

April 7, 1964

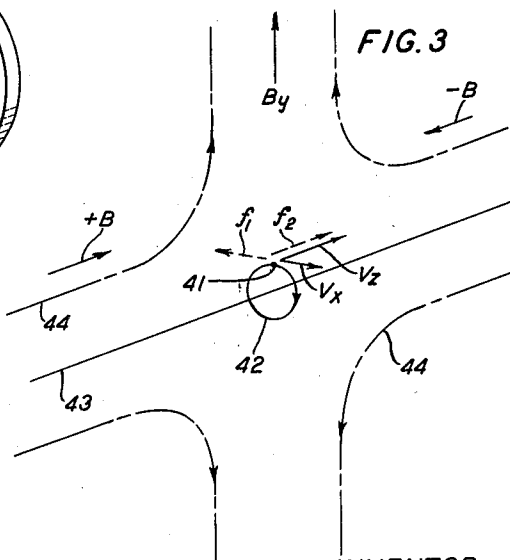
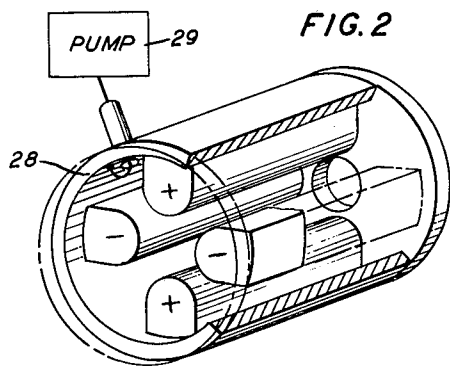
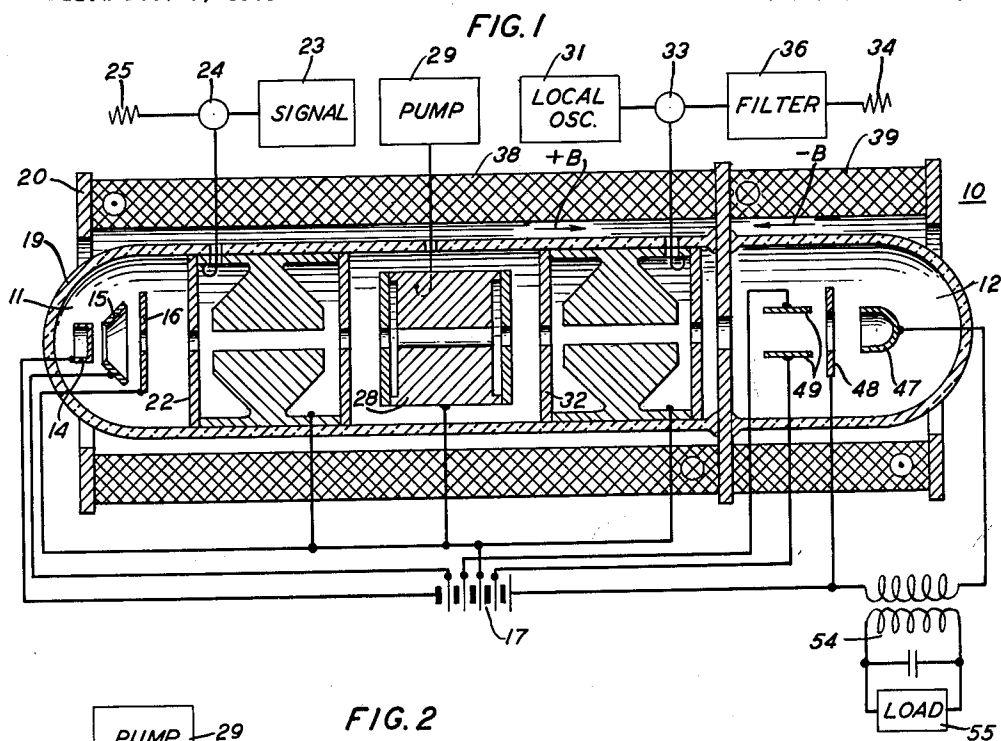
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3,128,432

CYCLOTRON-WAVE PARAMETRIC AMPLIFIER-MIXER TUBE

Filed Dec. 5, 1961

2 Sheets-Sheet 1



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FIG. 5

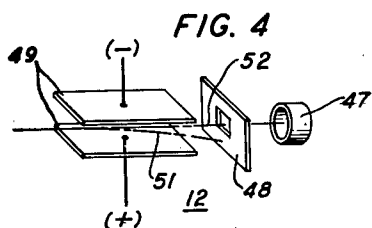
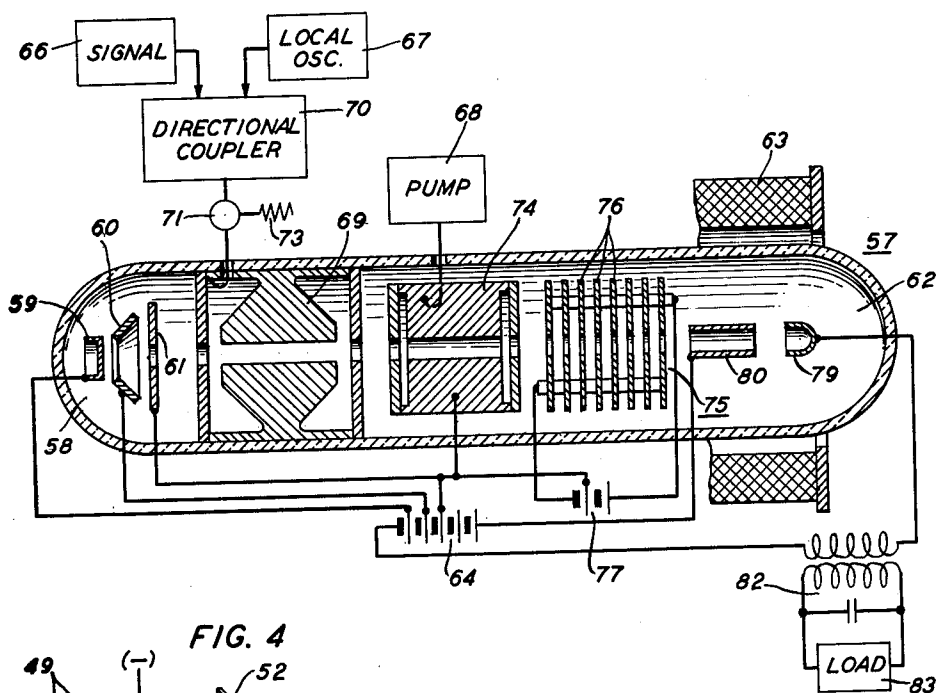


FIG. 6

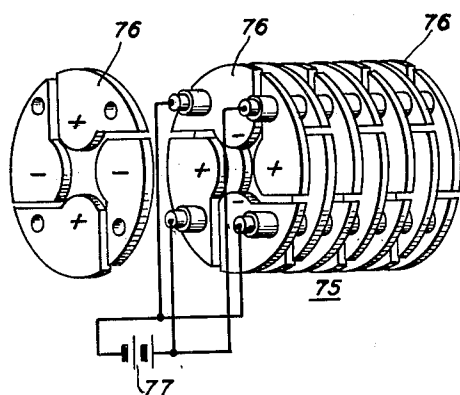
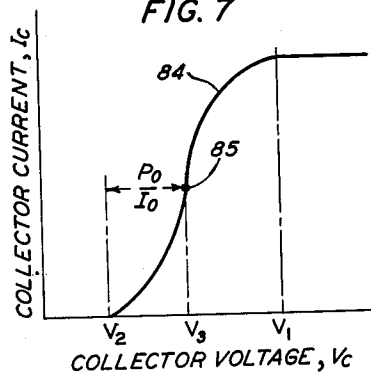


FIG. 7



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CYCLOTRON-WAVE PARAMETRIC AMPLIFIER-MIXER TUBE

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9 Claims. (Cl. 325-447)

This relates to electron beam devices and more particularly, to devices for amplifying and mixing high frequency electromagnetic wave energy.

One of the most important recent advances in the art of low noise microwave amplification is the cyclotron wave amplifier, known also as the quadrupole amplifier. By employing the principles of fast cyclotron wave parametric amplification, this device permits the direct removal of electron beam noise energy which would otherwise couple to the signal wave during the amplification process. It comprises an electron gun for producing 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 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 impart a rotational velocity component on the electrons of the beam; the phase positions of successive electrons as they pass through a fixed transverse plane define a cyclotron wave. Conversely, signal frequency cyclotron wave noise energy that is inherent in the beam is transferred to the input coupler and can thereafter be dissipated. The pump resonator comprises four poles in quadrature around the beam and is excited by pump power which is usually at twice the cyclotron frequency; this pump power interacts with the beam to amplify the signal cyclotron wave. The output coupler is identical with the input coupler and it extracts the amplified signal wave from the beam in the same manner that noise energy is extracted by the input coupler.

The cyclotron wave amplifier is used as a preamplifier in microwave receiver circuits and is generally followed by a mixer device, usually including a crystal detector, for converting the signal frequency to an intermediate frequency. In order that maximum use may be made of the low noise characteristics of the cyclotron wave amplifier, a mixer circuit should be used which has a sufficiently low noise figure; however, a separate mixer circuit meeting these requirements adds to the weight and complexity of the microwave receiver.

Accordingly, it is one object of this invention to provide a single electron beam device which will act as both a microwave preamplifier and mixer.

Another requirement for low noise reception is high gain amplification by the preamplifier; the receiver noise figure decreases with increasing preamplifier gain. It has been found that in many cases if the cyclotron wave preamplifier is operated at its maximum gain, the output of the mixer circuit will be distorted under conditions of high input power because of an insufficient dynamic range of the mixer; in other words, the output power of most microwave mixers does not increase linearly with input power under conditions of high power produced by the cyclotron wave preamplifier.

Accordingly, it is another object of this invention to provide microwave frequency mixing over a high dynamic range.

These and other objects of my invention are attained in

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an illustrative embodiment comprising the electron gun for forming an electron beam and projecting it along a path toward a collector. A longitudinal magnetic focusing field establishes a cyclotron mode of wave propagation within the beam. In accordance with known cyclotron wave amplification principles, noise is stripped from the beam and signal wave energy is caused to propagate within the beam as a fast cyclotron wave. The signal cyclotron wave is thereafter amplified by a quadrupole pump resonator through interaction with pump frequency energy of approximately twice the signal frequency.

According to one feature of this invention, local oscillator energy is also transferred to the cyclotron mode of the beam. This local oscillator energy may also be amplified in the pump resonator or it may be transferred to the beam downstream from the pump resonator.

It is another feature of this invention that the amplified signal wave and the local oscillator wave be converted to synchronous waves. This conversion can be effected by the devices disclosed in either the application of Ashkin et al., Serial No. 31,941, filed May 26, 1960, now Patent No. 3,054,964, issued September 18, 1962, or the application of R. C. Miller, Serial No. 157,215, filed December 5, 1961. As pointed out in these applications, a synchronous wave is defined by the relative displacements of successive electrons from the central axis of the beam. When a cyclotron wave is converted to a synchronous wave, rotational electron kinetic energy must necessarily be converted to longitudinal or drift kinetic energy. I have found that one component of the resultant longitudinal velocity variations is representative of the difference of frequencies of the local oscillator and signal waves.

It is a feature of one embodiment of this invention that a hollow auxiliary collector be located between the mode conversion apparatus and the primary collector. The primary collector is at a voltage which is at or below the cathode potential while the auxiliary collector is at a relatively high positive voltage. In the absence of longitudinal velocity modulations, the primary collector acts as a repeller and the electrons are collected by the high potential auxiliary collector. On the other hand, the intermediate frequency defined by the difference of the local oscillator and the signal frequencies is manifested by longitudinal velocity increments which cause some of the electrons to reach the primary collector so that an intermediate frequency current output can be taken therefrom.

According to a feature of another embodiment of this invention a pair of parallel deflection plates and an auxiliary collector mask are located between the mode conversion apparatus and the primary collector. In this embodiment, the primary collector is at a sufficiently high potential to collect all electrons that are directed thereto. The deflection plates, however, deflect the slower moving electrons against the auxiliary collector mask so that only the higher velocity electrons are permitted to impinge on the primary collector. As in the former case, the electrons impinging on the primary collector are representative of the difference frequency or intermediate frequency.

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

FIG. 1 is a sectional view of one embodiment of the invention;

FIG. 2 is a perspective view of the pump resonator of the device of FIG. 1;

FIG. 3 is a representation of the forces on an electron in the device of FIG. 1;

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FIG. 4 is a perspective view of the collector section of the device of FIG. 1;

FIG. 5 is a sectional view of another embodiment of this invention;

FIG. 6 is a perspective view of the electrostatic quadrupole mode conversion apparatus of the device of FIG. 5;

FIG. 7 is a graph of collector voltage versus collector current in the device of FIG. 5.

Referring now to FIG. 1, there is shown a schematic illustration of an electron beam device 10 comprising an electron gun 11 for forming and projecting an electron beam along a path toward a collector section 12. The electron gun is shown for illustrative purposes as comprising a cathode 14, a beam forming electrode 15 and an accelerating anode 16, which together with the collector are maintained at predetermined potentials by a battery 17. The various electrodes are maintained within a vacuum by means of an envelope 19 which may be of glass or other suitable material. Surrounding the envelope is a cylindrical magnet 20 which produces a longitudinal magnetic field B for focusing the beam and establishing a cyclotron mode of wave propagation within the beam.

An input coupler 22 comprising a resonant circuit that is tuned to the cyclotron frequency modulates the beam with signal frequency energy from a signal source 23. Fast cyclotron wave noise energy of the signal frequency is removed according to known principles from the beam by coupler 22 and is transmitted via a ferrite circulator 24 to a dissipative impedance 25. As the beam leaves input coupler 22 it carries signal frequency intelligence in the form of electron rotational energy.

This rotational energy is amplified as the beam flows through a quadrupole pump resonator 28, which is shown in perspective in FIG. 2. The pump resonator comprises four poles in quadrature around the beam and is excited by pump frequency energy from a source 29 in such a manner that adjacent poles have opposite instantaneous polarities, as is indicated in FIG. 2. The mechanism by which pump resonator 28 transfers pump energy to the beam to amplify the rotational velocity components of the electrons is known to workers in the art and will not be explained.

After amplification, the beam is modulated by local oscillator energy from a source 31 in a second input coupler 32. The purpose of the local oscillator frequency is to establish an intermediate frequency and so it is relatively close to the signal frequency. As is known in the art, an idler frequency, which is defined as the difference of the pump and signal frequencies, couples strongly to the signal frequency as a result of the parametric amplification process. Because the local oscillator and idler frequencies might otherwise form a spurious intermediate frequency, idler frequency energy is stripped from the beam by coupler 32 and transmitted via a ferrite circulator 33 to a dissipative impedance 34. A filter 36 prevents signal frequency energy from being transmitted to impedance 34 and may take any of a number of well-known forms. Filter 36 has the effect of mismatching coupler 32 to the beam at the signal frequency so that signal frequency energy is not extracted from the beam. In most situations the idler and local oscillator frequencies easily lie within the frequency pass-band of coupler 32 because both of these frequencies are relatively close to the signal frequency. However, even if the local oscillator frequency is at the fringes of the coupler pass-band, it is usually available in sufficient power to modulate the beam.

Consider next magnet 20, which comprises a first coil 38 that is wound in a clockwise direction and a second coil 39 that is wound in a counterclockwise direction. As a result of the abrupt change of direction of current in these coils the flux density in the beam abruptly changes direction as shown by the arrows labeled B and -B.

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The abrupt change in the direction (but not the magnitude) of the magnetic field converts cyclotron wave energy to synchronous wave energy.

The conversion process can be appreciated from a consideration of FIG. 3 which shows an electron 41 having a longitudinal drift velocity v_z and rotating clockwise in an orbit 42 with a tangential velocity v_x . Electron 41 is intended to represent an electron which has been modulated in the cyclotron mode and which therefore rotates around a central axis 43 at a cyclotron frequency ω_c given by:

$$\omega_c = B\eta \quad (1)$$

where B is the magnetic flux density and η is the charge-to-mass ratio of the electron. Electron 41 can also be considered as being representative of the center of mass of the electron beam of the device of FIG. 1 at a given time. The position of electron 41 is between coils 38 and 39 of magnet 20 and so the flux density changes direction in the manner shown by magnetic field lines 44.

As electron 41 enters the region of magnetic field reversal, it is acted upon by a diverging or vertical flux density component B_y . By the "left-hand rule" flux density B_y combines with velocity v_z to exert a force f_1 on the electron that induces counterclockwise rotation. This force is given by:

$$f_1 = ev_z B_y \quad (2)$$

where e is the charge on electron 41. By the same token, B_y acts with velocity v_x to exert a force f_2 given by:

$$f_2 = ev_x B_y \quad (3)$$

The result of these two forces is to increase v_z at the expense of v_x or in other words, to convert rotational kinetic energy to longitudinal kinetic energy.

As is explained in the aforementioned Miller application, a magnetic field reversal of the type shown in FIG. 1, wherein the magnetic fields in each direction are substantially equal and wherein the reversal is made within one-third of a cyclotron wavelength, converts electron rotational energy to longitudinal energy thereby causing electron 41 to drift with a longitudinal velocity equal to $\sqrt{v_z^2 + v_x^2}$. Because the magnetic field transition from B to -B is abrupt, electron 41 remains displaced from central axis 43 a distance equal to its original radius of rotation. Successive electrons having this type of displacement characteristic form a synchronous wave, and in the device of FIG. 1 the amplified signal frequency and the local oscillator frequency travel along the path surrounded by coil 39 as synchronous waves. It should be noted at this point that all of the converted cyclotron wave energy manifests itself as positive longitudinal velocity increments; there are no velocity decrements as in case of space-charge waves.

Collector section 12 comprises a primary collector 47, an auxiliary collector mask 48, and a pair of deflection plates 49. A perspective illustration of the collector section is shown on FIG. 4. In the absence of any electron velocity modulation the electric field produced between plates 49 coacts with the magnetic focusing field to deflect the beam along a path 51 terminated by an auxiliary collector mask 48. The electric field between plates 49 is adjusted to be barely sufficient to deflect an unmodulated beam, so that if the beam receives any longitudinal velocity increments it follows path 52 through an aperture in the auxiliary collector mask and impinges on primary collector 47. Because all energy conversions from cyclotron to synchronous waves result in positive longitudinal velocity increments, the current flowing in primary collector 47 is representative of the signal and local oscillator waves.

As can be appreciated from the following considerations, the current flowing in primary collector 47 has a frequency component that is equal to the difference of the local oscillator and signal frequencies; the device of FIG. 1 therefore acts as a mixer, and more particularly,

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as a square-law device. One characteristic of any mixer is that an A.-C. input must produce a D.-C. component at the output. This is true of the device of FIG. 1 because the net electron current must always flow from collector 47 to battery 17. Another characteristic of a mixer is that it must be a nonlinear device, i.e., its output current must bear a nonlinear relationship to its input current.

In the input couplers 22 and 32 of FIG. 1, electrical energy is converted to electron rotational kinetic energy. With reference to FIG. 3, the rotational velocity v_x of electron 41 represents rotational energy produced by an input current flowing during some time increment, or:

$$\Delta W_{in} = i_{in}^2 R \Delta t = \frac{1}{2} m v_x^2 \quad (4)$$

where ΔW_{in} is an increment of input energy, i_{in} is input current, R is resistance, Δt is a time increment, and m is the mass of electron 41. From Equation 4:

$$i_{in} \propto v_x \quad (5)$$

After velocity v_x has been converted to longitudinal velocity, it causes electron 41 to impinge upon the primary collector, causing an output current i_{out} given by:

$$i_{out} = \frac{di}{dV_e} \Delta V_e \quad (6)$$

where

$$\frac{di}{dV_e}$$

is the derivative of primary collector current with respect to primary collector voltage, and ΔV_e is the incremental voltage of the electron resulting from its incremental longitudinal velocity. Voltage increment ΔV_e is given by:

$$e \Delta V_e = \frac{1}{2} m v_1^2 \quad (7)$$

where e is the charge on electron 41 and v_1 is the incremental longitudinal velocity resulting from the cyclotron wave-synchronous wave conversion which, of course, is proportional to v_x of proportionality (5).

From Equations 6 and 7:

$$i_{out} \propto v_x^2 \quad (8)$$

and from Equations 5 and 8:

$$i_{out} \propto i_{in}^2 \quad (9)$$

The latter proportionality qualifies the device of FIG. 1 as a square-law detector. This is advantageous because a higher proportion of the output current is at the intermediate frequency than is true of other non-linear devices. If the local oscillator wave is defined by $\cos \omega_1 t$ and the signal wave is defined by $\cos \omega_2 t$, then from proportionality (9), the output current is:

$$i_{out} \propto (\cos \omega_1 t + \cos \omega_2 t)^2 \quad (10)$$

$$i_{out} \propto (\cos^2 \omega_1 t + 2 \cos \omega_1 t \cos \omega_2 t + \cos^2 \omega_2 t) \quad (11)$$

$$i_{out} \propto \cos^2 \omega_1 t + \cos (\omega_1 t + \omega_2 t) + \cos (\omega_1 t - \omega_2 t) + \cos^2 \omega_2 t \quad (12)$$

In the device of FIG. 1, a tank circuit 54 which is tuned to the component $\cos (\omega_1 t - \omega_2 t)$ is coupled to primary collector 47 so that a difference frequency, or intermediate frequency, is transmitted to a load 55. The device of FIG. 1 therefore functions as both a preamplifier and a mixer.

Various possible modifications of my invention are illustrated by the device 57 of FIG. 5. Device 57 comprises an electron gun 58, having component electrodes 59, 60, and 61, for forming and projecting an electron beam toward a collector section 62. The beam is focused by a single cylindrical magnet 63 that extends the length of the device and produces a uniform unidirectional field within the beam. A battery 64 biases the various electrodes at proper predetermined potentials.

Signal, local oscillator, and pump frequencies are transmitted to the device from sources 66, 67, and 68, respec-

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tively. The signal and local oscillator sources are connected to an input coupler 69 through a directional coupler 70 and a ferrite circulator 71. Energy from these sources modulates the beam in the cyclotron mode in the same manner as described with reference to FIG. 1, while cyclotron wave signal and idler frequency noise components are stripped from the beam by coupler 69 and transmitted to a dissipative impedance 73. The functions of the two input couplers of FIG. 1 are combined in the single input coupler 69 only through a judicious choice of input frequencies; the signal, idler, and local oscillator frequencies must be sufficiently close to lie within the frequency pass-band of the input coupler. In practice this condition may obtain fairly frequently because a low intermediate frequency requires a small difference of signal and local oscillator frequencies while very low noise amplification generally requires corresponding signal and idler frequencies (a condition that results from a pump frequency at twice the signal frequency). Also, the frequencies chosen must be such that the spurious intermediate frequency defined by the local oscillator and idler frequencies can be discriminated against.

Pump energy is transferred to the beam by a quadrupole pump resonator 74 in the same manner as in FIG. 1. However, the local oscillator cyclotron wave, in addition to the signal cyclotron wave, is amplified in the pump resonator.

The amplified local oscillator and cyclotron waves are converted to synchronous waves by an electrostatic quadrupole array 75 in accordance with the principles of the aforementioned Ashkin et al. application. The quadrupole array comprises a series of quadrupoles 76 which are biased by a battery 77 to produce an electrostatic field throughout the electron beam that alternates spatially in both the circumferential and longitudinal senses. The structure of the quadrupole array and the electrostatic polarities of the component poles can best be seen in the perspective view of FIG. 6.

As is pointed out in the Ashkin et al. application, cyclotron waves will be converted to synchronous waves if the distance between adjacent quadrupoles 76 is substantially equal to one-half of a cyclotron wavelength and if the longitudinal length L of the quadrupole array 76 meets the condition:

$$L = \frac{2n-1}{2} \frac{\pi v_x B}{|\text{grad } E_b|} \quad (13)$$

where n is any integer, v_x is the longitudinal drift velocity of the beam, and $|\text{grad } E_b|$ is the electric field gradient at the beam axis. As in the device of FIG. 1, the cyclotron wave-synchronous wave conversion is necessarily accompanied by longitudinal electron velocity increments that are representative of the signal and local oscillator waves.

The collector section 62 of the device of FIG. 5 comprises a primary collector 79 that is maintained at or below the cathode potential by battery 64, and an auxiliary collector 80 that is maintained at a relatively high potential. The potential of the auxiliary collector 80 is kept high enough to collect the beam in an unmodulated condition. The primary collector 79 is at a low enough potential to repel an unmodulated beam, but it is of a sufficiently high potential to collect those electrons that receive longitudinal velocity increments. The current flowing in collector 79 therefore contains an intermediate frequency component which is extracted by a tank circuit 82 and transmitted to an appropriate load 83.

The potentials to be used on the primary and auxiliary collectors can be appreciated from a consideration of FIG. 7 wherein curve 84 represents a typical collector current versus collector voltage characteristic. Taking curve 84 as the current-voltage characteristic of auxiliary collector 80, voltage V_1 indicates the minimum voltage which is sufficient to collect all the electrons of an unmodulated beam and therefore to produce a maximum

collector current I_c . Taking curve 84 as the current voltage characteristic of the primary collector 79, point 85 is a desirable position at which to collect the modulated electrons having velocity increments because it lies on a linear portion of the curve and therefore permits collector current variations to manifest, for example, any amplitude modulation that might be present on the signal wave. If the local oscillator power is designated P_o and the beam current is I_o , then the voltage V_2 at which primary collector 79 should be biased, is given by:

$$V_2 = V_3 - \frac{P_o}{I_o} \quad (14)$$

where V_3 is the equivalent voltage of the point on the current-voltage characteristic at which collection is desired, which in this case is the voltage at point 85. Equation 14 does not take into account the signal frequency power because it is usually negligible with respect to the local oscillator power.

It is quite obvious that a number of workable combinations can be made from the various elements of FIGS. 1 and 5; for example, the quadrupole array 75 of FIG. 5 can be combined with the collector section 12 of FIG. 1. Also, it is possible that collector sections other than those described herein can be devised by those skilled in the art for discriminating between unmodulated electrons and electrons that contain longitudinal velocity increments. Such modifications should not detract from the inventive concept which permits high microwave frequency amplification and mixing in a single electron beam device. Further, it can be shown that devices which establish an intermediate frequency according to this inventive concept have much higher dynamic ranges than those of crystal detectors, which have previously been used for microwave mixing.

It is to be understood that the foregoing embodiments are only illustrative of the inventive concepts involved. Various 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 mixer tube comprising:

means including a cathode for forming and projecting a beam of electrons;

means for producing a longitudinal magnetic focusing field along the beam;

means downstream from the cathode for extracting cyclotron wave noise energy from the beam;

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

means for causing local oscillator frequency energy to propagate along the beam as a cyclotron wave;

means for converting the signal frequency and local oscillator frequency cyclotron waves to synchronous waves;

means comprising a first electron collector for collecting only those electrons that transmit synchronous waves;

means comprising a second electron collector for collecting the remainder of the electron beam;

said electron collectors being downstream from the converting means;

and a resonant circuit connected to said first electron collector for transmitting electrical current therefrom;

said resonant circuit being tuned to a frequency substantially equal to the difference of the local oscillator and signal frequencies.

2. The mixer of claim 1 further comprising:

a pair of deflection plates on opposite sides of the beam located between the converting means and the first electron collector;

the second electron collector being located between the deflection plates and the first electron collector;

and means for producing an electrostatic field between

the deflection plates which is sufficiently intense to deflect unmodulated electrons toward the second electron collector but which is not sufficiently intense to deflect toward the second electron collector electrons which have longitudinal velocity increments resulting from synchronous wave modulations.

3. The mixer of claim 1 wherein the means for causing signal frequency propagation and the means for causing local oscillator frequency propagation comprise a single cavity resonator surrounding part of the electron beam with both a source of signal frequency energy and a source of local oscillator frequency energy being connected to said resonator.

4. A mixer tube comprising:

means including a cathode for forming and projecting a beam of electrons;

means for producing a longitudinal magnetic focusing field along the beam;

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

means for causing local oscillator frequency energy to propagate along the beam as a cyclotron wave;

means for converting the signal frequency and local oscillator frequency cyclotron waves to synchronous waves;

means comprising a first electron collector for collecting only those electrons that transmit synchronous waves;

means comprising a second electron collector for collecting the remainder of the electron beam;

the electron collectors being downstream from the converting means;

and a resonant circuit connected to said first electron collector for transmitting electrical current therefrom.

5. The mixer of claim 4 wherein the resonant circuit is tuned to a frequency substantially equal to the difference of the local oscillator and signal frequencies.

6. The mixer tube of claim 4 further comprising:

means located between the cathode and the means for causing signal frequency energy propagation for extracting cyclotron wave noise energy from the beam.

7. An electron-discharge device comprising:

means including a cathode for forming and projecting a beam of electrons;

means for producing a longitudinal magnetic focusing field along the beam;

means for extracting spurious cyclotron wave noise energy from the beam;

first input coupling means for causing signal frequency energy to propagate along the beam as a cyclotron wave;

means downstream from the input coupling means and the extracting means for parametrically amplifying the signal frequency cyclotron wave energy in the beam;

second input coupling means for causing local oscillator frequency energy to propagate along the beam as a cyclotron wave;

means downstream from the amplifying means for converting the signal frequency and local oscillator frequency cyclotron waves to synchronous waves;

means comprising a first electron collector for collecting only those electrons that transmit synchronous waves;

means comprising a second electron collector for collecting the remainder of the electron beam;

said electron collectors being downstream from the converting means;

and a resonant circuit connected to said first electron collector for transmitting electrical current therefrom.

8. The electron-discharge tube of claim 7 wherein the resonant circuit is tuned to a frequency substantially equal to the difference of the local oscillator and signal frequencies.

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9. The electron-discharge tube of claim 7 further comprising:

a pair of deflection plates on opposite sides of the beam located between the converting means and the first electron collector;

the first collector being located on the undeflected path of the beam;

the second electron collector being removed from the undeflected path of the beam;

and the means for producing an electrostatic field between the deflection plates which is sufficiently intense to deflect unmodulated electrons toward the

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second collector, but which is not sufficiently intense to deflect toward the second collector electrons that have longitudinal velocity increments resulting from synchronous wave modulations.

References Cited in the file of this patent

UNITED STATES PATENTS

2,657,305	Knol et al. -----	Oct. 27, 1953
2,805,333	Waters -----	Sept. 3, 1957
2,820,139	Adler -----	Jan. 14, 1958
3,054,964	Ashkin et al. -----	Sept. 18, 1962