

Jan. 8, 1963

E. I. GORDON

3,072,817

ELECTRON DISCHARGE DEVICE

Filed June 19, 1959

3 Sheets-Sheet 1

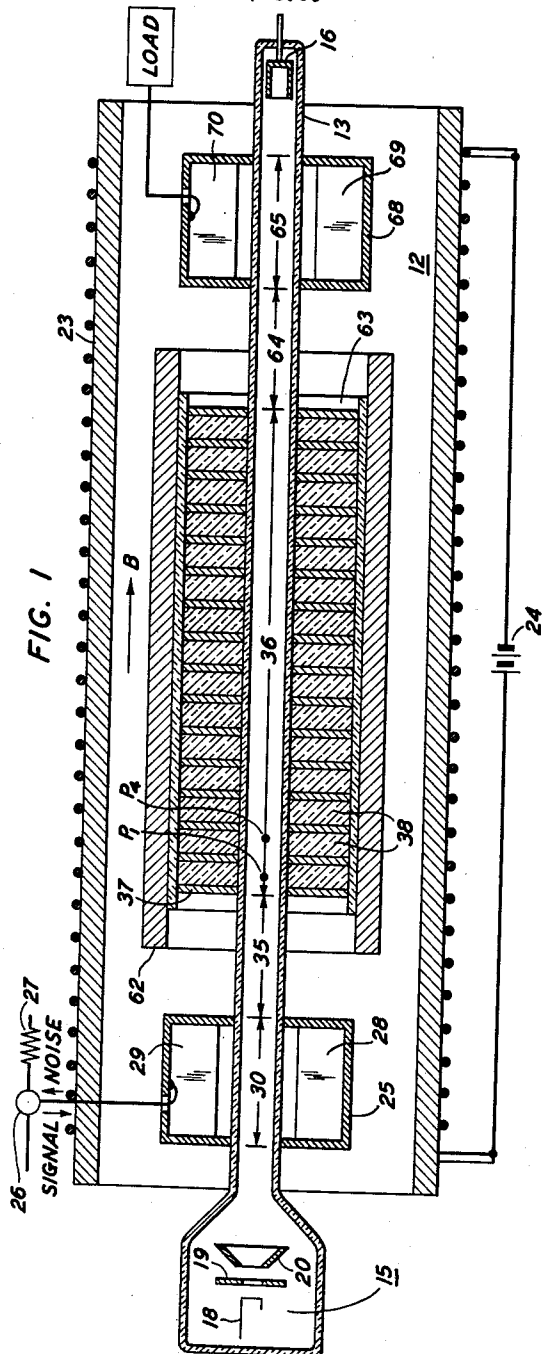


FIG. 1

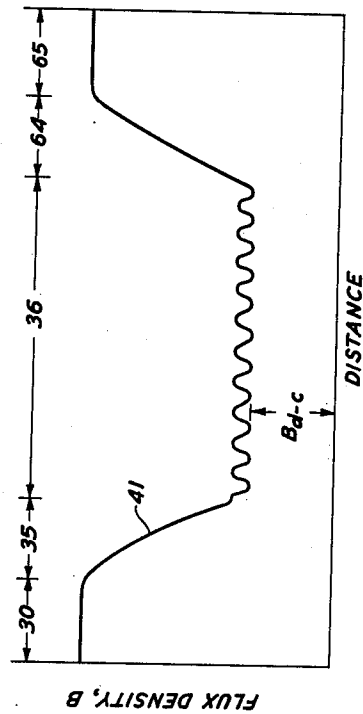


FIG. 2

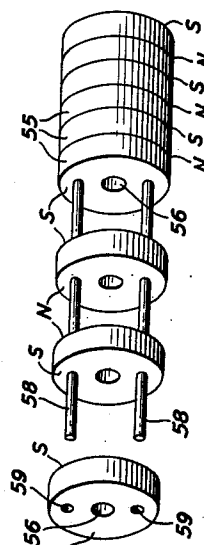


FIG. 8

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FIG. 3

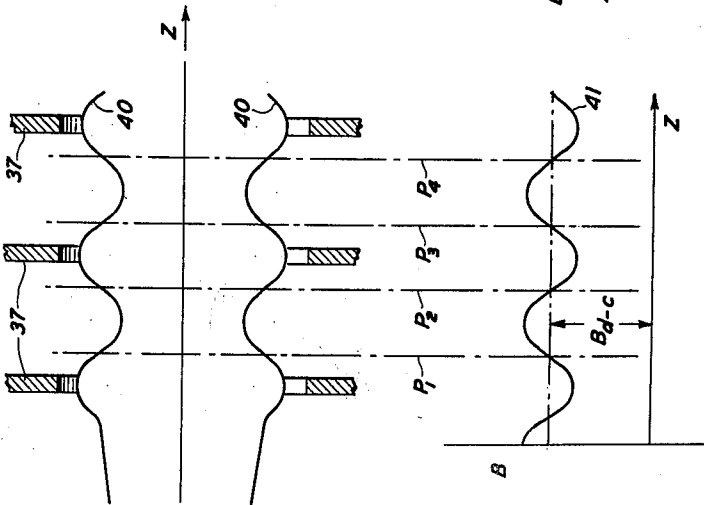
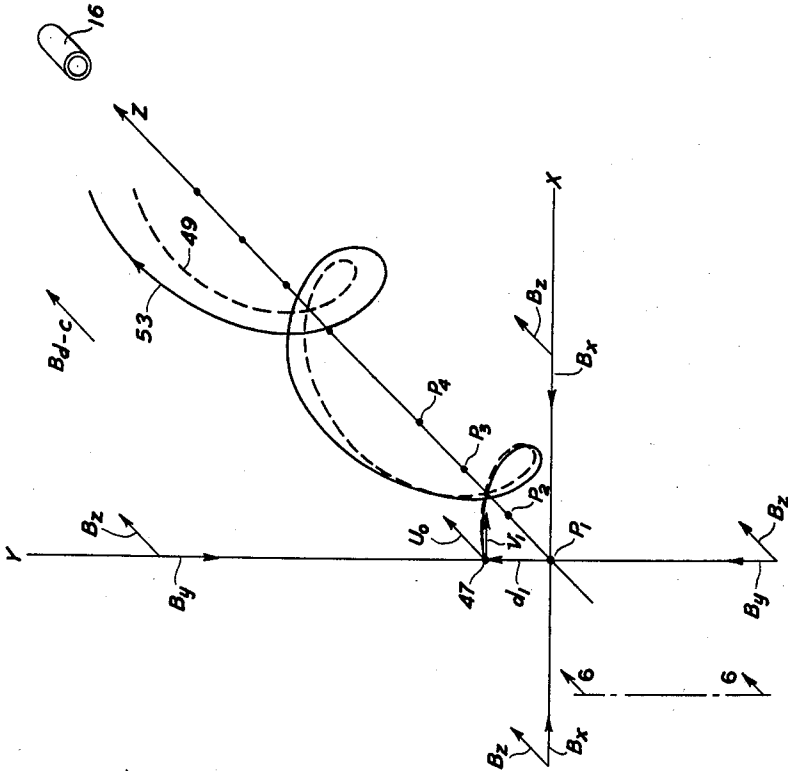


FIG. 4



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ELECTRON DISCHARGE DEVICE

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23 Claims. (Cl. 315—3)

This invention relates to electron discharge devices and more particularly to such devices of the parametric amplifier type.

Of the many advances made in the microwave art in recent years, one of the most important is the discovery that the principles of parametric amplification can be used to attain many desirable results. The term "parametric amplifier" in general refers to a family of electrical devices in which amplification is achieved through the periodic variation of a circuit parameter. As applied to high frequency electron discharge devices the term generally refers to a device in which a signal wave is used to modulate an electron beam, the signal modulations being subsequently amplified through periodic variations of certain beam or circuit parameters by the use of a "pump" frequency.

One type of electron discharge tube parametric amplifier is described in C. F. Quate application Serial No. 698,854, filed November 25, 1957. Because the device disclosed in the Quate application effects amplification through principles which are completely different from those of prior devices such as the conventional traveling wave tube, many of the inherent deficiencies of these devices are avoided. In the conventional traveling wave tube, for example, amplification can only take place through signal wave interaction with space charge waves propagating in the slow mode of the beam, whereas gain in the parametric amplifier may be produced through interaction with fast mode space charge waves. This is significant in that slow mode energy is at a lower level than the D.-C. kinetic energy of the beam, while energy propagating in the fast mode represents energy in excess of the D.-C. kinetic energy of the beam. As a result, substantially all of the inherent beam noise within a predetermined bandwidth can be removed from the fast space charge waves, whereas such removal is quite difficult, if not impossible, when coupling takes place in the slow mode. Hence, the Quate device, by operating in the fast mode, is capable of producing low noise amplification.

Detracting from the obvious advantages of the Quate device, however, are certain deleterious second order effects. The necessary beam parameter variation of the Quate device is attained by coupling a pump frequency wave onto the beam. Amplification then results through the mixing of the signal and pump frequency waves on the beam. Such mixing, however, in turn results in the production of certain sideband frequencies which may be degrading since they tend to couple with the pump and signal frequencies. As a result, beam noise which exists at these sideband frequencies becomes amplified with the signal and manifests itself at the output. Further, the coupling per se may impede the parametric amplification process and thereby reduce the tube gain.

These disadvantages can be substantially reduced through the use of a parametric amplifier arrangement of the cyclotron resonant type. The magnetic focusing field of a cyclotron resonant device is adjusted such that the cyclotron frequency of the beam is approximately equal to the frequency of the signal input wave. The phrase "cyclotron frequency" refers to the angular velocity at which a particle in a magnetic field will rotate if a force transverse to the magnetic field is applied thereto. In this case, the magnetic field is in the same direction as the

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beam flow. The transverse force to produce rotation results from a transverse electric field which is a function of the amplitude of the signal wave during some time increment in which the beam passes through a signal input coupler. Since the radius of rotation of a particle rotating at a cyclotron frequency is a function of the force thereon transverse to the magnetic field, the radius of rotation of beam particles in a cyclotron resonant device is a function of the signal input wave which is coupled to the beam. One may therefore think of beam modulation at the cyclotron frequency through the use of transverse electric fields as being a modulation of the radii of rotation of beam particles. Energy waves which propagate by means of such electron rotation are generally referred to as cyclotron waves.

Although this form of wave propagation is obviously different than space charge wave propagation resulting from longitudinal modulation through axial displacement of beam particles, as utilized in the conventional traveling wave tube and in the aforementioned Quate device, one may consider them to be analogous in terms of propagation velocity. Just as space charge waves may propagate the fast or slow mode, cyclotron waves of a given frequency may travel at either of two modes of propagation. Slow mode propagation takes place at a lower phase velocity than the D.-C. translational velocity of the beam and is representative of an energy level which is lower than the D.-C. kinetic energy of the beam. Energy in excess of the D.-C. beam kinetic energy is transmitted in the fast mode, or at a higher phase velocity than the translational velocity of the beam. Hence, noise may be "stripped" from the beam of a cyclotron resonant device in the signal bandwidth of the fast mode in the same manner as described with reference to the Quate device. Subsequent to the removal of certain fast mode noise and the introduction of a signal wave onto the beam, pump frequency power is applied to the beam to effect parametric amplification.

The main advantage of the conventional cyclotron resonant device with respect to the Quate device lies in the fact that the dispersion of the beam is appreciably greater than that of the Quate device. Dispersion refers to the inverse relationship between the propagation velocity and the frequency of a propagating wave. It can be shown that the phase velocities of cyclotron waves of an electron beam decrease very sharply with increasing frequency as compared to space charge waves. As a result, the higher frequency upper sideband waves of a cyclotron resonant device are greatly removed, in terms of phase velocity, from the signal wave and are therefore out of synchronism with the signal wave to an appreciable degree. Hence, the effective beam-to-beam coupling between the upper sideband frequencies and the signal frequency is greatly reduced.

In addition to the significant advantages of the aforementioned beam type parametric amplifiers, I have found that through the use of my invention, as will be explained hereinafter, certain other advantages are attainable. In both of the forementioned parametric devices amplification is achieved through the transformation of pump power into signal power. In a sense, this is a disadvantage by comparison to the conventional traveling wave tube in that an additional high frequency power source is required.

Further, it is, generally speaking, a condition of maximum parametric amplification that a circuit parameter be varied at substantially twice the signal frequency. When such a device is being used for amplification of extremely high frequency signal waves, say in the millimeter wavelength region, it may be very difficult to produce such high frequency pump power oscillations.

It is, therefore, an object of this invention to obviate the necessity of introducing pump input power into an

electron discharge device of the parametric amplifier type.

It is a further object of this invention to reduce the ratio of parametric variations to signal frequency in an electron discharge device of the parametric amplifier type.

These and other objects of my invention are attained in an illustrative embodiment thereof wherein a coupler such as an input cavity resonator is used to introduce signal energy onto an electron beam flowing from an electron gun to a collector and also to extract noise frequencies therefrom. A magnetic focusing field is directed parallel with the path of flow of the electron beam thereby giving rise to an inherent cyclotron or rotational frequency of the beam particles. The focusing field in the input region is adjusted such that the inherent cyclotron frequency is approximately equal to the frequency of the signal wave. The input resonator is resonant at the signal frequency, and hence the cyclotron frequency, to insure strong coupling between the signal wave and the fast cyclotron mode of the beam through a synchronous phase relationship between electric fields produced by the signal and the beam particles rotating at the cyclotron frequency. The electric fields of the input resonator are transverse to the path of flow and the direction of the magnetic focusing field, thereby modulating the radius of rotation of the individual beam particles in accordance with the varying amplitude of the signal input wave. Noise is extracted from the beam within the signal bandwidth by the reverse operation, i.e., spurious rotational energy is given up to the input coupler. Since the beam particles have, in addition to their rotational velocity, a translational velocity due to their projection from the electron gun, they will follow a helical path from the input resonator to the collector, the radius of curvature of their paths being indicative of transmitted signal energy. This radius of curvature is increased in a drift region through the conversion of translational energy to rotational energy as will be described hereinafter. Since the radius of curvature of the electron paths is indicative of transmitted signal energy, the increase in rotational energy is actually an increase or amplification of the propagating signal energy which is attained at the expense of D.-C. beam translational energy. Subsequent to amplification, the beam is allowed to flow through an output device such as a cavity resonator where the amplified signal energy is extracted from the beam.

It is a feature of this invention that the magnetic focusing field in the amplification or "drift" region of the tube be "scalloped" or of spatially alternating flux density. Since these alternations or parametric variations are arranged spatially along the drift region, they must be a function of the translational velocity of the beam. As will be more fully explained hereinafter, beam translational or drift energy will be converted to rotational energy in the drift region if the individual electrons "see" an alternating magnetic field whose frequency is in synchronism with the frequency of rotation of the electrons. Since the energy for amplification comes from the beam itself, the beam can be considered as supplying its own "pump" energy. This pump energy is, of course, kinetic energy due to the translational velocity of the beam.

It is a feature of one embodiment of this invention that an array of ferromagnetic plates or discs be utilized in the drift region for periodically deflecting the magnetic focusing field. These plates are equispaced along the drift region and have central apertures therein for permitting passage of the electron beam. Since each plate deflects the magnetic field, the frequency, with respect to distance, of the magnetic field alternations depends upon the spacing of the plates. If it is desired that the rotating electrons experience a full cycle of magnetic field alternation during each half-cycle of their rotation, the spacing between adjacent plates is made equal to the translational distance that an electron travels during one-half cycle of its rotation.

It is a feature of another embodiment of this invention that an array of permanently magnetized plates or discs be utilized in the drift region for creating a spatially alternating magnetic field. Each of these plates has a central aperture therein for permitting passage of the electron beam and has oppositely polarized faces. Each plate is contiguous with adjacent plates such that any two plate faces in contact are of like polarity. Each plate is of a predetermined thickness to insure proper synchronism of the alternating field with the beam. This embodiment is advantageous in that the amplitude of the alternating field may be made very large.

Since the utility of the foregoing embodiments depends upon a directly proportional relationship between the cyclotron frequency and the frequency of spatial alternations, and since the cyclotron frequency must be made approximately equal to the signal frequency at the input, it is seen that the spatial alternations must have a very high frequency when being used to induce amplification of a very high frequency signal wave. In such a situation, the aforementioned discs must be physically very thin. I have found, however, that if one lowers the magnetic focusing field after the signal has been coupled onto the beam, the spatial alternations or "pump" frequency may be lowered. This is due to the fact that the cyclotron frequency is proportional to the magnetic field flux density and therefore becomes lower with decreasing magnetic field. After amplification has taken place, the magnetic field may be raised to its former level.

Accordingly, it is another feature of this invention that the magnetic focusing field be lower in the drift region than in the input or output regions. This may be accomplished in various ways as by utilizing a ferromagnetic cylinder in the drift region which is parallel to the magnetic field and surrounds the array of discs. The cylinder serves to deflect the magnetic field and hence reduces the flux density in the drift region.

These and other features of my invention will become clearly understood from the following detailed description, taken in conjunction with the attached drawing, in which: FIG. 1 is a sectional view of one illustrative embodiment of my invention;

FIG. 2 is a graph of the magnetic flux density along the axis of the device of FIG. 1 versus distance along the length of this device;

FIG. 3 is an enlarged view of a portion of FIG. 1;

FIG. 4 is a representation of the path of an electron along the drift region of the device of FIG. 1;

FIG. 5 is an illustration of the forces acting on an electron in one plane of FIG. 4;

FIG. 6 is a view taken along line 6—6 of FIG. 4;

FIG. 7 is a view taken along line 7—7 of FIG. 6; and

FIG. 8 is a partially exploded view of disc structures which can alternatively be used in the device of FIG. 1.

Referring now to FIG. 1, there is shown an electron discharge device 12 embodying the principles of the present invention. Located at opposite ends of an evacuated envelope 13 which, for example, is of glass or any other suitable material, are an electron gun 15 and a collector electrode 16. Electron gun 15 is shown for illustrative purposes as comprising an emissive cathode 18, a beam-forming electrode 19, and an accelerating anode 20. These elements of electron gun 15 serve to form and project a beam of electrons along a path toward collector 16. The voltage sources for maintaining the various electrodes at proper predetermined potentials are not shown for the sake of brevity and clarity. The electron beam is contained within predetermined boundaries and prohibited from impinging against envelope 13 by means of a magnetic field in the direction shown by the arrow labeled B. The magnetic focusing field may be maintained through the use, for example, of a hollow cylindrical electromagnet 23 which is energized by a voltage source 24, or may be any one of a number of well known forms.

Downstream from electron gun 15, that is, at a position closer than the gun to collector 16, is a signal input and noise extraction cavity resonator 25. A signal wave from a source such as coupling arrangement 26 is used to excite resonator 25 with a predetermined electric mode such that an electric field is produced which is transverse to the magnetic field B. Ridges 28 and 29 in the resonator 25 serve to concentrate the electric field in the vicinity of the beam in the input region 30.

Any charged particle which is contained within a magnetic field will rotate if a force transverse to the magnetic field is applied thereto. The angular velocity of such rotation is

$$\omega_b = Bq/m \quad (1)$$

where B is the flux density of the magnetic field and q/m is the charge-to-mass ratio of the particle. ω_b , the angular velocity of the particle, is generally known in the art at the cyclotron frequency. The tangential velocity v_1 of the particle is, of course, a result of the transverse force. The radius of rotation of such a particle is given by

$$r = \frac{mv_1}{Bq} \quad (2)$$

In the device of FIG. 1, the transverse electric field produced in input region 30 is proportional to the amplitude of the signal wave. As a result, transverse forces which are proportional to the amplitude of the signal wave are applied to the individual electrons of the beam. These forces cause individual electrons to rotate at the cyclotron frequency.

Since the cyclotron frequency is proportional only to the flux density and the charge-to-mass ratio, the magnetic field can be adjusted to make the cyclotron frequency substantially equal to the resonant frequency of resonator 25. When this condition is met, each electron experiences a change of electric field during each half-cycle of its orbit and therefore substantially complete transfer of signal energy to the beam results. One can see that as the amplitude of signal wave decreases, the radius of the orbits which are thereby produced correspondingly decreases. As the signal power increases, the opposite is true. Hence, the radius of the individual electron orbits in a given plane of the beam is indicative of the signal energy transferred to the beam in some small increment of time. It should also be pointed out at this juncture that since the electrons also have a translational velocity, due to their projection from gun 15, they will travel a helical path toward collector 16.

A signal wave which is coupled to the beam as described above propagates along the beam as a cyclotron wave. This cyclotron wave is produced by adding energy to the beam and will propagate in the fast cyclotron mode, i.e., at a phase velocity which is faster than the D.-C. translational velocity of the beam. As is well known in the art, energy which propagates in the fast mode represents a kinetic energy level which is higher than the kinetic energy level of the D.-C. unmodulated beam.

Resonator 25 is of the general type known in the art as the Cuccia coupler. As explained in the article "The Electron Coupler," R.C.A. Review, volume 10, pages 270-303, June 1949, by C. L. Cuccia, such a device may be used to perform the dual function of coupling energy to, and extracting energy from, an electron beam. In the present case, fast mode noise energy which propagates as cyclotron waves within the bandwidth of frequencies of the signal wave will be transferred to resonator 25 and thereafter be dissipated by load 27. It is to be understood that any of a number of other well known methods for extracting noise may be utilized in the present device. For example, a separate resonant circuit could also be used for this purpose. Coupling arrangement 26 and load 27 could also be any of a number of well known devices such as a ferrite circulator or any type of signal

source which could also serve to dissipate the extracted noise energy.

Subsequent to its travel through input region 30, the beam passes through a first transition region 35, the purpose of which will be explained hereinafter. Thereafter, the beam passes through amplification or drift region 36. Surrounding drift region 36 are a series of ferromagnetic discs 37 separated by ceramic spacers 38.

The ferromagnetic discs periodically deflect the magnetic flux lines which are produced by electromagnet 23. Such periodic deflection results in a spatially alternating flux density in drift region 36. This spatial alternation in the drift region is illustrated graphically in FIG. 2 wherein curve 41 indicates the change of flux density with respect to distance. FIG. 3 is included to illustrative two deflected flux lines 40 and their relationship to the flux density curve 41 at corresponding points P_1 , P_2 , P_3 and P_4 along the drift region 36. As can be seen by this figure, the flux density increases as the flux lines converge, whereas the flux density decreases as the lines 40 diverge.

The effect of the periodically varying flux density will be better understood with reference to FIGS. 4, 5, 6 and 7. FIG. 4 is a graphical illustration of a portion of drift region 36 wherein the z axis represents the direction of beam flow or the direction of D.-C. translational velocity. A schematic showing of collector 16 is included to show that the direction of flow is in the direction of the arrowhead on the z axis. Other elements, such as discs 37, are not shown for the sake of clarity. Letters P_1 through P_4 indicate equispaced positions along the z axis corresponding to like positions in FIG. 3. Points P_1 and P_4 are shown in FIG. 1 for purposes of reference.

Consider first an electron 47 in the x-y plane of position P_1 on an instantaneous path having a center of curvature or center of rotation which corresponds to the center of the beam. As previously explained, electron 47 has a tangential velocity v_1 and a translational velocity U_0 which, in the absence of other forces, would cause it to follow a helical path 49 having a radius of rotation d_1 . At position P_1 the converging flux lines 40 (shown in FIG. 3) result in flux density vectors B_x , B_y and B_z . Since the field is converging, components B_x and B_y are directed inwardly, toward the z axis. B_z , of course, is in the same direction as the focusing field B_{d-c} and acts to exert a centripetal or focusing force on the electron.

FIG. 5 is an illustration of the x-y plane of FIG. 4 at position P_1 . The crosses B_z and U_0 indicate that those vectors are going "into the paper." By the familiar left-hand rule, one can see that converging flux density vectors B_x and B_y will result in a force on any electron having a velocity in the direction of U_0 . The direction of any such force in the x-y plane of P_1 is shown by force lines 52. Since the B components mutually cancel at the center of the beam, the magnitude of force lines 52 varies in direct proportion to distance from the center. Due to the symmetry in drift region 36, the force lines form concentric circles as shown. The solid portions of the force lines indicate relative magnitude.

At position P_1 , electron 47 will be acted upon by a force f_1 which is in the same direction as its angular velocity. This force tends to increase the tangential velocity component v_1 , thereby tending to increase the radius of rotation of electron 47 by Equation 2. At position P_1 , however, the flux density in the z direction is increasing due to the converging field, as can be seen in FIG. 3. By equation 2 this increasing field B tends to decrease the radius of rotation. It can be shown that the increasing flux density B has more effect on the radius of rotation than the increased tangential velocity v_1 . As a result, the radius of rotation becomes smaller, and electron 47 commences to follow a new path 53, rather than path 49.

FIG. 6 is a trace of this new path. When electron 47 reaches position P_2 , the flux lines 40 are diverging, as

seen in FIG. 3. As a result, flux density vectors B_x and B_y (not shown) are directed away from the z axis. Force f_2 is therefore in a counterclockwise direction at position P_2 and opposes the tangential velocity. From FIG. 3 it is seen that the flux density at P_2 is decreasing. Just as at position P_1 , the changing flux density and the force f_2 act to produce opposite effects on the radius of rotation. At position P_2 the decreasing flux density tends to increase the radius while f_2 tends to reduce it. Force f_2 , however, is smaller than f_1 which acted at P_1 because d_2 is smaller than d_1 . Hence, force f_2 will not detract from the effect of changing flux density to as great a degree as f_1 . From position P_2 to P_3 the radius of rotation will therefore increase to a greater extent than the decrease which took place between P_1 and P_2 .

One can see that the foregoing process is repeated once during each half-cycle of the rotation of electron 47. From P_3 to P_4 the radius becomes smaller, but upon passing through P_4 the radius increases to a greater degree than the preceding decrease. Since the radius of rotation is an indication of the signal energy transmitted by the beam, the change of radius of rotation δ_y is representative of the signal gain for one cycle of electron rotation. Electron 47 will continue to gain rotational energy, as shown in FIG. 4, during its spiral travel to collector 16.

It is apparent from the foregoing that the frequency of rotation of the electrons must be synchronized with the frequency (with respect to distance) of the spatial alterations of flux density. This synchronism is accomplished by making the spacings between discs 37 dependent upon the translational velocity U_0 and the cyclotron frequency ω_b . A comparison of FIGS. 3 and 6 shows that the flux density alternates at twice the cyclotron frequency.

When the proper conditions of synchronism are met, the rotational energy of the electrons will be increased at the expense of D.-C. translational energy. This can be clearly seen from FIG. 7 which is a view of path 53 taken along the z axis. At position P_1 , the tangential velocity v_1 of electron 47 is shown as a dot to indicate that it is coming "out of the paper." Force lines 56 indicate the direction and relative magnitude of the forces which may result on an electron moving in the plane of P_1 with a velocity in the direction of v_1 . At P_1 , it can be seen that force f_1' opposes velocity U_0 . At position P_2 , however, the flux density is diverging and B_x will act with v_1 to exert a force f_2' in the same direction as v_2 . From FIG. 6, the distance from the z axis, d_2 at P_2 is smaller than d_1 . Since the magnitudes of force lines 56 vary in direct proportion to distance from the z axis, the force f_2' at P_2 will be smaller than force f_1' . As a result, there is a net decrease of translational velocity as the electron moves through the half-cycle from P_1 to P_2 . The same process occurs as the electron rotates through succeeding half-cycles. The net loss of translational energy as the electron moves through one cycle can be represented by δ_z , the difference in translational distance traveled by an electron moving along path 53 and an electron in a steady field traveling along path 49.

It should be pointed out that the paths 49 and 53 are not necessarily to scale. The translational lag δ_z is shown as being rather large only for purposes of illustration. In actual practice, and by rigorous theoretical proof, it can be shown that in most cases a spatially alternating magnetic field of uniform frequency, as shown in FIG. 2, is sufficient to maintain the desired synchronism with the rotating electrons. If exact synchronism is desired, however, it can be seen that discs 37 should be closer together near the downstream end of drift region 36 to compensate for translational lag δ_z . This is a design problem which is similar to the problem of maintaining synchronism between the helix and beam of a conventional traveling wave tube.

As can be seen from the analysis of amplification, the rotational gain which an electron experiences is due to

the spatially alternating flux density in the drift region. FIG. 8 shows an arrangement of permanently magnetized discs 55 which can be substituted for the ferromagnetic disc and ceramic spacer arrangement of FIG. 1 for producing a spatially alternating magnetic field of large amplitude. The arrangement shown can be fitted over envelope 13 by means of central apertures 56. Discs 55 are fitted together by rods 58 of non-permeable material, such as brass, which extend through apertures 59. As is clear from the drawing, opposite faces of discs 55 are of opposite polarity to give the desired scalloped magnetic field. The spatially alternating field can be superimposed on the D.-C. field produced by electromagnet 23.

In the device as hereinbefore described, it can be appreciated that extremely high frequency signal input waves would necessitate a correspondingly high cyclotron frequency. As the cyclotron frequency increases, the frequency (with respect to distance) of magnetic alternations must increase to preserve proper synchronism. It can be seen that the spacing between discs 37, or alternatively the thickness of discs 55 of FIG. 8, must be very small to produce such high frequency alternations. This is disadvantageous in that if discs 55 are made very thin, they cannot produce a very strong magnetic field; further, the mechanical problems in producing extremely thin discs 37 and spacers 38 can be very serious.

I have found that the aforementioned problem can be resolved through the use of a lower D.-C. magnetic focusing field in the drift region than in the input and output regions. As previously pointed out, the cyclotron frequency in input region 30 must necessarily be approximately equal to the signal frequency. In the drift region, this condition is not necessary. Surrounding the drift region 36, I therefore include means for decreasing the cyclotron frequency comprising a ferromagnetic cylinder 62 separated from discs 37 by a ceramic spacer 63. Cylinder 62 serves to deflect the flux lines throughout the beam in the same manner as previously described with reference to discs 37. As illustrated in FIG. 3, this deflection results in a reduction of flux density in drift region 36. Since by Equation 1 the cyclotron frequency is directly proportional to the flux density, the cyclotron frequency is lower in the drift region than in the input region. Hence, the required frequency of field alternations is reduced and, as a result, the thickness and spacing of discs 37 may be made larger.

Downstream from drift region 36 is a second transition region 64 and an output region 65. As can be seen from FIG. 1, ferromagnetic cylinder 62 does not surround the output region so that the flux density in the beam, and hence the cyclotron frequency, is the same at output region 65 as at input region 30. This equivalency is illustrated in FIG. 2. Output resonator 68, together with ridges 69 and 70 therein, is identical to input resonator 25. Rotational beam energy is again at the proper signal frequency in output region 65 and is extracted in the same manner by which noise energy is extracted in input region 30. This rotational energy is, of course, amplified signal energy and upon extraction is appropriately transmitted to a load, as shown.

As can be appreciated from the foregoing discussion, an electron discharge device which is constructed according to the principles of the present invention is capable of effecting low noise amplification of a signal wave. Since all signal wave propagation is in the fast cyclotron mode, spurious noise may be stripped from the beam. No independent source of pump power is needed since all of the energy for amplification comes from the translational kinetic energy of the beam. Although amplification is a result of beam parameter variations, these variations need not be as correspondingly high as the signal frequency because the beam cyclotron frequency can be reduced in the drift region.

It is to be understood, however, that the above-described arrangements are merely illustrative of the appli-

cation of these principles of the present invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of this invention.

What is claimed is:

1. An electron discharge device comprising means for forming and projecting a beam of electrons along a path, means for producing a magnetic field along said path thereby focusing said beam, input means for causing signal energy to propagate along said beam as a cyclotron wave, output means for extracting said signal energy from said beam, and means for converting translational kinetic energy of said electrons to rotational kinetic energy comprising means interposed between said input means and said output means for spatially periodically deflecting said magnetic field.

2. The electron discharge device of claim 1 wherein said deflecting means comprises an array of ferromagnetic plates.

3. An electron discharge device comprising gun means for forming and projecting a beam of electrons along a path, means for producing a magnetic field which extends along said path thereby focusing said beam, input means along said path for converting signal energy to electron rotational energy whereby said electrons are caused to rotate at a predetermined frequency, means for increasing said electron rotational energy, output means for extracting said rotational energy from said beam, and means for decreasing said frequency of rotation in the region between said input and output means comprising a ferromagnetic cylinder surrounding said beam and extending substantially from said input means to said output means.

4. A high frequency amplifier comprising means for projecting a beam of electrons along a path with a predetermined velocity, means for producing a focusing field which is substantially parallel with said path, input means for causing said electrons to rotate at a predetermined frequency whereby said electrons are caused to travel in helical paths, means for increasing the radius of rotation of said electrons comprising an array of ferromagnetic plates having central apertures therein for permitting passage of said beam, a ferromagnetic cylinder surrounding said array for reducing said frequency of rotation, and output means for extracting rotational energy from said beam.

5. The high frequency amplifier of claim 4 wherein the distance between adjacent plates of said array is a function of said predetermined velocity and said predetermined frequency.

6. An electron discharge device comprising means for forming and projecting a beam of electrons in a longitudinal direction whereby said electrons exhibit a predetermined translational kinetic energy, means for producing a magnetic field in said longitudinal direction, input means for producing transverse forces on said beam thereby causing said electrons to rotate at a predetermined frequency and exhibit rotational kinetic energy, output means for extracting said rotational energy from said beam, said input means and said output means being spaced apart by a drift region, and means included in said drift region for converting certain of said translational kinetic energy of said beam of electrons into rotational energy comprising an array of longitudinally spaced ferromagnetic elements for distorting said magnetic field.

7. The electron discharge device of claim 6 wherein the distance between adjacent ferromagnetic elements is substantially equal to the longitudinal distance traveled by an electron of said beam during one-half cycle of its rotation.

8. An electron discharge device comprising means for forming and projecting a beam of electrons in a longitudinal direction whereby said electrons exhibit a predetermined translational kinetic energy, means for producing a magnetic field in said longitudinal direction,

input means for producing transverse forces on said beam thereby causing said electrons to rotate at a predetermined frequency and exhibit a certain rotational kinetic energy, means for converting certain of said translational kinetic energy of said beam of electrons into rotational energy comprising an array of permanently magnetized plates, and means for extracting said rotational energy from said beam.

9. The electron discharge device of claim 8 wherein the thickness of said plates is substantially equal to the longitudinal distance traveled by an electron during one-half cycle of its rotation.

10. A parametric amplifier comprising an electron gun for forming and projecting a beam of electrons along a path, means for producing along said path a magnetic field having a certain flux density, said magnetic field giving rise to an inherent cyclotron frequency of said electrons, means for extracting certain noise which propagates on said beam at said cyclotron frequency, means for coupling a signal wave to said beam at said cyclotron frequency comprising an input resonator which is substantially resonant at said cyclotron frequency, means for extracting signal wave energy from said beam comprising an output resonator which is substantially resonant at said cyclotron frequency, said input and output resonators being spaced apart by a drift region, and means for inducing parametric amplification of said signal wave on said beam comprising means for producing a magnetic field having unidirectional and spatially alternating components in said drift region.

11. The parametric amplifier of claim 10 further comprising means for reducing said flux density in said drift region.

12. The parametric amplifier of claim 10 wherein said means for producing said spatially alternating magnetic field comprises an array of equispaced ferromagnetic plates, the spacing between adjacent plates being a function of said cyclotron frequency.

13. The parametric amplifier of claim 10 wherein said means for producing said spatially alternating magnetic field comprises an array of stacked permanently magnetized plates, the thickness of said plates being a function of said cyclotron frequency.

14. A parametric amplifier comprising an electron gun for forming a beam of electrons and for imparting translational kinetic energy to said beam, a collector, an envelope enclosing said electron gun and said collector, magnet means substantially surrounding said envelope, means for imparting rotational kinetic energy to said beam and for removing certain noise waves from said beam comprising an input resonator, means adjacent said collector for extracting said rotational kinetic energy from said beam comprising an output resonator, means interposed between said input and output resonators for converting certain beam translational kinetic energy to beam rotational energy comprising an array of ferromagnetic discs, each of said discs having an aperture therein for permitting passage of said beam, spacers between each of said discs, and a hollow ferromagnetic cylinder surrounding said array.

15. A parametric amplifier comprising an electron gun for forming a beam of electrons and for imparting translational kinetic energy to said beam, a collector, an envelope enclosing said electron gun and said collector, magnet means surrounding a portion of said envelope, means for imparting rotational kinetic energy to said beam and for removing certain noise waves from said beam comprising an input resonator, means adjacent said collector for extracting said rotational kinetic energy from said beam comprising an output resonator, means interposed between said input and output resonators for converting certain beam translational kinetic energy to beam rotational energy comprising a plurality of magnetized discs each of which has opposite magnetic polarities at opposite faces thereof, adjacent ones of said

discs having contiguous faces of like polarity, and a hollow ferromagnetic cylinder surrounding said plurality of discs.

16. An electron discharge device comprising means for forming and projecting a beam of electrons in a longitudinal direction whereby said electrons exhibit a predetermined translational kinetic energy, means for producing a focusing field for focusing said beam in said longitudinal direction, means for extracting certain fast cyclotron mode noise waves from said beam, input means for producing a predetermined fast cyclotron wave on said beam thereby causing said electrons to rotate at a predetermined frequency and exhibit rotational kinetic energy, means for converting certain of said translational kinetic energy into rotational energy comprising an array of axially spaced structures arranged along said beam, and means for extracting said rotational energy from said beam.

17. The electron discharge device of claim 16 wherein the longitudinal distance between successive ones of said structures is substantially equal to the longitudinal distance traveled by an electron during one-half cycle of its rotation.

18. A parametric amplifier comprising an electron gun for forming a beam of electrons and imparting translational kinetic energy thereto, a collector, an envelope enclosing said electron gun and said collector, magnet means surrounding a portion of said envelope for focusing said beam, input means for causing signal energy to propagate along said beam as a fast cyclotron wave, output means for extracting said fast cyclotron wave signal energy, said input and output means defining a drift region therebetween, and means in said drift region for converting certain of said translational kinetic energy to fast cyclotron wave energy comprising means for producing a spatially alternating field in said drift region.

19. The parametric amplifier of claim 18 further including means for reducing the frequency of said spatially alternating field necessary to effect said energy conversion comprising a hollow ferromagnetic cylinder surrounding said drift region.

20. The parametric amplifier of claim 19 wherein said means for producing said spatially alternating field comprises an array of ferromagnetic plates axially arranged along said drift region.

21. A parametric amplifier comprising an electron gun for forming and projecting a beam of electrons along a path, means for producing along said path a magnetic field having a predetermined flux density, said magnetic field giving rise to an inherent cyclotron frequency of said electrons, an input resonator which is substantially resonant at said cyclotron frequency, said input resonator comprising means for causing electromagnetic waves within a predetermined frequency bandwidth to propagate along said beam as fast cyclotron waves and for extracting fast cyclotron wave noise energy from said beam which is within said frequency bandwidth, an output resonator which is resonant at said cyclotron frequency, said output resonator comprising means for extracting fast cyclotron waves which are within said frequency bandwidth, said input resonator and said output resonator defining a drift region therebetween, means for parametrically amplifying said fast cyclotron waves within said frequency bandwidth comprising means for producing a spatially alternating field in said drift region, and means for reducing said cyclotron frequency in said drift region comprising means for reducing said flux density in said drift region.

22. The parametric amplifier of claim 21 wherein said means for producing said spatially alternating field comprises an array of equispaced ferromagnetic plates, the spacing between adjacent plates being a function of said cyclotron frequency.

23. The parametric amplifier of claim 21 wherein said means for reducing said flux density comprises a ferromagnetic cylinder surrounding said drift region.

References Cited in the file of this patent

UNITED STATES PATENTS

35	2,830,223	Mihran	Apr. 8, 1958
	2,843,788	Peter	July 15, 1958
	2,847,607	Pierce	Aug. 12, 1958
	2,925,520	Cutler et al.	Feb. 16, 1960
40	2,945,153	Chang	July 12, 1960
	2,959,740	Adler	Nov. 8, 1960

FOREIGN PATENTS

45	R. Adler: A Low-Noise Electron-Beam Parametric Amplifier, Proc. of the I.R.E., vol. 46, No. 10, pages 1756, 1757, October 1958.
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