

Aug. 26, 1958

C. F. QUATE ET AL
HIGH FREQUENCY APPARATUS

2,849,650

Filed June 10, 1955

2 Sheets-Sheet 1

FIG. 1

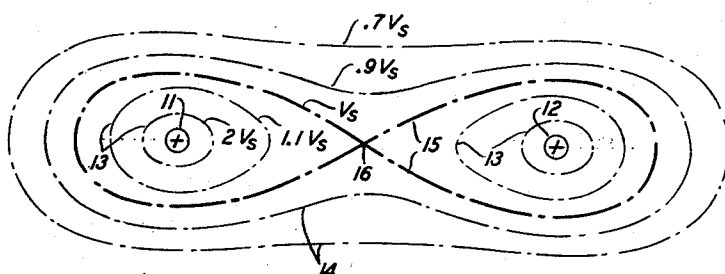


FIG. 2

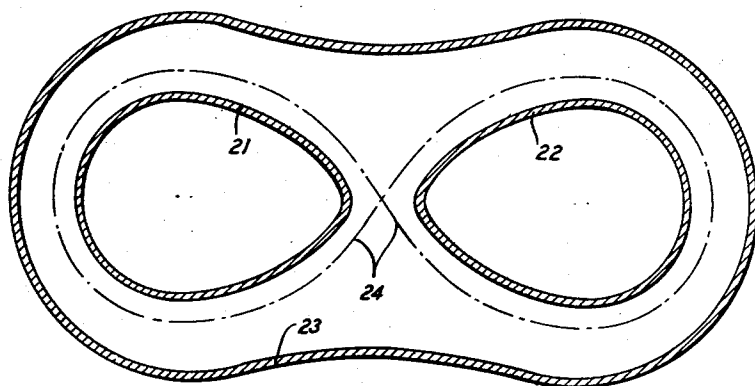
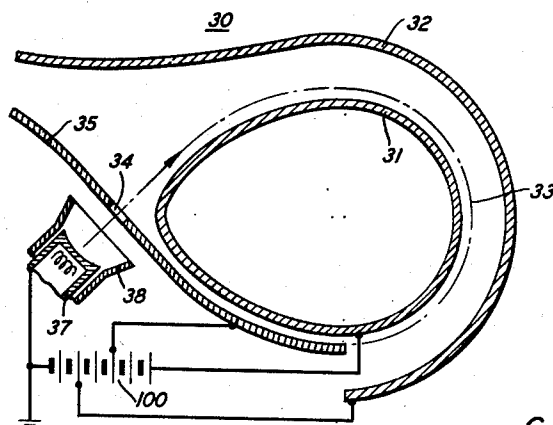


FIG. 3



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FIG. 4

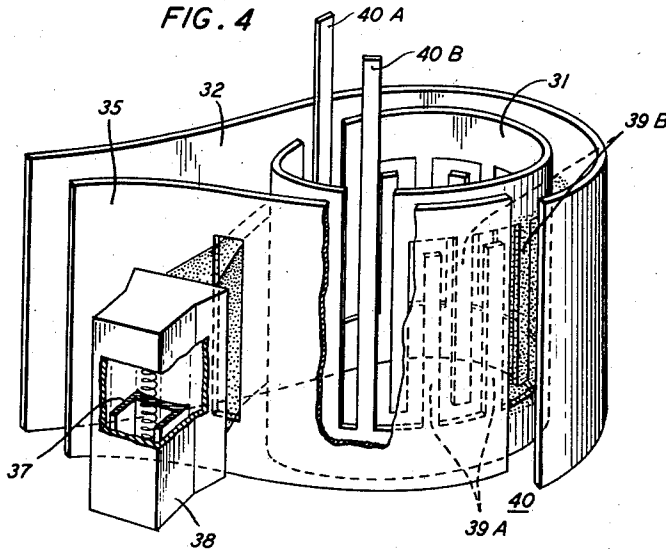


FIG. 5

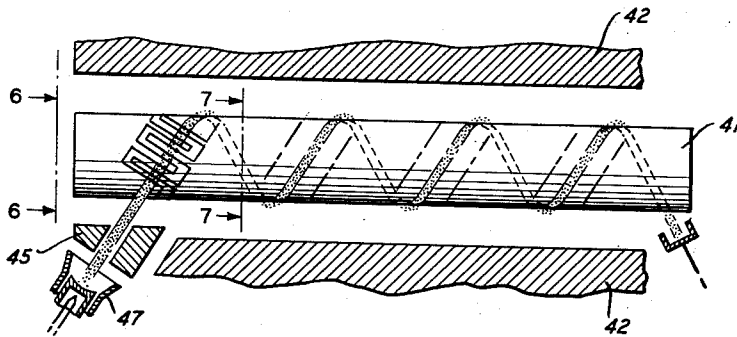


FIG. 6

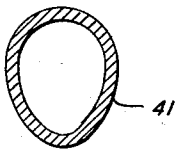
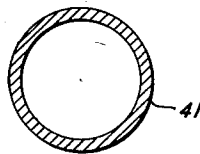


FIG. 7



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HIGH FREQUENCY APPARATUS

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Application June 10, 1955, Serial No. 514,422

6 Claims. (Cl. 315-3.5)

This invention relates to radio frequency apparatus, and more particularly to such apparatus which utilizes the interaction between an electron beam and an electromagnetic wave to amplify the wave.

There has recently been reported in the literature a radio frequency oscillator which has been described as a "magnetless magnetron." Such an oscillator comprises a coaxial pair of circularly cylindrical electrodes of which the inner is maintained at a potential positive with respect to the outer. In the interspace therebetween, an electron gun is positioned to inject electrons in a direction perpendicular to a plane through the common cylindrical axis of the electrodes at a velocity such that the electrons flow in paths substantially concentric with the electrodes, balanced between the centrifugal forces and the radially-inward electrostatic forces set up by the potential difference maintained between the two electrodes. Additionally, the inner electrode is slitted in an axial direction around its periphery and successive strips are connected to different conductors of a Lecher line to form a resonant system. In such a device, oscillations are set up at a frequency such that the electron transit time between equivalent points on two successive strips is approximately one half the period of the resonant system.

In operation, one half of the electrons which are injected gain energy from the high frequency fields set up by the resonant system, hence go faster and move out and away from the inner electrode where they influence the high frequency field less, while the other half of the electrons give up energy to the high frequency fields of the resonant system, are slowed down, and so move closer to the inner electrode where their influence on the high frequency fields is still greater. As a result, more energy is given up by the electrons to the resonant system than is abstracted therefrom, and stable oscillations are built up.

Operation at radio frequencies at which the tube dimensions may be relatively large is convenient in an oscillator of the kind described. However, in operation at higher frequencies where there is required relatively small tube dimensions, considerable difficulty is experienced in injecting electrons in sufficient numbers in the interspace between the two cylinders with the correct velocity necessary for stable flow. As a practical matter, operation much above several thousand megacycles becomes prohibitively difficult in an oscillator of the kind described.

The present invention relates, in one aspect, to improvements in an oscillator of the general kind described which facilitate the problem of beam injection and increase the efficiency of beam and wave interaction, making feasible the design of oscillators for operation at higher frequencies.

In still another aspect, the invention relates to the substitution for the resonant system in the oscillator described of a delay line adapted for propagating a travel-

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ing electromagnetic wave to make feasible traveling wave type operation.

To these ends, in an illustrative embodiment of the present invention an inner electrode serves as a delay line for propagating a traveling wave with which the electron flow interacts and an outer electrode in cooperation with an auxiliary electrode is arranged to set up in the interspace between the inner and outer electrodes a singular equipotential surface along which electrons properly injected will flow stably past the delay line. The singular equipotential surface formed is one which is characterized by a crossover region defined by the intersection of two portions of the singular equipotential surface. This crossover region is, in turn, characterized by an absence of electric field, and electrons may there be injected smoothly on the singular equipotential surface for flow therealong. The electrons there injected are provided from an electron gun which is positioned in a region external to the interspace bounded by the auxiliary electrode and the inner and outer electrodes. To minimize the gun's disturbance on the electrostatic field in this bounded interspace and to insure the injection of electrons with the correct velocity, the auxiliary electrode serves as the accelerating anode of the electron gun and one of its surfaces coincides with a portion of the singular equipotential surface encompassing the crossover region and the electron beam is projected for flow in the bounded interspace through an aperture in the accelerating anode at the crossover region.

In an oscillator embodiment of the backward wave type, one end of the delay line provided by the inner electrode is terminated to be substantially reflectionless while the other end is coupled to an output coupling connection. Various other oscillator arrangements which depend on reflections at the ends of the delay line similarly are feasible.

In an amplifier embodiment, input wave energy is applied to one end of the delay line and output wave energy is abstracted at the other end.

The invention will be better understood from the following more detailed description taken in conjunction with the accompanying drawings in which:

Fig. 1 is a plot of the equipotential lines of the electric field surrounding a pair of spaced line charges which will be helpful in an exposition of the basic principles of the invention;

Fig. 2 shows an electrode system suitable for establishing a potential distribution of the kind plotted in Fig. 2;

Fig. 3 shows a transverse cross section of an electrode system for use in the practice of the present invention;

Fig. 4 shows a perspective view of a tube in accordance with the present invention incorporating the electrode system shown in Fig. 3;

Fig. 5 shows as an alternative embodiment of the invention a traveling wave tube which utilizes a helical path of electron flow; and

Figs. 6 and 7 each show a different transverse cross section of a portion of the tube shown in Fig. 5.

Referring now more particularly to the drawings, in Fig. 1 there is plotted the equipotential lines in the plane of the drawing of the electric field surrounding a spaced pair of line charges 11, 12 which extend normal to the plane of the drawing. A similar plot is shown on page 10 of a book entitled "Static and Dynamic Electricity" by W. R. Smythe, 2nd Edition, McGraw Hill Book Company, Inc., New York. Surrounding the individual line charges is a series of closed equipotential lines 13 each of which is substantially concentric with one line charge. Surrounding the pair of line charges is a series of closed equipotential lines 14. Intermediate between

these two series of closed equipotential lines is the singular equipotential line 15 which resembles a figure eight and is characterized in the plane of the drawing by a crossover point 16 equidistant between the two line charges. This crossover point is a node at which the electric field is zero. The approximate potentials of each of the lines relative to the potential V_s of the singular equipotential line is indicated. As set forth more fully in the copending applications Serial No. 514,423, filed June 10, 1955, by R. Kompfner and W. H. Yocum and Serial No. 514,424, filed June 10, 1955, by R. Kompfner which relate to the electrostatic focusing of an electron beam for flow along a singular equipotential surface associated with an array of conductive elements, electrons injected with a correct velocity on such a singular equipotential line will, in the absence of other applied forces, be balanced between electrostatic and centrifugal forces if they follow along the surface and accordingly will follow along the surface. In three dimensions, the equipotential lines 13, 14, and 15 become equipotential surfaces and the crossover point 16 becomes a line extending normal to the plane of the drawing corresponding to the intersection of the forward and return portions of the singular equipotential surface.

The potential distribution shown in Fig. 1 can be simulated in an electrode system of the kind shown in Fig. 2, in which each of the line charges 11, 12 of Fig. 1 is replaced by a tear drop shaped cylindrical electrode 21, 22 which extends axially normal to the plane of the paper. Each of these electrodes has a surface which coincides with any one of the series of closed equipotential surfaces 13 shown in Fig. 1 and is maintained at the potential corresponding to that of such surface. Additionally, a bounding cylindrical electrode 23 extending axially normal to the plane of the paper is provided whose surface coincides with any one of the series of closed equipotential surfaces 14 of Fig. 1 and which is maintained at the potential corresponding to that of such surface. As a consequence there will be set up in the interspace therebetween a singular equipotential surface 24 corresponding to that of surface 15 of Fig. 1 which will serve as a stable trajectory for electrons properly injected thereon.

In a closed electrode system of this kind, it is possible to replace any of the electrodes shown by another electrode without disturbing the potential distribution of the interspace if the substituted electrode is made to coincide with an equipotential surface of the potential distribution and is maintained at the potential characteristic of the equipotential surface with which it coincides. Use of this general principle is made in the practice of the present invention.

In the present invention, in which only one electrode is necessary for use as the delay line for propagating a traveling wave with which the electron flow is to interact, it is desirable to modify the electrode system depicted appropriately. Moreover, provision must be made for injection of the electron beam on the singular equipotential surface in a manner to minimize disturbance of the potential distribution in the electrode system. In Fig. 3, there is shown the modified electrode system to be incorporated in embodiments of the invention.

In the electrode beam system 30 shown in Fig. 3, cylindrical electrodes 31 and 32 extending longitudinally normal to the plane of the drawing correspond, respectively, to the electrodes 21 and 23 of the electrode system shown in Fig. 2. Advantageously, the cylindrical electrode 32 coincides with only as much of an equipotential surface as is necessary to insure that there will be set up in the interspace a singular equipotential surface 33 which is characterized by a crossover line 34. An accelerating anode 35 extending longitudinally normal to the plane of the drawing, a portion of whose surface coincides with an extended portion of the singular equipotential surface 33 encompassing the crossover line, is apertured at the crossover line for projection therethrough of an electron

beam with the correct velocity for flow along the portion of this surface 33 extending transversely from the aperture into the interspace between electrodes 31 and 32. Behind the accelerating anode is positioned an electron gun, of known design, comprising an electron-emissive cathode 37 and the beam-forming electrode 38, each extending normal to the plane of the drawing. The accelerating anode 35 cooperates with the beam-forming electrode in collimating the electron emission into a well defined sheet beam for projection through the aperture in the accelerating anode 35 onto the singular equipotential surface 33 for flow therealong until collected.

For operation in the manner described, the cathode 37, the beam-forming electrode 38, and the outer electrode 32 are each maintained at potentials considerably negative with respect to the inner electrode 31. Additionally since the accelerating anode 35 is maintained at the potential corresponding to the singular equipotential surface 33, the electrons will inherently be injected with the velocity correct for stable flow along the singular equipotential surface 33. Such potential will be intermediate those on the inner and outer electrodes. The appropriate potentials are readily established by leads from a suitable voltage supply 100.

In accordance with one feature of the present invention, the accelerating anode 35 cooperates with the inner electrode 31 and the outer electrode 32 to provide an integrated electrode system for setting up the singular equipotential surface 33. The accelerating anode 35 also acts to shield the presence of the electron gun from the region bounded by it and electrodes 31 and 32 and makes possible the injection of an electron beam having a ribbon cross section and of high density on to the singular equipotential surface without effect on the potential distribution in the interspace.

In a typical arrangement, the longest and shortest dimensions of the inner electrode 31 may be about 1.8 inches and 1.5 inches, respectively, and there may be a separation of about a quarter inch between the outer surface of the inner electrode and the inner surface of the outer electrode, over the major portion of the outer electrode. For such a structure, typical operating voltages, with the voltage of the cathode of the electron gun as ground, are 1050 volts on the inner electrode, 470 volts on the outer electrode and 1000 volts on the accelerating anode.

In accordance with another feature of the present invention, the portion of the inner electrode 31 opposite the "active" portion of the singular equipotential surface (that along with the electron beam flows) is made to serve as a delay line for propagating electromagnetic wave energy having space harmonic components with a phase velocity equal to that of the electron flow for interaction between the wave energy and the flow. To this end, the electrode 31 is hollow and that portion adjacent the beam path is grooved to form thereof a folded or interdigital delay line for propagating the electromagnetic wave energy for interaction with an electron beam.

In Fig. 4, there are shown the basic elements of a traveling wave tube 40 which embodies the electrode system shown in Fig. 3. The envelope, lead-in connectors, spacers and support elements have been omitted for the sake of simplicity. It has been thought convenient to employ the same reference numerals in the two figures for corresponding elements. In this figure, the inner electrode 31 is shown slotted to form thereof a delay line for propagating a slow electromagnetic wave. In particular, the delay line is of an interdigital form, comprising a pair of sets of interleaved finger elements 39A, 39B which provide the folded or slow wave path. Coupling connections 40A, 40B are shown schematically to the two ends of the delay line.

It is, of course, feasible to make of electrode 31 any other suitable form of delay line for providing the slow wave components for interaction with the flow. In par-

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ticular, a succession of resonant slots may be provided around the periphery which are coupled together to form a delay line. Provided the various other operating potentials are appropriately chosen, the potential characteristic of the singular equipotential surface may be made to have any desired value, and, accordingly, the beam velocity may be chosen as desired. Interaction between the electron flow and a component of the wave energy propagating along the delay line is of the type known to workers in the traveling wave tube art.

For use as a backward wave oscillator, oscillatory wave energy is abstracted at the coupling connection 40A to the end of the delay line upstream (i. e. more adjacent in the direction of flow of the point of injection of the beam). Additionally, the other, or downstream end, of the delay line is terminated to be substantially reflectionless, either by connecting the coupling connection 40B to an external matching termination or by the insertion internally of lossy material which dissipates incident wave energy, for example, as a resistive coating on dielectric inserts between the finger elements.

For modulating the oscillatory frequency, the potentials on each of elements 31, 32 and 33 may be varied proportionally to vary the potential of the singular equipotential surface and thereby the beam velocity and the oscillatory frequency.

For use in oscillators of the kind which involve reflections at the ends of the delay line, such ends can be made suitably reflective by impedance mismatches connected to the coupling connections 40A, 40B.

For use as a backward wave amplifier, the input signal is applied to the downstream end of the delay line by way of connection 40B and the output wave abstracted at the upstream end of the delay line by way of connection 40A. In such operation, care must be taken to avoid exceeding the starting current for backward wave oscillations.

For use as a conventional forward wave amplifier, the input signal is applied from an input source by coupling connection 40A at the upstream end of the delay line and the output wave abstracted for use by the load by way of coupling connection 40B at the downstream end of the delay line. In this mode of operation, it may be advantageous to insert lossy material along the intermediate portion of the delay line to inhibit the effect of reflections arising from mismatches at the coupling connections to the line.

The basic embodiment described may be modified to increase the length of the delay line beyond the length of the circumference of a cross section of the inner electrode. In the modified embodiment shown in Figs. 5, 6 and 7, the inner electrode 41 is adapted to form a delay line which winds helically as shown schematically for several turns around the periphery of the inner electrode. Inasmuch as the delay line is shown only schematically, the details of its structure and the input and output connections have been omitted. To provide electron flow in a helical path corresponding to that of the delay line for continuous interaction between the beam and the propagating wave, the electrons are injected from an electron gun 47 to have a component of velocity in the direction parallel to the axis of the inner and outer electrodes 41 and 42, and in the direction of winding of the wave path to provide a steady axial drift in their flow as they circulate around the inner electrode resulting in a helical flow path matching that of wave propagation.

However, to insure that the electron flow continues in a concentric path around the inner electrode after the first traversal around this electrode, the cross section of the inner electrode 41 is tapered from the teardrop shape shown in Fig. 6 it has initially at the region of beam injection to modify the path of the singular equipotential surface from its original configuration to a circular configuration shown in Fig. 7 establishing a circularly concentric surface of stable flow. Additionally, the auxiliary

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electrode 45 is used merely at the region of injection. Moreover, the surface configuration of the outer electrode is also tapered to effect the desired transition in the configuration of the singular equipotential surface of stable flow and beyond the region of injection becomes a circular electrode surrounding inner electrode 41.

Alternatively, the inner electrode may be slotted to provide in the axial direction a spaced succession of parallel delay lines of the kind typical of the embodiment shown in Fig. 3. The output end of each line is coupled to the input end of the succeeding line to form in effect a continuous delay line comprising a series of interconnected sections. An electron gun provides a plurality of electron beams, one for flow past each parallel section.

It is, accordingly, to be understood that the specific embodiments described are merely illustrative of the general principles of the invention. Various other embodiments may be devised by a worker in the art without departing from the spirit and scope of the present invention.

What is claimed is:

1. In an electron discharge device, in combination, means for establishing a singular equipotential surface characterized by a crossover region, said means comprising an outer electrode and an inner electrode, said inner electrode comprising a slow wave circuit for propagating an electromagnetic wave and having a teardrop-shaped cross-section over at least a portion of its length, an auxiliary electrode having a surface defining a portion of the singular equipotential surface encompassing the crossover region and being apertured at the crossover region, and means positioned external to the region bounded by the inner and outer electrodes and the auxiliary electrode for projecting an electron beam through the aperture in the auxiliary electrode for flow along another portion of the singular equipotential surface for interaction with the propagating electromagnetic wave.

2. An oscillator comprising the combination of claim 1, in further combination with means for terminating one end of the slow wave circuit to make it substantially reflectionless, and means coupling to the other end of the slow wave circuit for abstracting oscillatory energy.

3. An amplifier comprising the combination of claim 1 in further combination with means for applying input wave energy to one end of the slow wave circuit and means for abstracting output wave energy coupled to the opposite end of the slow wave circuit.

4. An electron discharge device comprising means for establishing a singular equipotential surface characterized by a cross-over region, said means including an inner substantially cylindrical electrode having a teardrop-shaped cross-section over at least a portion of its length and comprising a slow wave circuit for propagating a slow electromagnetic wave, an outer electrode at least partially encompassing said inner cylindrical electrode, and an auxiliary electrode having a surface defining a portion of the singular equipotential surface, including said cross-over region, and being apertured at said cross-over region, and means for projecting an electron beam through said aperture in said auxiliary electrode for flow along another portion of said singular equipotential surface for interaction with an electromagnetic wave propagating on said slow wave circuit.

5. An electron discharge device in accordance with claim 4 further comprising means for maintaining said outer electrode at a negative potential with respect to said inner electrode.

6. An electron discharge device comprising means for establishing a singular equipotential surface characterized by a cross-over region, said means including an inner substantially cylindrical electrode having a teardrop-shaped cross-section over at least a portion of its length and comprising a slow wave circuit for propagating a slow electromagnetic wave, an outer electrode at least partially encompassing said inner electrode, an auxiliary

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electrode having a surface defining a portion of the singular equipotential surface, including said cross-over region, and being apertured at said cross-over region, and means for projecting an electron beam through said aperture in said auxiliary electrode with a component of velocity parallel to the longitudinal axis of said inner electrode for flow along another portion of said singular equipotential surface for interaction with an electromagnetic wave propagating on said slow wave circuit.

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