March 26, 1946. O. E. DOW 2,397,411

OSCILLATOR CIRCUIT

Filed April 24, 1941

Fig. 1.

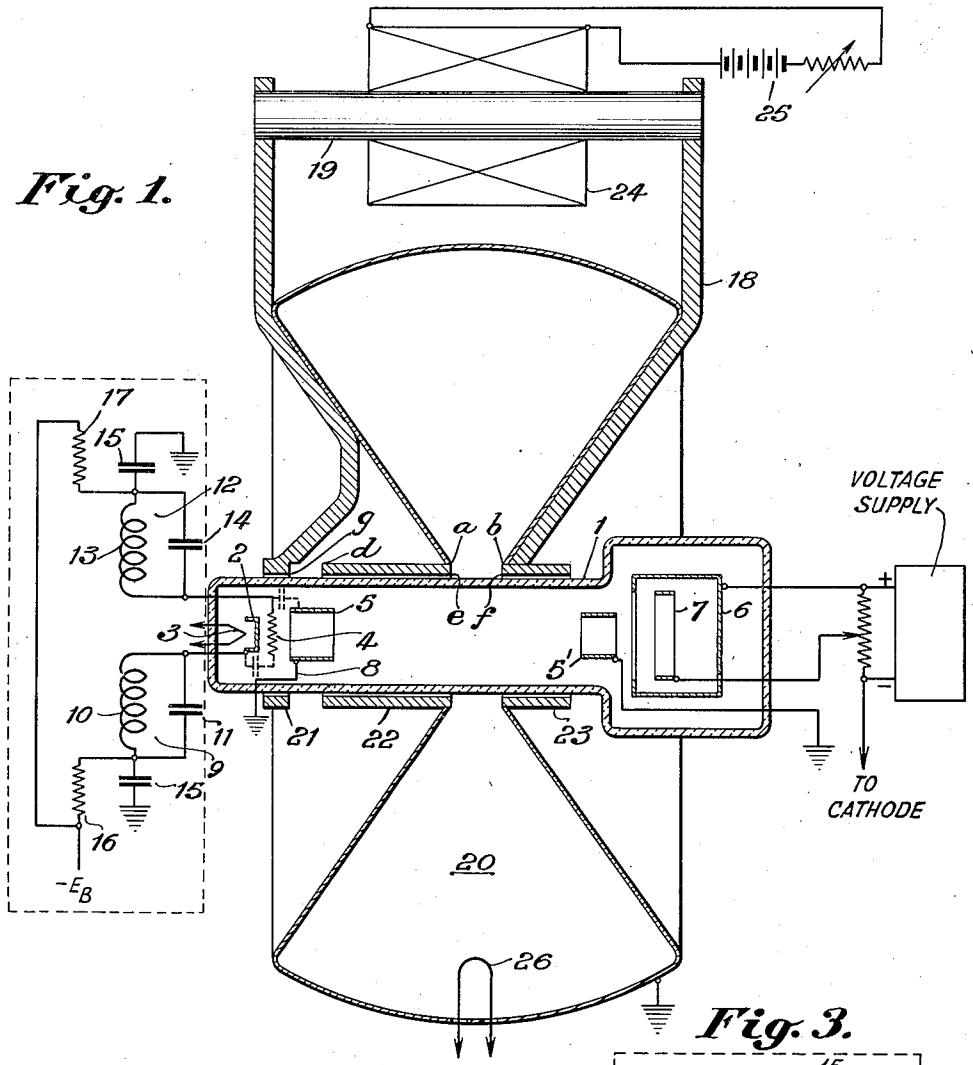


Fig. 3.

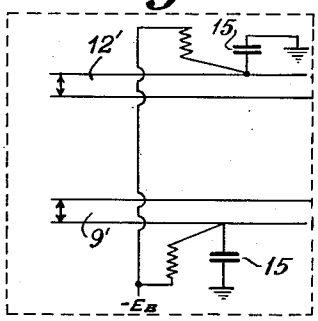
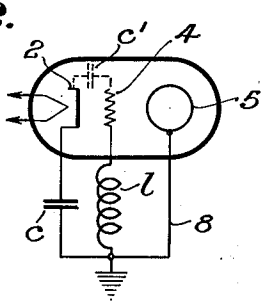


Fig. 2.



INVENTOR
Orville E. Dow
BY H. S. Grover
ATTORNEY

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OSCILLATOR CIRCUIT

Orville E. Dow, Port Jefferson, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

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19 Claims. (Cl. 315—5)

This invention relates to an electron discharge device oscillator circuit for use in generating ultra high frequency waves of the order of 300 megacycles and higher, and more particularly to an electron coupled oscillator.

One of the objects of the present invention is to provide an electron coupled oscillator of the inductive-output type. The term "inductive output" is used to designate generally an electron discharge device, wherein the kinetic energy of the electron beam is transferred to the resonator circuit inductively.

For a general description of an inductive output electron discharge device, reference is made to an article published in Proceedings of the I. R. E., March, 1940, pages 126 et seq., by Messrs. A. V. Haeff and L. S. Nergaard.

Another object of the present invention is to provide an ultra high frequency oscillation generator of the inductive-output type capable of generating oscillations of the order of 300 megacycles and higher, wherein the oscillator portion is isolated from the resonator circuit and consists of a grounded anode type of triode structure.

In accordance with the preferred embodiment of the present invention, there is employed an electron discharge device having within an evacuated envelope a group of electrodes at one end constituting an oscillator portion for emitting a density modulated electron beam, and an electron collector electrode at the other end for gathering the electrons after they have traversed the length of the tube. Surrounding the envelope intermediate its ends and located between the oscillator electrodes and the collector electrode, there is provided a high Q, low loss tank circuit, preferably in the form of a surface of revolution. This surface of revolution might be cylindrical in form, or may be constituted by a section approximating the sector of a circle with its vertex angle located adjacent the vacuum tube envelope and whose central plane cuts the axis of the vacuum tube structure substantially at right angles, thus, in effect, having its cross section approximating the form of an hour-glass. Other types of cavity resonators may be employed, such as, for example, a toroid, it being understood that the invention is not limited to any particular form of tank circuit. For focussing the electrons, there is provided a pair of magnetic lenses each constituted by a leakage field surrounding the envelope of a vacuum tube, although it will be obvious that, if desired, any uniform axial magnetic field can be employed for focussing purposes.

One advantage of the present invention is that the resonator or tank circuit of the inductive-output tube is completely divorced or isolated from the oscillating electrode structure portion of the tube. The resonator may be suitably dimensioned so that its resonant frequency is the same as or a suitable harmonic multiple of the oscillating frequency of the oscillator electrode portion of the tube.

A detailed description of the invention follows in connection with a drawing, Fig. 1 of which schematically illustrates one suitable form of electron coupled inductive-output type of tube embodying the principles of the invention; Fig. 2 illustrates a circuit which is electrically equivalent at the operating frequency to the oscillator electrode portion of the tube of Fig. 1, and which is given in order to aid in an understanding of the operation of the oscillator electrode portion of Fig. 1; and Fig. 3 illustrates a modification of that portion of the system of Fig. 1 shown within the dash line rectangle.

Referring to Fig. 1 in more detail, there is shown an electron discharge device comprising a vacuum tube structure consisting of an evacuated glass envelope 1 containing within it a cathode 2, a heater 3, a grid 4, ring-like accelerator electrodes 5 and 5', a collector electrode 6, and a suppressor electrode 7. The heater 3 is supplied with energy from a suitable alternating current energy source (not shown). The cathode 2, grid 4 and accelerator 5 are so connected as to form, in effect, a grounded anode oscillator. For this purpose, the accelerator electrode 5, which is the hollow open-ended type, is grounded for radio frequency potentials by means of connection 8. The cathode 2 is connected to a tuned circuit 9 comprising an inductance 10 and a condenser 11, which last circuit is tuned to a frequency lower than the operating frequency of this oscillating electrode portion. The grid 4 is connected to another tuned circuit 12 comprising an inductance 13 and a condenser 14. This last circuit is tuned to a higher frequency than the oscillation frequency of the oscillator portion of the tube. Both tuned circuits 10 and 12 are by-passed to ground for radio frequency energy by means of condensers 15, 15. Resistor 16 is a cathode bias resistor and resistor 17 is a grid resistor, both of which supply suitable bias to the cathode and grid, respectively. In actual practice, circuits 9 and 12 will be constructed in the form of transmission line sections having uniformly distributed constants and which are preferably adjustable in length. These transmission line sections may be

of the concentric line type or any suitable parallel conductor system. Such an arrangement is schematically shown in Fig. 3. The dash line rectangles of Figs. 1 and 3 may be substituted for each other. In Fig. 3, tuned circuits 12' and 9' correspond to circuits 12 and 9 of Fig. 1. The interelectrode capacities between the cathode, grid and accelerator electrode 5 (the accelerator acting as an anode, so to speak) are shown in dotted lines within the envelope.

Before proceeding with a discussion of the remaining structure of the electron discharge device of Fig. 1, a description will be given of the operation of the oscillator portion constituting the cathode 2, grid 4 and accelerator electrode 5 by particular reference to Fig. 2. Referring to Fig. 2, it will be noted that the accelerator electrode 5, the grid 4, and the cathode 2 are connected to a common point of fixed radio frequency potential, here designated as ground. The tuned circuit of the oscillator is formed by a condenser C in series with an inductance L and the interelectrode capacity C', which elements determine the frequency of oscillation. The condenser C, in circuit with the cathode, represents the capacitive path from the cathode 2 to ground, by virtue of the fact that the tuned circuit 9 is tuned to a lower frequency than the operating frequency of the oscillator. The inductance L in circuit with the grid represents the inductive path from the grid 4 to ground, by virtue of the fact that the tuned circuit 12 is tuned to a higher frequency than the operating frequency. It will thus be evident that, in effect, the cathode 2, the grid 4, and the accelerator electrode 5 form a grounded triode oscillator. The electrons emitted from the cathode 2 which do not impinge on the grid 4 pass completely through the anode or accelerator electrode 5 which is hollow and open at both ends, and are thus available to induce charges in the resonator or tank circuit 20 of Fig. 1, which is described hereinafter.

The operation of the oscillator electrode portion 2, 4, 5 is essentially the same as that of a grounded anode triode oscillator operating at much lower frequencies. The electrons which are grouped, due to the difference in potential between the cathode 2 and the grid 4, generate a voltage across the effective frequency controlling oscillatory circuit of the oscillator (designated C, L and C', Fig. 2). The voltage across C is then stepped up or raised to a higher voltage at the control grid. The voltages on the cathode and the grid are cophasal in character although that on the grid is higher than that on the cathode. Putting it in other words, the grid is driven harder than the cathode but cophasally. The cathode swings negative with respect to ground and also with respect to accelerator electrode 5 to a direction to increase the electron beam current. Grid 2 also swings negative to a greater magnitude, thus making it negative with respect to the cathode, and this results in a decrease of electron beam current, thus giving it the negative resistance characteristics essential for the generation of oscillations. When the electron beam which is broken up into groups leaves the grid plane and traverses the accelerator electrode 5, as far as the grid and cathode are concerned, the electrons appear to impinge upon or strike the electrode 5, so that in effect the accelerator electrode 5 acts as grounded anode. If, however, the electrons were allowed to strike the accelerator electrode 5, this would result in a high loss of energy and low efficiency and it is for this reason that the electrons are focussed by the magnetic lens *g* and *d*, described later, to cause them to continue their travel along the axis of the tube to be later collected at the far end, after they have induced charges in the resonator 20. It should be observed that the accelerator 5 has substantially zero impedance to ground, which is necessary for most efficient operation. The electron transit time over the length of the accelerator 5 is so short that the resultant current induced in the accelerator electrode circuit is small, and this results in a low accelerator voltage even though the condition of zero impedance of the lead is not met, i. e., even though the lead 8 has appreciable reactance to ground.

In the system of Fig. 1, it should be noted that the cathode 2 is maintained at a negative potential with respect to the accelerator electrodes 5 and 5' and with respect to the collector electrode 6 and the suppressor electrode 7. The collector electrode may be operated at any suitable positive voltage relative to the cathode. In practice, the collector electrode 6 is maintained at a sufficiently positive potential with respect to the cathode to draw out all of the electrons in the active portion of the vacuum tube envelope. The suppressor electrode 7, which serves to gather secondary electrons which may emanate from collector electrode 6, produced by electron bombardment, is maintained at a less positive potential than the collector electrode. The accelerator electrodes 5 and 5' are oppositely disposed with respect to the gap of the tank circuit 20 and, although shown grounded, are at a high positive potential with respect to the cathode.

Surrounding the exterior of the glass envelope 1 and located intermediate the two accelerator electrodes 5 and 5', there is provided a high Q low loss circuit 20 in the form of a surface of revolution whose axis of revolution is coincident with the electron beam emanating from the cathode 2. This tank circuit, it should be noted, is symmetrically arranged around the glass envelope 1. In order to obtain a desired high impedance across the gap *a*, *b* of the tank circuit for matching the impedance of the vacuum tube structure and to obtain the desired high Q circuit, the configuration of tuned circuit 20, as shown by the cross section of revolution through the axis of revolution in the plane of the drawing, should approximate two equal sectors with their vertex toward the glass envelope 1. The dimensions of the tank circuit 20 as measured from the center of the glass envelope 1 toward the arc of the sector is approximately one-quarter of the length of the communication wave corresponding to the resonant frequency of the tank. If desired, means (not shown) may be provided for varying the width of the gap *a*, *b* with a consequent variation between the sides of the gap. Tank circuit 20 is preferably made of a high electrically conducting material, such as copper. For focussing the electron beam, there are provided a pair of magnetic lenses in series relation constituted by gaps *g*, *d* and *e*, *f*, formed by spaced iron sleeves 21, 22 and 23, which surround the glass envelope 1 and are serially arranged with respect to an iron magnetic path. This magnetic path includes a strip of iron 18 which is placed adjacent to the sides of the upper sector of the tank 20 and which is completed through an iron core 19, in turn surrounded by the electromagnetic field coil or solenoid 24 excited by a direct current source of supply 25.

In the operation of the electron discharge device of the invention, the density modulated beam emanating from the oscillator electrode portions 2, 4 and 5, will, by virtue of its passage across the gap *a*, *b* of the tank circuit 20, induce charges on the inside of the tank 20 at the resonant frequency of the tank. The dimensions of the tank circuit 20 may be such that the resonant frequency corresponds to the frequency of oscillation of the oscillator electrode portion 2, 4, 5, or corresponds to a harmonic frequency thereof. In effect, the electrons emanating from cathode 2 are bunched into groups, and these groups excite the tank circuit 20 at the group frequency or a harmonic thereof (depending upon the dimensions of the tank 20) as these groups of electrons pass the gap *a*, *b*. If the excitation frequency (group frequency) is the same as or a submultiple of the resonant frequency of the tank circuit 20, a high impedance will exist across the gap *a*, *b* at this frequency, and consequently the induced currents will produce a high radio frequency voltage across the gap *a*, *b*.

What is claimed is:

1. An ultra high frequency electron discharge device system comprising within an evacuated envelope an electron source for producing a beam of electrons, a grid, an anode and an electron collector electrode, said anode being so constructed and arranged as to permit electrons to pass therethrough to said collector, a cavity resonator of predetermined dimensions having a gap located between said anode and said collector electrode, whereby electrons traveling between said electron source and collector induce charges in said resonator, and means coupled to said electron source, grid and anode to cause the same to produce oscillations whose frequency is related to the resonator frequency of said cavity resonator.

2. The method of operating an electron discharge device oscillation generator having within an evacuated envelope an oscillator electrode structure including a cathode and a collector electrode spaced from said oscillator structure, and resonant means coupled to said tlectrode structure in such manner as to cause the production of oscillations, which comprises creating an electron flow from said cathode which passes through said oscillator structure, modulating the density of the electrons passing through said oscillator structure, projecting said electrons in a substantially straight line to said collector electrode, deriving energy from said density modulated electrons at a point between said oscillator structure and said collector electrode, and resonating the derived energy at a frequency related to the frequency of oscillations of said oscillator structure.

3. An ultra high frequency electron discharge device system comprising an evacuated envelope having therein near one end an electron source for producing a beam of electrons, a grid and a hollow accelerator electrode, in the order named, a second accelerator electrode, and a collector electrode near the other end of said envelope, a tank circuit having a gap located in the space between said first accelerator electrode and said second accelerator electrode, whereby the passage of electrons across said gap induces charges in said tank circuit, said first accelerator electrode surrounding the electrons emanating from said electron source and having open ends, means coupled to said electron source, grid and first accelerator for causing the same to produce oscillations to modulate the electron stream, said tank circuit having such dimensions that it resonates at a frequency related to the frequency of said oscillations.

4. An ultra high frequency electron discharge device system comprising an evacuated envelope having therein near one end an electron source for producing a beam of electrons, a grid and a hollow accelerator electrode, in the order named, a second accelerator electrode and a collector electrode near the other end of said envelope, a tank circuit having a gap located in the space between said first accelerator electrode and said second accelerator electrode, whereby the passage of electrons across said gap induces charges in said tank circuit, said first accelerator electrode surrounding the electrons emanating from said electron source and having open ends, means coupled to said electron source, grid and first accelerator for causing the same to produce oscillations to modulate the electron stream, means for focussing said electrons to pass through the interior of said hollow accelerator electrode without impinging thereon, said tank circuit having such dimensions that it resonates at a frequency related to the frequency of said oscillations.

5. An ultra high frequency electron discharge device system comprising an evacuated envelope having therein near one end an electron source for producing a beam of electrons, a grid and a hollow accelerator electrode, in the order named, a second accelerator electrode and a collector electrode near the other end of said envelope, a tank circuit having a gap located in the space between said first accelerator electrode and said second accelerator electrode, whereby the passage of electrons across said gap induces charges in said tank, means for maintaining said accelerator electrodes at a positive potential relative to said electron source and at a low impedance to energy of the operating frequency, said accelerator electrodes surrounding the electrons emanating from said cathode and having open ends, means coupled to said electron source, grid and first accelerator for causing the same to produce oscillations to modulate the electron stream, said tank circuit having such dimensions that it resonates at a frequency related to the frequency of said oscillations.

6. An ultra high frequency electron discharge device system comprising an evacuated envelope having therein near one end an electron source for producing a beam of electrons, a grid and a hollow accelerator electrode, in the order named, a second accelerator electrode and a collector electrode near the other end of said envelope, a tank circuit having a gap located in the space between said first accelerator electrode and said second accelerator electrode, whereby the passage of electrons across said gap induces charges in said tank, means maintaining said accelerator electrodes at a positive potential relative to said electron source and at a low impedance to energy of the operating frequency, said accelerator electrodes surrounding the electrons emanating from said cathode and having open ends, means coupled to said electron source, a grid and first accelerator electrode for causing the same to produce oscillations to modulate the electron stream, magnetic means for focussing said electrons to pass through the interior of said accelerator electrodes and along the longitudinal axis of said envelope, said tank circuit having such dimensions that it resonates

at a frequency related to the frequency of said oscillations.

7. An ultra high frequency electron discharge device system comprising within an evacuated envelope a cathode, a grid, an electron permeable anode and an electron collector electrode in the order named, a cavity resonator of predetermined dimensions having a gap located between said anode and said collector electrode, whereby electrons traveling between said cathode and collector electrode induce charges in said resonator, and means coupled to said cathode, grid and anode to cause the same to produce oscillations whose frequency is related to the resonant frequency of said cavity resonator, said means including a connection of low impedance to energy of the oscillating frequency extending from said anode to ground and circuits for exciting said grid periodically at higher radio frequency potentials than but in phase with the cathode.

8. In combination, a triode oscillator having a cathode, a control electrode and an electron permeable anode which is connected to ground by a connection of negligible impedance to energy of the operating frequency, an electron collector electrode for collecting the electrons passing through said oscillator, an evacuated envelope surrounding the electrodes of said oscillator and the collector electrode, a resonator of predetermined dimensions surrounding said electron stream and having a gap located between said oscillator and said collector, said resonator being adapted to be excited by the passage of modulated electrons across said gap, and means for focussing the electrons to pass as a beam from said oscillator to said collector.

9. In combination, a triode oscillator having a cathode, a control electrode and an electron permeable anode which is connected to ground by a connection of negligible impedance to energy of the operating frequency, a tunable frequency determining circuit for said oscillator, said tunable frequency determining circuit including adjustable transmission line sections, an electron collector electrode for collecting the electrons passing through said oscillator, an evacuated envelope surrounding the electrodes of said oscillator and the collector electrode, a resonator of predetermined dimensions surrounding said electron stream and having a gap located between said oscillator and said collector, said resonator being adapted to be excited by the passage of modulated electrons across said gap, and means for focussing the electrons to pass as a beam from said oscillator to said collector.

10. In combination, a triode oscillator having a cathode, a control electrode and an electron permeable anode which is connected to ground by a connection of negligible impedance to energy of the operating frequency, an electron collector electrode for collecting the electrons passing through said oscillator, an evacuated envelope surrounding the electrodes of said oscillator and the collector electrode, a resonator of predetermined dimensions surrounding said electron stream and located between said oscillator and said collector, said resonator being adapted to be excited by the passage of modulated electrons across said gap, and means for focussing the electrons to pass as a beam from said oscillator to said collector.

11. An ultra high frequency electron discharge device system comprising within an evacuated envelope an electron source for producing a beam of electrons, a grid, an electron permeable anode and an electron collector electrode in the order named, a cavity resonator of predetermined dimensions having a gap located between said anode and said collector electrode, whereby electrons traveling between said electron source and collector induce charges in said resonator, and means coupled to said electron source, grid and anode to cause the same to produce oscillations whose frequency is related to the resonator frequency of said cavity resonator, said means including a biasing element for maintaining said grid at a negative potential relative to said electron source, and a source of polarizing potential for maintaining said anode at a positive potential relative to said electron source.

12. In combination, a triode having a cathode, a grid, and an electron permeable anode, a tunable frequency determining circuit for said triode and circuits for exciting said grid periodically at higher radio frequency potentials than but in phase with said cathode, said tunable frequency determining circuit including adjustable transmission line sections, an electron collector electrode for collecting the electrons passing through said triode, an evacuated envelope surrounding the electrodes of said triode and the collector electrode, a resonator of predetermined dimensions surrounding said electron stream and having a gap located between said triode and said collector, said resonator being adapted to be excited by the passage of modulated electrons across said gap, and means for focussing the electrons to pass as a beam from said triode to said collector.

13. In combination, a triode having a cathode, a grid, and an electron permeable anode, a tunable frequency determining circuit for said triode and circuits for exciting said grid periodically at higher radio frequency potentials than but in phase with said cathode, an electron collector electrode for collecting the electrons passing through said triode, an evacuated envelope surrounding the electrodes of said triode and the collector electrode, a resonator of predetermined dimensions surrounding said electron stream and having a gap located between said triode and said collector, said resonator being adapted to be excited by the passage of modulated electrons across said gap, and means for focussing the electrons to pass as a beam from said triode to said collector.

14. An oscillator having a cathode for producing a stream of electrons, a grid and an electron permeable anode, a parallel tuned circuit tuned to a frequency lower than the operating frequency connected between said cathode and ground, a parallel tuned circuit tuned to a frequency higher than the operating frequency connected between said grid and ground, a connection of negligible impedance to energy of the operating frequency connecting said anode to ground, whereby said grid is periodically excited at higher alternating potentials than but in phase with said cathode, and a resonant chamber having a gap located in the path of travel of said stream of electrons, whereby said chamber is inductively coupled to said stream and excited by the passage of electrons across said gap and through said chamber.

15. An oscillator having a cathode for producing a stream of electrons, a grid and an electron permeable anode, a parallel tuned circuit tuned to a frequency lower than the operating frequency connected between said cathode and ground, a parallel tuned circuit tuned to a frequency higher than the operating frequency connected between said grid and ground, and a connection of negligible

impedance to energy of the operating frequency connecting said anode to ground, whereby said grid is periodically excited at higher alternating potentials than but in phase with said cathode, and a load circuit means in energy transfer relation to said stream of electrons for inductively abstracting energy therefrom and so arranged that said stream does not impinge thereon.

16. An oscillator having a cathode, a grid and an electron permeable anode, a parallel tuned circuit tuned to a frequency lower than the operating frequency connected between said cathode and ground, a parallel tuned circuit tuned to a frequency higher than the operating frequency connected between said grid and ground, and a connection of negligible impedance to energy of the operating frequency connecting said anode to ground, whereby said grid is periodically excited at higher alternating potentials than but in phase with said cathode, an electron collector electrode for receiving the electrons passing through said anode, and a resonator circuit having a portion located between said anode and said collector and adapted to be excited by the passage of electrons therebetween.

17. An oscillator having a cathode, a grid and an electron permeable anode, an effective capacitance in the form of a tuned circuit tuned to a radio frequency lower than the operating frequency connected between said cathode and ground, an effective inductance in the form of a tuned circuit tuned to a radio frequency higher than the operating frequency connected between said grid and ground, a connection of negligible impedance to energy of the operating frequency connecting said anode to ground, whereby said grid is periodically excited at higher alternating potentials than but in phase with said cathode, and a cavity resonator located on the side of said anode opposite to said cathode and in the path of the electron stream, said cavity resonator having a gap through which said stream passes for inductively exciting said cavity resonator.

18. An oscillator having a cathode, a grid and an electron permeable anode, a tuned circuit tuned to a radio frequency lower than the operating frequency connected between said cathode and ground, a tuned circuit tuned to a radio frequency higher than the operating frequency connected between said grid and ground, a connection of negligible impedance to energy of the operating frequency connecting said anode to ground, whereby said grid is periodically excited at higher alternating potentials than but in phase with said cathode, and a load circuit in the form of a hollow resonator located on the side of said anode opposite said cathode and adapted to be coupled to said oscillator by virtue of inductive coupling to the electrons passing through said anode.

19. An oscillator having a cathode, a grid and an electron permeable anode, an effective capacitance in the form of a tuned circuit tuned to a radio frequency lower than the operating frequency connected between said cathode and ground, an effective inductance in the form of a tuned circuit tuned to a radio frequency higher than the operating frequency connected between said grid and ground, means for supplying a positive potential to said anode relative to said cathode, and a hollow resonant metallic body located on the side of said anode opposite said cathode, said resonant body having a gap located in the path of travel of said stream of electrons, whereby said resonant body is inductively coupled to said stream and excited by the passage of electrons across said gap and through said resonant body.

ORVILLE E. DOW.