Feb. 24, 1948. J. A. MORTON 2,436,397

ULTRA HIGH FREQUENCY OSCILLATOR

Filed Aug. 8, 1942

FIG. 1

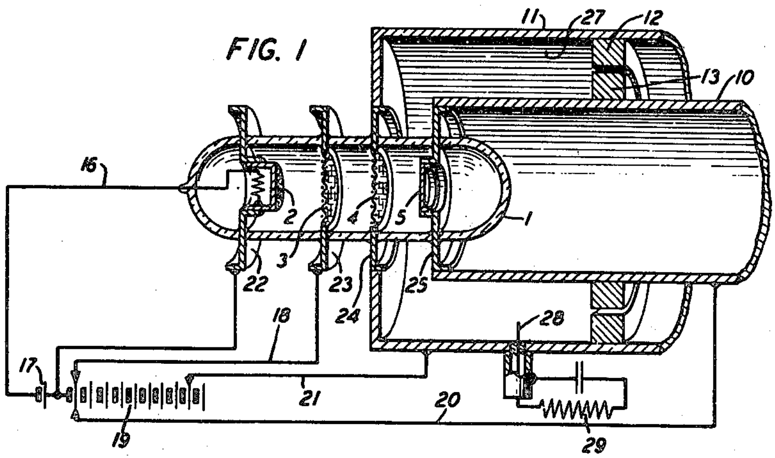


FIG. 2

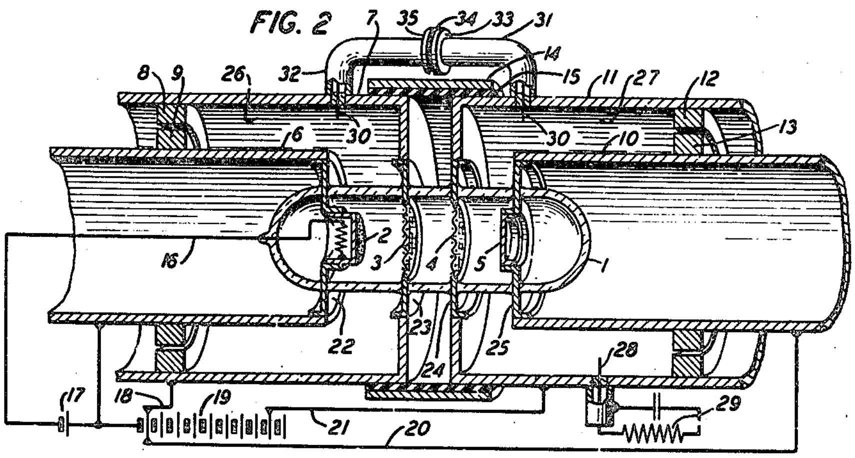
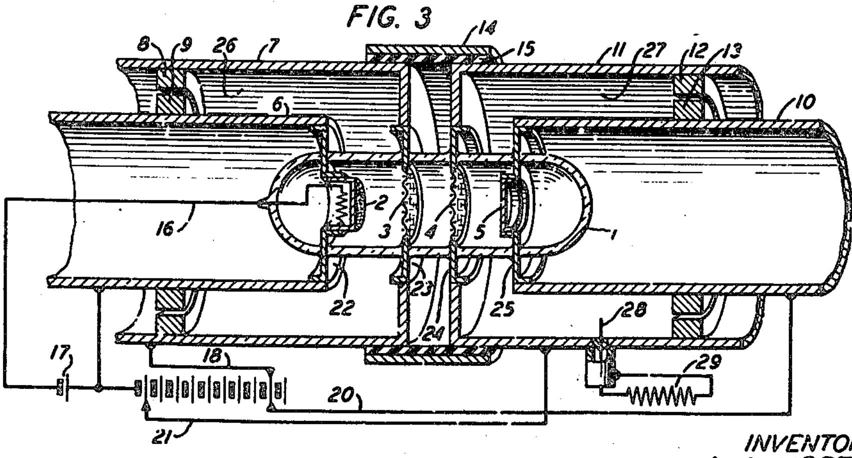


FIG. 3



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ULTRA HIGH FREQUENCY OSCILLATOR

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14 Claims. (Cl. 315—6)

1

This invention relates to electronic devices for the production of high frequency electrical energy and particularly to such devices characterized by the use of hollow closed resonators and in which electron transit time is a factor of importance.

An object of the invention is to provide an efficient oscillator capable of operation at high frequencies with relatively low direct current power supply voltages.

Another object is to provide such an oscillator incorporating the advantages of closed completely shielded high frequency circuits.

Another object is to provide such an oscillator of which the frequency is conveniently adjustable.

Another object is to provide such an oscillator which is relatively compact.

Another object is to provide such an oscillator having good frequency stability.

Resonant cavity type oscillators offer many advantages when energy at very high frequencies is to be generated. Such oscillators may employ a single cavity or a number of cavities and many different methods of operation may be employed. For example, a familiar type employing two cavity resonators utilizes the first cavity to vary the velocities of the electrons in an electron stream, a drift space between the two resonators to allow the accelerated electrons to overtake decelerated electrons thus producing density variations in the stream and a second resonator to be excited electrically by the density varied stream. The device of the present invention differs from this and other well-known resonant cavity oscillators in several respects while incorporating the advantages of the cavity resonator type of circuit.

A resonant cavity type of circuit is employed and through a portion of the high frequency field associated with that cavity when it is energized is directed a stream of electrons from a cathode. By suitable electrodes and biasing potentials applied thereto a direct current electric field is superposed upon the portion of the high frequency field traversed by the electron stream such that it opposes the flow of electrons tending to return them toward the cathode. Adjustments may be made so that electrons entering the high frequency field in such phase as to absorb energy and be accelerated will overcome the retardation of the direct current field and pass on through while electrons entering in such phase as to give up energy to the high frequency field and be decelerated will not be able to overcome the retardation of the direct current field and so will be reversed and accelerated in the opposite direction, again giving up energy to the high frequency field. Thus, since the energy giving electrons traverse the field twice while the energy absorbing electrons traverse the field only once the energy contributions preponderate and high frequency oscillations are sustained in the cavity resonator circuit. The output and efficiency of the device are enhanced by utilizing a resonant cavity input circuit energized by feedback from the output circuit to control the space charge current in a manner to eliminate from the electron stream the energy absorbing electrons which as explained above traverse the high frequency field only once and absorb high frequency energy rather than contribute to it.

2

The invention will be described more fully by referring to the accompanying drawing in which Fig. 1 illustrates the essentials of an oscillator in accordance therewith using a single high frequency circuit, an output circuit in the form of a cavity resonator, Fig. 2 shows a further development of the device using in addition to the cavity output circuit a cavity input circuit with a feedback circuit to energize it whereby the electron stream is modulated at the operating frequency and the efficiency of operation enhanced, and Fig. 3 shows a modification of the Fig. 2 device in which the oscillations are produced initially in the cavity input circuit which is electron coupled to the output circuit, half of the electrons exciting the input circuit and the other half exciting the output circuit.

Referring now to Fig. 1, an insulating evacuated envelope 1 contains the indirectly heated cathode 2, the grid electrodes 3 and 4 and the plate electrode 5, all of these being supported by and connected to the disc members 22, 23, 24 and 25, respectively, which are fused into the envelope 1 and serve to connect the electrodes to external circuits. The cavity resonator 27 is conveniently made in coaxial form as shown and is bounded by members 4, 24, 11, 12, 13, 10, 25 and 5. This resonator is the sole high frequency circuit of the oscillator proper in Fig. 1. The annular members 12 and 13 are spaced radially from each other to provide direct current insulation between electrodes 4 and 5 but the capacitance across the annular space between members 12 and 13 is made sufficiently large to provide a low impedance high frequency path thus effectively closing the resonator between the coaxial members 10 and 11. Members 13 and 12 are movable along members 10 and 11, respectively so that the size of the resonator 27 and consequently its resonant frequency may be varied thereby.

The cathode is heated through lead 16 from potential source 17. The grid electrode 3 is maintained at a potential near that of the cathode by lead 18 connecting to either potential source 17 or 19; the plate electrode 5 is maintained at a potential near that of the cathode by means of lead 20 connecting to either potential source 17 or 19; and the grid electrode 4 is maintained at a potential positive with respect to the cathode and the other electrodes by means of lead 21 connecting to potential source 19.

In operation, electrons emitted from the cathode 2 proceed in the direction of the plate electrode 5 under the influence of the grid electrode 4. Upon passing through the grid electrode 4 the electrons come under the influence of the high frequency field associated with the resonator 27 and impressed upon the space between the grid 4 and plate 5. Depending upon the phase of this field at the time an electron enters it the electron is accelerated or decelerated and consequently some electrons are accelerated and gain energy from the field while others are decelerated and give up energy to the field. The electrode potentials are made such that the electron transit time between the grid electrode 4 and the plate electrode 5 is approximately the period of one-half cycle of the frequency to which the cavity resonator 27 is tuned and also such that electrons which have gained energy and been accelerated are able to pass on to the plate electrode 5 where they are collected, in spite of the retardation due to the low potential of that electrode, while electrons which have given up energy and so lost velocity are stopped before reaching the plate electrode 5 and return toward the cathode yielding still more energy to the high frequency field as they again traverse the space between the plate 5 and grid 4. During each cycle therefore more energy is given to the high frequency field than is taken from it because the electrons which absorb energy traverse the field only once while those which give energy to the field traverse it again in the opposite direction and thus oscillations are maintained in the cavity resonator. High frequency energy thus generated in the resonator 27 may be delivered to a load circuit in any suitable manner such as through the coupling probe 28 to load resistor 29. It is desirable to dimension the tube so that the distance between grids 3 and 4 approximately equals that between grid 4 and plate 5 so that electrons returning toward the plate a second or third time will pass through the space between 4 and 5 in the proper phase.

With a tube operated in this manner and a condition of complete space charge in the region between the cathode 2 and grid 3, 24-centimeter oscillations were obtained with a bias potential of 60 volts between the grid 4 and the cathode 2 while 18-centimeter oscillations were had with a bias potential of 107 volts. The oscillations were easily obtained without critical adjustment of the circuit and the frequency of operation was readily changed by varying the tuning of the cavity resonator and the bias potentials. The output of the device may be varied by changing the biasing potential of the grid electrode 3 and consequently the output may be modulated by applying the modulating voltage to that electrode. It may be noted that while this device is operated with complete space charge between the cathode and the first grid electrode 3 the usual

Barkhausen oscillator, where rather close coupling exists between the various regions of the tube, does not oscillate very well when space charge exists near the cathode.

While extremely satisfactory performance is had with the arrangement of Fig. 1 it is apparent that half of the emission of the cathode, represented by the electrons which enter the high frequency field at a time to absorb energy and be collected at the plate electrode 5, not only do not contribute to the high frequency output but actually absorb high frequency energy. This situation is improved in the arrangement of Fig. 2 where means are provided whereby the electrons leave the vicinity of the grid 3 in groups and in the proper phase to send the groups into the field of the high frequency output circuit in the space between the electrodes 4 and 5 at the proper time to deliver energy to the oscillations. In this way the useless electrons which in the operation of Fig. 1 absorb energy from the high frequency circuit are eliminated. In Fig. 2 a cavity resonator 26 is connected to the cathode 2 and the grid electrode 3 in the same manner as the resonator 27 is connected to the grid electrode 4 and the plate electrode 5. This resonator when energized impresses a high frequency voltage between the cathode 2 and the grid electrode 3 and the biasing potentials are adjusted so that electrons from the cathode pass the grid 3 and on to grid 4 only during the half cycles of the impressed high frequency voltage when the grid 3 is made positive with respect to the cathode 2. The resonator 26 is bounded by members 3, 23, 7, 8, 9, 6, 22 and 2. Members 8 and 9 are spaced to provide direct current insulation between the cathode 2 and grid electrode 3 and are movable along the coaxial members 6 and 7 to change the size and tuning of the resonator. As between members 12 and 13 there is sufficient capacitance between members 8 and 9 to effectively close the resonator for high frequencies. The conducting sleeve member 14 which is insulated for direct current from electrodes 3 and 4 by an insulating sleeve member 15 serves to complete the shielding of the space between electrodes 3 and 4. The cavity resonator 26 may be energized at high frequency by means of any suitable feedback connection to the output resonator 27. In Fig. 2 such a connection is provided by the coaxial line 30, 31, 32 of which the central conductor 30 projects into the field spaces of the resonators to couple therewith. The flanges 33 and 35 with the insulating spacer 34 provide direct current insulation between the electrodes 3 and 4 and at the same time provide a high frequency connection between the sections 31 and 32 of the outer conductor of the coaxial line. The length of the line must be made such that the energy is introduced into the resonator 26 in such phase relation to the energy in resonator 27 that a maximum number of electrons in each group released by the grid electrode 3 enters the space between electrodes 4 and 5 in the proper phase to give up maximum energy to the resonator 27. Ordinarily this condition is indicated by maximum high frequency output of the device. It will be seen that in Fig. 2 the cathode is heated and the various electrodes are biased by means of the potential sources 17 and 19 generally the same as in Fig. 1 and that a load resistance 29 is coupled to the resonator 27 in the same manner in Figs. 1 and 2.

Tests of a circuit according to Fig. 2 showed a high frequency output approximately twice that of the Fig. 1 arrangement indicating the effectiveness of the high frequency control of the electron stream in increasing the output and efficiency.

Fig. 3 illustrates a modification of Fig. 2 in which the feedback connection is dispensed with and the relative biasing potentials are changed to alter the over-all mode of operation. With the exception that the feedback circuit is eliminated the electrodes and the high frequency resonator circuits are arranged the same as in Fig. 2. The electrode biasing potentials, however, are different in Fig. 3 than in Fig. 2, the grid 3 and plate 5 being made positive with respect to the cathode while grid 4 is made approximately the same potential as the cathode. In this arrangement high frequency oscillations are generated in the resonator 26 in much the same manner as in the resonator 27 in the Fig. 1 arrangement. Electrons which cross the space between the cathode 2 and the grid 3 in the phase of the high frequency field associated with the resonator 26 to give up energy to it and on that account are retarded will not be able to overcome the retardation of the low potential electrode 4 and so will be returned toward the cathode and will again traverse the space between the cathode 2 and the grid 3, in the opposite direction, again giving energy to the resonator 26. The result of this multiple crossing of the space between 2 and 3 by the energy giving electrons is a preponderance of energy giving traversals of the space which sustains the oscillations in the resonator 26 in the manner the oscillations are sustained in resonator 27 of Fig. 1. However, the oscillations generated in resonator 26 are not coupled directly to the load circuit as were the oscillations generated in resonator 27 of Fig. 1. The electrons which cross the space between the cathode 2 and the grid 3 in the phase of the high frequency field to absorb energy from it are accelerated so that they are able to overcome the retardation of the low potential electrode 4 and pass that electrode, after which they are accelerated and collected by the plate electrode 5. These electrons reach electrode 4 and cross the space between 4 and the plate electrode 5 in groups at the frequency of the oscillations in the resonator 26 and, therefore, generate energy at that frequency in resonator 27. Resonator 27 then is the resonant output circuit and it is excited by the groups of electrons which have been accelerated during traversal of the space between electrodes 2 and 3 so that they are able to pass electrode 4. The load circuit 29 is coupled to the resonator 27 by means of the probe 28 as in the other figures.

In the arrangement of Fig. 3 the load is coupled to the frequency determining circuit (resonator 26) only through the electron stream so that an advantage of frequency stability is had. However, the arrangement is less efficient than that of Fig. 2 in that the retarded electrons do not contribute high frequency energy to the output circuit but are required nevertheless to energize the frequency control circuit comprising resonator 26 while the output circuit is energized by the accelerated electrons which can traverse the high frequency field only once before being collected.

What is claimed is:

1. A high frequency oscillator circuit comprising an electron discharge tube containing at least four planar electrodes namely an electron emitting cathode, a plate electrode, a first grid electrode between the cathode and the plate electrode and a second grid electrode between the first grid electrode and the plate electrode, a high frequency circuit comprising a substantially closed electrical resonator system comprising coaxial conducting members external to the said electron discharge tube and which includes the electron emitting surface of the cathode and the first grid electrode, a second high frequency circuit comprising a substantially closed electrical resonator system comprising coaxial conducting members external to the electron discharge tube and which includes the plate electrode and the second grid electrode and means for causing a flow of electrons along at least a portion of a path extending between the cathode and the plate electrode comprising a source of electric potential connected to each of the said electrodes and to at least one other said electrode whereby suitable potential differences are maintained between the various electrodes, the potential differences being such that the potential of the second grid electrode is maintained positive with respect to the cathode and to the other two electrodes and also such that the electron transit time between the second grid electrode and the plate electrode is substantially the period of one-half cycle of the resonant frequency of the second high frequency circuit.

2. A high frequency oscillator comprising an electron discharge tube containing at least four planar electrodes namely an electron emitting cathode, a plate electrode, a first grid electrode between the cathode and the plate electrode and a second grid electrode between the first grid electrode and the plate electrode, a high frequency circuit comprising a substantially closed electrical resonator system comprising coaxial conducting members external to the said electron discharge tube and which includes the electron emitting surface of the cathode and the first grid electrode, a second high frequency circuit comprising a substantially closed electrical resonator system comprising coaxial conducting members external to the said electron discharge tube and which includes the plate electrode and the second grid electrode, means for connecting the two high frequency circuits in feedback relation and means for causing a flow of electrons along at least a portion of a path extending between the cathode and the plate electrode comprising a source of electric potential connected to each of the said electrodes and to at least one other said electrode whereby suitable potential differences are maintained between the various electrodes, the potential differences being such that the potential of the second grid electrode is maintained positive with respect to the cathode and to the other two electrodes and also such that the electron transit time between the second grid electrode and the plate electrode is substantially equal to the period of one-half cycle of the resonant frequency of the second high frequency circuit.

3. A high frequency oscillator circuit comprising an electron discharge tube containing at least four planar electrodes namely an electron emitting cathode, a plate electrode, a first grid electrode between the cathode and the plate electrode and a second grid electrode located substantially midway between the first grid electrode and the plate electrode, a high frequency circuit comprising a substantially closed electrical resonator system comprising coaxial conducting members external to the said electron discharge tube and which includes the electron emitting surface of the cathode and the first grid electrode, a second high frequency circuit comprising a substantially closed electrical resonator system comprising coaxial conducting members external to the electron discharge tube and which includes the plate elec-

trode and the second grid electrode and means for causing a flow of electrons along at least a portion of a path extending between the cathode and the plate electrode comprising a source of electric potential connected to each of the said electrodes and to at least one other said electrode whereby suitable potential differences are maintained between the various electrodes, the potential differences being such that the potential of the second grid electrode is maintained positive with respect to the cathode and to the other two electrodes and also such that the electron transit time between the second grid electrode and the plate electrode is substantially the period of one-half cycle of the resonant frequency of the second high frequency circuit.

4. A high frequency oscillator comprising an electron discharge tube having a planar cathode, a planar, anode and at least one planar electron permeable electrode located therebetween such that an electron stream passing from the cathode to the anode traverses each of the spaces between the various electrodes, a cavity resonator comprising coaxial conducting members external to the said electron discharge tube and connected for high frequencies to two of the said electrodes other than the cathode which are adjacent to each other such that when the resonator is energized a portion of its alternating electric field is impressed upon the space between the electrodes connected to it, means for varying the resonator frequency comprising members slidable longitudinally between the said coaxial conducting members and means comprising a source of electric potential connected to each of the said electrodes and to at least one other said electrode for producing a stream of electrons from the cathode to the anode and for establishing fixed potential differences between the electrodes, the potential differences being such that of the two electrodes connected to the resonator the one located nearer the cathode is the more positive with respect to the cathode and, further, the potential differences and the distances between the electrodes being such that the electron transit time between the electrodes connected to the resonator is a period substantially equal to the period of one-half cycle of the resonant frequency of the resonator.

5. A high frequency oscillator comprising an electron discharge tube having two planar electron path terminating electrodes termed cathode and anode and at least one planar electron permeable electrode located therebetween such that an electron stream passing from the cathode to the anode traverses each of the spaces between the various electrodes, a cavity resonator comprising coaxial conducting members external to the said electron discharge tube connected to two of the said electrodes which are adjacent to each other and of which one is an electron path terminating electrode such that when the resonator is energized a portion of its alternating electric field is impressed upon the space between the electrodes connected to it, frequency control means comprising a movable member included with said resonator and means comprising a source of electric potential connected to each of the said electrodes and to at least one other said electrode for producing a stream of electrons from the cathode to the anode and for establishing potential differences between the electrodes, the potential differences being such that electrons traversing the path between the cathode and anode encounter an electron permeable electrode substantially positive with respect to the cathode and later encounter an electrode substantially negative with respect to the said permeable positive electrode whereby electrons are reversed and prevented from reaching the anode.

6. A high frequency oscillator circuit comprising an electron discharge tube containing at least four planar electrodes namely an electron emitting cathode, a plate electrode, a first grid electrode between the cathode and the plate electrode and a second grid electrode between the first grid electrode and the plate electrode, a high frequency circuit comprising a substantially closed electrical resonator system comprising coaxial conducting members external to the said electron discharge tube and which includes the electron emitting surface of the cathode and the first grid electrode, a second high frequency circuit comprising a substantially closed electrical resonator system comprising coaxial conducting members external to the electron discharge tube and which includes the plate electrode and the second grid electrode, frequency control means comprising a movable member included with each of the said resonator systems whereby the resonant frequency of each of the systems may be readily varied and means for causing a flow of electrons along at least a portion of a path extending between the cathode and the plate electrode comprising a source of electric potential connected to each of the said electrodes and to at least one other said electrode whereby suitable potential differences are maintained between the various electrodes, the potential differences being such that the potential of the second grid electrode is maintained positive with respect to the cathode and to the other two electrodes and also such that the electron transit time between the second grid electrode and the plate electrode is substantially the period of one-half cycle of the resonant frequency of the second high frequency circuit.

7. A high frequency oscillator comprising an electron discharge tube having two planar electron path terminating electrodes termed cathode and anode and at least one planar electron permeable electrode located therebetween such that an electron stream passing from the cathode to the anode traverses each of the spaces between the various electrodes, a cavity resonator comprising coaxial conducting members external to the said electron discharge tube connected to two of the said electrodes which are adjacent to each other and of which one is an electron path terminating electrode such that when the resonator is energized a portion of its alternating electric field is impressed upon the space between the electrodes connected to it, frequency control means comprising a movable member included with said resonator and means comprising a source of electric potential connected to each of said electrodes and to at least one other said electrode for producing a stream of electrons from the cathode toward the anode and for establishing potential differences between the electrodes, the potential differences being such that electrons traversing the path between the cathode and anode encounter an electron permeable electrode substantially positive with respect to the cathode and later encounter an electrode substantially negative with respect to the said permeable positive electrode so that part of the electrons in the stream are reversed and part are permitted to continue along the path to the anode.

8. A high frequency oscillator circuit comprising an electron discharge tube containing at least four planar electrodes namely an electron emit-

ting cathode, a plate electrode, a first grid electrode between the cathode and the plate electrode and a second grid electrode located substantially midway between the first grid electrode and the plate electrode, a high frequency circuit comprising a substantially closed electrical resonator system comprising conducting members external to the said electron discharge tube which includes the electron emitting surface of the cathode and the first grid electrode, a second high frequency circuit comprising a substantially closed electrical resonator system which includes the plate electrode and the second grid electrode, frequency control means comprising a movable member included with each of the said resonator systems whereby the resonant frequency of each of the systems may be readily varied and means for causing a flow of electrons along at least a portion of a path extending between the cathode and the plate electrode comprising a source of electric potential connected to each of the said electrodes and to at least one other said electrode whereby suitable potential differences are maintained between the various electrodes, the potential differences being such that the potential of the second grid electrode is maintained positive with respect to the cathode and to the other two electrodes and also such that the electron transit time between the second grid electrode and the plate electrode is substantially the period of one-half cycle of the resonant frequency of the second high frequency circuit.

9. A high frequency oscillator comprising an electron discharge tube containing at least four planar electrodes namely an electron emitting cathode, a plate electrode, a first grid electrode between the cathode and the plate electrode, and a second grid electrode between the first grid electrode and the plate electrode, a high frequency circuit comprising a substantially closed electrical resonator system comprising coaxial conducting members external to the said electron discharge tube which includes the plate electrode and the second grid electrode, means for causing a flow of electrons along at least a portion of a path extending between the cathode and the plate electrode comprising a source of electric potential connected to each of the said electrodes and to at least one other said electrode whereby suitable potential differences are maintained between the various electrodes, the potential differences being such that the potential of the second grid electrode is maintained positive with respect to the cathode and to the other two electrodes and means comprising the first grid electrode for controlling at low frequency the high frequency output of the oscillator.

10. A high frequency oscillator comprising an electron discharge tube containing an electron emitting cathode, a plate electrode, a first grid electrode between the cathode and the plate electrode and a second grid electrode between the first grid electrode and the plate electrode, a high frequency circuit comprising a substantially closed electrical resonator system which includes the electron emitting surface of the cathode and the first grid electrode, a second high frequency circuit comprising a substantially closed electrical resonator system which includes the plate electrode and the second grid electrode, means comprising a movable member included with each of the said resonator systems for varying the resonant frequency of the two resonant systems and electric potential sources connected to the cathode and other said electrodes for maintaining suitable potential differences therebetween and for causing a flow of electrons along at least a portion of a path extending between the cathode and the plate electrode, the said potential differences being such that the first grid electrode and the plate electrode are maintained at potentials positive with respect to the cathode and the second grid electrode is maintained at a potential negative with respect to the first grid electrode and the plate electrode.

11. A high frequency oscillator comprising an electron discharge tube having two planar electron path terminating electrodes, one being a cathode and one an anode, and at least one planar electron permeable electrode located therebetween such that an electron stream passing from the cathode to the anode traverses each of the spaces between the various electrodes, a cavity resonator comprising coaxial conducting members external to the said discharge tube connected to two of the said electrodes which are adjacent to each other and of which one is an electron path terminating electrode such that when the resonator is energized a portion of its alternating electric field is impressed upon the space between the electrodes connected to it, means for varying the resonator frequency comprising members slidable longitudinally between the said coaxial conducting members, electric potential sources connected to the said electrodes for producing a stream of electrons from the cathode to the anode and for establishing potential differences between the electrodes, the potential differences being such that electrons traversing the path from the cathode toward the anode encounter an electron permeable electrode substantially positive with respect to the cathode and later encounter an electrode substantially negative with respect to the said permeable positive electrode.

12. A high frequency oscillator comprising an electron discharge tube containing at least four planar electrodes namely an electron emitting cathode, a plate electrode, a first grid electrode between the cathode and the plate electrode and a second grid electrode between the first grid electrode and the plate electrode, a high frequency circuit comprising a substantially closed electrical resonator system comprising conducting members preponderantly external to the said electron discharge tube and which includes the electron emitting surface of the cathode and the first grid electrode, a second high frequency circuit comprising a substantially closed electrical resonator system comprising conducting members preponderantly external to the electron discharge tube and which includes the plate electrode and the second grid electrode, frequency control means comprising a movable member included with each of the said resonator systems whereby the resonant frequency of each of the systems may be readily varied and means for causing a flow of electrons along at least a portion of a path extending between the cathode and the plate electrode comprising a source of electric potential connected to each of the said electrodes and to at least one other said electrode whereby suitable potential differences are maintained between the various electrodes, the potential differences being such that the potential of the second grid electrode is maintained positive with respect to the cathode and to the other two electrodes.

13. A device according to claim 5 in which the said resonator includes the said anode.

14. A device according to claim 5 in which the said potential differences and the distances be-

tween the electrodes are such that the electron transit time between the electrodes connected to the resonator is a period substantially equal to the period of one-half cycle of the said alternating electric field.

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