April 16, 1968 J. M. OSEPCHUK 3,378,718

CROSSED-FIELD TRAVELING WAVE ELECTRON REACTION DEVICE EMPLOYING CYCLOTRON MODE INTERACTION

Filed June 2, 1966 3 Sheets-Sheet 1

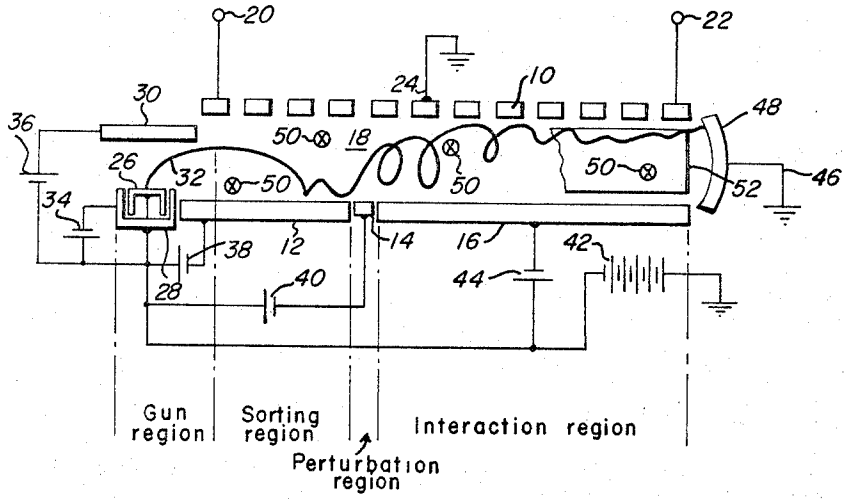


FIG. 1

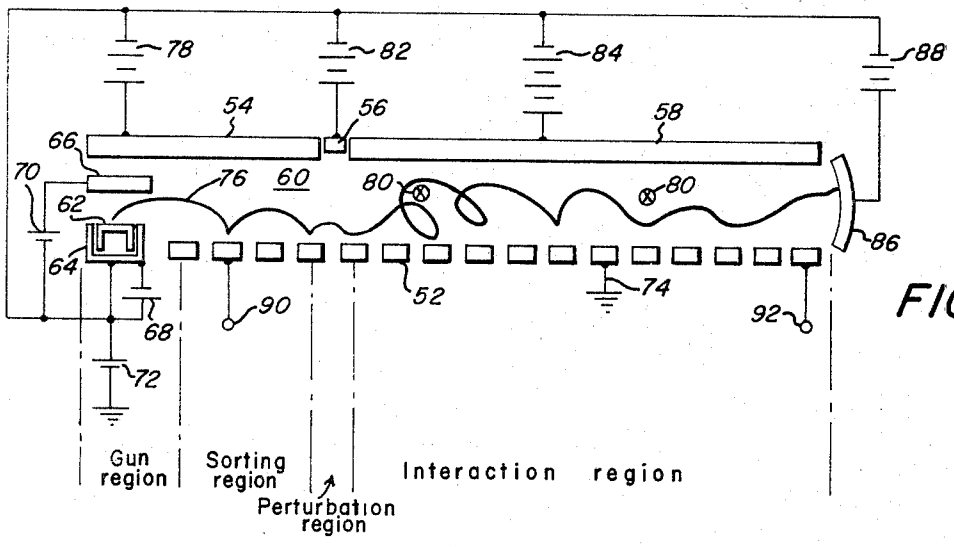


FIG. 2

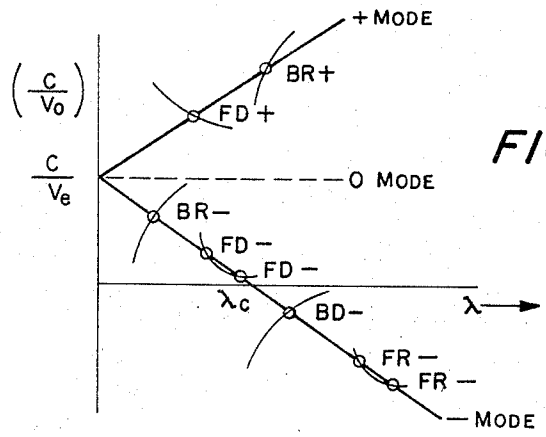


FIG. 4

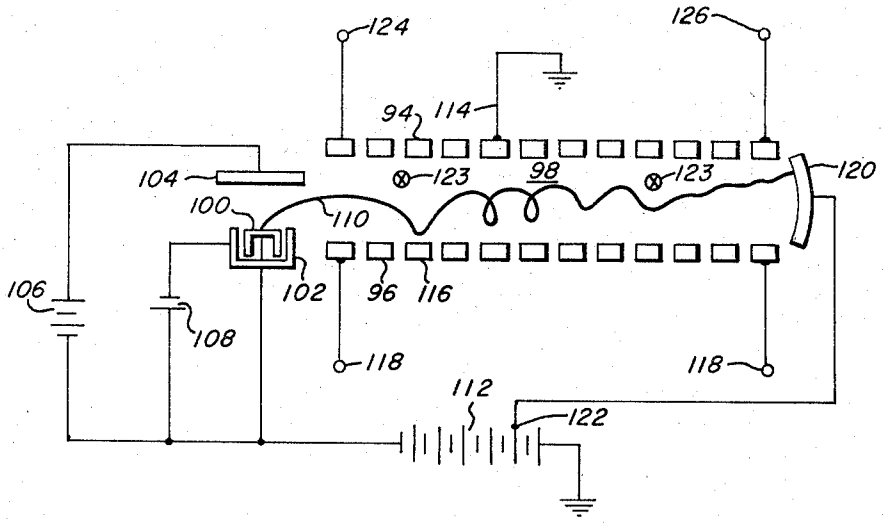
INVENTOR
JOHN M. OSEPCHUK
BY Robert T. Dunn
AGENT

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CROSSED-FIELD TRAVELING WAVE ELECTRON REACTION DEVICE EMPLOYING CYCLOTRON MODE INTERACTION

Filed June 8, 1966 3 Sheets-Sheet 1

FIG. 3



INVENTOR
JOHN M. OSEPCHUK
BY Robert T. Dunn
AGENT

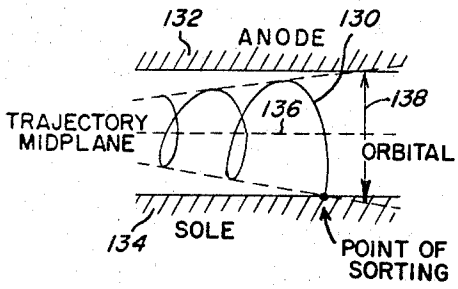


FIG. 5

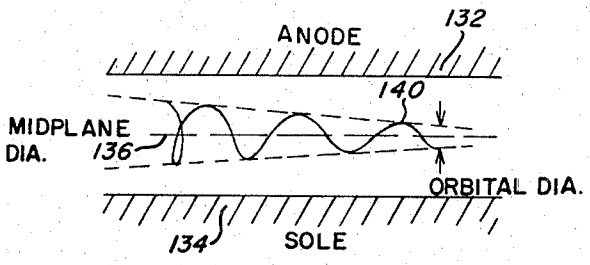


FIG. 6

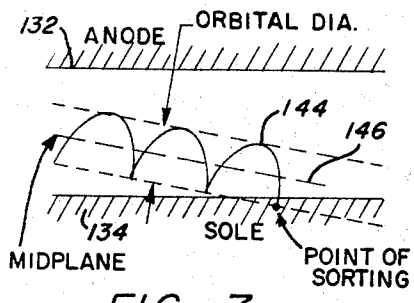


FIG. 7

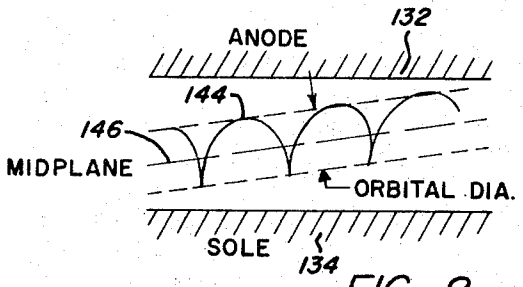


FIG. 8

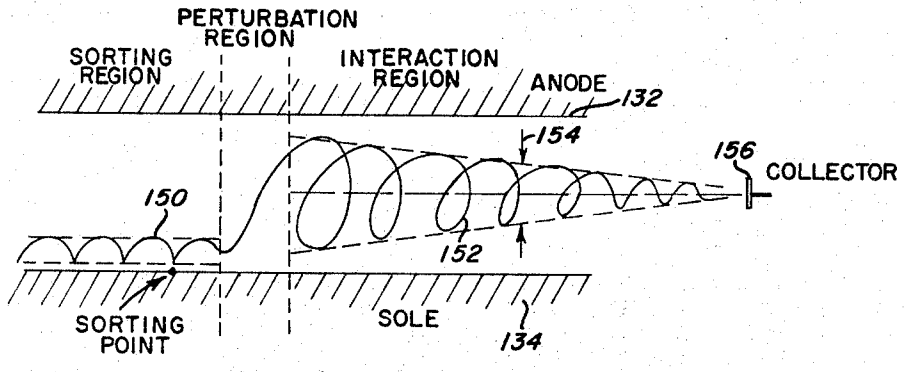


FIG. 9

INVENTOR
JOHN M. OSEPCHUK
BY Edgar O. Rost
ATTORNEY

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3,378,718

CROSSED-FIELD TRAVELING WAVE ELECTRON REACTION DEVICE EMPLOYING CYCLOTRON MODE INTERACTION

John M. Osepchuk, Concord, Mass., assignor to Raytheon Company, Lexington, Mass., a corporation of Delaware

Continuation-in-part of application Ser. No. 106,266, Apr. 28, 1961. This application June 2, 1966, Ser. No. 562,030

5 Claims. (Cl. 315—3.5)

This is a continuation-in-part of my copending United States patent application Ser. No. 106,266, filed on Apr. 28, 1961 and assigned to the assignee of the present application. The present invention pertains generally to traveling wave electron reaction devices, and more particularly to traveling wave electron reaction devices employing cyclotron mode interactions.

The use of cyclotron mode interaction has been suggested in the past in connection with traveling wave devices characterized by fast wave interaction in an unloaded waveguide. Exemplary devices of this type are disclosed in U.S. Patent No. 2,591,350, issued to Elmer J. Gorn and assigned to the assignee of the present invention. This utilization of cyclotron mode interaction in a fast wave device (where the ratio of the velocity of light to the phase velocity of the interacting wave is less than unity) finds ready application in the art of very high frequencies. However, where cyclotron mode interaction is employed in an unloaded waveguide, a relatively high magnetic field is necessary (relative, that is, to other types of devices in the same application), and for high voltage-tuning rates it is necessary to employ rather high voltages.

An alternative approach to very high frequency applications is the more conventional design utilizing the velocity synchronism mode with slow wave structures, such as where C/V_0 is in the neighborhood of 15 to 30. This approach offers the advantages of relatively low required voltages and magnetic field, along with high voltage-tuning rates. However, severe problems are encountered with respect to delay line heat dissipation and in the fabrication of the very small components involved.

It is accordingly a primary object of the present invention to provide a traveling wave electron reaction device of a new structure, affording operational characteristics which represent a desirable and practical compromise between the operational characteristics of the prior art devices.

An additional object of the present invention is to provide a traveling wave electron reaction device of the cyclotron interaction type having greatly improved operational characteristics.

Another object of this invention is to provide a traveling wave electron reaction device employing a slow wave structure, but having greatly improved characteristics in comparison with the slow-wave devices of the prior art.

In accordance with the present invention, the above and other objects are achieved by means of a traveling wave electron reaction device utilizing a slow wave structure and employing a cyclotron mode interaction. Means are provided to form a nonlinear or cycloidal beam of electrons, and means including the slow wave structure are provided for establishing a region of interaction between the electron beam and an electromagnetic wave propagated along the slow wave structure. The magnetic field applied to the interaction region and the voltages applied between the several elements of the device are such as to establish cyclotron mode interaction therein defined by the equation:

$$C/V_0=C/V_e[1\pm\lambda/\lambda_c] \quad (1)$$

where C is the velocity of light, V_0 is the phase velocity of the interacting wave, V_e is the average velocity of the electron beam, λ is the free-space wavelength of the propagated wave and λ_c is the free-space wavelength corresponding to the cyclotron frequency.

In the present invention, the cyclotron frequency is substantially equal to the apparent frequency of waves experienced by the beam electrons or, in other words, the apparent Doppler shifted frequency of the waves with respect to the moving reference frame of the electrons. This apparent Doppler shifted wavelength, λ_r, is related to the free-space wavelength λ, V_0 and V_e by the familiar Doppler frequency equation:

$$1/\lambda_r=1/\lambda\left[1-\frac{V_e}{V_0}\right] \quad (2)$$

in which V_0 is positive when in the same sense as V_e. If the Doppler equation is solved for λ and the resulting expression substituted in the cyclotron mode interaction Equation 1, it will be seen that $\lambda_r=\lambda_c$.

The beam velocity V_e is determined by the applied voltages and magnetic field in accordance with the relation:

$$V_e=\frac{V_p+V_n}{dB}$$

where V_p and V_n are the respective voltages (with respect to cathode) of the positive and negative electrodes bounding the interaction space (i.e., V_p+V_n is the voltage difference between the delay line and its opposite electrode), d is the distance between the delay line and the opposite electrode, and B is the strength of the applied magnetic field.

With the above considerations and objects in mind, the invention itself will now be described in connection with a preferred embodiment thereof given by way of example and not of limitation, and with reference to the accompanying drawings, in which:

FIG. 1 is a schematic representation of a preferred form of the traveling wave electron reaction device of the present invention;

FIG. 2 is a schematic representation of an alternate form of the traveling wave electron reaction device of the present invention;

FIG. 3 is a schematic representation of another form of the traveling wave electron reaction device of the present invention;

FIG. 4 is a phase-velocity diagram illustrating operational characteristics of the devices shown in FIGS. 1 through 3, with the free-space wavelength of the propagated wave plotted on the abscissa, and with the ratio of the velocity of light to the phase velocity of the interacting wave plotted on the ordinate;

FIGS. 5 and 6 are illustrative representations of electron trajectories in cyclotron modes in favorable and unfavorable phase;

FIGS. 7 and 8 are illustrative representations of electron trajectories in velocity-synchronism modes in comparable phase relationships; and

FIG. 9 is an illustrative representation of the desired electron trajectory in a device of the present invention utilizing the cyclotron modes.

As stated above, the invention pertains generally to traveling wave electron reaction devices, those devices which utilize the prolonged interaction between a stream or beam of charged particles (such as electrons) and a guided electromagnetic wave traveling along a wave re-

tardation circuit. The invention pertains more particularly to traveling wave devices employing crossed electric and magnetic fields, such devices being referred to as M-type devices. M-type devices may be operated as amplifiers or oscillators, and may be further classified as either forward wave devices or backward wave devices. As is well known, a backward wave device is characterized by an electron beam traveling in one direction, with the energy of the induced wave traveling in the opposite direction. In a forward wave device, the electron beam and the energy of the induced wave travel in the same direction.

The usual crossed-field type of traveling wave device utilizes an elongate delay line spaced from a coextensive electrode, commonly referred to as the sole, and a DC field is established between the delay line and the sole, with the delay line usually constituting the positive electrode and the sole comprising the negative electrode. The space between the delay line and the sole is termed the interaction region. In one type of crossed field device, an electron beam is produced in an electron gun and is projected into the interaction region along a substantially linear path therethrough. In such devices, phase focusing is employed to modulate the beam by means of a process of bunching the electrons therein.

The present invention employs a new concept of electron sorting in combination to achieve cyclotron mode interaction. This sorting may be done in a limited region at the beginning of the interaction region and/or may be done in the extended region of interaction. The primary objective is to remove at a negative electrode the electrons which gain orbital energy. The advantage of using a separate sorting region is that it allows the sorting to be done under conditions of pure cycloids with electron collection at the cusps of the cycloid with minimum and near-zero waste of kinetic energy of the removed and collected electrons. After the removal of the electrons having relative or orbital velocity a decrease in the orbital diameter of the beam when referenced to an average or midplane of the trajectory follows. Coupled with the sorting phenomena to provide a beam having a decreasing orbital diameter, we consider the recognition in the art that cyclotron modes presents a space-time harmonic relationship, or expressed in another manner, the beam presents a periodic structure in space which is not present in velocity-synchronism mode interaction devices. Relatively large signal devices therefore are attainable utilizing cycloidal beams which are heavily density modulated by sorting. Throughout the specification then, reference will be directed to cyclotron mode interaction to describe the mechanism whereby bunching of electrons in the beam is accomplished by phase sorting rather than phase focusing. In addition, the devices under consideration will involve signal energy beams with no true small signal or linear region to result in nonlinear beams. The term cyclotron mode therefore will denote the use of a heavily bunched cycloidal electron beam having relatively large signal perturbations thereby yielding a nonlinear device. In contradistinction many prior art devices employ only linear beam trajectories in which cyclotron waves appear as small signal perturbations with some form of parametric pumping required to increase the orbital energy in the slightly perturbed linear beam to yield amplification of the small signal energy. Such devices are commonly referred to in the art as cyclotron wave devices.

Referring now particularly to FIG. 1, one form of the traveling wave electron reaction device of the present invention is shown as comprising a delay line **10** and a plurality of sole members **12**, **14** and **16** generally defining therebetween an interaction region **18**. Delay line **10** may be constructed to be either a forward or backward wave structure, and the high frequency input may be applied to terminal **20**, in which case the high frequency output is taken at terminal **22**. Alternatively, the RF input may be applied to terminal **22**, with the output appearing at terminal **20**. As shown in the drawing, the delay line **10** is grounded as at **24**.

An electron gun including cathode **26**, grid member **28** and accelerating electrode **30** projects a beam of electrons into interaction region **18** along a cycloidal path **32**. Grid electrode **28** is suitably biased in a negative polarity with respect to cathode **26** by means of a voltage source indicated at **34**. Accelerating electrode **30** is maintained at a positive potential with respect to cathode **26** by means of a voltage source **36**.

As a matter of convenience, electrode **12** referred to above as one portion of the sole electrode, will be referred to as the sorting electrode, and a voltage source **38** is connected between sorting electrode **12** and cathode **26** so as to maintain the former at a suitable potential (either slightly positive or negative) with respect to the latter. Further, electrode **14** will be referred to as the beam-perturbation electrode, and a voltage source **40** is connected between electrode **14** and cathode **26** in such polarity as to place a potential on electrode **14** which is negative with respect to cathode **26**. Electrode **16** is the main sole electrode, and will be referred to simply as the sole electrode. A voltage source **42** is connected between ground and cathode **26**, rendering cathode **26** negative with respect to ground. As a result, delay line **10** is rendered positive with respect to cathode **26**; also a suitable source **44** is connected to sole electrode **16**, whereby electrode **16** is given a small potential (either positive or negative) with respect to cathode **26**. As shown, electrode **16** is negative with respect to the cathode. Further, by means of ground connection **46** to a collector electrode **48**, the collector is made positive with respect to cathode **26**.

The uniform or steady-state magnetic field employed in interaction region **18** is represented by circles **50** having crosses therein to indicate that the direction of the magnetic field is perpendicular to the plane of the paper and directed into the paper. This magnetic field may be produced by any suitable means such as a permanent magnet, one of the poles of which is indicated in broken-away form at **52** in FIG. 1.

The operation of the structure shown in FIG. 1 will be described in detail, along with the description of operation of the structures of FIGS. 2 and 3, in connection with the description of FIGS. 4–9. It is sufficient here to note that the electron gun of FIG. 1, comprising cathode **26**, grid **28** and accelerating electrode **30** projects a beam of electrons into interaction region **18** along a substantially cycloidal path indicated generally as **32** in FIG. 1. As a result of this cycloidal projection of electrons, along with the effects of magnetic field **50** and the electric field perpendicular thereto between delay line **10** and sorting electrode **12**, an electron sorting operation takes place in that portion of interaction region **18** which is generally defined by sorting electrode **12**. Desirably, the trajectory will be one of decreasing orbital diameter since electrons having the unfavorable phase or large orbital motion will have been removed.

As the electron beam continues in interaction region **18**, it will continue to follow a generally cycloidal path to the perturbation region. As will become more evident later in this description, it may be desirable to increase the transverse energy of the beam for increased efficiency. Accordingly, a perturbation is effected by means of beam perturbation electrode **14**. As may be seen in FIG. 1, the cycloidal motion of the electron beam appears substantially increased after the beam passes to the right of the beam perturbation electrode **14**, with a subsequent reduction in such motion taking place as a result of energy exchange in the crossed-field interaction. In this final interaction region the electron beam has an initial trajectory of large orbital diameter, followed by a region of gradually reducing diameter until the point of collection at electrode **48**.

The design of the remaining portion of interaction

region 18, including the polarity and magnitudes of the voltages applied thereto, as well as the magnitude of the magnetic field passing therethrough, is such as to satisfy Equation 1 above. Electrons which are not absorbed from the beam in delay line 10 or sole electrode 16 are collected by collector electrode 48. By means of this cyclotron mode interaction, the several advantages set forth herein are obtained when an RF signal is applied at terminal 20 (in the case of a forward wave device), with the RF output appearing at terminal 22, or, alternatively, with the RF input being applied to terminal 22 (in the case of a backward wave device), with the corresponding RF output being taken at terminal 20.

The structure of FIG. 1 is exemplary of the application of the present invention to a traveling wave device wherein the delay line or slow wave structure is positive with respect to the cathode. This has been the common polarity for delay lines in the traveling wave devices of the prior art, especially in connection with those traveling wave devices employing phase focusing. The use of electron sorting (as opposed to phase focusing) has made it possible to provide traveling wave electron reaction devices in which the delay line is negative with respect to the cathode. Such a device is shown in FIG. 2 herein, illustrating the application of the present invention to a traveling wave electron reaction device with a negative delay line.

Referring now particularly to FIG. 2, the structure shown includes a delay line 52, a sorting electrode 54, a beam perturbation electrode 56 and a sole electrode 58, all generally defining the interaction region 60. An electron gun assembly is positioned at one end of interaction region 60, such gun assembly including a cathode 62, a grid electrode 64 and an accelerating electrode 66. A source 68 of suitable voltage is connected between grid 64 and cathode 62 to maintain the former at a potential negative with respect to the latter. Voltage source 70 is connected between accelerating electrode 66 and cathode 62 to maintain the former at a potential which is positive with respect to the cathode. Cathode 62 is connected to ground through a suitable source of DC voltage 72, thereby placing delay line 52 at a small potential (negative, as shown in FIG. 2) with respect to cathode 62 in view of ground connection 74 on delay line 52.

The electron gun assembly in FIG. 2 serves to project a beam of electrons 76 along a substantially cycloidal path through the sorting portion of interaction region 60, such portion being generally defined by and co-extensive with sorting electrode 54. As in connection with FIG. 1, this sorting action takes place as a result of the positive potential applied (with respect to cathode 62) to sorting electrode 54 by means of voltage source 78, as well as the perpendicular magnetic field represented by the circles 80 having crosses therein to indicate a magnetic field direction into the paper, again, as in FIG. 1.

Perturbation of the beam 76 is achieved by means of beam perturbation electrode 56, the latter being held at a positive potential with respect to cathode 62 by means of voltage source 82. Thereafter in the travel of the electron beam, the cyclotron mode interaction takes place in the main interaction region which is substantially coextensive with sole electrode 58, the latter being positive with respect to the cathode 62 by virtue of the connection to voltage source 84, as shown. Those electrons which are not taken up by sole electrode 58 or the delay line 52 are collected by collector electrode 86, which is made positive with respect to cathode 62 by voltage source 88. The operation of the structure shown in FIG. 2 is substantially the same as shown in connection with FIG. 1, and such operation will be described in more detail hereinafter.

In a manner similar to that of FIG. 1, the RF input to the delay line 52 in FIG. 2 may be applied to terminal 90, with the output then appearing at terminal 92, this being the case for forward wave operation; alternatively, the RF input may be applied to terminal 92 and the output taken at terminal 90, providing backward wave operation.

Another modification that may be made in the structure of a traveling wave electron reaction device in accordance with the present invention is shown in FIG. 3, wherein the sole-type elements of FIGS. 1 and 2 are replaced by a second delay line. In FIG. 3 first and second delay lines 94 and 96, respectively, define therebetween an interaction region 98. At one end of interaction region 98 there is an electron gun assembly including a cathode 100, a grid electrode 102 and an accelerating electrode 104. Accelerating electrode 104 is connected to the positive terminal of a voltage source 106, the negative of which is connected to cathode 100; as a result, accelerating electrode 104 is positive with respect to the cathode. A voltage source 108 is connected between grid electrode 102 and cathode 100 in such polarity as to maintain the former negative with respect to the latter. This electron gun assembly serves to project a beam of electrons into interaction region 98 along a substantially cycloidal trajectory 110. Cathode 100 is rendered negative with respect to ground by virtue of its connection thereto through a source of DC voltage 112, and since delay line 94 is connected to ground at 114, delay line 94 is positive with respect to the cathode 100. In order to provide beam perturbation, suitable means analogous to those in prior figures, or an additional electrode or magnetic field perturbation, may be included in the area of element 116, for example. Also, as will be understood by those skilled in the art, the terminals 118 may be connected to an RF circuit, either alternatively or in addition to the aforementioned connections to terminals 124 and 126 of delay line 94. Collector electrode 120 is rendered positive with respect to cathode 100 by virtue of the connection of collector electrode 120 to source 112 at tap 122. The magnetic field in FIG. 3 is represented by circles 123.

It will be understood that the two delay lines 94 and 96 in FIG. 3 combine operationally to form one propagating system of suitable design. RF input may be applied to delay line 94 at terminal 124, whereupon the RF output of the forward wave device appears at 126. Alternatively, the RF input may be applied to terminal 126 to provide backward wave operation with the RF output being taken at terminal 124. The electron sorting, perturbation and cyclotron mode interaction all take place in the structure of FIG. 3 in a manner analogous to that described in connection with FIGS. 1 and 2.

Considering now the operation of the structures of the present invention, as shown in FIGS. 1 through 3, and referring to FIGS. 4–9, it will be understood that the optics of the electron gun assembly provides a beam of electrons which is injected into the interaction region along a desired cycloidal trajectory. In the sorting portion of the interaction region the beam is exposed to the RF fields and as a result the unfavorably phased electrons experience an increase in relative or orbital energy due to the effect of such fields. These unfavorably phased electrons are collected by the sorting electrode (that is, the sorting portion of one of the members serving as a negative boundary to the interaction space). Where desired, suitable means may be applied to the sorting electrode for suppressing secondary emission.

The trajectory of the unfavorably phased electrons is depicted in FIG. 5 as indicated by line 130 in the initial region between the anode or slow wave structure 132 and sole electrode 134. The trajectory midplane is shown by dotted line 136 and the orbital diameter is diagrammatically illustrated by line 138. As such electrons having increased orbital energy traverse this region they resemble rolling circles traversing ever larger paths to define an increasing orbital diameter in relation to the trajectory midplane. In view of the fact that for cyclotron mode interaction the energy source is the kinetic energy asso-

ciated with the orbital or transverse motion of the electrons about the average trajectory of translation the desirable trajectory is indicated by line **140** in FIG. 6. It will be observed that it is the electrons which lose orbital energy and therefore exhibit a decrease in orbital diameter which are considered to be in favorable phase. The midplane of reference **136** remains fixed in the two views FIGS. 5 and 6.

The differences of cyclotron mode interaction in relation to synchronous mode interaction will be evident in considering FIGS. 7 and 8. In the latter interaction mechanism the electron trajectories **144** desirably maintain a constant orbital diameter through the region between the anode **132** and sole **134**. The midplane **146**, however, is noted in FIG. 7 to be directed toward the sole where it is dissipated prematurely before interaction with the high frequency waves on the anode delay line. Such electrons are considered to be unfavorably phased. In FIG. 8 after sorting the midplane **146** is now oriented correctly but the orbital diameter of the trajectory has not been altered. Efficient interaction with the high frequency circuit then follows.

In FIG. 9 the ideal trajectory of the present invention is illustrated. With a separate sorting region in the initial path a near zero waste of kinetic energy will ensue by removal of the electrons having the rather large orbital energies. The idealized trajectory path is indicated as line **150**.

Then in the beam perturbation region the favorably phased electrons come under the influence of the beam perturbation electrode and as a result these electrons follow the most suitable trajectories **152** in the remaining or main interaction region. In some cases the desired perturbation may be that of an increase of transverse energy above that existing in the cycloidal trajectory (i.e., a value of 3 or 4 for the ratio of transverse energy to translational energy instead of 1). This increase of energy (as permitted by cut off restrictions in the main interaction region) can be used for increased efficiency.

As the electrons traverse the main interaction region the orbital diameter is decreasing, line **154**, making for efficient cyclotron mode interaction and the electrons finally arrive at the collector electrode **156** with little orbital energy. As will be understood by those skilled in the art, after some unfavorably phased electrons have been removed in the sorting region the remaining unfavorably phased electrons in the main interaction region will tend to be drawn or focused into the favorable phase due to the effects of the space charge.

The devices of the present invention may operate in any of six cyclotron modes, which modes may be denoted FD+, FD−, FR−, BR+, BR− and BD−. The first letter of the mode designation (F or B) denotes the direction of power flow as forward or backward, respectively, with respect to the beam direction. The second letter (D or R) denotes the nature of the interacting spatial harmonic as direct or reverse, respectively, the spatial harmonic being direct or reverse where its associated group velocity or power flow is in a direction which is, respectively, the same as or opposite to the direction of the phase velocity. The third symbol of the mode designation (the plus sign or minus sign) denotes which of the two resonance conditions obtains in the definition of the cyclotron mode interaction given by the equation:

$$C/V_o = C/V_e[1 \pm \lambda/\lambda_c]$$

where C is the velocity of light, V_o is the phase velocity of the ineracting wave, V_e is the average velocity of the electron beam, λ is the free-space wavelength of the propagated wave and λ_c is the free-space wavelength corresponding to the cyclotron frequency.

These six cyclotron modes of interaction are illustrated in the phase-velocity diagram comprising FIG. 4 herein. As may be seen, the free-space wavelength of the propagated wave is plotted as the abscissa, while the ratio C/V_o is plotted as the ordinate. In FIG. 4 various branches of sample phase velocity characteristics are illustrated with the occurrence of the resonance conditions of the foregoing equation being shown by the various intersections in the diagram.

As to the practical applications of traveling wave electron reaction devices in accordance with the present invention, it is instructive to consider the particular applications to which the several cyclotron modes are adapted. For example, the FD+ mode is useful in narrow band voltage-tunable amplifiers either at low frequencies or at high voltages. In either case, the size of the delay line elements is considerably smaller than that resulting from conventional velocity resonance interactions. The BR+ and BR− modes are useful in obtaining voltage-tunable backward oscillation or amplification. In the case of the BR+ mode, oscillation may be obtained at frequencies higher than those obtainable in conventional M-type backward wave oscillators having the same delay line structure dimensions and the same magnitudes of voltage and magnetic field. The FD− and FR− modes provide wide band forward amplification with dispersive structures. Forward wave amplification with the use of a reverse spatial harmonic is made possible. The BD− mode presents the novel aspect of backward wave oscillations utilizing interaction with a direct spatial harmonic.

As stated above, where importance is placed upon efficient operation at very high frequencies the present invention constitutes a highly desirable compromise between two approaches employed by the prior art. In what may be referred to as the conventional design approach, a velocity synchronism mode was utilized, resulting in practically low values of voltage and magnetic field, along with high voltage tuning rates, but also presenting severe problems with respect to delay line dissipation and mechanical fabrication of the very small components involved. The ratio in this conventional approach lies generally in the range of 15 to 30.

A second approach to very high frequency operation in the past was the use of cyclotron mode interaction in connection with an unloaded waveguide, resulting in fast wave operation. Here, there is no serious problem of heat dissipation or mechanical fabrication, but a high field, along with high voltage tuning rates, but also presenting severe problems with respect to delay line dissipation and mechanical fabrication of the very small components involved. The ratio C/V_o in this conventional approach lies generally in the range of 15 to 30.

A second approach to very high frequency operation in the past was the use of cyclotron mode interaction in connection with an unloaded waveguide, resulting in fast wave operation. Here, there is no serious problem of heat dissipation or mechanical fabrication, but a higher magnetic field is necessary, as well as a much higher voltage in order to achieve high voltage tuning rates. The ratio C/V_o here is less than unity.

In the structures of the present invention the magnitudes of voltage and magnetic field are sufficiently low to be practical, and yet the delay line dimensions are sufficiently greater so as to afford ease of mechanical fabrication, as well as obviating the aforementioned problem of heat dissipation. The general range of ratio C/V_o for structures in accordance with the present invention is approximately unity to 15.

With particular comparison of the structures of the present device with those of the second aforementioned approach of the prior art, it should be noted that such fast wave structures of the prior art provide only the FD− and BD− modes of interaction; in sharp contrast, the present invention provides six cyclotron interaction modes.

The invention has been described above in considerable detail, and particularly with reference to the several em-

bodiments shown. However, it will be apparent to those skilled in the art that the invention is also applicable to modifications of these illustrated structures. For example, in certain cases the accelerator electrode of the grid electrode, or both, of the electron gun assembly may be eliminated as a separate electrode, with an extension of the anode cylinder acting as an accelerator, and an extension of the sorting electrode acting as a grid. In general, the position and potential of the main sole electrode are such that the same DC electric field results in the main interaction region as exists in the sorting region. The over-all sole electrode may be combined into one unitary element instead of the three shown herein in a manner analogous to that where the sole electrode is a second delay line. Hence, the invention is not to be considered as limited to the particular details given, nor to the specific application to which reference has been made during the description of the invention, except insofar as may be required by the scope of the appended claims.

What is claimed is:

1. A crossed-field traveling wave electron reaction device of the cyclotron mode interaction type comprising:

means for providing a periodic nonlinear beam of electrons along a path;

means including a slow wave structure for guiding an electromagnetic wave;

an elongate electrode member spaced from said slow wave structure and bounding therewith an electron beam path including a sorting region, a perturbation region and an interaction region;

means for establishing an electric field in each of said regions transverse to the path of said electron beam and means for establishing a uniform magnetic field transverse to said electric field and said electron beam in each of said region;

said crossed electric and magnetic fields in said sorting region initiating removal of electrons having a large transverse component of motion to result in a beam trajectory in said perturbation and interaction regions having an orbital diameter of gradually reducing dimensions about a fixed reference midplane dened by the average trajectory of translation of said beam along said path and cause said electrons to interact with said high frequency electromagnetic waves to establish a cyclotron mode velocity-phase resonance relationship defined by the equation:

$$C/V_o=C/V_e[1\pm\lambda/\lambda_c]$$

where C is the velocity of light, V_o is the phase velocity of said interacting wave, V_e is the average velocity of said electron beam, λ is the free-space wavelength of said propagated wave, λ_c is the free-space wavelength corresponding to the cyclotron frequency and the ratio C/V_o is in the range of unity to 15.

2. An M-type traveling wave electron reaction device of the cyclotron mode interaction type comprising:

a slow wave delay line structure;

an elongate sole electrode spaced from said slow wave structure and bounding therewith an electron beam path including a sorting region, a perturbation region and an interaction region;

means for producing and injecting a periodic nonlinear beam of electrons disposed adjacent to one end of said electrom beam path;

means for establishing an electric field in each of said regions transverse to the path of said electron beam and means for establishing a uniform magnetic field transverse to said electric field and said electron beam in each of said regions;

said crossed electric and magnetic fields in said sorting region initiating removal of electrons having a large transverse component of motion to result in a beam trajectory having a gradually reducing cross-section about a fixed reference midplane defined by the average trajectory of translation of said beam along said path;

said perturbation region further including an electrically polarized electrode for imparting to electrons traversing said sorting region a larger transverse energy in relation to translational energy and cause said beam of reducing cross-section to interact with high frequency electromagnetic wave fields on said slow wave structure to establish a cyclotron mode velocity-phase resonance relationship defined by the equation:

$$C/V_o=C/V_e[1\pm\lambda/\lambda_c$$

where C is the velocity of light, V_o is the phase velocity of said interacting wave, V_e is the average velocity of said electron beam, λ is the free-space wavelength of said propagated waves, λ_c is the free-space wavelength corresponding to the cyclotron frequency, and the ratio C/V_o is in the range of unity to 15; and

a collector electrode positioned at the opposing end of said beam path to intercept said electron beam.

3. An M-type traveling wave device in accordance with claim 2 wherein said sole electrode member comprises a second slow wave delay line structure.

4. An M-type traveling wave device in accordance with claim 2 wherein said slow wave delay line structure is rendered positive with respect to said electron beam producing means.

5. An M-type traveling wave device in accordance with claim 2 wherein said slow wave delay line structure is rendered negative with respect to said electron beam producing means.

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HERMAN KARL SAALBACH, *Primary Examiner.*

S. CHATMON, JR., *Assistant Examiner.*