ELECTROMAGNETIC WAVE GENERATOR

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Fig.1

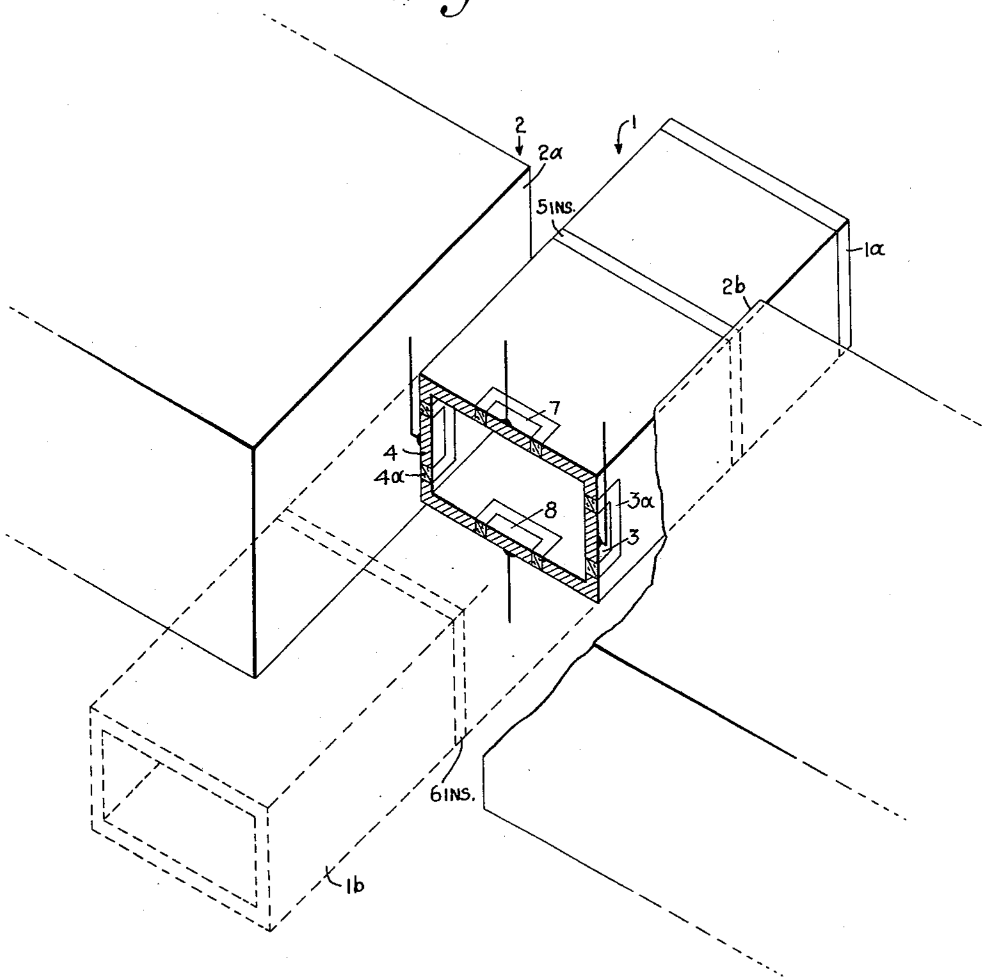

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Fig. 2

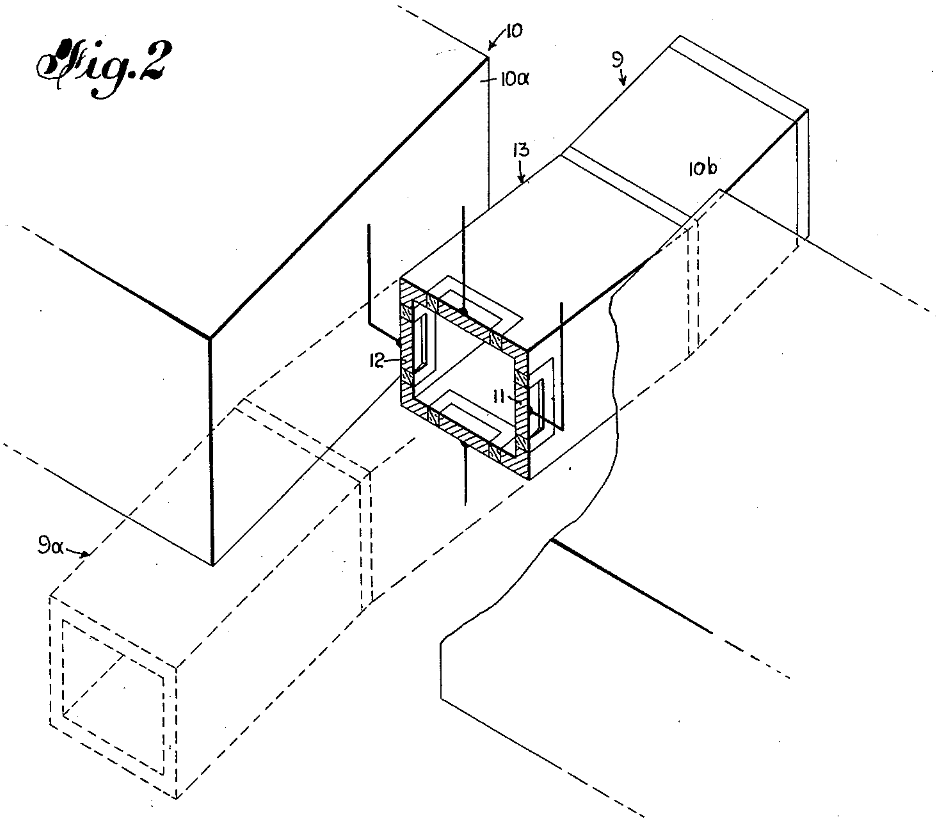
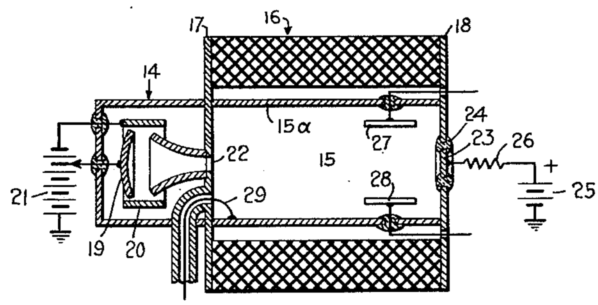


Fig. 3



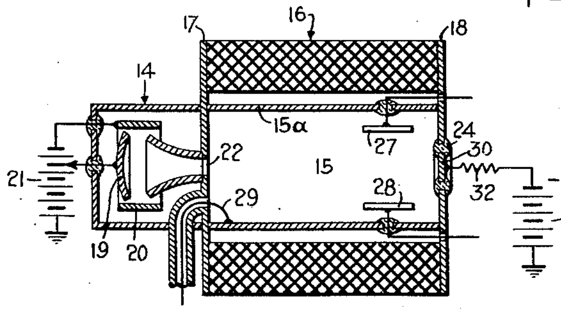


Fig. 4

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United States Patent Office

2,817,045

Patented Dec. 17, 1957

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2,817,045

ELECTROMAGNETIC WAVE GENERATOR

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Application February 5, 1952, Serial No. 270,034

5 Claims. (Cl. 315—39)

This invention relates to electromagnetic wave generators and more particularly to means for generating electromagnetic waves having extremely short wavelengths.

At the present time there is a great need for millimeter wave generators. The term millimeter wave as used herein refers to electromagnetic wave energy having a wavelength less than one centimeter. Redesigning centimeter wave generators to produce millimeter waves results in mechanical demands which are extremely difficult to meet, and even when these mechanical demands are met, the resulting generators are very fragile and capable of only very little power output.

One of the objects of this invention, therefore, is to produce an improved generator of ultra-high frequency electromagnetic waves without the aforementioned difficulties.

Another object of this invention is to provide a device for the conversion of direct currrent energy into radio frequency energy through the agency of the oscillations of electrons in a uniform unidirectional magnetic field.

According to a feature of our invention, we provide a gaseous medium having free electrons within a substantially uniform unidirectional magnetic field. This gaseous medium having free electrons is an electron beam and/or an electron gas created in an electric discharge. It is produced through the agency of an electric field whose lines of force are parallel with the lines of force of the aforementioned magnetic field. Appropriate waveguide structures are provided as output coupling means for the oscillating energy of the electrons.

A further feature of this invention is the addition of auxiliary electrodes to supply an additional electric field, transverse to the first mentioned electric field and therefore also to the magnetic field, to produce circular or spiral components of motion of the electrons in the gaseous medium.

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a diagrammatic perspective view partly in cross section of one form of millimeter wave generator in accordance with the principles of our invention;

Fig. 2 is a perspective view of an alternate embodiment of this invention having an oblique waveguide section; and

Figs. 3 and 4 are schematic illustrations of millimeter wave generators having cylindrical resonant cavities in accordance with the principles of this invention.

Referring to Fig. 1 of the drawing, the millimeter wave generator shown therein includes a rectangular waveguide section **1** closed at one end **1***a*. A substantially uniform unidirectional magnetic field is provided by a permanent magnet **2**. In lieu of the permanent magnet **2** solenoids or electromagnets may be utilized to provide the magnetic field across a section of waveguide **1**. An electric discharge is provided parallel to the magnetic field by means of electrodes **3** and **4**. The center of electrodes **3** and **4** may be spaced substantially a quarter wavelength or odd multiple thereof from the closed end **1***a* of waveguide **1**. In some applications of this device where it is desired to match a load, the distance between the center of electrodes **3** and **4** and the closed end of waveguide section **1** may vary substantially from a quarter wavelength. The electrodes **3** and **4**, properly insulated as indicated at **3***a* and **4***a*, may be part of the magnet's pole faces **2***a* and **2***b*, or they may be part of the walls of waveguide **1** as shown. The space in the waveguide between magnetic pole faces **2***a* and **2***b*, hereafter called the interaction volume, may be sealed off by walls **5** and **6** which are composed of an appropriate dielectric such as glass. The interaction volume will contain a suitable gas or mixture of gases at a suitable pressure or an electron beam in a high vacuum.

When the interaction volume contains a gas, such as helium, or a gas mixture, such as neon and argon, at an appropriate pressure, in the range of 10^{-3} to 10 millimeters Hg, a dense gas discharge plasma is created by an electric discharge between electrodes **3** and **4**. The electrons in this plasma, in the absence of a magnetic field, will tend to oscillate at an angular frequency ω_p dependent upon the electron density N_0, the dielectric constant of free space ϵ_0, the electron e, and mass m according to the formula:

$$\omega_p^2=\frac{e^2N_0}{m\epsilon_0}$$

with all quantities measured in MKS units. The frequency

$$f_p=\frac{\omega_p}{2\pi}$$

is termed the plasma frequency. An electron in a uniform unidirectional magnetic field, subject to forces with components transverse to this field, will have an oscillating component of motion. The angular frequency ω_H of this oscillation is dependent upon the magnetic flux density B, the electron charge e, and mass m according to the formula

$$\omega_H=\frac{eB}{m}$$

with all quantities measured in MKS units. The frequency

$$f_H=\frac{\omega_H}{2\pi}$$

is termed the electron gyroresonant frequency. When the electron gyroresonant frequency f_H, as determined by the intensity of the magnetic field, is substantially equal to the frequency f_p of the plasma electron oscillations, the electron oscillations will be exceptionally strong, as a resonance phenomenon. This oscillating electron gas will radiate electromagnetic energy into waveguide **1***b* at substantially the gyroresonant frequencies and harmonics thereof. Appropriate waveguide structures and filters can be added so that the output will be at the desired frequency, either a fundamental or a harmonic thereof.

To insure that the electrons traversing the waveguide section between electrodes **3** and **4** will not just follow a straight line path but will have some component of oscillating, angular motion such as is present if the electron path be spiral, auxiliary electrodes **7** and **8** may be added. The additional voltage between electrodes **7** and **8**, creating an electric field perpendicular to the electron path between electrodes **3** and **4** and the magnetic lines of force, provides an additional source of energy to force each individual electron to follow a path having an oscillating, angular component of motion. If the additional voltage source, electrodes **7** and **8**, is present, then there need not be a resonance of the plasma frequency f_p and the electron gyrofrequency f_H to obtain strong radiations of electromagnetic energy into the waveguide structure. For any electron density in the plasma, there will be strong radiation if the electron motion has a strong oscillating, angular component.

In the absence of a gas discharge plasma, an electron emissive cathode can be utilized to provide an electron beam in vacuum between electrodes **3** and **4**. This electron beam will not have sufficient electron density to provide useful medium-like oscillations, and thus the additional electric field provided by auxiliary electrodes **7** and **8** is necessary to force each electron in the electron beam to oscillate at gyroresonant frequency f_H. The oscillating electrons will radiate electromagnetic energy into the approximate waveguide structure at gyroresonant frequency and harmonics thereof, as heretofore explained.

Referring to Fig. 2, a millimeter wave generator similar to the device of Fig. 1 is shown comprising a rectangular waveguide **9** having a section **13** thereof at an oblique angle to the magnetic field lines of force from a magnet **10**. Magnet **10** provides a substantially uniform unidirectional magnetic field across the interaction volume of the waveguide contained between the magnetic pole faces **10***a* and **10***b*. The interaction volume contains an electron gaseous medium as in the device of Fig. 1. Electrodes **11** and **12** are constructed parallel to magnetic pole faces **10***a* and **10***b* and at an acute angle to the longitudinal axis of section **13**. The electric field between electrodes **11** and **12** is parallel with the magnetic field between pole faces **10***a* and **10***b*. The axis of the section **13** of waveguide containing the interaction volume forms an oblique angle with lines of force of the magnetic field.

The energy from the electrons which is radiated into the waveguide of Fig. 1 might be termed an "end-fire" radiation, that is the energy is radiated in substantially the same plane as the oscillating angular component of motion of the electrons. If the "broadside" radiation, that is radiation in a direction perpendicular to the angular component of motion of the electrons, is stronger than the end-fire radiation, then the waveguide section **13** of Fig. 2, being oblique to the magnetic lines of force, has a more favorable geometry for launching electromagnetic radiation into the transmission waveguide **9***a* because the angle between the axis of waveguide section **13** and the broadside direction is substantially less than 90 degrees.

Referring to Fig. 3 of the drawing, the ultra-high frequency generator therein shown includes a source of electrons **14**, a cylindrical cavity section **15** and an electromagnetic coil **16** disposed concentrically about the cavity section **15**. The electromagnetic coil **16** is terminated on each side by end plates **17** and **18** which are composed of a material having a high permeability. End plates **17** and **18** confine the magnetic field to the cylindrical cavity **15**. The cylindrical wall **15***a* comprises a non-magnetic conductor. The source of electrons **14**, external to the magnetic field, comprises a cathode **19** and an annular beam focusing electrode **20**. A negative voltage is applied to cathode **19** by voltage source **21**, and the focusing electrode **20** is biased negatively with respect to cathode **19**.

The beam of electrons from electron source **14** traverses the cylindrical cavity **15** through the central aperture **22** in end plate **17** to the anode **23**. Anode **23** is insulated from end plate **18** by dielectric ring **24**, and a positive potential is applied to the anode from voltage source **25** through resistor **26**. Auxiliary electrodes **27** and **28** provide an electric field transverse to the electron beam from electron source **14**.

In the absence of a magnetic field, any electron oscillations in the cylindrical cavity take place in response to the radio-frequency fields in the cavity and therefore have a frequency determined by the geometry of the cavity. The addition of the transverse electric field provided by electrodes **27** and **28** and the axial magnetic field provided by the magnet **16** produce electron motions with oscillating components at the electron gyroresonant frequency. At the resonance of the electron gyroresonant frequency and the radio frequency cavity frequency, the interaction of the electrons with the radio frequency field of the cavity resonator will cause strong electromagnetic waves to be produced which may be coupled to a load by means of a coaxial loop **29**.

One variation of the device of Fig. 3 which will be equally effective to produce electromagnetic waves of extremely short wavelengths is shown in Fig. 4. The anode **30** of Fig. 4 is connected to a source of negative voltage **31** through resistor **32**, thus instead of functioning as a collector electrode as the anode **23** of device in Fig. 3, it now acts as a repeller electrode. By thus repelling the electron stream from cathode **19**, an electron cloud is formed within the cylindrical cavity **15**. The electrons within this electron cloud are caused to oscillate in a manner heretofore described. A probe **29** inserted into cylindrical cavity **15** couples the oscillatory energy from the electron cloud to a load.

While we have described above the principles of our invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of our invention as set forth in the objects thereof and in the accompanying claims.

We claim:

1. An electromagnetic wave generator comprising a hollow waveguide structure, an ionizable gaseous medium within said structure, electrode means to produce an electron flow along a given path through said medium to ionize said medium and produce a dense gas discharge plasma whose electrons tend to oscillate at a given plasma frequency, means for producing a unidirectional magnetic field in said medium with its lines of force parallel with said given path and of such a magnetic flux density as to cause the electrons of said plasma to oscillate at a gyroresonant frequency substantially equal to the frequency of the plasma oscillations, and output coupling means associated with said waveguide structure for coupling electromagnetic wave energy radiated by the electron oscillations from said medium.

2. An electromagnetic wave generator according to claim 1, wherein said hollow waveguide structure includes a rectangular waveguide having its major transverse axis parallel to said magnetic lines of force.

3. An electromagnetic wave generator according to claim 1, wherein said electrode means to produce an electron flow includes electrodes positioned on opposite sides of said waveguide structure and means to insulate said electrodes from said waveguide.

4. An electromagnetic wave generator according to claim 1, wherein said means to produce a magnetic field includes a magnet having pole faces disposed on opposite sides of said waveguide.

5. An electromagnetic wave generator according to claim 1, wherein the density of the electrons in the plasma and the magnetic flux density are such as to substantially fulfill the equation

$$\sqrt{\frac{e^2N_0}{m\epsilon_0}}=\frac{eB}{m}$$

where e=electron charge, B=magnetic flux density, m=electron mass, ϵ_0=dielectric constant of the plasma, and N_0=density of free electrons.

References Cited in the file of this patent

UNITED STATES PATENTS

2,521,760	Starr	Sept. 12, 1950
2,558,664	Pease	June 26, 1951
2,579,654	Derby	Dec. 25, 1951
2,580,007	Dohler	Dec. 25, 1951
2,591,350	Gorn	Apr. 1, 1952
2,602,908	Linder	July 8, 1952