

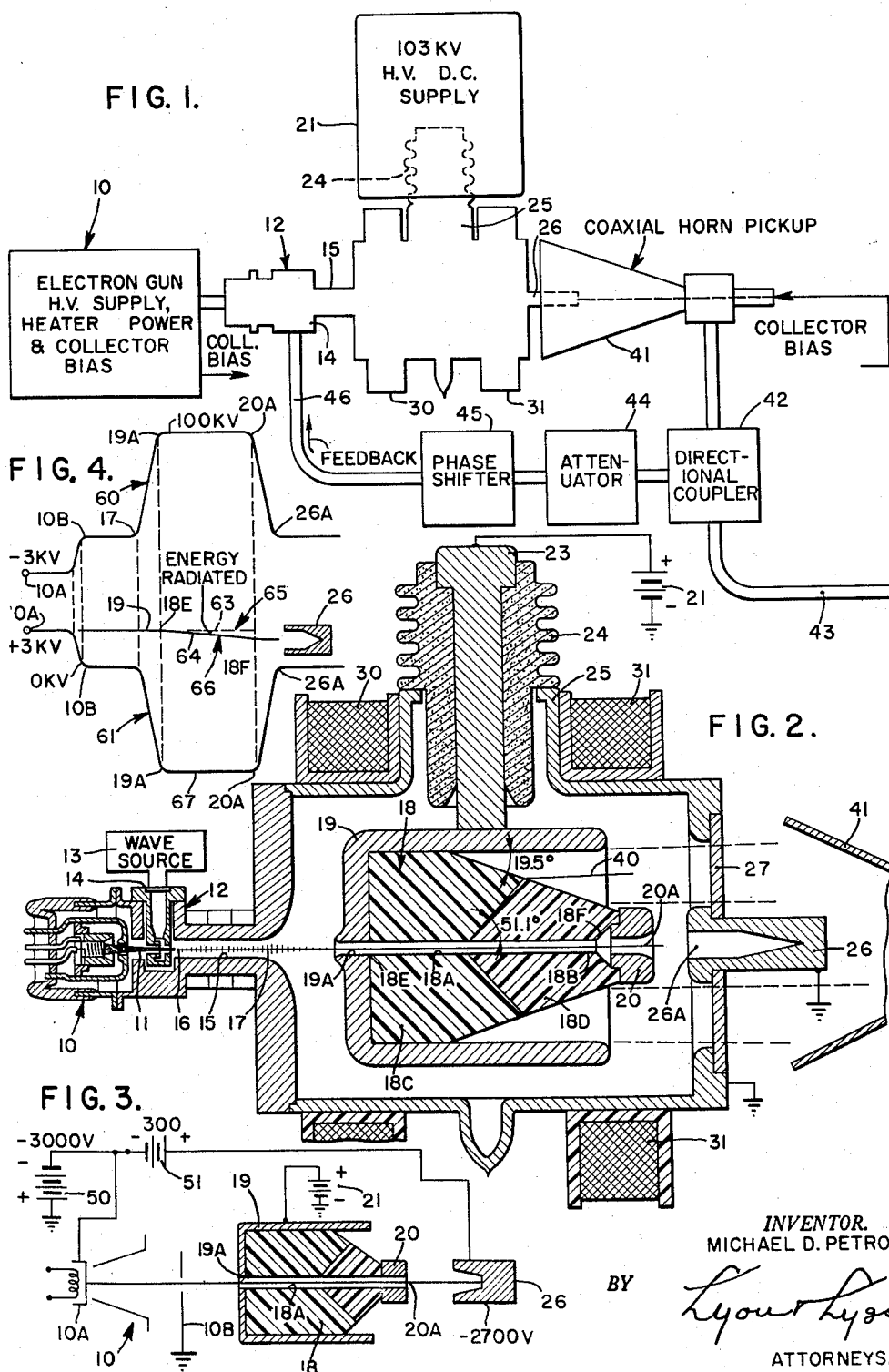
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APPARATUS USING CERENKOV RADIATION

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APPARATUS USING CERENKOV RADIATION
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The present invention relates to means and techniques for generating electromagnetic energy having a wavelength of 10 centimeters to 1 centimeter and is particularly applicable for the efficient generation of electromagnetic energy of shorter wavelength as, for example, millimeter waves.

In general, the apparatus disclosed herein involves a high voltage beam of bunched electrons passing through an apertured portion in a dielectric medium, the electrons in its passage through said apertured portion having a velocity greater than the phase velocity of electromagnetic waves in such medium for the production of so-called Cerenkov radiation. Such radiation is considered as being due to the effect of difference between the velocity of the electrons in their passage through said apertured portion and that of its associated electric and magnetic fields in the dielectric medium.

Electromagnetic or Cerenkov-type radiation is considered analogous to the shock wave accompanying a projectile travelling at supersonic speed. This type of radiation was reported by P. A. Cerenkov in 52 Physical Review, page 379, in 1937; and certain theoretical aspects of the same were discussed by I. Frank and I. Tamm in Rend. Acad. Sci. URSS, 14, 109 (1937). Low efficiency use of the Cerenkov effect for the production of millimeter wave energy is reported by Coleman and Enderby in the Journal of Applied Physics, volume 31, No. 9, page 1695, September 1960.

The present invention involves new structural arrangements whereby Cerenkov-type radiation is produced more efficiently and at much greater output power levels.

It is therefore an object of the present invention to provide a generator for millimeter waves that operates more efficiently and with the production of greater power outputs than was heretofore considered possible.

In achieving these results, the apertured dielectric medium is disposed in an electrostatic structure which provides a uniform electrostatic field within the same, such structure being charged at a sufficiently high electric potential, to accelerate the electron beam to a sufficiently high velocity immediately before entering the dielectric medium such that the Cerenkov effect is realized during the time that the electrons drift through the dielectric medium and the potential energy of the electrons defines an electrostatic well. The arrangement is such that electrons upon entering the well are accelerated by the potential applied to the electrostatic structure enclosing the same, the electrons then drifting through the medium without any substantial change in their potential energy, and after the electrons leave the medium, the same are decelerated with the result that the electrons leave the well with relatively small energy.

It is therefore another object of the present invention to provide a generator of this character in which the dielectric medium, encased in a Faraday-type cage which defines a potential well for electrons, is disposed in a metallic chamber maintained at a lower potential than the potential of the cage such that the beam of electrons is accelerated before entering the dielectric medium and then decelerated after leaving the dielectric medium.

Another object of the present invention is to provide a generator of this character in which the electron beam accelerating means comprises a high voltage source from which substantially no current is drawn in operation of

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the generator, thereby allowing use of a small high voltage source.

Another object of the present invention is to provide a self-sustaining oscillator for millimeter waves employing the Cerenkov effect.

Another object of the present invention is to provide an arrangement of this character wherein the electron beam collector which collects the electrons after passage through the dielectric medium is biased such that improved energy conversion efficiency results when used either as an amplifier or as an oscillator.

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. This invention itself, both as to its organization and manner of operation, together with further objects and advantages thereof, may be best understood by reference to the following description taken in connection with the accompanying drawings in which:

FIGURE 1 illustrates a system embodying features of the present invention in which the structure in FIGURE 2 is disposed in a system in which energy is fed back from the output to the input to achieve an oscillating condition.

FIGURE 2 is generally a transverse sectional view through a structure embodying features of the present invention arranged as an amplifier.

FIGURE 3 illustrates in more detail the manner in which the electron collector is biased either when the structure functions as a generator or as an oscillator.

FIGURE 4 illustrates graphically various voltage and energy relationships in the system shown in FIGURE 1.

The arrangement shown in FIGURE 2 includes a conventional 3-kilovolt electron gun structure 10 which incorporates conventional means for producing electrons, for accelerating the electrons and for focusing them in a beam 11 of 3-kilovolt energy. Such beam 11 comprising a D.C. current of .15 ampere enters the re-entrant cavity structure 12 which is resonant at a frequency of 30,000 megacycles ($\lambda=1$ centimeter) for purposes of producing a velocity modulation on the entering beam, i.e. to produce a bunched electron beam. This re-entrant cavity structure 12 is considered of conventional construction and has a shunt impedance of approximately 100,000 ohms. When the arrangement functions as an amplifier as shown in FIGURE 2, approximately 10 milliwatts of 1 centimeter wave power (30,000 megacycles) introduced from conventional source 13 at 14 produces a voltage of about 30 volts across the gap in the cavity. The drift distance in the drift tube 15 between points 16 and 17 is approximately 3 centimeters. The intensity of the fundamental component in the bunched current at point or region 17 is thus approximately .3 ampere. The gap distance in the cavity structure 12 is less than one-half of a millimeter so that the transit time is appreciably smaller than the period of the R.F. voltage applied to the cavity structure from source 13.

The electrons in the bunched beam at point 17 are insufficient to produce the Cerenkov effect. Novel means are provided for accelerating the bunched electron beam to a sufficiently high velocity to achieve the Cerenkov effect in the dielectric material 18 having the apertured portion or bore 18A extending therethrough, through which the bunched electron beam passes or drifts. This bore 18A has a diameter of approximately 4 millimeters. This dielectric medium 18, approximately 10 centimeters long, is disposed within the electrostatic structure or cage defined generally by the accelerating electrode 19 and electrode 20. The electrode 19 is generally cup-shaped with a central apertured portion 19A and the electrode 20 is generally in the form of a centrally-apertured cylinder, these two electrodes 19 and 20 being interconnected electrically by a very thin metallic film 18B of approxi-

mately 10^{-6} centimeter thickness which lines the apertured portion 18A of the dielectric medium 18 and interconnects electrically the electrodes 19 and 20.

These two interconnected electrodes 19 and 20 are supplied with an electric potential, supplied from D.C. source 21 which has its ungrounded positive terminal connected to the high potential terminal 23 extending through the ceramic insulating bushing 24 in grounded housing 25. The lower end of the terminal 23 is connected to the cup-shaped electrode 19 as, for example, by welding or brazing to support the assembly comprising electrodes 19, 20 and dielectric medium 18 with the apertured portions of these last three mentioned elements aligned with the direction of electron beam travel. For these purposes, the dielectric medium 18, as will be seen from the drawings, has a cylindrical base portion 18C which is snugly fitted within the cup-shaped electrode 19 and integrally formed with the base portion 18C is a truncated conical portion 18D having its end recessed to snugly receive the electrode 20.

The D.C. voltage source 21, of, for example, 103 kilovolts, connected to the electrodes 19 and 20 is of sufficiently high value to establish the depth of the potential well defined by electrodes 19 and 20 so that bunched electrons in region 17 are accelerated and enter the well at 19A travelling with velocities larger than the speed of waves in the medium 18, i.e. on entering the well the electrons have an energy equal to the well potential. The bunching of the beam is not only preserved, but also "stiffened" because of energy gain. It takes more power to debunch a higher energy beam. After passing or drifting through the medium apertured portion 18A and radiating some of their energy via the Cerenkov effect, the electrons leave the potential well at 20A and impinge on the grounded collector electrode 26 mounted in an apertured portion of the radiation transparent window 27 of evacuated casing 25.

It will be observed that the bunched electrons are accelerated and thus gain energy in their transit from the point or region 17 to the point or region 19A defining the entrance to the potential well; and that such electrons are decelerated and thus lose energy in their transit between points or regions 20A and 26A corresponding to the apertured portion of electrode 20 and the entrance into the apertured portion 26A of the collector electrode 26. Also, electrons emerging from the potential well at 20A have their energy lowered from their energy value at point or region 19A substantially only by the amount of energy such electrons contribute to the Cerenkov radiation.

The geometry of the conducting surfaces between points or regions 17 and 19A is such that the bunched beam is focused properly when it enters the beam hole at 19A. Calculations indicate that when a 103-kilovolt, .15 ampere beam enters at point or region 19A in parallel flow, it can traverse the entire length of the beam hole 18 in the dielectric without spreading enough to impinge on the walls of the hole. Should random electrons impinge on the wall of hole 18A, the metal coating 18B provides a leakage path for any such electrons lost from the beam.

The electrons in the beam enter the beam trap at 26A and strike the walls of the trap 26 with energies approximately equal to 3 kilovolts minus whatever energy each electron gives up to Cerenkov radiation inside the dielectric medium. Since no charge is deposited on the 103-kilovolt electrode 19 in the process, the power needed to maintain this voltage is negligible. The beam power inside the hole 18A in the dielectric is equal to approximately 15.5 kilowatts. To maintain this high a power where only a small fraction of it is used, practically no power is consumed in the 103-kilovolt charging power supply. Thus, the 103-kilovolt power supply is a relatively small and simple component of the system.

An axial magnetic field of about 200 gauss is provided

by the coils 30 and 31 which encircle casing 25 to aid in steering the beam through hole 18A. With such a magnetic field a misalignment of about $.5^\circ$ in the direction of the beam can be tolerated. Additional coils, if desired, may be disposed around the drift tube 15 for setting up the proper focusing conditions; or electrostatic focusing means may be interposed between regions 17 and 19A.

The electrons in the bunched beam passing through the hole 18A in the dielectric medium 18 have a velocity equal to approximately $.562c$ where c is the velocity of light in free space. The dielectric medium may be barium borosilicate glass (Corning Glass 8460) which has a dielectric constant of 8.05 at 25,000 megacycles and a loss tangent or power factor equal to .006 at 25,000 megacycles. The index of refraction of the dielectric material is substantially equal to 2.83. Consequently, the conditions for Cerenkov radiation are satisfied and the waves are radiated with a propagation vector making an angle of 51.1 degrees with respect to the longitudinal axis of the dielectric medium as indicated in FIGURE 2. These waves are incident on the conical surface boundary of the medium at the Brewsterian angle and are totally refracted in such a way that outside the medium the propagation vector is parallel to the axis. The resultant parallel beam of transverse magnetic waves illustrated by the line 40 passes through a non-reflecting ceramic window 27 which forms a part of casing 25. These waves can be used either directly as a beam or collected into a wave guide using a coaxial horn pickup 41. The power radiated by the beam may be calculated. Assuming a .3 ampere fundamental component of the bunched current, the wave power generated is approximately 8.5 watts. Taking the loss tangent of .006 into account, the wave power emerging from the window 37 of the device is approximately 7 watts.

A beam current of .15 ampere that loses 8.5 watts of power requires that the average energy loss of individual electrons in the beam be about 56 volts. Consequently, in passing through the dielectric the electron velocity between regions 19A and 20A drops only approximately .025%. The electron beam is therefore essentially a constant velocity beam which drifts through the hole 18A.

The diameter of hole 18A is of importance in establishing the intensity of radiation of different frequencies. The hole diameter is such that radiation at a frequency of 30,000 megacycles predominates with radiation of higher frequencies, i.e. at the harmonic frequencies of 30,000 megacycles being considerably lessened.

It will thus be seen that the arrangement shown in FIGURE 2 operates essentially as a power amplifier for amplification of the 30,000 megacycle power supplied from source 13 with the increased power being obtained from energy supplied to the electron beam in the electron gun 10.

In the system shown in FIGURE 1, the arrangement functions as an oscillator with resonant cavity 12 being the frequency-determining element of the system. For these purposes the energy collected by coaxial horn 41 is applied to directional coupler 42 which allows most of the energy to be transferred to the wave guide 43 and some of the energy to be applied as feedback energy through attenuator 44, phase shifter 45 and wave guide 46 to the input 14 of resonant cavity 12 for producing and sustaining an oscillatory condition wherein the Cerenkov radiation is predominantly of a frequency of 30,000 megacycles.

Increased efficiency results when the electron collector 26 is at a potential more comparable to the electron accelerating potential supplied to the electron gun. This is accomplished by applying a biasing potential to the collector 26 as indicated in FIGURE 1 and shown in more detail in FIGURE 3.

The electron gun 10 in FIGURE 3 has a negative 3,000-

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volt potential applied to its cathode 10A from the negative ungrounded terminal of source 50 as the electron accelerating potential, the anode 10B being grounded. The electron collector 26 is no longer grounded but is maintained at a potential of approximately minus 2,700 volts with respect to ground, the same being accomplished by connecting the 300-volt bias source 51 between collector 26 and cathode 10A. As a result, the collector 26 is biased to produce a greater deceleration of electrons between the regions 20A and 26A and consequently the electrons impinge on the collector 26 with lower velocities, thereby dissipating less heat than if, for example, the collector 26 were grounded and the bias supply not used.

FIGURE 4 illustrates graphically, but not necessarily to scale, the voltages and electron energies in the system shown in FIGURE 1 with respect to an emitted electron, the upper trace 60 illustrating voltages at various points in the system and the lower trace 61 illustrating electron energies in the system.

Referring to trace 60, the voltage at the cathode 10A of the electron gun is minus 3 kilovolts and the voltage changes to zero volts at the grounded anode 10B and continues at a zero level to the point or region 17 from where it changes to 100 kilovolts at the bore 19A in electrode 19. This voltage remains at that level between regions 19A and 20A and falls to zero volts at the entrance 26A to grounded electron collector 26.

Referring to trace 61, which represents electron energy in kilovolt electrons, this energy at the cathode is plus 3 kilovolts, the energy being considered plus since the negative voltage at the cathode multiplied by the negative charge on the electron results in a positive quantity. The potential energy at the grounded anode 10B is considered to be zero, the energy at point or region 19A minus 100 kilovolts but when the electron begins to travel past the region 18E which corresponds to the entrance to the dielectric medium 18, the same begins to cause energy to be radiated due to the Cerenkov effect and this is indicated by the inclined line extending between points 18E and 18F which correspond to the ends of the dielectric medium.

The energy which is radiated is thus indicated by the arrows 65 and 66 between lines 63 and 64. The distance between line 64 and line 67 (that line between points 19A and 20A of trace 61) indicates the total energy of the electron and it will be seen that the same diminishes between points 18E and 18F due to radiation. The energy of the electron is lessened in the region between 20A and 26A as also indicated. The electron energy in the last-mentioned region may be lessened further by biasing the electron collector 26 as illustrated in FIGURE 3. It will thus be seen that an electrostatic well is provided with respect to an electron, such electrostatic or potential well being defined by the trace 61 between the points 17 and 26A thereon. In order that an electron may traverse such well, the energy supplied by the electron gun, i.e. 3-kilovolt energy, is sufficient to assure the same.

While the particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from this invention in its broader aspects and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

I claim:

1. A generator of electromagnetic waves comprising, means for producing a beam of electrons, means velocity-modulating said beam to produce a bunched beam of electrons, a dielectric material having an apertured portion therethrough through which said bunched beam passes, means accelerating said bunched beam to a linear velocity such that said linear velocity of said bunched beam passing through said apertured portion is greater than the phase velocity of electromagnetic waves of the bunching

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frequency in said material, said accelerating means comprising an electrode effectively encompassing said material as an electrostatic shield, and a high voltage source connected to said electrode, said electrode providing an electrostatic well of constant potential through which said beam passes.

2. A generator of electromagnetic waves comprising, a source supplying a bunched electron beam, an apertured dielectric medium through the apertured portion thereof said bunched electron beam travels, a nonresonant electrostatic structure enclosing said medium and means charging said structure to a potential to accelerate the electrons in said bunched beam to a speed greater than the phase velocity of electromagnetic waves of the bunching frequency in said medium to produce electromagnetic waves in said medium.

3. A generator as set forth in claim 2 in which said electrostatic structure comprises a cup-shaped electrode having an apertured portion in the base portion thereof aligned with the apertured portion in said medium.

4. A generator as set forth in claim 3 in which said medium has a conical portion with the apex portion thereof extending in the direction of electron beam travel, and said medium is retained in said cup-shaped electrode.

5. A generator as set forth in claim 4 in which said conical portion is truncated, a generally cylindrical electrode of smaller diameter than said cup-shaped electrode mounted on the truncated portion of said medium and connected electrically to said cup-shaped electrode.

6. A generator as set forth in claim 5 in which said cylindrical electrode and said cup-shaped electrode are electrically interconnected by means of a thin metallic coating which lines the apertured portion of said medium.

7. A generator as set forth in claim 3 including an evacuated casing within which said cup-shaped electrode and medium are mounted, a high voltage terminal insulatedly mounted on said casing and supporting said electrode and medium as a unit, and at least one coil mounted on said casing with the axis of said coil corresponding generally to the axis of the apertured portion in said medium.

8. A generator as set forth in claim 7 in which said casing comprises a conductive but radiation-transparent window through which radiation from said medium passes.

9. A generator as set forth in claim 8 in which an electron collector electrode is mounted in the center of said window and conductively connected thereto and to said casing.

10. In a system of the character described, an electron gun having an electron-accelerating element and producing an accelerated electron stream, means acting on said electron stream and producing a bunched electron stream, an electron collector, a dielectric medium aligned with said bunched electron stream and interacting therewith to produce Cerenkov radiation before said beam impinges on said collector, an electrode effectively encompassing said material as an electrostatic shield, a voltage source connected to said electrode, said electrode providing an electrostatic well of constant potential through which said beam passes, and a conductive connection between said element and said collector.

11. A system as set forth in claim 10, including a voltage source in said conductive connection maintaining said collector and said element at different potentials.

12. A charged particle beam system comprising, means for producing a bunched beam of particles, an electrostatic structure defining a region free of electric fields through which said bunched beam passes, dielectric means in said region interacting with said bunched beam for producing Cerenkov radiation dependent on the presence of said beam, means for accelerating the particles in said beam prior to their entering said region, means for decelerating said particles after leaving said region, and means for collecting said particles after deceleration by

the last means, said structure providing an electrostatic potential well for the beam.

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