March 23, 1943. E. G. LINDER 2,314,794

MICROWAVE DEVICE

Filed June 25, 1940

Fig. 1.

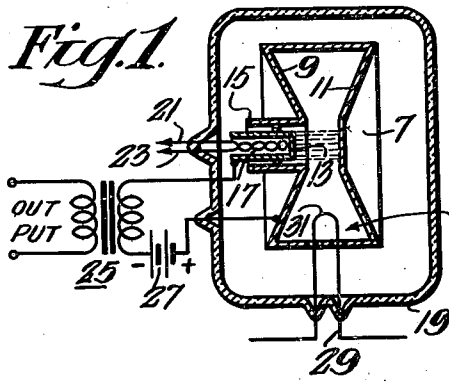


Fig. 2.

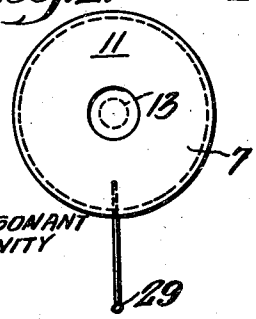


Fig. 3.

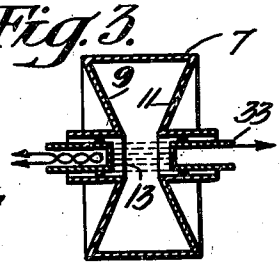


Fig. 4.

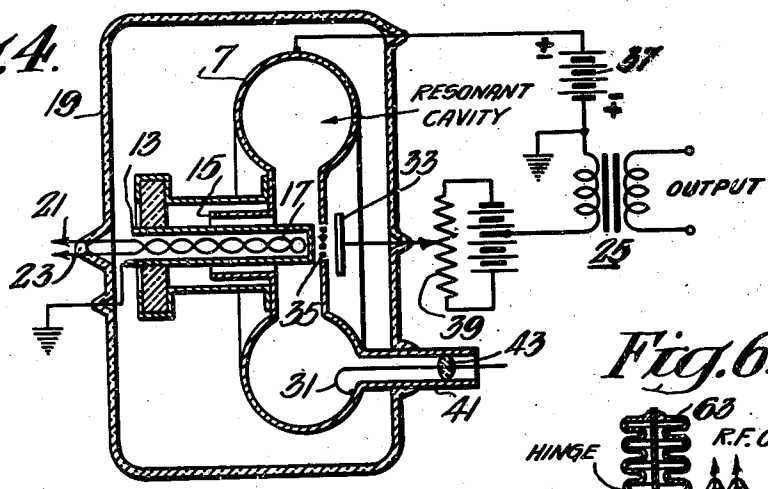


Fig. 5.

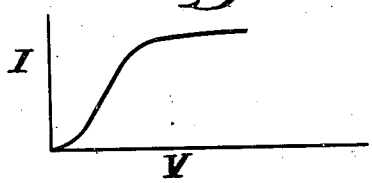
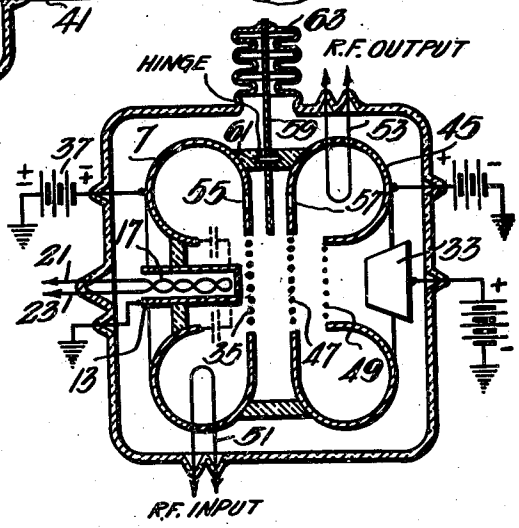


Fig. 6.



Inventor

Ernest G. Linder

By

Attorney

Patented Mar. 23, 1943 2,314,794

UNITED STATES PATENT OFFICE

2,314,794

MICROWAVE DEVICE

Ernest G. Linder, Philadelphia, Pa., assignor to Radio Corporation of America, a corporation of Delaware

Application June 25, 1940, Serial No. 342,235

1 Claim. (Cl. 250—27)

This invention relates to ultra high frequency devices, and more particularly to methods of and apparatus for generating, detecting and amplifying microwave radio energy by means of resonant cavities.

I am aware of devices in which a constant stream of electrons is caused to flow through a resonant cavity in such a manner that the standing waves therein accelerate some electrons and decelerate others to produce spaced groups of electrons. This system is known as velocity modulation, and the total number of electrons leaving the cathode over a given period of time is constant. It is the principal object of this invention, however, to provide means in a resonant cavity device whereby control is effected by varying the electron emission itself. Other objects include the provision of an improved resonant cavity device; the provision of an improved resonant cavity microwave detector; the provision of a multielement resonant cavity discharge device; the provision of a diode rectifier in which interelectrode capacities do not deleteriously affect the operation of the device: and the provision of a resonant cavity discharge device which may be operated as an amplifier, rectifier or oscillator.

The foregoing objects are accomplished by means of a device in which the emitting surface of an electron-producing cathode is mounted in a resonant cavity so that it is directly affected by the standing waves which are set up therein. The cavity electrode itself may function as an anode electrode, or a separate anode may be provided. In an alternative embodiment of this invention, a grid electrode is employed to aid in controlling the electron stream. In another embodiment, two resonant cavity electrodes are provided, one being coupled to the input electrodes and the other being coupled to the output electrodes.

The invention will be better understood from the following description when considered in connection with the accompanying drawing in which Figure 1 is a cross section of a resonant cavity diode detector; Figure 2 is a plan view of a resonant cavity electrode; Figure 3 is a cross section of an alternative diode arrangement; Figure 4 is a cross section of a triode resonant cavity discharge device; Figure 5 is a curve useful in explaining the operation of this invention; and Figure 6 is a cross section of an oscillator or amplifier having two resonant cavity electrodes. Similar reference numerals refer to similar elements throughout the several figures of the drawings.

Referring to Figs. 1 and 2, within an evacuated glass envelope 19 a member 7 including a resonant cavity is mounted. This cavity is bounded by the member 7 which is a metallic electrode in the form of a cylinder having conical reentrant ends 9 and 11. It is to be understood that the invention is not limited to a device having this particular shape. A cathode electrode 13 is centrally located in one end 9 of the cavity electrode 7, and is capacitively coupled thereto, for example, by means of a conductive sleeve 15 which is connected to the cavity electrode 7. The cathode 13 may be of the oxide-coated type commonly used in cathode ray tubes and the like. It is heated by a conventional heating element 17, the leads 21 and 23 to which are brought out through the glass envelope 19 in the usual manner. The primary winding of an output transformer 25 is serially connected with a battery 27 between the cathode 13 and any convenient point on the cavity electrode 7. Standing waves of ultra high radio frequency energy are set up within the cavity by any convenient means; for example, a dipole antenna 29 may be coupled through a transmission line which terminates in a loop 31 within the cavity.

I have not illustrated specific means for mounting the various elements of the tube within the envelope 19, since the mounting is conventional and will be apparent to those skilled in the art.

In the operation of this embodiment of my invention, the cathode 13 emits electrons from its end surface, which electrons follow trajectories through the narrow portion of the resonant cavity, as indicated by the dotted lines, and impinge on the opposite end of the cavity electrode. It will be noted that the cavity electrode is maintained at a positive potential with respect to the cathode.

When modulated radio frequency energy of the proper frequency is received by the dipole antenna 29, it is transferred to the resonant cavity, and causes standing waves to be formed therein. The lines of electric force of these standing waves are parallel to the electron trajectories so that the amplitude of the current flowing in the anode-cathode circuit, which includes the output transformer, is determined by the amplitude or intensity of the standing waves. Variations in the standing waves due to modulation of the received signal, therefore, produce variations in the anode-cathode current, which, in turn, produce modulation-frequency output currents in the secondary of the output transformer 25.

The number of lines of electric force is a maximum between the surface of the cathode and the opposite end of the resonant cavity electrode which functions as anode. Since the cathode is closely coupled to the cavity electrode, it forms a part of the high frequency circuit, and the electric field has a maximum effect on the emission of electrons. This is an outstanding advantage of the resonant cavity type of tube. Another advantage is that the capacity between the cathode and the effective anode, that is, the portion of the cavity electrode to which the electrons flow, does not act as a short circuit to the applied radio frequency, as is the case in a conventional diode where the cathode and anode are connected across the input circuit.

For best operation, the distance between the cathode and the effective anode must be such that the electron transit time is less than a half period. The electron transit time depends upon the distance to be travelled and the potential of the anode with respect to the cathode. In order to determine the limiting distance X beyond which the tube will not operate as a diode, consider a plane cathode and anode, as in Fig. 1, separated by a distance X. Then it is known that

$$I=\frac{\sqrt{2}}{9\pi}\left(\frac{e}{m}\right)^{1/2}\frac{V^{3/2}}{X^2}a \qquad (1)$$

where I=space current
e=charge of an electron
m=mass of an electron
V=anode voltage
a=cathode area in square centimeters

Substituting known values (1) becomes

$$I=2.3\cdot10^{-6}\cdot V^{3/2}\cdot X^{-2}\cdot a \text{ amperes} \qquad (2)$$

The transit time t is given by the equation:

$$t=3.57\cdot10^{-8}\cdot V^{-1/2}\cdot X \qquad (3)$$

or

$$t=\left(\frac{2m}{e}\right)^{1/2}\cdot V^{-1/2}\cdot X \qquad (4)$$

Thus, both I and t are functions of V and X only, and, if t is given, I is determined as a function of either V or X alone; or, if t and I are given, V and X are determined uniquely. If X is taken as the distance at which the transit time is equal to a half period, V may be determined. I may be obtained from a knowledge of the maximum current emission produced by a given cathode structure.

Thus, from (2) and (4):

$$X=1.15(10^{28})\frac{t^3I}{a} \qquad (5)$$

Assuming I=.02 ampere, and, for an operating frequency of 3000 m. c., $t=0.17\times10^{-9}$, so from (5)

$$X=0.17 \text{ m. m.}=.007 \text{ in.}$$

and from (3)

$$V=11.6 \text{ volts}$$

It is to be understood that this value is a maximum. The transit time preferably should be less than a half period.

In the embodiment described above, the resonant cavity electrode itself functioned as the anode. Somewhat better results may be obtained by providing an anode which may have a D. C. potential applied to it different from that applied to the resonant cavity. Such an arrangement is illustrated in Fig. 3, in which the cathode 13 is mounted in the resonant cavity electrode as before, but which employs a separate anode 33 capacitively coupled to the end of the resonant cavity electrode opposite the cathode. Close coupling is provided so that both anode 33 and cathode 13 function as an integral part of the resonant chamber or cavity at high frequencies.

An arrangement is illustrated in Fig. 4 in which a grid electrode is mounted on the end of the cavity electrode opposite the cathode to provide triode operation. The resonant cavity electrode itself is seen to have a somewhat different shape from that previously described. The rounded construction illustrated functions in the same manner. The cathode 13 is centrally mounted in and capacitively coupled to one end of the resonant cavity electrode 7, as before. That portion of the resonant cavity electrode opposite the cathode is provided with an aperture in which a grid 35 is mounted. The grid is directly connected to the resonant cavity electrode and, therefore, like the cathode, forms a part of the high frequency circuit. The lines of electric force which control the electron emission from the cathode are formed as in the preceding case. In the present instance, however, instead of being collected by the cavity electrode, the electrons pass through the grid and are collected by the anode which is positioned just outside the cavity near the grid. As a result, variations in the amplitude of the standing waves due to modulation of the received signal causes like modulation of the space current flow to the anode, thus producing modulation frequency currents in the output transformer 25.

It will be observed that a battery 37 is connected between ground, or cathode, and the cavity electrode 7 so that the potential of the latter may be made positive or negative. The anode 33, also, may be given a positive or a negative potential, by suitable adjustment of potentiometer 39, the exact value of which is best determined by trial.

The input transmission line in this instance is made in the form of a concentric line 41, although an open line may be employed. Since the line extends into the evacuated region of the tube, it is sealed off by a glass seal 43.

As in the preceding case, the spacing between cathode and grid and the grid voltage must be adjusted so that the electron transit time through the resonant cavity is less than a half period at the operating frequency. In making these calculations, it is necessary to consider the effect of the d-c field produced by the anode, since the field will tend to pass through the grid into the cathode grid region. In such a case, V in the equations given above relating to the diode tube must be considered as an effective voltage, and will depend on the grid structure, anode potential, and spacing of the electrodes. This effect, however, is well known, since it is also applicable to conventional triode tubes. A discussion of it is found, for example, in Van Der Bijl's book, "Thermionic Vacuum Tube," paragraph 52 on page 146.

If the cathode emission current I of a tube of the type illustrated in Fig. 1 be plotted as a function of the anode voltage V, the resultant curve will be approximately of the type illustrated in Fig. 5. Velocity modulation tubes of the type referred to above, in which a constant stream of electrons is sent into a resonant cavity, operate along the horizontal portion of the curve. That is, an increase in the anode voltage does not cause an increase in the net anode current, but merely accelerates a group of electrons. Tubes

of the present type, however, operate on an elbow of this curve in a manner similar to ordinary diodes and triodes, since, as pointed out above, the anode and/or grid voltage actually controls the space current.

A radio frequency amplifier tube is illustrated in Fig. 6, employing two resonant cavity electrodes 7 and 45 positioned back to back, and open along their central axis for the passage of electrons.

The input portion of this tube is substantially identical to the device shown in Fig. 4, and need not be described again in detail. For convenience, the adjacent surfaces of the two resonant cavities are made flat so that the transit time, focusing and coupling may be properly controlled. As before, the cathode 13 is capacitively coupled to the reentrant end of the first cavity 7, this coupling being indicated by the dotted capacitors.

The output cavity electrode 45 is interposed between the grid 35 and the anode 33. The opposite faces of the cavity are in line with the axis of the electron stream and contain an accelerating grid 47 and a shield grid 49. After passing through the shield grid, the electrons are collected by the anode 33 as before. Input is applied to the first resonant cavity by a transmission line 51, and output taken from the second cavity by a transmission line 53. The electron current passing through the first or input cavity is modulated by the ultra high frequency signals applied to the input and set up amplified standing waves by means of induction in the second or output resonant cavity which are available in amplified form at the output terminals.

As before, the cathode to first grid spacing and the electrode potentials are adjusted and designed to keep the transit time below a half period. The purpose of the accelerating grid 47 is to impart greater velocity to the electrons, and thus make greater energy available at the output, since the high velocity electrons set up in the resonant cavity more intense standing waves than low velocity electrons. Since the electron velocity is greater between the accelerating and shield grids 47 and 49, the spacing between them may be increased proportionately for a given transit time. While grid 49 has been termed a "shield" grid, it is to be understood that all the grids also act as shields to confine the radio frequency energy within the confines of the two resonant cavities. They also prevent excessive inward fringing of the d-c fields due to the other electrodes. The anode 33 is a decelerating electrode, and it dissipates the remaining electron energy.

If it is desired to use such a tube for the production of ultra high frequency oscillations, it is necessary to provide a feedback path between the output and input cavities. This is readily accomplished by providing two aligned openings 55 and 57 in the cavities, thus permitting the r-f field in the output resonator to leak back into the input resonator. A shield 59 is provided, pivoted, for example, at a point 61 and movable between the two apertures, thereby permitting the amount of feedback to be controlled. A convenient method of operating the shield 59 may be employed. For example, a flexible air-tight bellows 63 is sealed into the glass envelope 19, or it may be operated by magnetic means.

In operation as an amplifier, this tube functions as a conventional triode, except that resonant cavities are used as output and input electrodes.

It will be understood that the described discharge devices have particular utility at ultra high frequencies. Several modifications have been shown which make possible amplification and oscillation, as well as rectification. While the invention has been described by means of several specific embodiments, it is to be understood that these are merely illustrative of the invention, the scope of which is to be determined only by the spirit of the appended claim.

I claim as my invention:

An ultra high frequency detector comprising a resonant cavity electrode having an apertured end, a tubular member forming a projection of said electrode and surrounding said aperture, a cathode having an electron emissive surface located within said tubular member outside of said cavity electrode and insulated therefrom whereby regions of said cathode immediately adjacent said emissive surface are capacitively coupled to said tubular member, means for causing an electron stream to flow through said resonant electrode comprising means for applying a positive potential to said electrode with respect to said cathode, means for establishing standing waves of modulated high frequency energy in said cavity electrode, means for varying the electron current from said cathode in response to the amplitude of said standing waves, and output means coupled to said resonant cavity electrode and responsive to said changes in electron current.

ERNEST G. LINDER.