

[54] COHERENT MICROWAVE GENERATORS
[75] Inventors: Moshe Friedman; Melvin Herndon,
both of Washington, D.C.

[73] Assignee: The United States of America as
represented by the Secretary of the
Navy, Washington, D.C.

[22] Filed: Nov. 14, 1972

[21] Appl. No.: 306,466

[52] U.S. Cl. 315/3, 315/5, 315/39

[51] Int. Cl. H01j 23/16, H01j 29/96

[58] Field of Search 315/4, 5, 39, 3.5 X, 68, 39.3

[56] References Cited

UNITED STATES PATENTS

3,254,261	5/1966	Sturrock	315/3.5
3,259,786	7/1966	Phillips	315/3.5 X
3,206,635	9/1965	Phillips	315/39
3,474,283	10/1969	Arnett	315/5 X
3,457,450	7/1969	Feinstein et al.	315/5
3,489,943	1/1970	Denholm	315/5
2,942,144	6/1960	Weibel	315/4 X

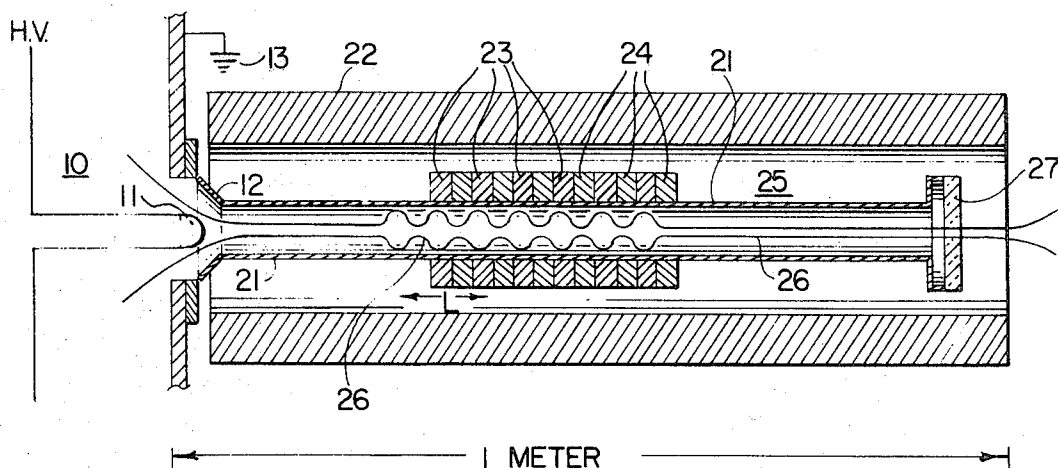
3,353,053	11/1967	Bott	315/4 X
3,102,211	8/1963	Sturrock	315/3.5 X
3,129,356	4/1964	Phillips	315/39.3 X

Primary Examiner—Rudolph V. Rolinec
Assistant Examiner—Saxfield Chatmon, Jr.
Attorney, Agent, or Firm—R. S. Sciascia; Arthur L.
Branning; M. L. Crane

[57] ABSTRACT

A device for producing intense electromagnetic radiation from the interaction of an intense relativistic electron beam and a spatially modulated magnetic field in combination with a homogenous magnetic field region. The device is magnetically tuneable and capable of producing high level radiation of narrow or wide bandwidth over an extremely large range of wavelengths. The device produces microwave energy of the order of 10^8 to 10^9 watts in the 3 cm to 1 mm wavelength region with a secondary objective to produce electromagnetic energy of the order of 10^8 watts at wavelengths shorter than 1 mm.

7 Claims, 8 Drawing Figures



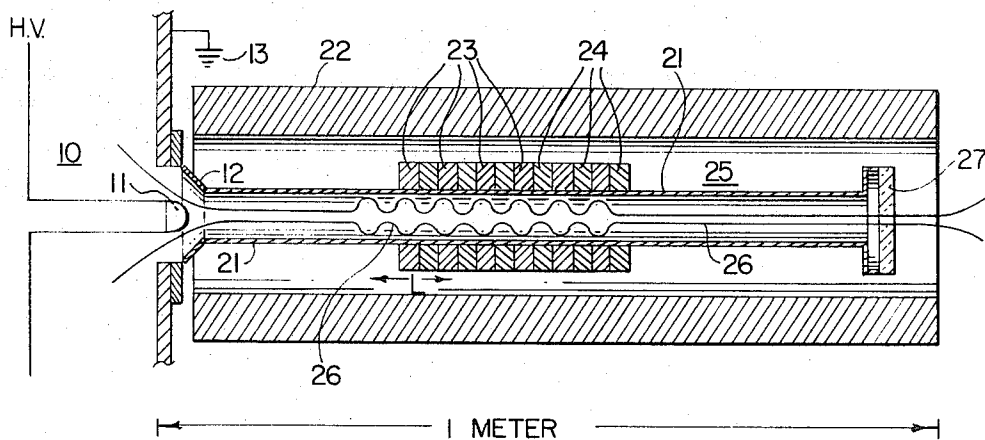


FIG. 1

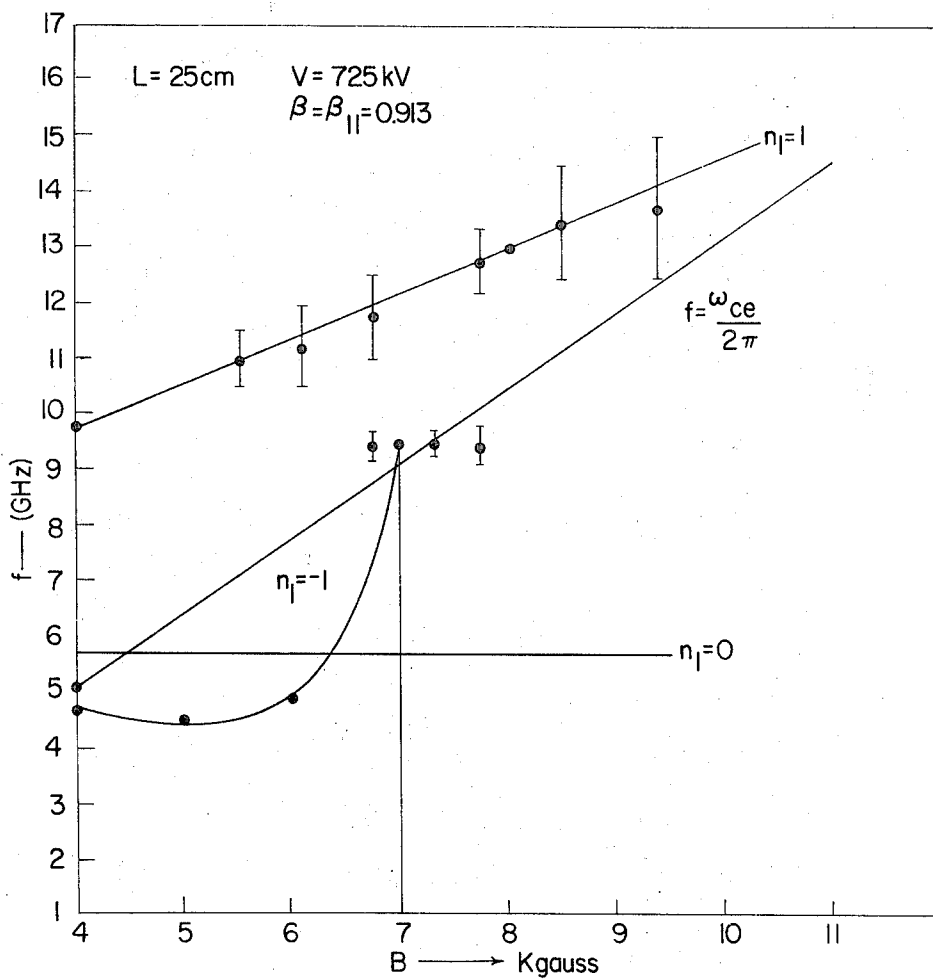


FIG. 8

FIG. 3

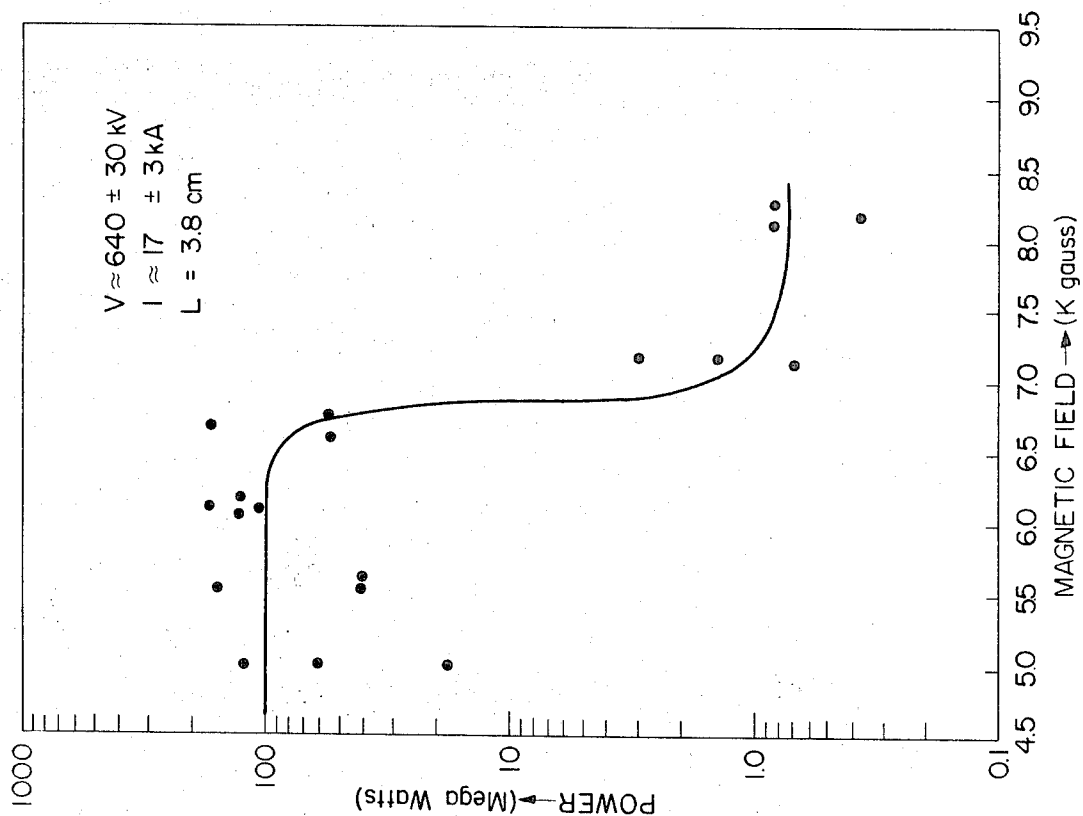


FIG. 2

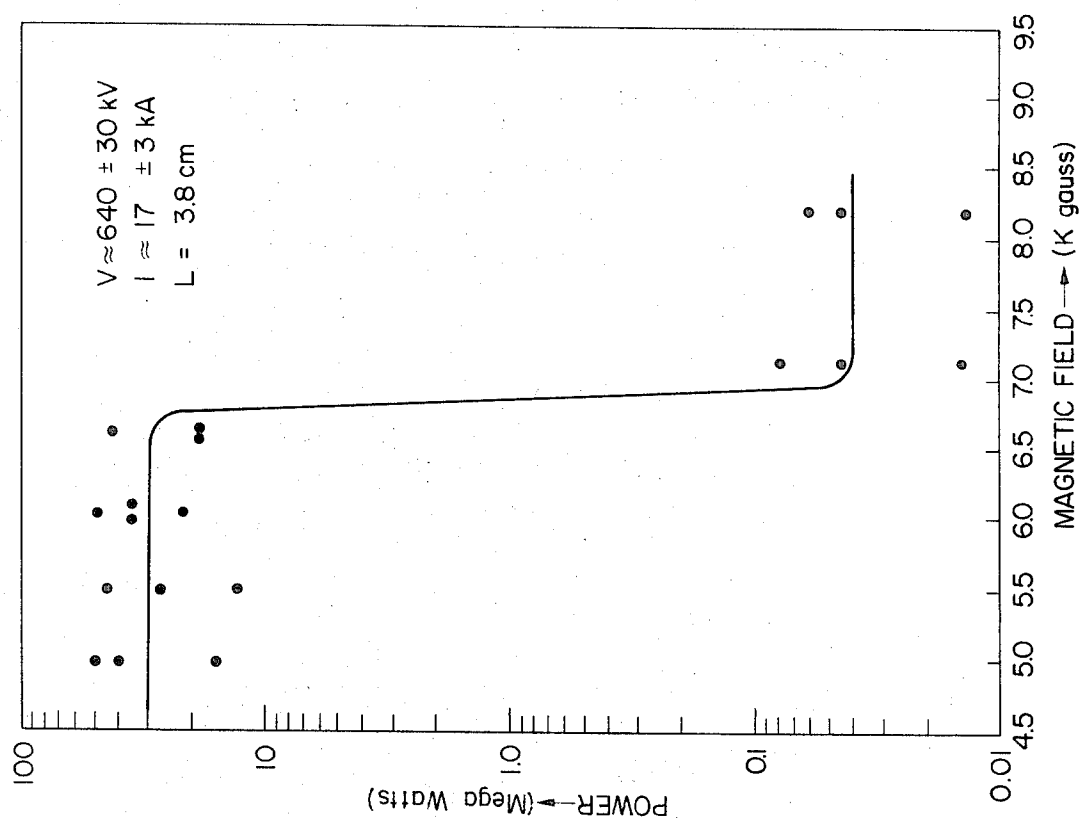


FIG. 4

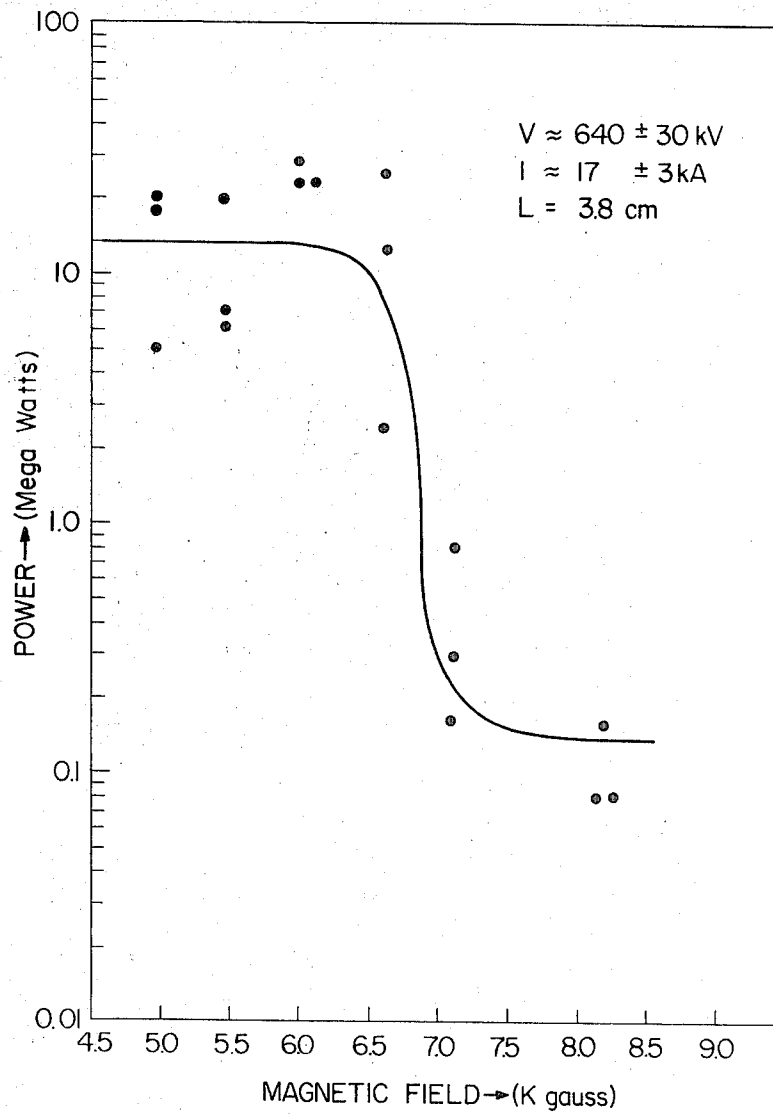


FIG. 5

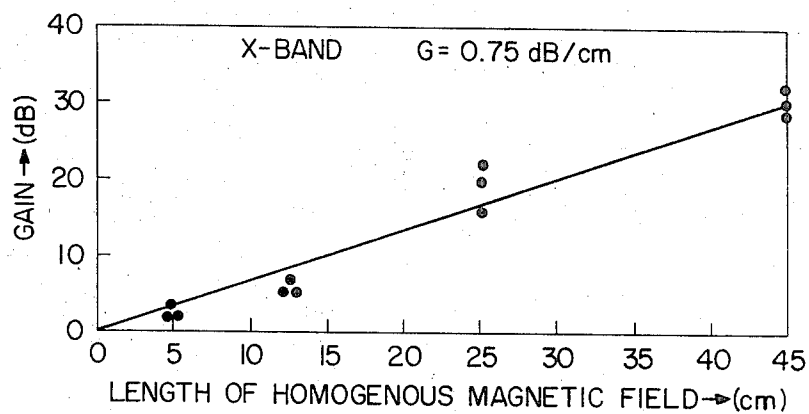


FIG. 7

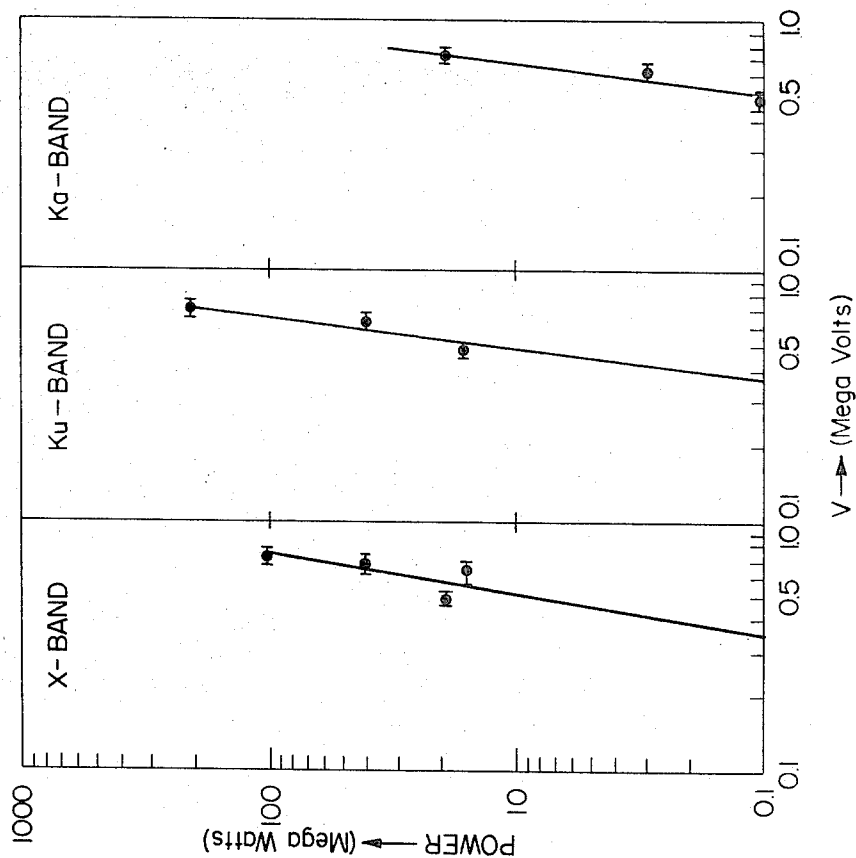
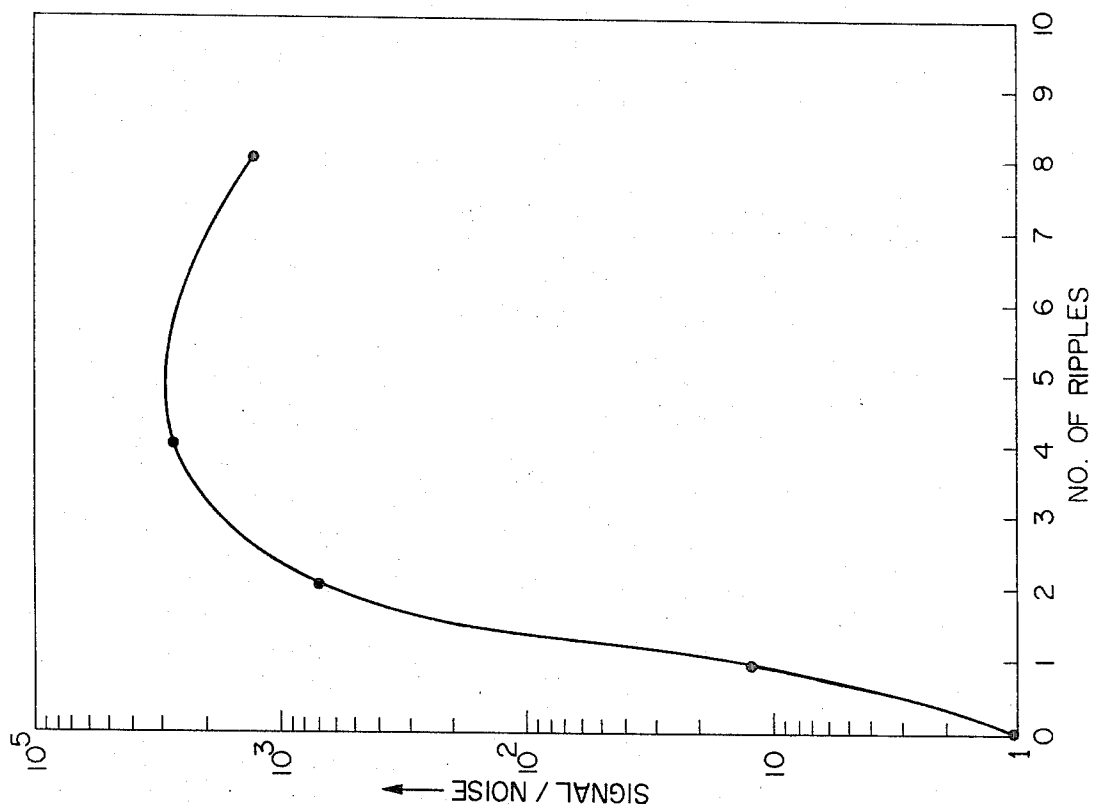


FIG. 6



COHERENT MICROWAVE GENERATORS

CROSS REFERENCE TO RELATED PATENT APPLICATION

This device makes use of an annular electron beam accelerator such as set forth in patent application Ser. No. 175,888 filed Aug. 30, 1971, now U.S. Pat. No. 3,700,945. The electron beam accelerator is additionally set forth in The Review of Scientific Instruments, Vol. 41, No. 9, pages 1334-1335, September 1970.

BACKGROUND OF THE INVENTION

This invention is related to microwave generators and more particularly to a system through which the energy of electrons is converted into coherent microwave radiation.

Conventional type devices have been developed to produce microwaves which have been limited in the microwave power generated for wavelength less than 3 cm. Several nonconventional types have been developed to produce intense microwave radiation, one of which is described in U.S. Pat. No. 3,259,786. Such systems do not operate at high current and power levels and are restricted to structural changes to produce microwave radiation of different power levels and different frequencies.

SUMMARY OF THE INVENTION

The device of this invention produces intense microwave emissions by use of a modulated magnetic field region in combination with a homogeneous magnetic field region which follows the modulated magnetic field region. The magnetic field parameters are chosen such that a nonadiabatic process converts the electron motion parallel to the magnetic field into perpendicular motion in a relative short distance and the electrons are allowed to drift in the homogeneous magnetic field. Azimuthal and longitudinal bunching results from the electron beam-magnetic field interaction, growing radio frequency waves are produced, and the spectral distribution is also controlled by a non-linear interaction. By varying the magnetic field intensity, power of the order of 10^8 watts with narrow or wide bandwidths at the fundamental frequency (10^{10} Hz) and in harmonics may be produced. The device has been set forth in an article "Microwave Emission Produced by the Interaction of an Intense Relativistic Electron Beam with a Spatially Modulated Magnetic Field" by M. Friedman and M. Herdon published in Physical Review Letters, Vol. 28, number 4, pages 210-212, Jan. 24, 1972.

OBJECTS OF THE INVENTION

It is therefore an object of the present invention to provide a device for emission of coherent microwave radiation which may be easily tuned for different output frequencies or harmonics thereof.

Another object is to provide an intense microwave generator which emits radiation with a spectral distribution that can be controlled and changed by the variable magnetic-field.

Other objects and advantages of the invention will become obvious to one skilled in the art upon reviewing the following specification when considered with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a schematic drawing of the overall device.

FIG. 2 illustrates the Rf power at the X-band, as a function of magnetic field.

FIG. 3 illustrates the Rf power, at the Ku-band, as a function of magnetic field.

FIG. 4 illustrates the Rf power, at the Ka-band, as a function of magnetic field.

FIG. 5 illustrates the power gain as a function of the length of the homogeneous magnetic field region.

FIG. 6 illustrates the power gain at X-band vs the number of ripples in the modulated magnetic field.

FIG. 7 illustrates the output radio frequency power as a function of beam voltage.

FIG. 8 illustrates the dependency of the radio frequency spectrum on the magnetic field intensity.

DETAILED DESCRIPTION

Now referring to the drawing, there is shown by illustration in FIG. 1 a schematic of the microwave generator made in accordance with the teaching of this invention. As shown, the generator includes an annular electron beam injection gun 10 made in accordance with the teaching of copending patent application Ser. No. 175,888 filed Aug. 30, 1971 now U.S. Pat. No. 3,700,945. The beam injection gun is represented by a cathode 11 to which a high voltage is connected and an anode 12 which is grounded at 13. The cathode is a smooth paraboloid with a rough-circular-band area that enhances electron emission. The electron beam emission is in the form of a hollow beam. The anode is in the shape of a truncated cone with its curvature equal to that of the cathode at the smallest distance between them.

The annular electron beam generator is operatively arranged adjacent to a waveguide 21 made of a non-magnetic material such as stainless steel coaxially arranged within a magnetic field produced by a solenoid 22. The waveguide size is selected according to the desired frequency band of operation and diameter of the electron beam. Positioned about the waveguide within the magnetic field, there is arranged a magnetic field modulating structure. This structure is formed by a series of iron rings 23, and aluminum rings 24, alternately arranged about the waveguide coaxial therewith. The combined widths of the iron and aluminum rings determines the fundamental wavelength of the output radiation. The magnetic field produced by the solenoid is modulated by the iron-aluminum ring structure to produce ripples in the magnetic field. The magnetic field beyond the iron aluminum ring structure is uniform and provides a homogeneous magnetic field region 25 through which the electrons interact with the magnetic field and rf emission is enhanced. The magnetic field lines are shown by lines 26. The waveguide 21 is closed at the output end by a window which permits evacuation of the waveguide during operation to about 10^{-4} Torr and the high intensity microwave energy to pass therethrough. The output radiation is directed into any suitable structure for its intended use.

During operation, a beam of relativistic electrons are directed into the modulated magnetic field which varies in space. Through a nonadiabatic process in the modulated magnetic field region, perpendicular motion is introduced onto the electron beam. The nonadia-

batic process has a resonance feature in which the width of the resonance depends on the amplitude of the ripple in the magnetic field and the number of ripples caused by the modulating structure and the average magnetic field intensity. The electron beam drifts from the modulated magnetic field region to the homogeneous magnetic field region. During passage through the homogeneous magnetic field, strong bunching of the electrons occur, which during interaction therewith, the electrons lose perpendicular motion and produce micro-wave radiation.

As an example of an operational device, the waveguide is a stainless steel tube having an inside diameter of 5 cm with a length of one meter within a magnetic field of 5.5 KG. The aluminum and iron rings that produce a rippled magnetic field have a width of 1.9 cm each to produce a period of 3.8 cm for a beam propagating within the waveguide. The length of the waveguide along which the ripple magnetic field is produced is 30 cm and the length of the homogeneous magnetic field is 40 cm.

In operation of the above device, a pulsed voltage is applied to the solenoid to produce a magnetic field. This magnetic field is modulated by the iron-aluminum rings and is homogeneous along the remainder of the waveguide. Once the magnetic field has reached its maximum magnitude a high voltage pulse is applied between the cathode and anode of the electron emission generator to produce an electron beam with a 1.7 cm radius with a voltage of about 680 KV and a current of 16KA with a pulse time period of 50 nsec.

The device under the above conditions produced microwave signals in the X-band (6.5 to 12 GHz), Ku-band (12.4 - 18.0 GHz) and Ka-band (26.5 - 40 GHz).

The power and frequency spectrum of the *rf* radiation has been found to depend strongly on the strength of the magnetic field, the ripple amplitude, the beam voltage and the length of the homogeneous field with little dependency upon the beam current and the number of ripples in the modulated magnetic field. The dependency of the *rf* power on magnetic field is shown by FIGS. 2-4.

The homogeneous magnetic field region following the rippled field is an important structural feature of the device and is essential for production of high power. FIG. 5 illustrates the power gain as a function of the length of the homogeneous field region. The electrons on passing through the homogeneous magnetic field are bunched and the power gained is proportional to the length of the homogeneous magnetic field.

As previously set forth, the iron and aluminum rings within the magnetic field modulates the magnetic field. FIG. 6 illustrates the power gain at X-band vs the number of ripples in the modulated magnetic field. It has been determined that the relative ripple size is very important in the operation of the device. For a large change in the magnetic field relative to the applied field (approximately 15%) the electrons have been found to intersect the walls of the drift tube and are lost. For small changes the output power decreases considerably.

FIG. 7 illustrates the output radio frequency power as a function of beam voltage. As noted, the power increases very fast with an increase in voltage.

FIG. 8 illustrates the dependency of the radio frequency spectrum on the magnetic field intensity for ripple wavelength of 2.5 cm. Changing the magnetic field

intensity changes the frequency of the *rf* radiation. The frequency depends on the magnetic field according to the approximate relation.

$$f = A_1 + A_2 B \text{ where}$$

A_1 and A_2 are constant depending on the parameters of the device and B is the magnetic field intensity.

The device is not limited to short single pulse operation. It can be operated on a DC or CW basis, pulse basis at a given repetition frequency or pulse basis with a finite number of pulses. The above modes are determined mainly by the power sources for the electron generator and magnetic solenoid. Hence for DC or CW operation, a DC voltage would have to be applied to the electron generator to obtain a continuous stream of electrons and in a like manner a DC voltage is needed for a constant magnetic field from the solenoid. However, the DC supply for the magnetic field could be eliminated in some cases by the use of permanent magnets or super conductors. For pulsed mode operation, the requirements on the power supplies are somewhat relaxed. That is, the supply need only to be sufficient to replace, during the interpulse cycle, the energy lost during the pulse cycle. Here, the only requirement on the magnetic field is that it should be constant during passage of electrons through it. Thus, permanent magnets, and Dc or pulsed solenoids can be used.

The configuration of the magnetic field is not limited to a uniformly modulated one as obtained with the iron-aluminum structure. Hence, helical magnetic field, cusped magnetic field and/or configuration which acts non-adiabatically on the electrons passing through it can be used. It is through the choice of magnetic field configuration that a given *rf* mode can be selected.

The structure for modulating the magnetic field can consist of any ferromagnetic and/or diamagnetic material used in combination, iron-aluminum, or singly-iron helix. Ultimately, super conducting coils shaped to provide the desired field could replace the solenoid and modulating structure.

The wavelength or drift tube can be circular, square, rectangular, coaxial, elliptical or of any desired cross-section or logarithmic, exponential, binomial, aperiodic or periodic in extent. In a like manner, the electron beam cross-section, which is usually chosen according to the waveguide cross-section can be of most any desired shape with electron density and/or velocity as additional variables of the beam. The desired beam cross-sections can be obtained using properly shaped cathodes and anodes on the foil-less diodes or from any electron gun or emitter designed to provide a given beam shape at the levels required for proper operation of the device desired herein.

The process is reversible, that is with an appropriate structure and the injection of microwave energy, electrons can be accelerated to high velocities.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A coherent microwave generator which comprises: a centrally positioned coaxially aligned waveguide, means disposed coaxially about the length of said waveguide for providing a magnetic field paralleling the axis of said waveguide,

5

a magnetic field modulating structure positioned around and along a portion of said waveguide within said magnetic field for modulating the magnetic field along a linear region of said waveguide, a homogeneous field region in axial alignment and adjacent said modulated magnetic field region, means for projecting high energy electrons into said waveguide along the axis thereof, whereby the electrons on passing through said modulated magnetic field region and said homogeneous magnetic field region experience forces which causes them to emit microwave radiation.

2. A coherent microwave generator as claimed in claim 1; wherein, said means for providing a magnetic field is a solenoid.

3. A coherent microwave generator as claimed in claim 2; in which, said magnetic field modulating structure includes side-by-side axially aligned rings made of magnetic

6

and nonmagnetic materials alternately positioned around said waveguide in said magnetic field modulating region.

4. A coherent microwave generator as claimed in claim 3; wherein, said magnetic field is variable, whereby the frequency of the rf radiation is governed by the magnetic field intensity.

5. A coherent microwave generator as claimed in claim 4; wherein, said rings of magnetic material are made of iron.

6. A coherent microwave generator as claimed in claim 5; wherein, said rings of nonmagnetic material are made of aluminum.

7. A coherent microwave generator as claimed in claim 6; wherein, said electrons projected into said waveguide are a hollow beam.

* * * * *

25

30

35

40

45

50

55

60

65