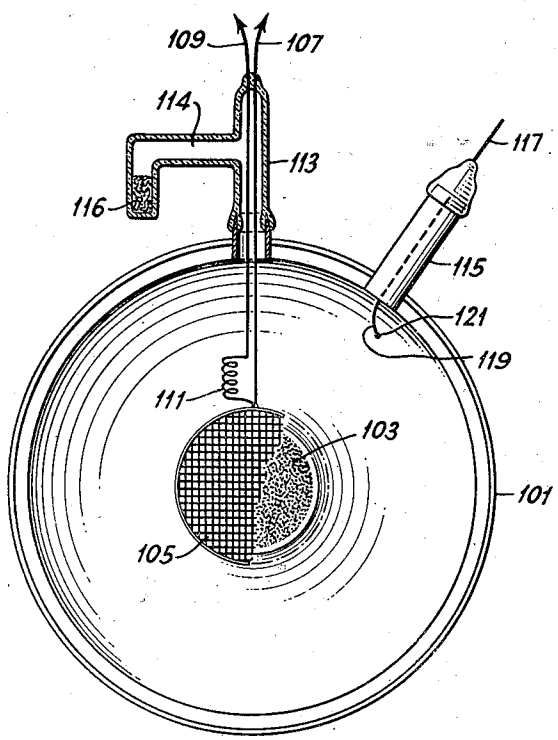


Fig. 3



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Fig. 2

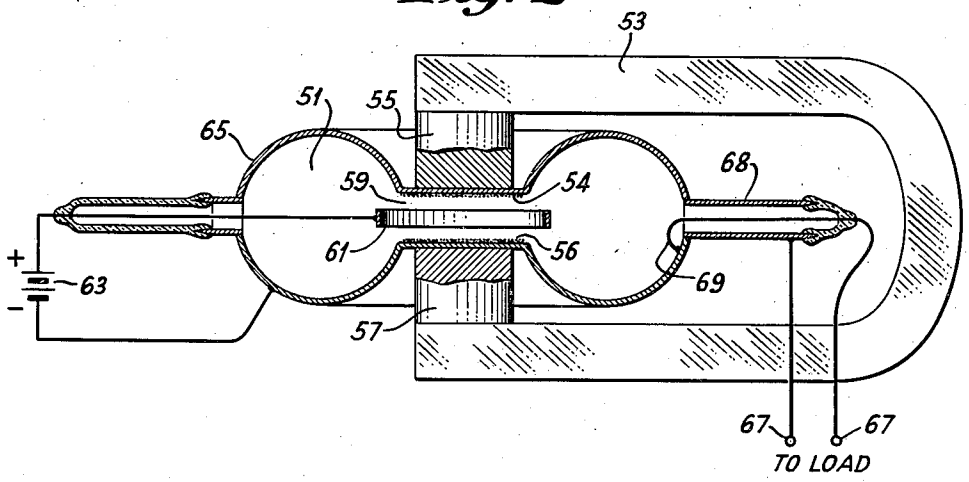
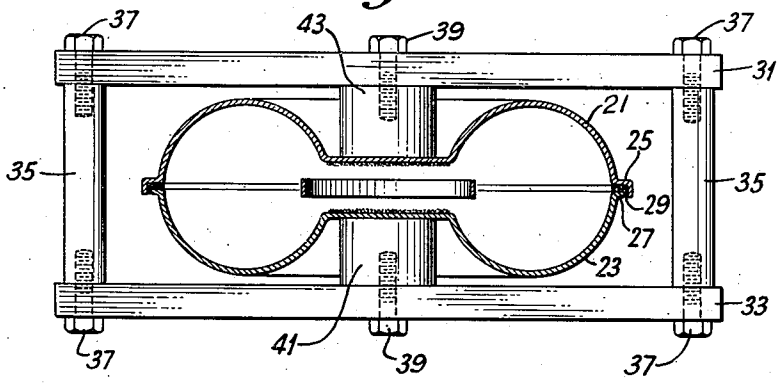


Fig. 4



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UNITED STATES PATENT OFFICE

2,295,396

ELECTRONIC DEVICE

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Application October 7, 1939, Serial No. 298,365

5 Claims. (Cl. 250—27.5)

This invention relates to electronic devices and in particular to electronic devices designed for operation at exceedingly high frequencies. In one modification of the invention, a tube of the general type known as an electronic multiplier is provided. This tube is capable of efficiently and simply producing relatively large oscillatory power at frequencies of the order of 1000 megacycles, for instance. By some slight modification of the tube, this invention relates to a method of using a tube of the above and later to be described type as a detector, amplifier or modulator of ultra-high frequencies with considerable increase in efficiency over the efficiencies now known to those skilled in the art.

Using the term "dynamic multiplier" it will be understood that the invention relates to tubes of the type which make use of secondary electron emission in which the primary and secondary electrons may occupy the same space and traverse substantially the same paths, which paths may be in the same or in opposite directions, and the change in path from primary to secondary status occurs sequentially.

The type of tube provided by applicant is a hollow metal structure of substantially toroidal or doughnut shape except that instead of having a hole through the center of the toroid, the tube provides a continuous surface having a flattened central portion on either side of a plane normal to the axis of revolution, which plane bisects the generated surface. On the interior of the hollow tube so provided, the flattened portions or plateaus formed from the above described continuous surface portion, are suitably treated so as to provide an efficient secondary electron emissive surface. Lying in the plane bisecting the tube, as above described, is a circular electrode positioned symmetrically and in register with the two flattened plateau portions. By supplying positive potential to the circular electrode from a source, whose negative pole is connected to the wall of the metal tube, electrons in the region of the flattened or plateau sections are accelerated toward the central electrode. This electrode, which functions as an anode, is electron permeable, and preferably is a perforated or open structure. The applied voltage causes the electrons to be accelerated so rapidly as to provide exceedingly high electron velocity so that the electron stream overshoots the anode and, in fact, reaches or impinges upon the opposite plateau surface to eject therefrom secondary electrons also. These secondary electrons, in turn, are accelerated by the central electrode in a similar fashion so that they, in turn, reach the first named surface and each of these secondary electrons now ejects from the impacted surface more secondary electrons. The process, therefore, continues to build up and the cloud of electrons passing from one plateau to the other sets up an oscillatory current in the shell of the metal tube itself so that the resultant current path is from the plateau around the circular portion of the tube to the other plateau. By suitably affixing a small loop of wire within the tube, inductive coupling is provided which enables a load circuit to be supplied with the oscillatory current from a pair of conductors connected to the loop and to the metal shell or wall of the tube proper. It will thus be appreciated that a very simple structure is provided by the invention, which structure permits the efficient generation of ultra-high frequencies of a stable frequency which is determined by the geometry of the metal tube itself.

It should be noted that since the tube and electrode present a symmetrical structure, substantially equal accelerating and decelerating fields are provided. However, the movement of the electrons produces a flow of current in the metal shell and, in so doing, produces a potential rise in the direction of movement of the electron between the two plateaus. This potential, in turn, sets up an accelerating field which when added to the initial accelerating field gives the electrons sufficient terminal velocity to eject secondary electrons.

In some instances, shock excitation may be applied to the tube to set up an oscillating potential wave between the two plateaus to aid the acceleration of the electrons. Due to the high Q resonant circuit provided by the tube's geometry, the induced oscillations have relatively large amplitude and will persist for a relatively long period, enabling the electron stream to attain its optimum value.

Due to the fact that the form of the structure can be likened to a loop with capacity loading generating a surface of revolution, an exceedingly high Q circuit results. This makes possible the easy generation of extremely high or ultra-high frequency oscillations.

The invention, therefore, provides a major step forward in the communication field, for example, by being able to generate at high efficiency relatively large units of oscillatory energy at exceedingly high frequencies.

In the past, to produce ultra-high frequency energy of the same order of frequency as the

invention can provide, exceedingly complicated devices were required. These devices were recognized as quite inefficient so that while it was possible to generate frequencies on the order of 1000 megacycles, the actual amount of power which could be so produced did not exceed a few watts.

By this invention, however, useful high or ultra-high frequency energy on the order of one kilowatt or more may be readily produced. Accordingly, the main object of this invention is to produce a more efficient generator of ultra-high frequencies of relatively large power output and stable frequency.

Another object of the invention is to produce a new type of metal electronic tube useful as an oscillator, modulator, amplifier or detector of ultra-high frequencies.

A further object of the invention is to provide a hollow metal electronic tube for producing ultra-high frequency oscillations of a stable frequency, which frequency shall be determined primarily by the dimensions or geometry of the metal tube proper.

A further object of the invention is to provide a new method of making dynamic multiplier tubes.

A further object of the invention is to provide an ultra-high frequency oscillator having large power output at stable frequency which may be suitable for use in radio relay transmitters and particularly for wave guide transmission systems.

Other objects of the invention are to produce an ultra high frequency oscillator of high efficiency and output and of stable frequency which can be easily frequency modulated mechanically, together with other objects which will become more apparent upon reading the detailed description following, taken together with the drawings in which Figure 1 shows diagrammatically the tube embodying the invention together with circuit connections thereto when the tube is used as an oscillator.

Figure 2 shows the electronic magnetic modification of the embodiment of my invention in Figure 1. Figure 3 shows a section view of a tube embodying the invention, while Figure 4 shows a jig suitable for use during the fabrication and processing of the tube disclosed in this invention.

Turning now to the drawings, the invention will be described in detail:

Figure 1 shows the toroidal doughnut shape metal tube, the main body 3 of which may be made of any suitable metal such as copper, silver, suitable plated "Svea" metal, aluminum, or any suitable metal which shall have relatively high conductivity, at least moderate mechanical strength and mechanical working properties. The interior of the plateaus 5 and 6 are so treated as to provide a highly efficient secondary electron emissive surface. Affixed symmetrically to one end of the tube is an insulating tube 10 through which a conductor 9 passes. At the end of the conductor 9 is attached electron permeable electrode 12 serving as an anode. The electrode 12 may be a thin perforated disc or may be a mesh-like structure such as shown as element 105 in Figure 3. The mesh is preferably a coarse one made with relatively fine wires in order that the electrons shall not be impeded in their passage from plateau 5 to the other (opposite) plateau 6. Positive potential from the source 7 is supplied to the anode 12 through the serially connected inductance or choke 8 while the negative pole of the source is connected directly to tube metal wall 3. Output energy is obtained by affixing within the tube a small loop 11 to the wall 3 to which loop is connected a conductor 13 which passes through a metal tube 15 sealed to the tube 1. The conductor 13 is suitably insulated from the tube 15. As shown by the drawing, a coaxial cable 17 is supplied to feed the output energy picked up inductively by the loop 11 to the terminals 19 for transferring the oscillatory energy developed within the tube to any suitable load circuit.

As also described above, the electrons in the region of the surface 6, for example, are accelerated by electrode 12 to such a high velocity that they pass through the interstices of the mesh and impact upon the surface 5 to release therefrom secondary electrons. By suitably preparing and sensitizing the surfaces 5 and 6, it is possible to obtain a very high ratio of released secondary electrons for each primary electron impacted upon the prepared surface and this ratio while usually of the order of 4 or 5 to 1, may be greatly increased by surface treatment and characteristics. The secondary electrons so ejected are, in turn, accelerated in the direction of the electrode 12 and these secondary electrons, after passing through the interstices of the grid, impact upon the surface 6, each of which then ejects a large number of secondary electrons; whereupon the newly ejected secondary electrons are, in turn, impacted upon the surface 5 so that there results a rapidly increasing flow of electrons in the space intermediate the two plateaus 5 and 6, the magnitude of the electron cloud being limited finally by space charge considerations.

The impacting of the cloud of electrons, however, upon surface 5, for example, causes current to flow through the conducting wall of the tube 3 along the path indicated by the arrows back to the plateau 6. Following the electronic impact on surface 5 and the reverse flight of the cloud of electrons, which eventually impinge upon the plateau 6, there is a reversal of the flow of current. It will thus be appreciated that an oscillatory current flows along substantially circular paths in the metal wall of the tube. It is this oscillatory flow, of course, which induces current of the same frequency in the loop 11. Since provision is made to connect loop 11 to a load circuit, oscillatory energy may be fed to a load circuit by induction.

It will be readily appreciated that the dimensions of the circular portion of the tube, together with the spacing between the plateaus which fixes the capacity loading, will determine the frequency of the generated oscillations. Also, to some extent, the frequency will be affected by the supplied potential from the source 7. The influence of voltage source 7 on the frequency of the generated oscillations, however, when increased above the threshhold point at which oscillations commence, is quite small, that is to say, there is a region over which the potential source 7 may be varied considerably without producing any substantial change in the frequency of the generated oscillations. Since the form of the tube is a highly efficient one with respect to the distributed capacity and inductance, an exceedingly high Q oscillatory circuit is provided by suitably selecting the metal with respect to its conductivity. The circulating current losses are maintained at a minimum value so that the slightest shock excitation enables the tube to commence oscillating and thereafter the oscillations will be maintained at a stabilized

frequency. Of course, it is not necessary to rely wholly upon the form of the tube shown in Figure 1, since it is possible also to make use of an electromagnetic field acting in conjunction with a superimposed electrostatic field to produce oscillations. Such a modification is shown in Figure 2.

In Figure 2 the same form of the tube 65 is preserved. The tube shape can be described as being substantially that of a torus intersected by two parallel planes which lie symmetrically above the long or the longitudinal axis of the tube 51. Positioned within the tube 51 is an electrode 61 formed from an annular cylinder so as to provide a thin wall ring-like electrode which is positioned symmetrically with respect to the two parallel surfaces 54 and 56. The interior of the parallel surfaces are suitably sensitized so as to provide the desired secondary emission. Appropriate connections from the electrode 61 and the metal wall 65 to an energizing source of energy 63 are provided. Positioned externally to the tube, and in contact with the parallel surfaces 54 and 56, are two pole pieces 55 and 57 which are, in turn, in intimate contact with a fixed magnet 53. The fixed magnet may be formed from one of the modern magnetic alloys (e. g., that known in the art as "Alnico") having a high retentivity and permeability so as to provide a strong magnetic field. The lines of force of the produced field are perpendicular to the parallel surfaces 54 and 56. Frequently, a magnetic shunt may be provided to regulate or control the intensity of the effective magnetic field to provide optimum operating conditions.

A loop 69 makes contact with the interior of the metal wall 65 and an appropriately insulated lead is provided to make connections to a desired load circuit. The lead passes through a metal tube 68 which tube is fastened to the metal wall 65. Connection is provided by the terminals 67 so that current induced in the loop 69 by the oscillatory current between the parallel surfaces 54 and 56 is made available at the output terminals 67. The magnetic field supplied is desirable when used with the ring-like electrode 61 so that the electrons emitted from the sensitized surfaces 54 and 56 will follow substantially parallel paths perpendicular to the surfaces and to avoid having the electrons follow paths directly to the anode 61 which would, of course, tend to reduce the efficiency of operation. The frequency of the generated oscillations again is determined primarily by the dimensions or geometry of the tube 51 and only to a second order by the value of the supplied potential from the source 63. The intensity of the oscillations will depend to some extent upon the strength of the magnetic field supplied by the magnet 53.

It will be appreciated, of course, that an electro-magnet may be substituted for the fixed magnet 53 and that modulation, therefore, of the electron stream between the parallel surfaces 54 and 56 may be effected by varying the intensity of the electromagnetic field.

In Figure 3, which shows a cross-sectional view of a tube similar to that shown in Fig. 1 but at right angles to the plane of the section shown in Fig. 1, certain of the features of the tube are shown in somewhat more detail. The major difference in the showing at Fig. 3 is the fact that the coupling tube connection 115 is spaced from the electron permeable electrode egress tube at an acute angle, while in Fig. 1 the two tubes have a common axis. The parallel surface 103 is shown beyond the grid-like anode electrode 105. The positive potential for electrode 105 is supplied through the conductor 107 which is brought to the interior of the tube through a glass tube 113 sealed to the metal portion of the tube 101. This is usually provided by means which is known in the art as a Housekeeper seal, or, alternatively, Fernico tubes or eyelets and glass beads may be used for making the seals. Seals of the latter type frequently are used in present day construction of metal thermionic tubes in common use.

The loop 119 makes contact with the metal wall of the tube 101 at a point 121. The point at which contact is made may be varied within broad limits and still provide effective coupling to the load or output circuit which is connected to the tube by means of a conductor 117 connected to the loop 119 and a connection to the metal tube 115 from which the lead 117 is insulated.

It is sometimes desirable, in order to expedite and initiate the generation of oscillations within the tube to provide an auxiliary source of light from which light may fall upon the secondary electron emissive surface to eject therefrom electrons, since such surfaces, as a general rule, exhibit photoelectric properties. For this purpose a coil filament 111 is fastened substantially at the junction point of lead 107 and the electrode 105. Connection is made to the other end of the coil filament 111 by means of conductor 109. By connecting an appropriate source of voltage to conductors 107 and 109, the filament 111 may be brought to incandescence to effect emission of photoelectrons from the prepared surface 103. Any electrons so released will then be accelerated by the electrode 105 in such a direction that they impinge upon the secondary electron emissive surface opposite the surface 103. In accordance with the release of secondary electrons and the control thereof, as above explained, oscillations within the tube are developed and sustained.

In constructing an electron tube of the type hereinabove described, it is desirable to provide means for maintaining the component parts of the tube in fixed relation during the processing steps which include, of course, evacuation. It will be readily appreciated that unless some precautions are taken during the evacuation process the difference between atmospheric pressure and the pressure within the tube will result in considerable external force acting upon the two halves of the tube to place the tube in compression causing flexing of the elements and the development thereupon of many harmful and undesirable strains. To avoid these effects a jig is provided which will maintain the component parts of the tube in fixed relation during the processing of the tube. One form of jig is shown in Figure 4. By taking recourse to a jig of this character, the tube may be formed from two spun pieces of copper 21 and 23. The spun half of the tube 23 is provided with a lip 27 while the spun half of the tube 21 is provided with a beaded edge 25, the outermost edge of which is slightly larger in diameter than that of the lip 27.

Metal cylinders 41 and 43 are suitably fastened to the exterior of the parallel surfaces of the tubes in any suitable manner, such as by soldering, brazing or welding. The unfastened end of the cylinders are then suitably drilled and tapped. The height of the cylinders is greater than the height of the tube.

Two rigid metal plates 31 and 33 support the two halves of the tube 21 and 23 and suitable bolts 39 pass through these members and engage with the tapped holes of the cylinders 41 and 43. To rigidly affix the tube portion 21 to the supporting member 31 and the tube portion 23 to the supporting member 33, spacing members 35 are positioned between the two supporting members 31 and 33 and held in position by suitable bolts 37.

It will be appreciated that by this form of construction the two halves of the tube are maintained in fixed relationship to each other independently of the interior pressure thereof.

As will be explained in detail below, with the two halves of the tube so positioned, it is relatively simple to seal the halves by using an appropriate high melting point solder, which can be flowed between the two edges 25 and 27 to form a metal seal 29, and which remains solid during all subsequent baking. In more detail, the processing of the tube is as follows:

The two halves of the tube 21 and 23 may be formed either by punching the sheet metal which may be copper, for example, with an appropriate die or alternatively, by spinning sheet metal in a lathe around an appropriate form. By using the same form but different sizes of sheet metal, the appropriate edges 27 and 25 can easily be provided. The two halves so formed then have the cylindrical portions 43 and 41 affixed thereto and mounted in the jig shown in Figure 4. The tube 113 which may be formed of glass, for example, may then be sealed in place by use of a seal of the Housekeeper type, above referred to, and may be equipped with a side arm 114 containing at the sealed-off end thereof a source of caesium 116. Prior to the placing of the two halves of the tubes together, the anode electrode, as for example 105, may be positioned within the tube together with the filament 111. The conductors 107 and 109 connecting to these elements, project outside the tube so that the glass tube 113 may be slipped thereover.

Having now affixed the tubes 113 and 115, together with electrode 105, the two halves of the tube may now be sealed together as described above by the use of a soldering compound, such as Silfos, silver solder, or the sections may be welded together to provide an airtight container.

It should be mentioned at this point that following the forming of the two halves of the tube and prior to their assembly, it is, of course, desirable to thoroughly clean the interior of the metal in order to make the degassing of the tube somewhat easier. Where the plateau portions of the tube are to be made secondary electron emissive by the use of caesium, it is desirable to treat the interior surface of the tube when using copper so as to prevent the excessive take-up of caesium in the portions of the tube other than the plateau surface. For this purpose a vitreous layer may be placed over the interior of the tube except over the plateau portion or alternatively, the entire interior surface of the tube may be gold plated, the gold layer preventing the copper metal from oxidizing during subsequent processing steps. Where gold plating is resorted to, the plateau portions are silver plated following the gold plating. Where a vitreous coating or enamel is supplied over the interior surface of the tube with the exception of the plateau portions, the plateau portions are silver plated although, naturally, other methods such as sputtering, evaporating, or the like, may be used to provide the desired surface covering of silver. The two halves may then be brought together in a jig for the further steps of the assembly.

Following the assembling of the tube, a high vacuum system is connected either to the metal tube 115 or to the glass tube 113 and evacuation of the tube started. Simultaneously with this, the tube may be heated, as for example by baking. The baking is continued at usual degassing temperature, while the vacuum system is operating to exhaust the tube, until it is evidenced by the pressure within the tube that the tube is thoroughly degassed, as is well known in the prior art and to those skilled in the art.

Oxygen is then introduced into the tube at a lower temperature such as room temperature, and ionized by the usual method to oxidize the silver covered plateau portions of the tube. Thereafter the excess oxygen is evacuated and the side arm 114 is heated to drive over from the source 116, caesium vapor which caesium vapor condenses or deposits upon the silver oxide surface of the plateau. By maintaining the temperature of the tube at approximately 200 degrees C. for an appropriate time period, the caesium forms a highly complex surface with the silver oxide to sensitize the entire surface and render it an efficient emitter of secondary electrons. During the time of this latter period of heating, the evacuating pumps are run continuously so as to remove any excess caesium vapor and following the sensitization of the silver-oxide-caesium surface, the tube is sealed off.

It will be readily appreciated, of course, that the above described steps for providing the efficient secondary emissive surface are substantially the same as that used in the art for preparing such surfaces for photoelectric emission. In the instant application, however, instead of controlling the period of heating the tube for such a length of time as to provide maximum photoelectric sensitivity of the surface the duration of heating is extended to a somewhat longer time period because it has been found that optimum secondary emission occurs when the heating operation is for a longer time period than that which provides optimum photoelectric sensitivity.

It will be further appreciated since it is important to avoid the formation of copper oxide during any of the above described brazing or welding operations, that it is desirable to pump hydrogen into the tube during the operation so as to provide a reducing atmosphere and thus avoid oxidation. The completely processed tube may now be removed from the jig and connected in a suitable circuit to produce oscillation or may be left in the jig while operating.

In view of the fact that a relatively small tube is thus provided which is capable of developing large power output, it will be recognized that it is desirable to supply cooling to the tube in order to avoid destruction of the prepared secondary emissive surface. This cooling may readily be achieved by placing the tube in a cooling medium which may take the form of a simple container with flowing water in which the tube is merely immersed. Likewise suitable fins may be provided on the outer casing for air cooling. It will likewise be recognized that since the tube structure has some of the features of a Sylphon box, the spacing between the opposite plateaus may be varied by application of external pressure. Since this spacing changes the effective capacity of the tube without, however, changing the effective inductance substantially, it will be readily

recognized that mechanical movement of the two plateau surfaces by the application of external forces enables the operator to obtain precise setting of the frequency of the oscillations. For example, a tube having its largest diameter of approximately 3½ inches with a radius of the cylindrical portions equal to about 1¼ inches and the spacing between the plateaus on the order of ⅜ inch will generates a frequency on the order of 1000 megacycles. The plateau portions under a pressure of 15 pounds per square inch will have the distance separating them diminished approximately 1/25 inch. It will thus be readily appreciated that by changing the external pressure, as by regulating the depth of the cooling fluid, one is able to obtain a reasonably wide range of variation of frequency. By the same analogy, it will be appreciated that the tube provided by the invention may be readily modulated mechanically to provide a frequency modulated source of oscillations which is useful, for example, in providing a self-registering barometer such as used in meteorological and aircraft work.

Amplitude modulation, of course, can be obtained by varying the plate or anode voltage of the tube, as for example, by coupling a source of modulating potential to inductance 8 (see Figure 1) alternatively to raise and lower the anode potential. Where it is desirable to use the tube as a detector, the source of potential 7 may be of such a value that oscillations take place in the curved region of the anode voltage-current characteristic of the tube. By coupling to the inductance 8, for example, or otherwise inserting the voltage to be detected in series with source 7, the voltage will be alternately raised and lowered. When the modulated potential is positive, for example, greater secondary electron multiplication takes place, and therefore, provides an enhanced output but on the negative half cycle of the voltage wave to be detected, the output of the tube will be diminished, and consequently, there will be an asymmetrical voltage output obtained from the terminals 19 as is required for detection.

For using the tube as an amplifier, the voltage source 7 is maintained at a value one-half way between that which provides maximum amplitude of oscillation and that value at which oscillations just begin to take place. The voltage to be amplified may be connected in series with the source 7 in any of the ways known to those skilled in the art so as to alternately raise and lower the effective voltage acting between the metal wall 3 and electrode 12 in Figure 1. This form of connection then provides an amplified current output which may then be furnished to any suitable load circuit through the transmission line 17 and terminals 19.

It will be further recognized that the invention provides a source of oscillations which are particularly useful for systems employing wave guides such as described in the October 1936 issue of the Proceedings of the Institute of Radio Engineers, by Barrows. This is because of the fact that tubes built in accordance with the invention develop the ultra-high frequencies necessary for use in wave guide transmission systems, and such ultra-high frequency is easily obtainable at relatively large power outputs. Since the wave guide method of transmission finds greatest effectiveness with ultra-high frequencies, it will be readily appreciated that the presently described invention is of such character as to simplify such types of transmission systems.

Having now described my invention, what I claim is:

1. An electronic device comprising an evacuated hollow metallic toroidal shell having two parallel imperforate secondary electron emissive surfaces in register with each other, an accelerating electron permeable electrode positioned between said imperforate surfaces and a substantially aperiodic inductive coupling member connected to the interior of said shell.

2. An electronc device comprising an evacuated hollow metallic toroidal shell having two parallel imperforate secondary electron emissive surfaces in register with each other, an accelerating grid electrode positioned between said imperforate surfaces, and a substantially aperiodic inductive coupling member connected to the interior of said shell.

3. An electronic device comprising an evacuated hollow metallic toroidal shell having two parallel imperforate secondary electron emissive surfaces in register with each other, an accelerating ring-electrode positioned between said imperforate surfaces, and a substantially aperiodic inductive coupling member connected to the interior of said shell.

4. An electronic device comprising an evacuated hollow metallic toroidal shell having two parallel imperforate secondary electron emissive surfaces in register with each other, an accelerating electron permeable electrode positioned between said imperforate surfaces, means to produce an electromagnetic field perpendicular to the parallel surfaces, and a substantially aperiodic inductive coupling member connected to the interior of said shell.

5. An electron device comprising an evacuated hollow metallic toroidal shell having two parallel imperforate secondary electron emissive surfaces in register with each other, an electron-permeable electrode positioned between said imperforate surfaces, a substantially aperiodic inductive coupling member connected to the interior of said shell, a conductor connected to said electrode, an incandescible filament having one end connected to the junction of said conductor and said electrode and a second conductor connected to the other end of said filament.

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