

Oct. 29, 1963

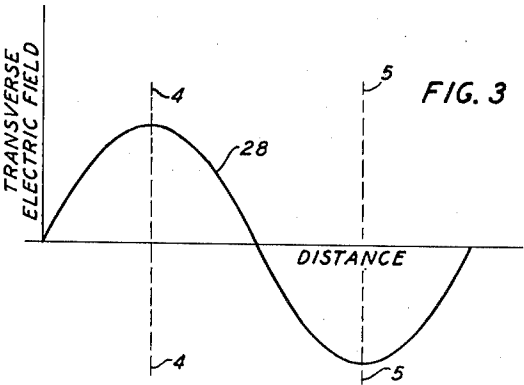
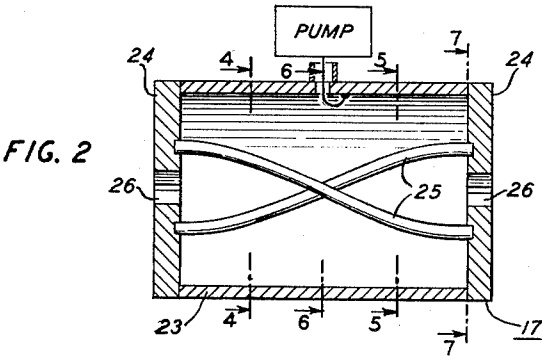
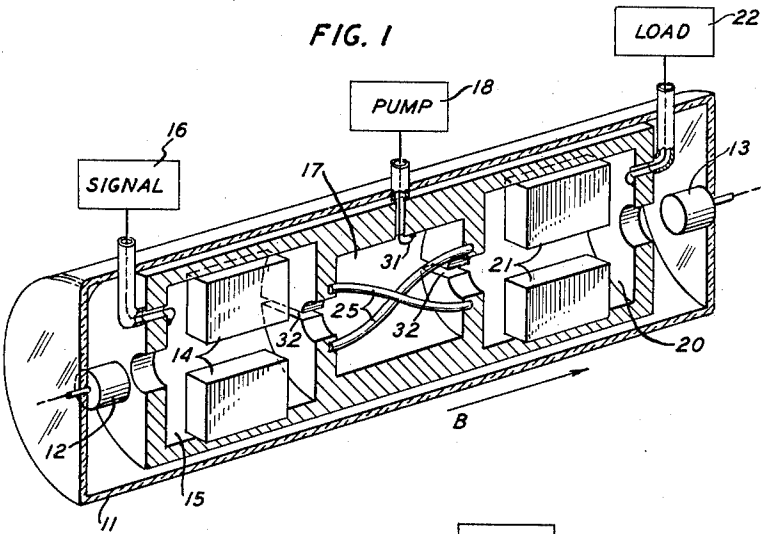
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3,109,146

CYCLOTRON WAVE ELECTRON BEAM PARAMETRIC AMPLIFIER

Filed April 19, 1962

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 4

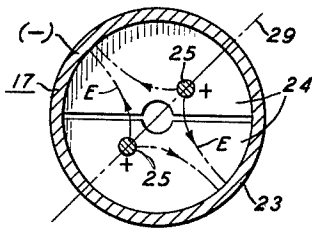


FIG. 5

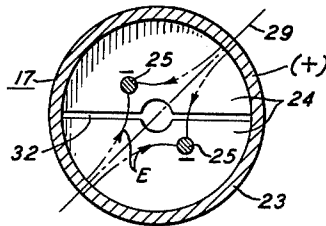


FIG. 6

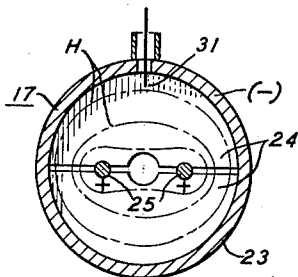
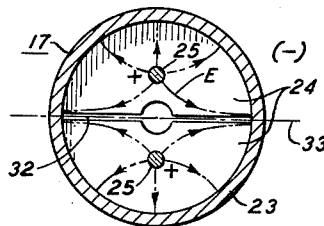


FIG. 7



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1

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7 Claims. (Cl. 330-4.7)

This invention relates to electron beam devices and more particularly to cyclotron wave parametric amplifiers.

One of the serious drawbacks of electron beam amplifiers, such as the klystron and traveling wave tube, has been the spurious noise which necessarily accompanies the generation of an electron beam. A recent important advance in the art is the cyclotron wave parametric amplifier, known also as the quadrupole amplifier, which, by employing the principles of fast cyclotron wave parametric amplification, permits the direct removal of beam noise energy which would otherwise couple to the signal wave during the amplification process.

The electron gun of this device produces a beam that flows successively through an input coupler, a quadrupole amplifying resonator, and an output coupler. The beam is immersed in a uniform magnetic field which establishes a cyclotron frequency at which the electrons will rotate if acted upon by forces transverse to the field.

The input coupler is a resonant circuit that is tuned to the cyclotron frequency, and comprises a pair of parallel poles on opposite sides of the beam. When the input coupler is excited by a signal wave, electric fields are produced between the poles which are capable of exciting a signal cyclotron wave on the beam. Conversely, cyclotron wave noise energy at the signal frequency, which is inherent in the beam, is transferred to the input coupler and can thereafter be dissipated. The pump resonator is excited by pump power which is usually, although not necessarily, twice the cyclotron frequency; this pump power interacts with the beam to amplify the signal cyclotron wave. A necessary condition for amplification is the production of quadrupole electric fields throughout the beam within the pump coupler; hence the term "quadrupole amplifier." The output coupler is identical with the input coupler and it extracts the amplified low noise signal wave from the beam.

One drawback of the cyclotron wave parametric amplifier is the fact that the pump resonator ordinarily can only be a half wavelength long. If the pump resonator is a full wavelength long, electric fields produced throughout the beam will reverse direction at the midpoint of the coupler. As a result, electrons that gain energy in the upstream half of the coupler will lose energy in the downstream half and vice versa, and there will be no net amplification of the signal cyclotron wave. The length limitation of the pump resonator can be a very important consideration because the cyclotron wave gains energy as an exponential function of distance. Additional gains can theoretically be achieved by using two or more pump couplers between the input and output couplers. If this is done, however, each successive pump coupler must be very carefully positioned so that successive pump fields are in spatial synchronism. This type of amplification is also relatively inefficient because the exponential gain with respect to distance is successively terminated.

One type of full wavelength coupler is described in the United States patent application of A. Ashkin, Serial No. 126,938, filed July 26, 1961. In this device, two poles on opposite sides of the beam are substituted for the quadrupole of the conventional pump resonator. Each of the poles has a V-shaped surface along half of

2

its length and a curved surface over the other half. The change in configuration of the poles compensates for the inherent reversal of the electric field. This type of resonator is relatively complicated and may present certain fabrication problems.

Accordingly, it is an object of this invention to increase the gain obtainable in a cyclotron wave parametric amplifier through the use of a single pump resonator of simple structure.

More specifically, it is an object of this invention to provide a pump resonator for a cyclotron wave parametric amplifier which may be a full wavelength long or longer.

These and other objects of the invention are attained in an illustrative embodiment thereof which comprises an electron gun for producing an electron beam which flows successively through an input coupler, a pump resonator that is excited from a source of pump frequency wave energy, and an output coupler. According to one feature of the invention, the pump resonator comprises a hollow conductive cylinder which is a full wavelength long at the pump frequency and which surrounds two rods that are twisted through 180 degrees in the form of a bifilar helix section. The resonator is excited by pump energy in the $++$ mode, that is, the instantaneous polarity of the cylinder is opposite that of the rods. In accordance with the invention, the twist of the rods compensates for the electric field reversal which necessarily results from full wavelength operation.

The resonator also includes a pair of apertured end plates to which the helical rods are attached. It is another feature of this invention that a slot be cut through the end plates of the resonator directly between the two rods. As will be explained hereafter, this feature insures excitation in the $++$ mode.

These and other objects and features of the invention will be more clearly understood from a consideration of the following detailed description taken in conjunction with the accompanying drawing in which:

FIG. 1 is a perspective illustration of a cyclotron wave parametric amplifier employing the principles of my invention;

FIG. 2 is a sectional view of a microwave frequency pump resonator of the type used in the amplifier of FIG. 1;

FIG. 3 is a graph illustrating electric field intensity with respect to distance in the pump resonator of FIG. 1;

FIG. 4 is a view taken along line 4-4 of FIG. 2.

FIG. 5 is a view taken along line 5-5 of FIG. 2.

FIG. 6 is a view taken along line 6-6 of FIG. 2; and

FIG. 7 is a view taken along line 7-7 of FIG. 2.

Referring now to FIG. 1 there is shown an illustration of a cyclotron wave parametric amplifier comprising an electron gun 12, for forming and projecting an electron beam toward a collector 13. A magnet (not shown) produces a longitudinal magnetic field B for focusing the beam and establishing cyclotron modes of wave propagation within the beam. The beam is maintained within a substantial vacuum by an envelope 11 which may be of glass or other suitable material. An input coupler 15 comprising a resonant circuit that is tuned to the cyclotron frequency modulates the beam with signal frequency energy from source 16 and removes fast cyclotron wave noise from the beam. The modulation results from transverse signal electric fields produced between parallel poles 14 of coupler 15. Likewise, inherent beam noise excites transverse electric field energy on poles 14 which is conveniently removed.

After modulation the signal frequency energy propagates as a cyclotron wave. The beam then passes through a pump resonator 17 which is normally tuned to twice the

cyclotron frequency and is excited by pump power of twice the cyclotron frequency from a source 18. The pump resonator transfers energy from source 18 to the cyclotron mode of the beam, thereby amplifying the signal cyclotron wave. An output coupler 20 comprising parallel poles 21 extracts the amplified signal frequency energy from the beam and transmits it to an appropriate load 22.

Although the input, pump, and output resonators are shown as portions of a single block, each could constitute a separate and distinct element. FIG. 2 is a sectional view of a pump resonator of the type shown in FIG. 1 and can be considered as being a separate and distinct element. The resonator comprises an outer wall 23, two end plates 24 and two rods 25 which are twisted through 180 degrees in the form of a bifilar helix section. Central apertures 26 in the end plates 24 permit passage of the electron beam. Pump resonator 17 is one wavelength long at the pump frequency. Normally the transverse electric field which would be produced along the cavity axis would reverse direction at the midpoint of the pump cavity as shown by curve 28 of FIG. 3.

As was pointed out in the aforementioned Ashkin application, conventional pump resonators cannot be a full wavelength long because of the electric field reversal illustrated in FIG. 3. When the beam enters a pump resonator roughly half of the electrons are in a proper phase condition to gain energy while the other half loses energy. Normally, if the electric field reverses direction as shown in FIG. 3 the electrons that gain energy along the upstream portion will lose energy in the downstream portion because of the reversed direction of the electric field. Hence, the conventional pump resonator is not capable of full wavelength operation.

As will be appreciated from FIGS. 4 and 5, the 180 degree twist of rods 25 fully compensates for the inherent electric field reversal in the resonator 17. FIG. 4 is a section taken along a plane which is approximately one-quarter the distance along resonator 17 while FIG. 5 is a section taken along a plane which is approximately three-quarters the distance along the resonator.

As will be described more fully hereafter, pump resonator 17 is excited such that the instantaneous polarity of rods 25 is opposite that of outer wall 23. It can easily be seen from FIG. 4 that this mode of excitation invariably produces quadrupolar electric fields E within the electron beam. Assuming an instant in time in which rods 25 are at a maximum positive potential with respect to the outer wall, quadrupolar fields E will tend to focus the beam along an imaginary plane 29.

At plane 5—5 of FIG. 2, the relative polarities at the same instant of time are just the opposite of those at plane 4—4 because of the aforementioned electric field reversal. As shown in FIG. 5, the rods 25 are at a negative potential with respect to the outer wall. However, because of the intervening 90 degree twist of rods 25 between planes 4—4 and 5—5, the quadrupolar electric fields E still tend to focus the electrons along a plane 29 just as in FIG. 4. Hence, the electrons of the beam do not "see" the field reversal shown in FIG. 3. Those electrons which are in a proper phase at plane 4—4 to gain energy are also in a proper phase to gain energy at plane 5—5. It can therefore be appreciated that the twist of rods 25 compensates for the field reversal which inherently results from full wavelength operation.

It should be noted that the angular rate of twist with distance of rods 25 is just one-half the rate of change of the transverse electric field. As seen in FIG. 3, the electric field changes by 180 degrees between planes 4—4 and 5—5, while rods 25 are twisted through 90 degrees along the same distance, as can be seen from FIGS. 4 and 5. Along the entire length of pump resonator 17 the electric field goes through 360 degrees while rods 25 describe 180 degrees. From these considerations it can be appreciated that resonator 17 can be of any desired length. For example, if it were made two wavelengths long (720

degrees), rods 25 would be made to describe 360 degrees along its length.

Consider next the method of exciting resonator 17 in the proper mode of oscillation. Referring to FIG. 6, it can be appreciated that regardless of the instantaneous polarities of rods 25 and outer wall 23, the magnetic field lines H of the desired mode of oscillation are always transverse to the axis of the resonator, as well as being transverse to the instantaneous electric field lines. Magnetic coupling probe 31 is therefore positioned in a plane parallel to the axis of the resonator so that when it is excited it can produce a magnetic field parallel with lines H and thereby support the desired oscillation mode.

The oscillation mode described, wherein the central rods 25 are of a like instantaneous polarity is known as the ++ mode, as opposed to the +- mode wherein the rods are of opposite instantaneous polarity. It is sometimes possible for magnetic coupling probe 31 to excite a +- mode in resonator 17 because this mode is also characterized by a magnetic field that is transverse to the resonator axis. Excitation of the +- mode can be prevented by including slots 32 in plates 24 as shown in FIGS. 7 and 1. Referring to FIG. 7, it can be seen that the electric fields from the opposite poles 25 are in opposition along a plane 33 so that no vertical currents are transmitted across plane 33 on either of the end plates 24. Insertion of slot 32 in end plate 24 does not therefore affect the ++ mode. The +- mode, however, is supported by end plate current flowing between the oppositely polarized rods 25. Slots 32 constitute an open circuit with respect to such currents and thereby prevent the formation of a +- mode.

It should be pointed out that slots 32 are not always necessary for the successful formation of a ++ mode. If the magnetic coupling loop 31 is located directly between poles 25 as shown in FIG. 6, there may be no excitation of the +- mode because this mode does not have a large magnetic field component that is transverse to the plane of the coupling loop at that position. The slots are nevertheless desirable to insure oscillation stability in the resonator.

The above-described devices are intended only to be illustrative of my invention. Numerous other arrangements may be made by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A cyclotron wave parametric amplifier comprising:
 - means for forming and projecting an electron beam along a path;
 - means for producing a magnetic field along said path thereby establishing a cyclotron mode of wave propagation within the beam;
 - means for causing signal frequency energy to propagate within said beam as a cyclotron wave;
 - said last-mentioned means comprising a first cavity resonator surrounding a first portion of said path and having a pair of parallel poles on opposite sides of the path;
 - a source of pump frequency energy;
 - said pump frequency being substantially twice said signal frequency;
 - a pump resonator surrounding a second portion of said path;
 - said pump resonator comprising a conductive cylinder which surrounds two conductive rods;
 - said rods being twisted through substantially 180 degrees in the form of a bifilar helix;
 - means for exciting the pump resonator substantially only in the ++ mode with pump frequency energy;
 - and means comprising a third cavity resonator for extracting signal frequency energy from said beam.
2. An electron beam device comprising:
 - means for forming and projecting an electron beam along a path;

5

means adjacent said path for modulating said beam in a cyclotron mode;

means adjacent said path for demodulating said beam;

a cavity resonator located adjacent said path and between said modulating means and said demodulating means;

said resonator comprising a conductive cylinder which surrounds two conductive rods;

an end plate on each end of said cylinder;

an aperture in each of said end plates for permitting passage of said beam;

said conductive rods being attached to said end plates on opposite sides of said aperture and describing helix segments around a portion of said path;

the number of turns of the helix segments being substantially equal to half the number of wavelengths along the length of the cavity resonator at its resonant frequency;

and means for exciting the cavity resonator substantially only in the $++$ mode with electromagnetic wave energy.

3. Electron beam pumping apparatus comprising:

a source of pump frequency energy;

a resonator which is substantially one wavelength long at said pump frequency;

said resonator comprising an outer wall which surrounds two conductive rods;

said rods being twisted through 180 degrees in the form of a bifilar helix;

and means for exciting said resonator substantially only in the $++$ mode with energy from said source.

4. An electron beam device comprising:

means for forming and projecting an electron beam along a path;

means for producing a magnetic field along said path thereby establishing a cyclotron mode of wave propagation within the beam;

means for causing signal frequency wave energy to propagate along said beam as a cyclotron wave;

a source of pump frequency energy;

said pump frequency being approximately twice the signal frequency;

a pump resonator comprising a conductive cylinder surrounding a portion of said path and having a pair of end plates with apertures in the centers thereof for permitting passage of said electron beam;

two conductive rods attached to said end plates on opposite sides of said apertures;

said rods describing helix segments around said path portion;

means comprising a magnetic coupling probe located in a plane substantially parallel with the central axis of said cylinder for exciting said pump resonator

6

substantially only in the $++$ mode with energy from said pump frequency source;

said pump resonator being n pump frequency wavelengths long;

said helix segments each describing n times 180 degrees of helical rotation along said path portion;

and means for extracting signal frequency wave energy from said beam.

5. Electron beam pumping apparatus comprising:

a source of pump frequency energy;

a resonator which is n wavelengths long at said pump frequency and which has a central axis;

said resonator comprising an outer wall and two end plates;

said end plates having apertures along said central axis;

two helical rods surrounding said central axis and being attached at their ends to said end plates on opposite sides of said apertures;

said helical rods describing substantially $n/2$ revolutions between said end plates;

and means for exciting said resonator substantially only in the $++$ mode with energy from said source.

6. An electron beam parametric amplifier comprising:

means for forming and projecting an electron beam along an extended path;

means for producing a magnetic field along said path thereby establishing cyclotron modes of wave propagation within said beam;

means adjacent said path for modulating said beam in a cyclotron mode;

means adjacent said path for demodulating said beam;

a source of pump frequency energy;

a cavity resonator located between said modulating and demodulating means;

said resonator comprising a conductive cylinder which is coaxial with said path;

a pair of end plates on opposite ends of said cylinder each of which have an aperture along said central axis;

two helical rods surrounding said central axis and being attached at their ends to said end plates on opposite sides of said apertures;

said helical rods each describing x revolutions between said end plates;

said resonator being substantially $2x$ wavelengths long at said pump frequency; and

means for exciting said resonator substantially only in the $++$ mode with pump frequency energy.

7. The parametric amplifier of claim 6 wherein each of said end plates contains a slot which is substantially perpendicular to a line connecting the points at which said rods are connected to the respective end plates.

No references cited.