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ULTRA HIGH FREQUENCY OSCILLATOR

Filed April 4, 1941 2 Sheets-Sheet 1

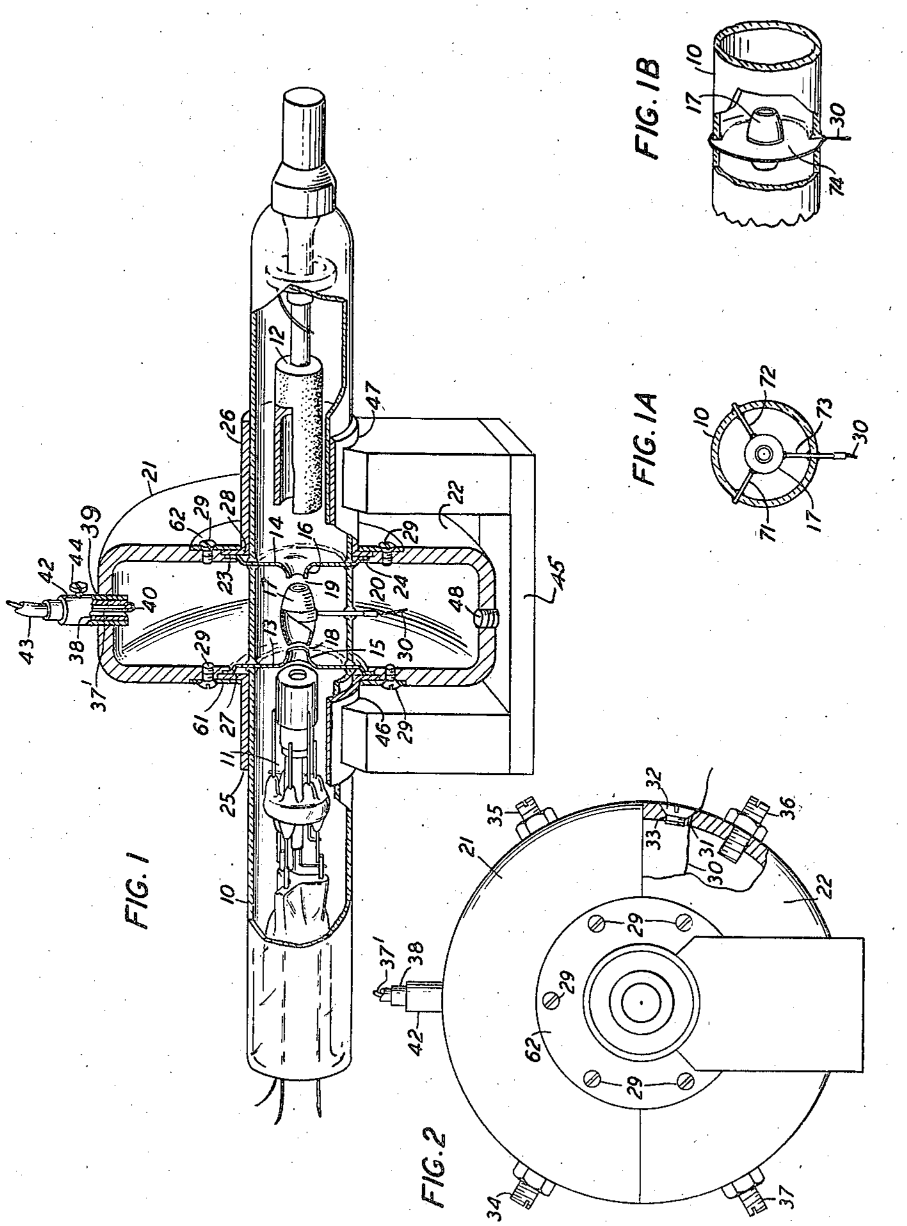
FIG. 1 FIG. 1A FIG. 1B FIG. 2

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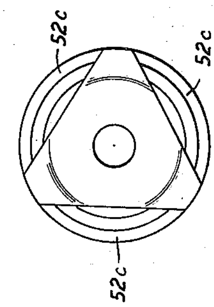

FIG. 4

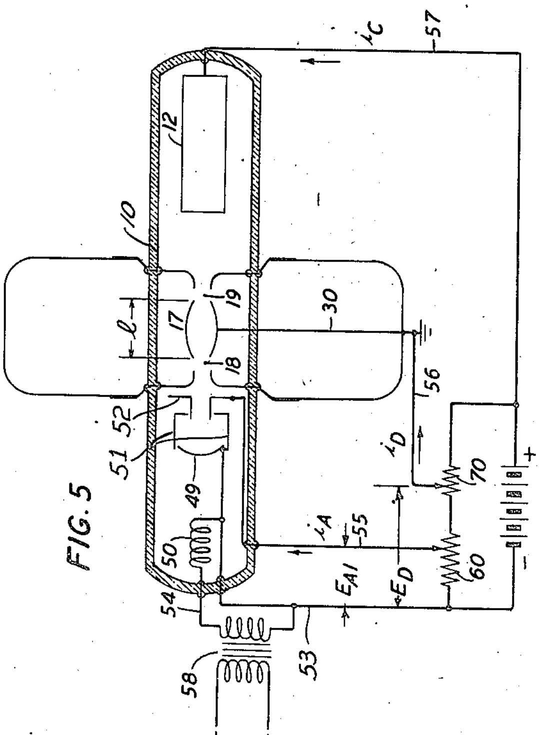

FIG. 5

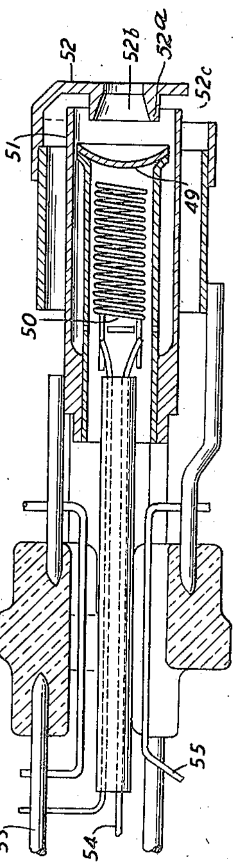

FIG. 3

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ULTRA HIGH FREQUENCY OSCILLATOR

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Application April 4, 1941, Serial No. 386,794

7 Claims. (Cl. 250—27.5)

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This invention relates to oscillators or generators of ultra-high frequency electromagnetic waves and currents and is particularly applicable to the generation of waves of a few centimeters or less in wave-length.

An object of the invention is to produce an oscillator having a higher degree of frequency stability and amplitude stability at the higher frequencies than have been heretofore obtainable.

Another object is to reduce the weight and bulk of an oscillator of this kind.

A further object is to simplify the manufacture, assembly and adjustment of the device.

The oscillator is of the type employing a single resonant cavity which is maintained in oscillation by direct interaction between the electromagnetic field of the resonator and the electrons in an associated electron stream. The electron stream interacts with the field at two gaps separated by a shielded drift space. In the first gap the electron stream is velocity varied by the electric field. Passing then through the drift space, the electron stream undergoes a grouping or bunching of electrons resulting from the velocity variation. The transit time of the electrons in the drift space is so adjusted that the electron groups arrive at the second gap in proper phase to contribute energy to the field. When the system is properly adjusted oscillations start spontaneously and are maintained by the energy contributed to the field cyclically by the electron stream.

A feature of the invention is the construction of the main body of the resonator in two half sections to facilitate manufacture and assembly. The resonant chambers are completed by a pair of disc electrodes extending through and sealed into the walls of the envelope which encloses the electron stream. Within the envelope and enclosed by the resonator is mounted a drift tube the ends of which, together with the two abovementioned electrodes, form the gaps hereinbefore referred to. The drift tube and the electrodes are provided with aligned apertures for the passage of the electron stream therethrough.

Another feature of the invention lies in improved means for joining the half sections of the resonator together and clamping them to the disc electrodes.

A further feature is connected with the use of a single battery or other suitable source to provide all the biasing potentials required for the operation of the oscillator. The heating current is not necessarily supplied from the same source as the biasing potentials and any or all of the

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currents and potentials may be supplied, if desired, from ordinary electric power mains. The collector current is preferably kept out of the potentiometer and returns directly to the biasing battery thereby permitting the use of a relatively light and compact potentiometer. In applications where the power output is the primary consideration and efficiency secondary, the electrons are preferably collected at the maximum battery potential in order, as above mentioned, to keep the collector current out of the potentiometer and also to avoid the alternative of an additional battery opposed to the biasing potential to reduce the effective potential at the collector electrode.

Another feature of the invention is the use of a permanent magnet as a source of focussing flux and a pair of magnetic collars fitting over the vacuum tube for the direction of flux.

Other features include a suitable shaping of the interior walls of the drift tube to further facilitate the focussing of the electron beam and the use of an improved electron gun as the source of the electron stream.

In the drawings,

Fig. 1 is a perspective view of a preferred embodiment of the oscillator, shown partially cut away;

Figs. 1*a* and 1*b* show alternative details which may be substituted in the arrangement of Fig. 1;

Fig. 2 is an end view of the oscillator of Fig. 1, shown partially cut away;

Fig. 3 is an enlarged detailed view of an electron gun suitable for use in an oscillator in accordance with the invention;

Fig. 4 is an end view of the electron gun of Fig. 3; and

Fig. 5 is a schematic diagram showing the auxiliary connections associated with the oscillator.

Referring to Figs. 1 and 2, a cylindrical insulating envelope 10, for example, a glass tube, encloses an electron gun shown generally at 11, and in greater detail in Fig. 3, together with an electron collecting electrode or collector 12. Between the electron gun 11 and the collector 12 there are sealed into and through the walls of the envelope 10 a pair of disc members 13 and 14 formed respectively into conical electrodes 15 and 16 coaxial with the electron gun and provided with aligned apertures at their respective apices for the passage therethrough of an electron stream from the electron gun. A tube 17, referred to herein as the drift tube, is axially mounted between the electrodes 15 and 16 and has aligned apertures at its ends for the entrance and exit of the electron beam. The electrodes 15 and 16, in cooperation with the respective adjacent ends of the drift tube 17, form a pair of gaps 18 and 19 which will be referred to respectively as the input gap and the output gap. The discs 13 and 14 and the drift tube 17 are preferably of highly conductive material, for example copper. The discs 13 and 14 are hermetically sealed into and through the walls of the tube 10 by any suitable process or form of seal, for example, a copper-glass seal. The drift tube 17 has attached to it a conductive rod 20, by which it is supported in position and by means of which electrical contact may be made from the exterior of the envelope 10. The conductor 20 is sealed into and through the wall of the envelope 10 through a glass bead or other suitable hermetic seal. Alternatively, three supporting rods 71, 72 and 73 may be employed as shown in Fig. 1*a*, or the drift tube may be supported by a disc electrode 74 as shown in Fig. 1*b*.

The discs 13 and 14 form a portion of the walls of a resonant chamber or cavity resonator together with a casing in two half sections 21 and 22, which sections fit closely together and are provided with milled semiannular surfaces 23 and 24, respectively, which fit snugly inside the edges of the disc members 13 and 14. A pair of cylindrical collars 25 and 26 of magnetic material, provided with flanges 27 and 28, respectively, are placed over the tube 10 and against the outer surfaces of the respective disc members 13 and 14. On one side of the casing a ring 61 and screws 29 are provided so that when the screws are tightened, the disc 13 and flange 27 are clamped securely between the ring 61 and surfaces 23 and 24 on the casing. A similar ring 62 and screws 29 are provided on the other side of the casing. A flexible lead 30 is connected to the conductive rod 20 and during assembly the lead 30 is passed through a small hole 31 in the casing section 22. When the assembly of the resonant chamber is completed the lead 30 is secured and a good electrical contact between the lead and the casing is obtained by tightening a set screw 32 in a larger threaded hole 33 adjacent to the hole 31, thus bringing the head of the screw 32 down upon the lead 30.

A plurality of plungers, in the form of screws 34, 35, 36 and 37, are threaded into the walls of the casing sections 21 and 22 for altering the size and shape of the resonant cavity for tuning purposes. A coaxial transmission line comprising an inner conductor 37′ and an outer conductor 38 is coupled into the chamber through a hole 39, the inner conductor 37′ terminating in the form of a small loop 40, the end of the loop being connected to the outer conductor 38. The end of the outer conductor serves as a plug which slides into a jack member 42 surrounding the hole 39. The coaxial line is extended, preferably by a flexible portion 43, to any suitable load circuit or point of utilization. A set screw 44 is provided for securing the plug in the jack 42.

A permanent magnet 45 has pole-pieces extending perpendicular to the main body, the pole-pieces being milled out with cylindrical depressions at 46 and 47 to form a cradle to support the cylindrical collars 25 and 26, respectively. The tube assembly including the collars is held to the permanent magnet by the magnetic force and, in addition, the lower half section 22 of the casing may be secured to the middle portion of the permanent magnet 45 by means of a screw 48. If desired, the magnet 45 may be attached to a base plate or other mounting in any suitable manner. A U-shaped magnet or one of other suitable shape may be used in place of the one illustrated.

The electron gun, as shown more clearly in Figs. 3 and 4, comprises a dished cathode 49 arranged to be heated by a heating element 50. The electrons emitted from the cathode 49 are formed into a conical beam by means of the shape of the cathode and by the presence of a shaping electrode 51. The electrode 51 is electrically connected with the cathode. An accelerating electrode 52 having a cylindrical portion 52*a* bounding a frusto-conical aperture 52*b*, serves to regulate the beam current and in conjunction with the shaping electrode 51 to focus the beam at approximately the center of the input gap 18. The accelerating anode 52 is provided with a plurality of apertures 52*c* to enable viewing of the gap between the juxtaposed portions of the electrodes 51 and 52 whereby these electrodes may be mounted accurately in a desired relation. One side of the heating element 50 may be connected to the cathode within the tube 10 and brought out by means of a common lead 53. In that case, the lead 53, together with the remaining heater lead 54 and a lead 55 from the accelerating electrode 52 constitute the external connections from the electron gun. The remaining electrical connections to the oscillator comprise a lead 56 connected with the walls of the resonant chamber and to the drift tube through lead 30 and rod 20, which lead 56 may conveniently be grounded or connected with the mounting plate, and a lead 57 connected to the collector 12. The leads 53, 54, 55 and 57 are brought out through the walls of the tube 10 in suitable presses or seals.

The interconnections of the oscillator with suitable sources of biasing potential and heating current are shown schematically in Fig. 5. 58 is a power transformer or other source of suitable current for operating the heating element 50. The lead 53 is connected to the negative terminal of a biasing battery or other source of biasing potential 59, the positive terminal of the battery being connected directly to the collector 12 through the lead 57. The lead 55 from the accelerating electrode 52 is connected to the variable contactor of a potentiometer 60, that is, one of the two potentiometers 60 and 70 connected in shunt across the battery 59. The lead 56 from the resonator is connected to the variable contactor of the potentiometer 70. If desired, the potentiometers 60 and 70 may be replaced by a single potentiometer with two variable contacts.

In the operation of the system as shown in the figures, the heating element 50 is supplied with suitable heating current from the source 58 to produce a suitable beam of electrons emanating from the cathode 49. The electrons emerge in the form of a solid cone. The voltage E_{A1} between the leads 53 and 55 is adjusted by means of the potentiometer 60 to a suitable value to insure a copious supply of electrons in the beam. Under the combined influence of the dishing of cathode 49, the effect of electrode 51 and of the accelerating electrode 52, the electrons reach an appropriate point focus preferably in the center of the gap 18, diverge again slightly in the interior of the drift tube 17, and by virtue of the magnetic field of the permanent magnet directed axially along the tube by means of the collars 25 and 26, are brought to another approximate point focus in the gap 19. The electrons again diverge slightly before being intercepted by the collector 12. The shape of the interior of the drift tube 17 is preferably curved to conform with the contour of the beam, which has been found from theoretical and practical considerations to approximate a sinusoidal curve, the walls of the tube being concave toward the inside.

Any non-uniformity in the density of the electron stream will cause a transient electromagnetic wave or disturbance to originate within the resonant chamber as the electron beam traverses the output gap **19**. The transient wave will be propagated through the interior of the resonant chamber to the input gap **18** where it will produce a velocity variation in the electron stream at that point. The electrons, thus differentiated as to velocity, will tend to arrange themselves into groups or bunches as the beam traverses the interior of the drift tube **17**. Upon reaching the output gap **19**, the resulting bunches of electrons, if they arrive in the proper phase, will contribute energy to the electromagnetic field of the resonant chamber by building up the transient oscillations. The energy delivered to this field by the electron stream at the output gap will, with proper adjustment, be greater than the energy required to maintain the field within the cavity. Accordingly, the oscillations in the resonant chamber will increase until limited by non-linear effects in the generating mechanism. Oscillations will then be maintained at a level where a condition of equilibrium exists between the energy taken from the electron beam and the energy dissipated in the cavity and its associated load circuit.

For oscillations of a given frequency to be sustained, it is necessary that the electron transit time in the drift space have one of a certain series of critical values. It is readily determined that this transit time must be approximately three-quarters of the cyclic time of the oscillations or else it must have some other one of the values determined by the following equation:

$$\theta = n + \tfrac{3}{4} \qquad (1)$$

where θ is the transit time in cycles and n is either zero or a positive integer.

To derive Equation 1, consider the instant of time when the electric field in the input gap **18** is changing from the direction opposing the passage of electrons to the direction aiding their passage. This instant will hereinafter be referred to as the instant of reference. Assuming that the gap is sufficiently short so that the force acting upon an electron while it traverses the gap may be considered constant, the electrons passing at the time above designated will be neither accelerated nor decelerated by the field. The electrons which have passed the gap **18** during the preceding half cycle have been slowed down and the electrons which will pass the gap in the succeeding half cycle will be speeded up. Consequently, as the electrons traverse the drift space, the electrons that have been accelerated will tend to catch up with those which have been decelerated and the center of a bunch or group of electrons will evidently reside in the neighborhood of those electrons which pass the gap at the instant of reference. In order to have this bunch of electrons contribute energy to the electric field to offset the damping of the field, the electron bunch must reach the output gap at an instant when the field across that gap is in opposition to the direction of motion of the electrons and to be most effective the electron bunch should arrive when the field strength is at a maximum. Evidently such an

instant occurs three-quarters of a cycle after the instant of reference. Other similar instants occur at intervals spaced a complete cycle apart and hence the appropriateness of equation (1) is demonstrated.

In order to secure a suitable value of θ in accordance with Equation 1, the transit time of the electrons may be adjusted by means of the potentiometer 70. The proper adjustment depends upon λ, the wave-length of the oscillations desired, l the length of the drift space, and E_D the direct current potential between the cathode and the resonant chamber. The following closely approximate relationship has been found to exist between θ and the above-mentioned variables:

$$\theta = \frac{500l}{\lambda\sqrt{E_D}} \qquad (2)$$

Combining Equations 1 and 2 and solving for E_D the following value is obtained:

$$E_D = \left(\frac{500l}{(n+\tfrac{3}{4})\lambda}\right)^2 \qquad (3)$$

where E_D is in volts, and l and λ are centimeters.

In an oscillator which has been built and successfully operated in accordance with the invention, the important dimensions and adjustments are as follows: The diameter of the resonant chamber is approximately 2¾ inches and the thickness of the chamber approximately ¾ inch. The oscillator was operated in the range of wave-lengths from about 9 to 10 centimeters. The biasing battery potential was about 720 volts of which in the neighborhood of 200 to 350 volts was impressed upon the accelerating electrode as E_{A1}. To illustrate the values of the other constants which were found to operate successfully, the values are given for a case in which the oscillator was adjusted by means of the tuning screws **34**, **35**, **36** and **37** to operate at a wave-length of 9.75 centimeters. The length l was ½ inch and n had the value 2. Using these values in Equation 3 it was determined that the proper value of E_D was approximately 600 volts which is within a few per cent of the experimentally observed value. The power output ranged from approximately 100 to 200 milliwatts, according to the particular adjustment of E_{A1} within the above-mentioned limits of 200 to 350 volts. The corresponding values of i_C ranged from 10 to 20 milliamperes. The current i_D was in the range from 1 to 4 milliamperes while the current i_{A1} was negligible.

The potentiometers **60** and **70** provide substantially independent adjustments. The setting of potentiometer **70** governs the value of transit time and is used in the frequency adjustment. The setting of potentiometer **60** governs the collector current and consequently serves to vary the power output of the oscillator. The power adjustment had substantially no effect upon the tuning adjustment and vice versa. The two potentiometers and one or more tuning plungers, such as **34** to **37**, inclusive, shown in Fig. 2, are the only adjustable elements required in the practical operation of the oscillator.

What is claimed is:

1. An ultra-high frequency electronic device comprising a cavity resonator substantially closed against the external radiation of power, said cavity resonator comprising a single cavity bounded by a single surface having a pair of relatively small apertures therein, said resonator being of relatively large dimensions and con-

taining a relatively narrow drift tube positioned within said cavity resonator coaxial with a line passing through said apertures, said drift tube being open at both ends, means for passing an electron stream through said chamber and said drift tube along the above-defined axis, said drift tube being only sufficiently large to accommodate the electron stream, and electrode means for accelerating the electrons in said stream.

2. An ultra-high frequency electronic device comprising an evacuated cylindrical envelope of insulating material, an electron gun and an electron collecting anode mounted within said envelope and along the axis thereof, a pair of disc electrodes extending through the wall of said envelope and hermetically sealed to said wall, said electrodes being substantially perpendicular to the axis of said envelope, a pair of conductive casing members forming together with said electrodes a substantially closed resonant chamber, means clamping said casing members and said disc electrodes together in electrical contact, a conductive tube mounted within said resonant chamber on the axis of said envelope, said disc electrodes and said conductive tube having axially aligned apertures to accommodate the passage of electrons from the electron gun toward the collecting anode.

3. An arrangement in accordance with claim 2 in which the walls of the said conductive tube are concave on the inside.

4. An arrangement in accordance with claim 2 in which the interior surfaces of the said conductive tube are concave toward the inside and have a shape in longitudinal section substantially following a sinusoidal curve symmetrical with respect to the axis.

5. An electronic device comprising an axially symmetrical electrode system for producing a concentrated conical beam, said system including a cathode having a dished electron emissive surface, an accelerating anode having a cylindrical portion coaxial with and opposite said surface and bounding a frusto-conical aperture tapering away from said surface, and a beam forming electrode having a right cylindrical inner surface encompassing and coaxial with said emissive surface and the cylindrical portion of said accelerating anode.

6. An ultra-high frequency electronic device comprising an evacuated cylindrical envelope of insulating material, a pair of disc electrodes extending through the wall of said envelope and hermetically sealed to said wall, said electrodes being substantially perpendicular to the axis of said envelope, a pair of conductive casing members forming together with said disc electrodes a substantially closed resonant chamber, a pair of flanged collars surrounding said cylindrical envelope, said pair of casing members presenting together a pair of plane surfaces each parallel to an adjacent surface of one of said collars, and means clamping each of said disc electrodes between the said parallel surfaces of the flange of one of said collars and said pair of casing members with electrical contact between said disc electrodes and said casing members, said clamping means also fastening said casing members together in electrical contact.

7. An ultra-high frequency electronic device comprising an evacuated cylindrical envelope of insulating material, a pair of disc electrodes extending through the wall of said envelope and hermetically sealed to said wall, said electrodes being substantially perpendicular to the axis of said envelope, a cavity resonator, the wall of which comprises two portions, one of said portions being integral with said evacuated envelope and comprising said disc electrodes, the other of said portions being conductively and demountably attached to said disc electrodes outside of said evacuated envelope, and a conductive tube mounted axially between said disc electrodes and spaced therefrom at both ends, said conductive tube being inside both said evacuated envelope and said cavity resonator.

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