June 29, 1965 J. FEINSTEIN ETAL 3,192,435

CROSS FIELDS NONRECIPROCAL ATTENUATOR ELECTRON DISCHARGE DEVICE

Filed March 21, 1960 2 Sheets-Sheet 1

FIG. 1

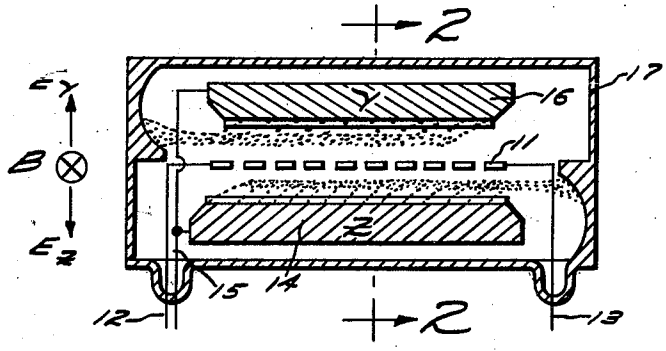
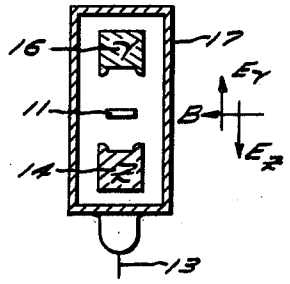


FIG. 2



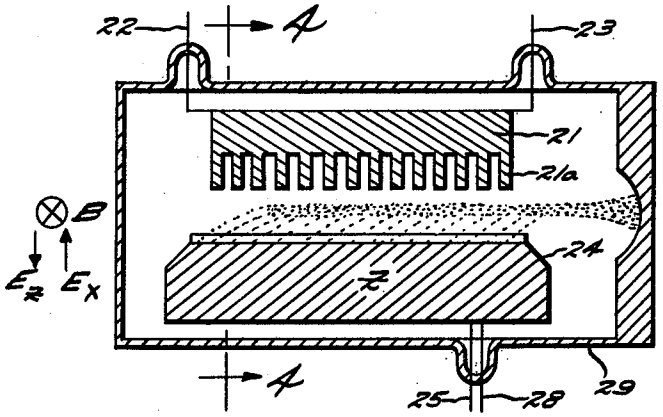


FIG. 3

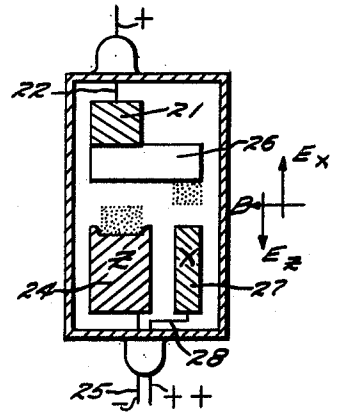


FIG. 4

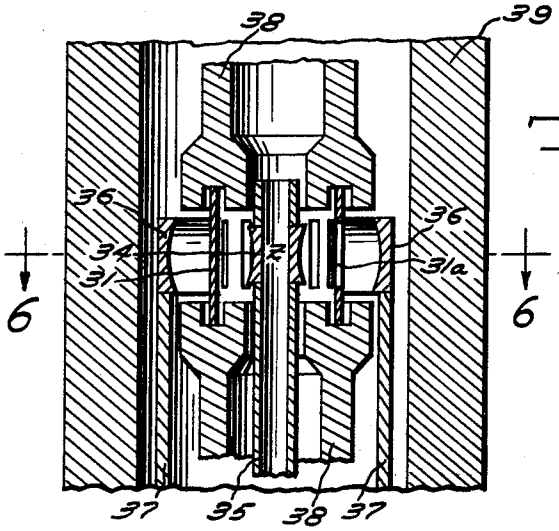
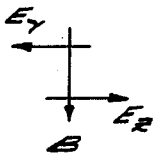


FIG. 5



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Fig. 6

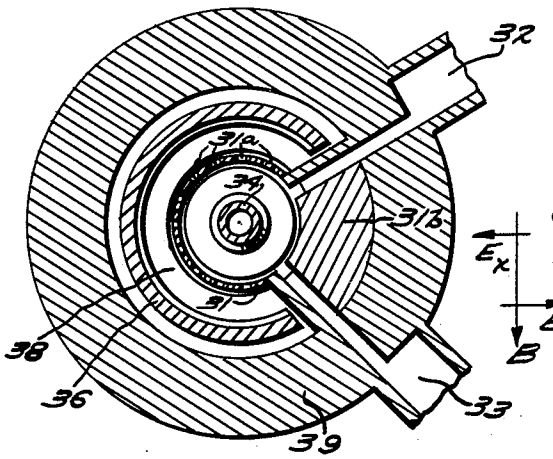


Fig. 7

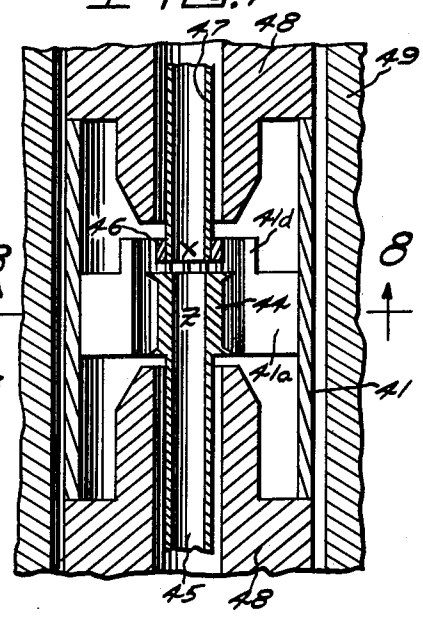


Fig. 8

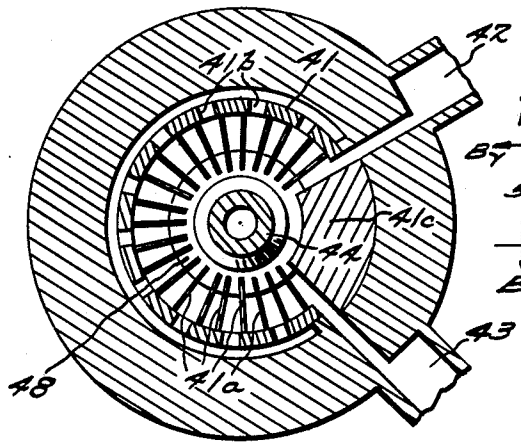
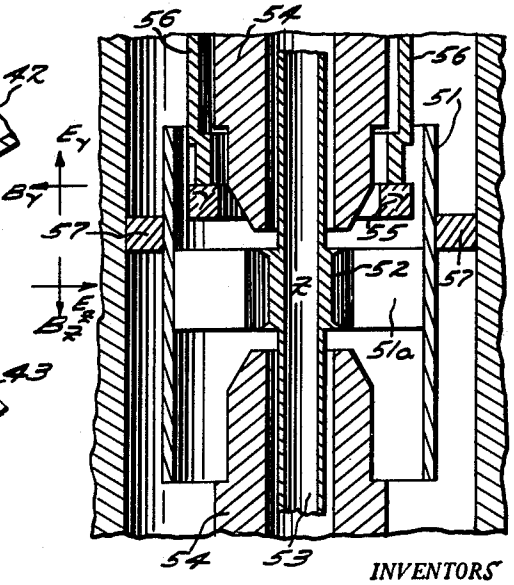


Fig. 9



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CROSS FIELDS NONRECIPROCAL ATTENUATOR ELECTRON DISCHARGE DEVICE

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The present invention relates in general to nonreciprocal attenuating means and more particularly to attenuating means for use in electron discharge devices using crossed electric and magnetic fields.

In the past it has been impossible to provide an electron discharge device of the crossed-field type with an internal attenuating means which would absorb waves reflected from the end of the circuit and traveling in a direction opposite to the direction of the main wave traveling along the circuit without attenuating the main wave traveling along the circuit.

It is known in crossed-field traveling wave electron discharge devices that electrons emitted from the cathode will travel at a velocity v determined from the equation

$$v=\frac{E}{B}$$

where E and B are the crossed electric and magnetic fields respectively.

In order for this beam traveling with the velocity v to transfer energy to the wave traveling on the slow wave circuit of the electron device, the velocity of the beam must be approximately the same as the phase velocity of a component of the field of the ultra-high frequency wave that is propagating in the slow wave circuit. If the velocity of the electrons and the phase velocity of the wave are not synchronous and the velocity of the electrons is less than the phase velocity of the wave, the beam of electrons will extract energy from a wave traveling in the same direction as the beam without extracting energy from waves traveling in the opposite direction.

Furthermore, attenuation can be produced at synchronism if electrons are emitted from portions of the anode.

There are several ways of producing an electron stream oppositely directed from the direction of the main electron stream in a crossed-field device as, for example, a magnetron and taking advantage of the inherent structure of the crossed-field device to aid in producing this oppositely directed electron stream. One way of producing this oppositely directed electron stream is by means of an electrode of the same polarity as the cathode but positioned on the opposite side of the anode from the cathode. Another way of producing this oppositely directed electron stream is to provide an electrode of the opposite polarity to the cathode on the same side of the anode as the cathode. Both of the illustrations just suggested take advantage of the existing magnetic field of the crossed-field device and of the existing electric potential of the anode. Still another way of producing this oppositely directed electron stream is to position an electrode of the same polarity as the cathode adjacent the anode and to change the magnetic field in the region between this electrode and the anode whereby electrons emitted from this electrode will travel in a direction opposite to the direction of the electrons emitted from the cathode.

The present invention utilizes portions of the structure which amplifies a wave on a slow wave circuit to produce a stream of electrons travelling in a direction opposite to the direction of the stream of electrons producing amplification of the main wave in order to attenuate reflected waves.

The principal object of the present invention is to provide an internal nonreciprocal attenuator for crossed-field traveling wave amplifying devices utilizing inherent features of such devices.

One feature of the present invention is the provision of a novel crossed-field device provided with an additional electrode besides the anode and cathode for producing a sub-synchronous stream of electrons to attenuate reflected waves on the slow wave circuit of the device.

Another feature of the present invention is the provision of a novel crossed-field electron discharge device provided with a cathode and an electrode positioned on opposite sides of the anode structure of the device whereby the electrode cooperates with the back side of the anode to produce a stream of electrons for attenuating reflected waves on the anode structure.

Another feature of the present invention is the provision of a novel crossed-field electron discharge device of the last aforementioned feature wherein the electrode and the cathode are at the same potential and the electrode is spaced from the anode a greater distance than is the cathode.

Another feature of the present invention is the provision of a novel crossed-field electron discharge device provided with a cathode and an electrode on the same side of the anode structure and of opposite potential with respect to the anode structure whereby the electrode cooperates with the anode to produce a stream of electrons which will attenuate reflected waves on the anode structure.

Still another feature of the present invention is the provision of a novel crossed-field electron discharge device wherein an auxiliary electrode of the same polarity as the cathode is positioned in close proximity to the anode, and means are provided for changing the direction of the magnetic field in the region between the auxiliary electrode and the anode for producing a stream of electrons which will attenuate reflected waves traveling on the anode structure in a direction opposite to the direction of the main traveling wave on the circuit.

Additional features and advantages of the present invention will become more apparent on a perusal of the following specification taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a side cross-sectional view of a linear electron discharge device embodiment of the present invention,

FIG. 2 is a cross-sectional view of the apparatus shown in FIG. 1 taken along line 2—2 in the direction of the arrows,

FIG. 3 is a side cross-sectional view of an additional linear embodiment of the present invention,

FIG. 4 is a cross-sectional view of the apparatus shown in FIG. 3 taken along line 4—4 in the direction of the arrows,

FIG. 5 is a side cross-sectional view of a circular electron discharge device embodiment of the present invention,

FIG. 6 is a cross-sectional view of the apparatus shown in FIG. 5 taken along line 6—6 in the direction of the arrows,

FIG. 7 is a side cross-sectional view of another embodiment of the present invention,

FIG. 8 is a cross-sectional view of the apparatus shown in FIG. 7 taken along line 8—8 in the direction of the arrows, and

FIG. 9 is a cross-sectional view of still another embodiment of the present invention.

Referring now to FIGS. 1 and 2, an anode structure 11 as of copper provided with a slow wave circuit as, for example, an array of slots therealong is provided with an R.F. wave input means comprising a lead-in

conductor 12, and an output means comprising a lead-in conductor 13 for directing an R.F. signal to be amplified over the anode slow wave circuit. A cathode 14, for example, a cold cathode of beryllium copper, the emission from which is initiated by the electric fields of the R.F. wave itself, is positioned adjacent the anode structure 11 for providing a stream of electrons which will cooperate with the electric field of the wave on the slow wave circuit on the anode 11 to amplify the wave traveling along this circuit. A cathode lead-in conductor 15 is provided for maintaining the cathode 14 at a negative potential with respect to the anode structure 11. A second cold cathode electrode 16 is positioned on the opposite side of the anode structure 11 from the cathode 14, and cooperates with the anode structure 11 for producing a stream of electrons which will move in a direction opposite to the direction of the electrons emitted from the cathode 14. The slow wave circuit is symmetrical about a longitudinal axis so that waves on the circuit can interact with electron streams on either side. The entire structure is sealed within a metallic vacuum envelope 17. Means are provided for applying a desired potential to the second cathode electrode 16. Magnetic means (not shown) are provided to produce a magnetic field B in the interaction regions between the anode and both the cathode and the second cathode electrode in a direction going into the paper in FIG. 1 and to the left in FIG. 2. With the cathode 14 at a negative potential with respect to the anode 11 an electric field E_z exists between the anode 11 and the cathode 14 and is directed toward the cathode 14. It is under the influence of the crossed magnetic field B and electric field E_z that electrons emitted from cathode 14 are directed along the circuit on the anode structure 11 to interact with a wave traveling thereon.

The same magnetic field B in conjunction with the second cathode electrode 16 is used to provide the internal nonreciprocal electron beam attenuation. With the electrode 16 at a negative potential with respect to the anode structure 11, an electric field E_y exists therebetween directed toward the electrode 16, and a sub-synchronous electron beam can be provided adjacent the anode structure 11 to absorb reflected waves on the circuit of the anode structure 11.

In order for a sub-synchronous interaction to take place the velocity of the electrons must be less than the phase velocity of the wave, and thus the ratio E/B must be reduced to produce a value less than the phase velocity of the reflected waves. This can be accomplished in several ways. The value of the magnetic field B can be increased in the interaction region. Also, since E is determined from the formula

$$E=\frac{V}{d}$$

where V and d are, respectively, the potential difference and the distance between the electrode 16 and the anode structure 11, the velocity of the electrons will be reduced if d is increased or V is decreased. In practice it is most convenient to increase d. This enables the electrode 16 to be at the same potential as the cathode 14, and then both can be connected to the same lead as shown in FIG. 1. Furthermore, it is difficult to change the value B in the region on one side of the anode 11 from the region on the other side.

Instead of being electron sources, the cathode 14 and the electrode 16 could be non-emitting plates which would merely aid in establishing the electric field in the device. In such a case an electron source and a collector would be required in order to provide the electron stream in the crossed-field region.

Referring now to FIGS. 3 and 4, there is shown an alternative embodiment of the present invention. An anode structure 21 as of copper provided with a slow wave circuit as, for example, a series of vanes 21*a* is provided with R.F. wave input and output lead-in conductors 22 and 23 respectively. A cathode 24, such as a cold cathode of beryllium copper, is provided adjacent to the anode structure 21 for providing an electron stream that will interact with a wave traveling on the anode structure 21. The cathode 24 is maintained at a negative potential with respect to the anode by means of a lead-in conductor 25. A magnetic means (not shown) provides a magnetic field B directed perpendicular to the electric field E_z that exists between the anode structure 21 and cathode 24. On the same side of the anode structure 21 as the cathode 24 and spaced from both the anode 21 and cathode 24 is an auxiliary anode electrode 27 maintained at a positive potential with respect to the anode 21 by a lead-in conductor 28. Tab portions 26 project from the side of the vanes 21*a* and extend out adjacent the auxiliary anode electrode 27. The electric field E_x between the auxiliary anode electrode 27 and the tab portions 26 of the anode structure 21 is directed from the auxiliary electrode 27 toward the anode 21, but since the electrode 27 is spaced from the cathode 24 the electric field E_x does not substantially interfere with the electric field E_z between the anode 21 and the cathode 24. Electrons will be emitted from the tab portions of the anode structure 21 and under the influence of the crossed-electric field E_x and magnetic field B will be directed in a direction opposite to that of the main stream emitted from the cathode 24. If the values d and V between the auxiliary anode electrode 27 and the anode structure 21 are properly arranged so that the electrons emitted from the anode tab portions 26 are synchronous with the reflected waves traversing the anode structure, the reflected waves traversing the anode structure will be attenuated.

Referring now to FIGS. 5 and 6, there is shown a cylindrical embodiment of the apparatus shown in FIGS. 1 and 2. A cylindrical anode 31 as of copper provided with a slow wave circuit as, for example, an array of slots 31*a* is supported concentric with and surrounding a cathode emitting surface 34 supported on a tubular support member 35. The circuit is interrupted by a block 31*b*. A radio frequency signal is applied to the anode 31 by means of an input waveguide 32 and is withdrawn therefrom by means of an output waveguide 33. Concentric with and spaced outwardly from the anode 31 is a second cathode electrode 36 such as a cold cathode supported on a tubular member 37. Cylindrical pole pieces 38 at each end of the interaction space between the anode and cathodes provide a magnetic field axially thereof. This entire structure is surrounded by an evacuated chamber 39.

With the cathode 34 and the second cathode electrode 36 positioned on opposite sides of the anode structure 31 oppositely directed electric fields are crossed with the axial magnetic field to provide counter-rotating electron streams or spokes of space charge. With one set of the spokes of space charge operating in a sub-synchronous manner reflected waves on the anode traveling in the same direction as the sub-synchronous spokes of space charge will be absorbed. By proper spacing and potentials of the two cathodes either a coaxial magnetron or an inside-out coaxial magnetron type structure can be produced and provided with the novel internal nonreciprocal attenuator illustrated here.

Referring now to FIGS 7 and 8 there is shown a cylindrical magnetron type embodiment of the structure shown in FIGS. 3 and 4. A cylindrical anode 41 is provided with a slow wave circuit consisting of inwardly directed resonator vanes 41*a* alternately slotted at 41*b*. An R.F. signal is fed to the anode 41 by means of an input waveguide 42 and taken therefrom by means of an output waveguide 43. A solid block 41*c* interrupts the slow wave circuit and separates the input from direct communication

with the output. A cylindrical cathode 44 is positioned axially within the anode 41 adjacent to the anode vanes 41*a* by means of a tubular cathode support member 45 extending out one end of the anode structure 41. An annular auxiliary anode electrode 46 is axially positioned within the anode 41 and spaced from the end of the cathode 44 by means of a tubular support member 47. Anode vane tab projections 41*d* project from the side of the anode vanes 41*a* and circumferentially surround the auxiliary anode electrode 46. Cylindrical magnetic pole pieces 48 extend axially within the ends of the anode member 41 and provide an axial magnetic field in the interaction space between the anode vanes 41*a* and both the cathode 44 and the auxiliary anode electrode 46. Rotating spokes of space charge between the cathode 44 and the anode 41 amplify the wave traveling on the anode 41 and counter-rotating spokes of space charge between the auxiliary anode electrode 46 and the anode tab projections 41*d* act as an attenuator for reflected waves traveling on the anode in the opposite direction from the main traveling wave that is being amplified.

As can be seen from the above described embodiments of the present invention an internal nonreciprocal attenuator is provided in a crossed-field electron discharge device utilizing the existing magnetic field therein to help create the attenuator.

Referring now to FIG. 9 there is shown another embodiment of the present invention. A hollow cylindrical anode structure 51 is provided with a slow wave circuit as, for example, inwardly projecting resonator vanes 51*a* alternately slotted for communication with the outside of the anode structure similar to the structure of FIG. 8. A cathode emitter 52 such as a cold cathode is concentrically positioned within the anode 51 adjacent the resonator vanes 51*a* by means of a tubular support member 53. Cylindrical pole pieces 54 extend in the ends of the anode structure 51 providing an axial magnetic field in the space between the cathode emitting surface 52 and the resonator vanes 51*a*. An annular auxiliary cathode electrode 55 is concentrically positioned within the anode structure 51 above the vanes 51*a* by means of a hollow cylindrical support member 56. Magnetic means such as, for example, an annular ring magnet 57 are provided for producing a radial outwardly directed magnetic field in the interaction region between the top of the vanes 51*a* and the auxiliary cathode electrode 55. By this construction, crossed electric and magnetic fields between the anode vanes 51*a* and the cathode 52 and between the top of the anode vanes 51*a* and the auxiliary cathode electrode 55 produce counter-rotating spokes of space charge, the first of which amplifies the main wave traveling on the anode 51 and the second of which, when subsynchronous, attenuates reflected waves on the anode 51 traveling in the opposite direction from the main traveling wave. As a further embodiment of the present invention a structure of a similar nature to that shown in FIG. 9 could be provided in an inside-out coaxial magnetron wherein the main cathode is outside the anode and the anode vanes project outwardly from the anode.

While the invention has been described above as utilizing counter-rotating electron streams for forward wave amplification and attenuation, the structure shown can be operated utilizing counter-rotating electron streams for backward wave amplification and attenuation. Fundamental as well as space harmonic operation is possible.

Since many changes could be made in the apparatus described above without deviating from the scope of the invention disclosed herein, the foregoing specification and drawings are intended as purely illustrative and not in a limiting sense.

What is claimed is:

1. An electron discharge device utilizing crossed electric and magnetic fields for the interaction therein comprising an anode structure adapted to propagate a main electromagnetic wave in one direction and other electromagnetic waves; means for applying signal electromagnetic waves to be amplified to said anode structure, means for extracting amplifying signal waves from said anode structure; electrodes positioned adjacent said anode structure for producing an electric field between said anode structure and each of said electrodes; means for producing a first electron stream between said anode structure and one of said electrodes, means for producing a second electron stream between said anode structure and the other of said electrodes, said second electron stream directed in a direction opposite to the direction of said first electron stream; and means establishing the velocity of the oppositely directed electron streams such that one of the electron streams interacts with and amplifies said applied signals electromagnetic wave traveling on said anode structure and the other electron stream interacts with and attenuates only electromagnetic waves moving in a direction on said anode structure opposite to that of the main wave thereby providing a nonreciprocal attenuator for the electron discharge device.

2. The electron discharge device of claim 1 characterized further in that said electrodes are positioned on mutually opposed sides of said anode structure and each of these mutually opposed electrodes is of negative potential with respect to the potential of said anode structure.

3. The electron discharge device of claim 2 characterized further in that said anode is of a generally cylindrical shape and said electrodes positioned on mutually opposed sides of said anode structure are concentric with said anode structure.

4. The electron discharge device of claim 2 characterized further in that the electrodes positioned on two mutually opposed sides of said anode structure are of the same potential and the electrode which is on the same side of the anode structure as the attenuating electron stream is positioned further from said anode structure than the electrode on the opposite side of said anode structure.

5. The electron discharge device of claim 1 characterized further in that said anode structure is a hollow cylindrical member with a plurality of equally spaced vanes projecting inwardly therefrom and surrounding one of said electrodes; another of said electrodes being positioned concentrically within said anode structure and spaced above said vanes on said anode structure; and including means for producing a magnetic field within the space between said anode structure and this other electrode to provide crossed electric and magnetic fields which will direct a stream of electrons in the space between this other electrode and said anode vanes in a direction opposite to the direction of the stream of electrons moving in the interaction space between said anode vanes and the one electrode.

6. An electron discharge device utilizing crossed electric and magnetic fields for the interaction therein comprising an anode structure adapted to propagate a main electromagnetic wave in one direction and other electromagnetic waves; a cathode spaced from said anode structure and having an emitting surface facing said anode structure, means for applying signal wave energy to be amplified to said anode structure, means for extracting amplified signal wave energy from said anode said cathode and said anode structure cooperating to create a first stream of electrons which amplifies said applied signal main wave traveling on said anode structure; and an electrode adapted to cooperate with said anode structure to produce a second stream of electrons directed in a direction opposite to the direction of said first stream for interaction with only waves moving in a direction opposite to that of the main traveling wave whereby said second stream of electrons provides a nonreciprocal attenuator for the electron discharge device.

7. The electron discharge device of claim 6 characterized further in that said cathode and said electrode are positioned on opposite sides of said anode structure.

8. Electron discharge device of claim 6 characterized further in that said electrode and said cathode are positioned on the same side of said anode structure, said cathode being maintained at a negative potential with respect to the potential of said anode structure and said electrode maintained at a positive potential with respect to the potential of said anode structure.

9. The electron discharge device of claim 6 characterized further in that said anode is of a generally cylindrical shape, and said cathode and said electrode are positioned on opposite sides of said anode and are concentric therewith.

10. The electron discharge device of claim 6 characterized further in that said cathode and said electrode are positioned on opposite sides of said anode structure; said cathode and said electrode are of the same potential; and said electrode is positioned further from said anode structure than is said cathode.

11. The electron discharge device of claim 6 characterized further in that said anode is a hollow cylindrical member with a plurality of equally spaced vanes projecting inwardly therefrom and surrounding said cathode; and said electrode is positioned concentrically within said anode and spaced above said vanes on said anode; and including means for producing a magnetic field within the space between said anode and said electrode to provide crossed electric and magnetic fields which will direct a stream of electrons in the space between said electrode and said anode vanes in a direction opposite to the direction of the stream of electrons moving in the interaction space between said anode vanes and said cathode.

12. An electron discharge device using crossed electric and magnetic fields for interaction therein comprising a hollow cylindrical anode structure provided with a slow wave circuit thereon adapted to propagate a main traveling wave in one direction and reflected waves in the opposite direction; a cylindrical first cathode member positioned axially within said anode structure defining an interaction region therebetween; a hollow cylindrical second cathode member positioned concentric with and outside said anode structure defining an interaction region therebetween; and means for producing an axial magnetic field within the interaction regions between said anode and said first and second cathodes, whereby counter-rotating spokes of space charge are provided on either side of said anode structure, one of said rotating spokes of space charge amplifying a wave traveling on said anode and the other spoke of space charge attenuating reflected waves traveling on said anode structure.

13. The electron discharge device of claim 12 wherein said first and said second cathodes are maintained at the same potential and the cathode producing the rotating spoke of space charge for attenuating reflected waves is positioned further from said anode than is the other cathode.

14. An electron discharge device utilizing crossed electric and magnetic fields for the interaction therein comprising a hollow cylindrical anode structure provided with inwardly projecting resonator vanes; a cylindrical cathode positioned concentrically within said anode structure, spaced from said resonator vanes, and maintained at a potential negative with respect to the potential of said anode structure; an annular auxiliary anode electrode positioned concentrically within said anode structure, spaced from said anode vanes and said cathode structure, and maintained at a potential positive with respect to the potential of said anode structure; and means for producing an axial magnetic field within the interaction region between the vanes on said anode structure and both said cathode and said auxiliary anode electrode, whereby in combination with said anode said cathode and said auxiliary anode electrode produce counter-rotating spokes of space charge one of which amplifies a wave traveling about said anode and the other of which absorbs reflected waves traveling about said anode in a direction opposite to that of the main traveling wave without absorbing the main traveling wave on said anode structure.

15. The electron discharge device of claim 14 characterized further in that the vanes of said anode are provided with axially extending portions which surround and are spaced from said auxiliary anode electrode.

16. An electron discharge device utilizing crossed electric and magnetic fields for the interaction therein comprising a hollow cylindrical anode structure provided with a slow wave circuit thereon adapted to propagate a main wave in one direction and reflected waves in the opposite direction; a cathode member positioned axially within said anode structure defining a first interaction region therebetween; an auxiliary electrode positioned within said anode structure defining a second interaction region therebetween; and means for producing a magnetic field within said first and said second interaction regions which cooperates with said anode structure said cathode and said auxiliary electrode to produce counter-rotating spokes of space charge one of which amplifies a wave traveling about said anode and the other of which absorbs reflected waves traveling about said anode in a direction opposite to that of the main traveling wave without absorbing the main traveling wave on said anode structure.

17. The electron discharge device of claim 16 wherein the magnetic fields in said first and said second interaction regions are parallel and axially aligned.

18. The electron discharge device of claim 16 wherein the magnetic fields in said first and said second interaction regions are at right angles to each other.

19. An attenuator utilizing crossed electric and magnetic fields comprising, in combination, a slow wave circuit adapted to propagate an electromagnetic wave, an electrode spaced from said slow wave structure, means for applying a voltage to said electrode more positive than the voltage of said slow wave circuit to establish an electric field between said slow wave circuit and said electrode, and means for providing a magnetic field within the region between said slow wave circuit and said electrode and directed perpendicular to said electric field, and said electric field and said magnetic field being of sufficient amplitude to produce a stream of electrons emitted from said slow wave circuit which interacts with and attenuates an electromagnetic wave propagated on said slow wave circuit said slow wave circuit being aligned with said electrode so that the mean direction of an electromagnetic wave traveling on said slow-wave circuit is parallel to the mean direction of the stream of electrons emitted from said slow-wave circuit.

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