HIGH-FREQUENCY AMPLIFIER

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FIG. 1.

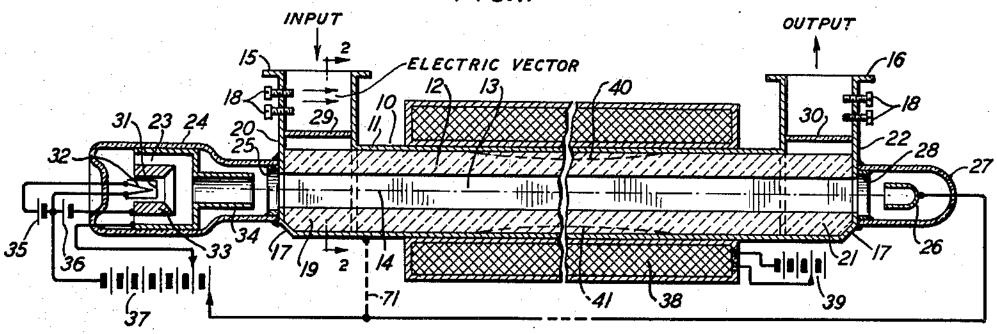


FIG. 2.

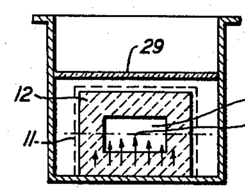


FIG. 3.

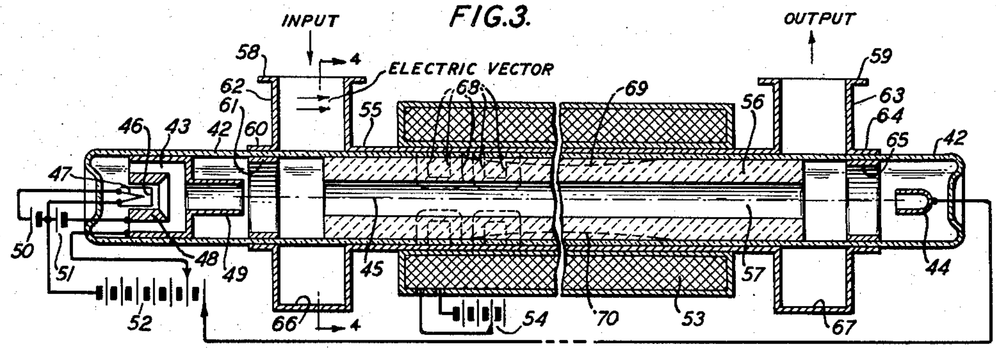
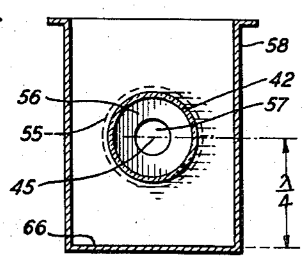


FIG. 4.



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HIGH-FREQUENCY AMPLIFIER

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This invention relates to devices for amplifying high frequency electrical waves, particularly such devices in which amplification is had through interaction between an electron stream and a high frequency electric field associated with the waves to be amplified over an extended distance such as a distance of more than a wavelength along the transmission path of the wave.

It is an object of the invention to provide devices capable of producing amplification of high frequency electrical waves over a wide band of frequencies.

Another object of the invention is to provide a high frequency wave amplifying device which shall be simple, rugged, and relatively easy of manufacture.

There have been proposed electron beam amplifying devices wherein amplification is achieved by the interaction between an electron stream and a pure traveling wave, that is, a wave which progresses continually in a single direction without reflection, along an extended path. The arrangement is such that the traveling wave has electric field components in the direction of the electron stream and there is substantial equality between the speed of propagation of the wave in the direction of the stream and the speed of the electrons in the electron stream. Under such conditions the electron stream reacts on the electric field and the electric field reacts on the electron stream in a manner such that the wave increases in amplitude as it progresses along the path. Since the interaction is continuous, the amplifying action may take place over a relatively wide range of frequencies.

The present invention is concerned with means whereby the substantial equality between the speed of the electrons and the speed of the traveling waves may be achieved. Particularly, the invention contemplates a wave transmission path incorporating material having a high dielectric constant along the path traveled by the waves to be amplified whereby the phase velocity of the waves may be reduced to a magnitude which may be readily produced in a concentrated stream of electrons. One embodiment of the invention utilizes a wave transmission path composed of a circular wave guide having a hollow core of high dielectric material such as titanium dioxide. The wave to be amplified is propagated along this transmission path in a predominantly transverse magnetic mode and longitudinal components of electric intensity associated with the wave interact with an electron stream passing through the hollow central portion of the core to

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produce the amplifying action. Another embodiment of the invention utilizes a wave transmission path composed of a rectangular wave guide having a hollow core of the high dielectric material and propagating the traveling wave in a predominantly transverse electric mode.

It is a feature of the invention that the transmission path is capable of propagating the waves to be amplified in the desired mode over a wide range of frequencies so that the inherent wide band amplification capabilities of the amplifying device may be more fully utilized.

The novel aspects of this invention are pointed out with particularity in the appended claims. The invention itself, together with further objects and advantages thereof, may be better understood by reference to the following detailed description taken in connection with the accompanying drawing, in which:

Fig. 1 shows an embodiment of the invention in which the wave transmission path through the amplifying device comprises a rectangular wave guide having a hollow dielectric core;

Fig. 2 is a cross-sectional view of the wave amplifying device of Fig. 1 taken along the line 2—2 and which further illustrates the input wave guide and the wave transmission path;

Fig. 3 shows an embodiment of the invention in which the wave transmission path through the amplifying device comprises a circular wave guide having a hollow dielectric core; and

Fig. 4 is a cross-sectional view of the wave amplifying device of Fig. 3 taken along the line 4—4 and which further illustrates the input wave guide and the wave transmission path.

Referring now to Fig. 1, there is shown a first embodiment of the traveling wave amplifying device of the invention. The arrangement shown comprises an electron beam tube including a wave transmission path 10 in the form of dielectric wave guide comprising a rectangular metallic shell 11 having a dielectric core 12 and a hollow interior region 13 about the longitudinal axis 14 of the guide. One end of the wave transmission path 10 may be designated as the input end and is provided with an input dielectric wave guide 15 whereby high frequency electrical waves may be introduced into the wave transmission path. The input wave guide 15 may preferably be of rectangular cross-section and joined to the transmission path wave guide 11 so as to form an electrically conductive connection. Similarly, at an output end of the wave transmission path 10 there is provided an output dielectric wave guide 16 of rectangular cross-section and conductively joined to the transmission path wave guide 11.

The junctions formed by the wave transmission path 10 and the input wave guide 15 and the output wave guide 16 form right angle "corner bends" for waves traveling through the amplifying device. In order that reflection effects at these corners be minimized over a wide band of frequencies, it is desirable that additional means be provided to improve the impedance match at the corners. Such means are well known in the art and may take the form of metallic corner strips 17 or tuning screws 18 as is shown in the drawing. Impedance match and coupling is also enhanced by a section 19 of the dielectric core 12 which extends through the input wave guide 15 to a far wall 20 of the guide. Similarly, at the output end a section 21 of the dielectric core extends through the output wave guide 16 to a far wall 22 of the output guide. It may be noted that of these three dielectric wave guides (10, the transmission path having the dielectric core 12, the input guide 15, and the output guide 16), the input and output guides 15 and 16, which may be as shown with the interior dielectric air having a dielectric constant substantially unity, may have quite different impedance characteristics than the guide 10, which employs the dielectric material 12 having a dielectric constant many times unity.

A source of electrons, which may be an electron gun 23 of well-known type, is provided at the input end of the wave transmission path 10 of the amplifying device. The electron gun 23 is enclosed by an envelope 24 of glass or quartz which may be joined to the input wave guide 15 by means of a projecting strip 25. At the output end of the wave transmission path, a collector anode 26 is enclosed by a second similar envelope 27 which may be joined to the output wave guide 16 by means of a projecting strip 28. The input wave guide 15 is closed off by a "window" 29 of mica or similar material while the output wave guide 16 is similarly closed off by a window 30. The entire device is thus sealed off and may be evacuated to the necessary degree.

The electron gun 23 comprises a cathode 31 having a heater 32, a focussing electrode 33, and an accelerating electrode 34. The heater 32 is supplied by a source conventionally represented as a battery 35 while the focussing electrode 33 is maintained at a proper potential for the formation of a concentrated stream of electrons by a source 36. The accelerating electrode 34 and the collector anode 26 are maintained at potentials suitable to produce an appropriate electron stream velocity through the interior region 13 of the wave transmission path 10 by a high potential source 37. The metallic wave guide structure may, if necessary, be maintained at a high potential by a connection 71 to the high potential source 37. In practical devices suitable electron stream velocities may be produced by potentials in the order of 1500 to 3000 volts although the exact value will be dependent upon the design of the wave transmission path 10.

The action of the electrodes of the device in forming a concentrated electron stream along the longitudinally axis 14 is aided by a solenoid 38 surrounding the wave transmission path 10 and energized by current from a source 39 so as to provide a strong unidirectional magnetic field along the axis of the device. The field due to the solenoid serves also to prevent deviation of the electron stream from its desired course due to an outside magnetic influence. It will be noted that in order to facilitate the action of the solenoid 38, the wave guides and other metallic portions of the device must be made of non-magnetic materials.

Referring now to Fig. 2 there is shown an illustrative cross-sectional view of the device of Fig. 1 taken along the line 2—2 through the input wave guide 15. The input wave guide 15, the mica window 29, and the dielectric core 12 are shown in section while the transmission path guide shell 11 is shown in dotted outline surrounding the dielectric core. It will thus be noted that the dielectric guide of the wave transmission path 10 is a composite structure including a metallic shell 11, the dielectric core 12, and the hollow interior region 13 surrounding the longitudinal axis 14.

In the operation of the device just described, high frequency waves from an external source are introduced through the input wave guide 15 in such a manner that there is induced in the guide a traveling wave having a predominantly transverse electric mode, preferably a TE_{10} mode. The waves travel through the input wave guide and are bent around the corner formed by the junction of the input wave guide and the wave transmission path 10. The wave is then propagated along the wave transmission path as a TE_{10} wave having electric vectors such as those illustrated in Fig. 2 as dotted lines. It will be realized that the electric waves traveling along the hollow interior region 13 of the dielectric core will be purely transverse only along the longitudinal axis 14. In the regions between the walls of the dielectric core 12 and the longitudinal axis 14, however, there will be longitudinal components of electric field.

When there is no wave traveling along the wave transmission path 10 the electron stream will move along the longitudinal central axis 14. However, when a wave is propagated along the wave transmission path at the same order of velocity as the electron stream it will be seen that the transverse component of electric field will serve to deflect portions of the electron stream to either side of the longitudinal axis. As the electron stream is deflected from the axial region into the region nearer the walls of the dielectric core, it will be seen that the electrons will enter regions having a longitudinal component of electric intensity. The electron stream will then be velocity varied in accordance with the variations of amplitude of the electric waves traveling along the wave transmission path. The initial interaction between the electron stream is slight, the wave serving initially only to produce waves of charge density and velocity in the electron stream. However, as the wave and the electron stream travel along the length of the wave transmission path and a wave is established in the electron stream, a condition is established in which the wave travels somewhat slower than the electrons forming the modulated stream and the electrons impart energy to the wave in a manner which increases the amplitude of the wave at a rapidly increasing rate. Thus the wave reaching the output wave guide 16 has an amplitude greatly in excess of that of the wave at the input wave guide 15.

The wave transmission path 10 serves as a path along which the waves to be amplified are propagated in order that they may react with the electron stream flowing therethrough. In order to perform these functions the wave transmission path must have characteristics such that the waves to be amplified travel along the path with a phase velocity of the same order as the velocity of the electron stream, and, the wave path must be of sufficient length so that a cumulative interaction between the electron stream and the wave take place for a sufficient period of time. The first requirement is satisfied in accordance with the invention by utilizing a wave transmission path having a high dielectric constant. The phase velocity of a wave propagating through a guiding medium is inversely proportional to the square root of the dielectric constant of the medium and it will be seen that reasonable values of phase velocities may be achieved by the use of materials having dielectric constants in the order of 100 at the frequency of the waves to be amplified. The second requirement is satisfied by the use of a wave transmission path having a length in the order of thirty to forty wavelengths of the wave to be amplified.

In order to achieve the desired high dielectric constant along the wave transmission path 10, the dielectric core 12 may be formed of a ceramic dielectric material such as, for example, titanium dioxide. Titanium dioxide will exhibit dielectrc constants in the order of 80 to 100 at high frequencies with relatively low losses. While other materials may well be utilized to achieve the desired dielectric characteristics, the alkaline earth titanates are particularly desirable in that they combine a high dielectric constant at high frequencies with a high order of dimensional stability and low attenuation factors. Furthermore, particular impedance characteristics along the wave transmission path may be achieved by appropriate mixtures of the titanates of barium, strontium, or calcium or combinations of those materials with titanium dioxide.

The amplified wave reaching the output wave guide 16 may, due to impedance discontinuities, be partially reflected so that a second wave is propagated along the wave transmission path in a direction opposite to the motion of the electron stream. While the mere presence of the reflected wave does not greatly affect the interaction between the electron stream and the wave traveling in the direction of the electron stream, it is essential that sufficient energy should not reach the input end of the wave transmission path so that a second reflection would cause the generation of self-sustaining oscillations. It will be realized that by the very nature of the dielectric core 12, a certain amount of dissipation of the wave reflected from the output end will take place along the length of the transmission path. However, in the event that the attenuation should be insufficient to dissipate the reflected wave, there may be introduced along the wave transmission path 10 an additional means for absorbing the reflected wave. This alternative means may take the form of a graphite coating on the dielectric core or an actual admixture of the graphite or similar wave absorbing material with the core material in the process of manufacture. Alternatively, where the core is formed of a ceramic such as titanium dioxide the appropriate dissipative action may be obtained by firing portions of the core under reducing conditions.

The dissipative material may preferably be introduced along the central portion of the core as is shown in Fig. 1 by the dotted lines 40 and 41. That such a distribution of attenuation along the wave transmission path is preferable will be apparent from a consideration of the fact that sufficient attenuation may be provided such that both the wave traveling in the direction of the electron stream and the reflected wave will be reduced to very low amplitudes after passing the attenuative portion. The wave traveling in the direction of the electron stream will, however, rapidly increase in amplitude after traversing the attenuating portion of the path due to the cumulative effect of the density variations of the electron stream previously produced by that wave, so that the effective amplification of the device is not reduced. For a more detailed description of the action of dissipative materials along the wave transmission path of traveling wave amplifying devices generally, reference may be made to United States Patent 2,575,383, issued November 11, 1951 to Lester M. Field.

Referring now to Fig. 3, there is illustrated an embodiment of the invention in which the wave transmission path of the amplifying device comprises a dielectric wave guide of circular cross-section and having a hollow dielectric core. There is shown an electron beam tube which comprises an evacuated container 42 enclosing therein an electron gun 43 of known construction and a collector anode 44 for forming a concentrated stream of electrons along a longitudinal axis 45 of the device. The electron gun 43 comprises a cathode 46 having a heater 47, a focussing electrode 48 and an accelerating electrode 49. The heater is supplied by a source conventionally represented as a battery 50 while the focussing electrode 48 is maintained at a proper potential for the formation of a concentrated stream of electrons by a source 51. The accelerating electrode 49 and the collector anode 44 are maintained at potentials suitable to produce an appropriate electron stream velocity along the length of the device by a high potential source 52. A solenoid 53 supplied by a source 54 serves to provide a strong unidirectional magnetic field along the axis of the device.

There is provided a dielectric wave guide having a shell 55 in the form of a metallic cylinder surrounding the evacuated container 42. Within the metallic cylinder 55 and the container 42 there is a dielectric core 56, also of circular cross-section, and having a hollow interior region 57 about the longitudinal axis 45. The wave transmission path thus formed is provided at an input end with an input dielectric wave guide 58 whereby high frequency electrical waves to be amplified may be introduced into the path and at an output end with an output dielectric wave guide 59 whereby the amplified waves may be transmitted to a load. The portions of the structure just described may be more readily visualized by reference to Fig. 4, wherein a cross-sectional view taken along the line 4—4 of Fig. 3 illustrates the input wave guide 58 and the container 42 in cross-section and the transmission path metallic shell 55 and the dielectric core 56 in outline.

The input wave guide 58 is provided with a projecting cylindrical strip 60 which cooperates with a cylindrical metallic strip 61 within the container 42 to effectively form an open circuited quarter wavelength stub and hence a low impedance path for waves flowing along an end wall 62 of the input wave guide. Similarly, the output wave guide 59 is provided along an end wall 63 with a projecting strip 64 which in turn cooperates with a cylindrical metallic strip 65 within the container 42.

Optimum coupling and impedance matching between the wave transmission path, formed by the metallic guide 55 and the dielectric core 56, and the input and output wave guides 58 and 59, over a wide range of frequencies may be obtained by spacing the longitudinal axis 45 of the device at distance of one-fourth to one-fifth wavelength from the ends 66 and 67 of the two guides respectively. Impedance matching and coupling may also be enhanced by projecting portions of the dielectric core 56 into the input and output wave guides as is illustrated in Fig. 3.

In the operation of the amplifying device of Fig. 3, the high frequency waves to be amplified are introduced into the input wave guide 58 in such a manner that the waves are propagated along the transmission path formed by the wave guide shell 55 and the dielectric core 56 in a predominantly transverse magnetic mode. The illustrative arrangement is such that when a wave having a TE_{10} mode is induced in the input wave guide 58, there will be produced in the wave transmission path a wave traveling in a TM_{01} mode and having electric field lines such as is shown by means of dashed lines at 68. The electric field of the traveling wave in the interior region 57 is then predominantly in the direction of the longitudinal axis 45 and the interaction with the electron stream is identical with that which takes place between the longitudinal components of electric field and the electron stream in the device of Figs. 1 and 2.

It is to be understood that the dielectric core 56 of the device of Fig. 3 is to be formed of titanium dioxide or other material having high dielectric constant and low loss in accordance with the considerations set forth with respect to the dielectric core 12 of Fig. 1. Likewise, the dielectric core 56 may be provided with dissipative central portions 69 and 70 following the same general consideration discussed in connection with the dissipative portions 40 and 41 of the dielectric core 12.

It will be realized that while the amplifying devices of the invention have been described and illustrated with reference to the lower modes of propagation of the traveling wave along the wave transmission path, higher modes of propagation may be utilized within the spirit of the invention so long as the electric field requirements of the devices are satisfied. Under such conditions it may be desirable to utilize mode limiting barriers in the wave transmission path in a fashion well known in the art It will also be realized that the rectangular input and output wave guides shown are by way of illustration and that circular wave guides or concentric transmission lines may readily be utilized.

What is claimed is:

1. An electron discharge device comprising a length of dielectric wave guide having, extending therealong, a hollow central core composed of a tubular member of material having a dielectric constant substantially greater than unity and forming a portion of a non-resonant high frequency wave transmission circuit, said length of wave guide having an input end and an output end and substantially impedance matching terminations at each said end, means for applying an electric wave to said input end, whereby the wave is transmitted through said length of dielectric guide to the output end at a phase velocity dependent upon the magnitude of said dielectric constant, and means for producing a stream of electrons along a path through said length of wave guide in the region of the traveling electric field associated with said transmitted wave and in the direction of travel of said field at a velocity substantially the same as said phase velocity.

2. An electron discharge device comprising a length of dielectric wave guide having, extending therealong, a hollow central core composed of a tubular member of material having a dielectric constant substantially greater than unity and forming a portion of a non-resonant high frequency wave transmission circuit, said length of wave guide having an input end and an output end and substantially impedance matching terminations at each said end, means for applying an electric wave to said input end, whereby the wave is transmitted through said length of dielectric guide to the output end at a phase velocity dependent upon the magnitude of said dielectric constant, means for producing a stream of electrons along a path through said length of wave guide in the region of the traveling electric field associated with said transmitted wave and in the direction of travel of said field at a velocity substantially the same as said phase velocity, and high frequency wave attenuating means distributed along said path and coupled to said field therealong in the region traversed by said electron stream.

3. An electron discharge device comprising a length of dielectric wave guide of material having a dielectric constant substantially greater than unity and forming a portion of a non-resonant high frequency wave transmission circuit, said length of wave guide having an input end and an output end and substantially impedance matching terminations at each said end, means for applying an electric wave to said input end, whereby the wave is transmitted through said length of dielectric guide to the output end at a phase velocity dependent upon the magnitude of said dielectric constant, and means for producing a stream of electrons along a path through said length of wave guide in the region of the traveling electric field associated with said transmitted wave and in the direction of travel of said field at a velocity substantially the same as said phase velocity, one of said impedance matching terminations comprising another length of dielectric wave guide.

4. An electron discharge device comprising a length of dielectric wave guide of material having a dielectric constant substantially greater than unity and forming a portion of a non-resonant high frequency wave transmission circuit, said length of wave guide having an input end and an output end and substantially impedance matching terminations at each said end, means for applying an electric wave to said input end, whereby the wave is transmitted through said length of dielectric guide to the output end at a phase velocity dependent upon the magnitude of said dielectric constant, and means for producing a stream of electrons along a path through said length of wave guide in the region of the traveling electric field associated with said transmitted wave and in the direction of travel of said field at a velocity substantially the same as said phase velocity, one of said impedance matching terminations comprising another length of dielectric wave guide of material having a dielectric constant substantially lower than that of the material of the first-mentioned length of wave guide coupled to said first-mentioned length of wave guide and having a conducting shell into which an end portion of the dielectric material of the first-mentioned length of wave guide projects.

5. The invention in accordance with claim 1, the said dielectric material of the said wave guide being substantially composed of titanium dioxide.

6. An electron discharge device comprising a length of dielectric wave guide having a central core, extending therealong, composed of a tubular member of barium titanate and forming a portion of a non-resonant high frequency wave transmission circuit, said length of wave guide having an input end and an output end and substantially impedance matching terminations at each said end, means for applying an electric wave to said input end, whereby the wave is transmitted through said length of dielectric guide to the output end at a phase velocity dependent upon the magnitude of said dielectric constant, and means for producing a stream of electrons along a path through said length of wave guide in the region of the traveling electric field associated with said transmitted wave and in the direction of travel of said field at a velocity substantially the same as said phase velocity.

7. An electron discharge device comprising a length of dielectric wave guide having a central core, extending therealong, composed of a tubular member of barium-strontium titanate and forming a portion of a non-resonant high frequency wave transmission circuit, said length of wave guide having an input end and an output end and substantially impedance matching terminations at each said end, means for applying an electric wave to said input end, whereby the wave is transmitted through said length of dielectric guide to the output end at a phase velocity dependent upon the magnitude of said dielectric constant, and means for producing a stream of electrons along a path through said length of wave guide in the region of the traveling electric field associated with said transmitted wave and in the direction of travel of said field at a velocity substantially the same as said phase velocity.

8. A device according to claim 3 in which said other length of wave guide and the first-mentioned length of wave guide are coupled effectively end to end, whereby energy transfer between them is longitudinal in both and the electric mode of transmission is the same in both said lengths of guide.

9. A device according to claim 3 in which said other length of wave guide and said first-mentioned length of wave guide are coupled side to end, whereby energy transfer between them is laterally in one guide and longitudinal in the other and the electric mode of transmission is different in the two.

10. The invention in accordance with claim 2, said wave attenuating means comprising a layer of graphite incorporated in said guide along the central portion of said extended path.

11. In a wave amplifier, a wave guide having extending therealong a hollow central core composed of a tubular member of material having a dielectric constant substantially greater than unity, means for producing a concentrated stream of electrons through the hollow core of said guide, means for transmitting high frequency waves to be amplified along said guide, said guide being adapted to cause a relatively continuous interaction between the electric field of said waves and said electron stream, and wave dissipative material incorporated along said guide in the region of said interaction.

12. The invention in accordance with claim 11, the said dissipative material being embodied in said dielectric core.

13. A device according to claim 3 in which along the center of the guide, the lines of force of the traveling electric field are directed predominantly transverse to the direction of travel.

14. A device according to claim 3 in which along the center of the guide, the lines of force of the traveling electric field are directed predominantly in the direction of travel.

15. In a wave amplifier, a dielectric wave guide having, extending therealong, a hollow central core composed of a tubular member of material having a dielectric constant substantially greater than unity, means for producing a concentrated stream of electrons through the hollow core of said guide, means comprising input and output dielectric wave guide portions coupled to said first-mentioned wave guide for transmitting high frequency waves into and out of said first-mentioned guide, said first-mentioned guide being adapted to cause a relatively continuous interaction between the electric field of said waves and said electron stream, and wave dissipative material incorporated along said guide in the region of said interaction.

16. A wave amplifier according to claim 15 in which the input and output ends of the first-mentioned guide are coupled to the sides of the input and output guide portions, respectively.

17. An amplifier according to claim 15 in which the lines of force of the electric field are substantially transverse along the center of the first-mentioned guide.

18. An amplifier according to claim 15 in which the lines of force of the electric field along the center of the first mentioned guide are substantially in the direction of the longitudinal axis of that guide.

GEORGE E. MUELLER.

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