

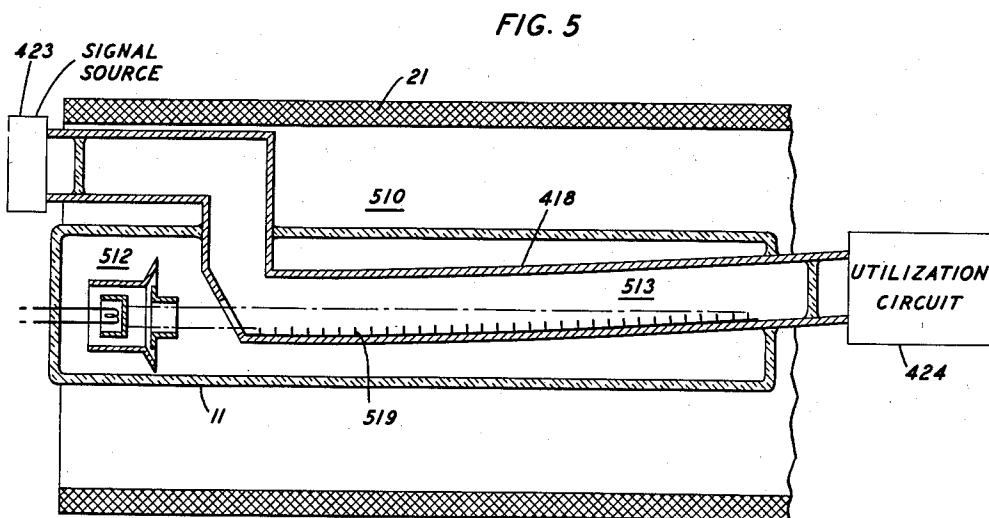
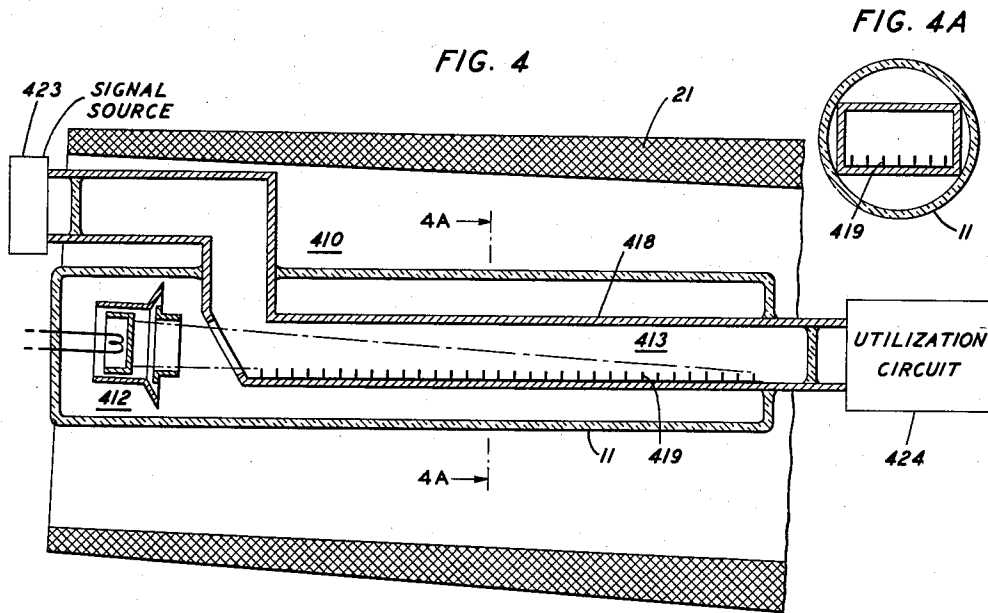
Sept. 29, 1959

C. C. CUTLER
TRAVELING WAVE TUBE

2,906,914

Filed Aug. 18, 1955

3 Sheets-Sheet 2



INVENTOR
C. C. CUTLER
BY
Arthur J. Torrighieri
ATTORNEY

Sept. 29, 1959

C. C. CUTLER
TRAVELING WAVE TUBE

2,906,914

Filed Aug. 18, 1955

3 Sheets-Sheet 3

FIG. 6

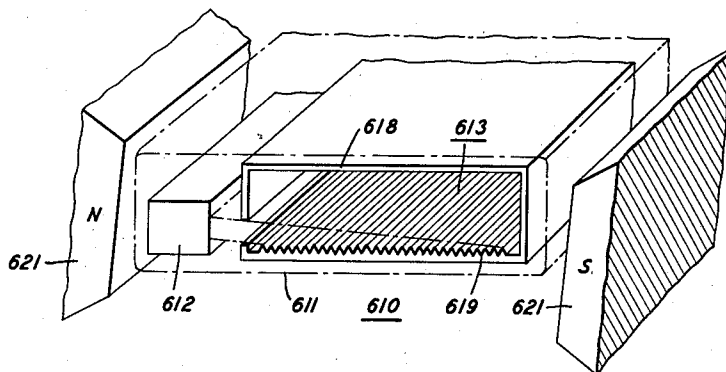


FIG. 7

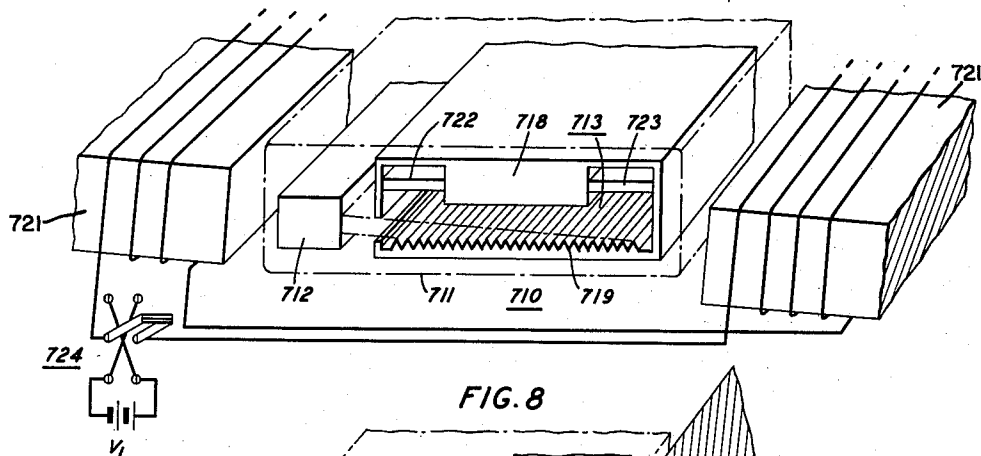
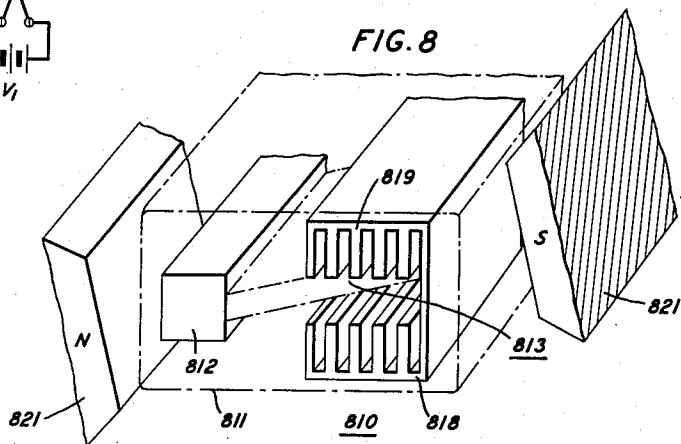


FIG. 8



INVENTOR
C. C. CUTLER
BY
Arthur J. Tomiglieri
ATTORNEY

1

2,906,914

TRAVELING WAVE TUBE

Cassius C. Cutler, Gillette, N.J., assignor to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

Application August 18, 1955; Serial No. 529,126

10 Claims. (Cl. 315—3.5)

This invention relates to a traveling wave tube for use as a high frequency amplifier or oscillator.

It is now generally understood that an interchange of energy takes place when an electron beam is projected in coupling relation with the field of a propagating electromagnetic wave, so long as the beam and the wave are traveling at substantially the same velocity. Various transmission circuits have been proposed for propagating an electromagnetic wave in amplifiers and oscillators utilizing this principle. With such circuits specially designed focusing arrangements are generally required for directing an electron beam parallel to the wave circuit and exceedingly close thereto for interaction with the wave propagating along the circuit.

The most popular wave circuit is perhaps a simple helix. Typically, an electron beam is projected along the axis of such a helix for interaction with a wave propagating along the helix. For very high frequency operation the dimensions of the helix are exceedingly small and the beam cross-sectional dimensions must likewise be small. Moreover, for operation at higher and higher frequencies, the field of a wave propagating along the helix is more closely confined to the helix, until at frequencies in the millimeter range and above the field is so closely confined to the helix that it is exceedingly difficult to focus a beam to pass within the region of the field without striking the helix. In practice, one must either use a low current beam which can be confined to a small diameter path along the axis of the helix or risk striking the helix. With a high current beam very often the beam strikes the first few turns of the helix causing serious damages to the finely dimensioned helix and obtaining substantially no amplification of the wave on the helix. When a low current beam on the axis is used, however, and focusing of the electron beam past the helix circuit is achieved, only those electrons adjacent the periphery of the beam are close enough to the helix to interact with the wave, the remainder of the electrons in the beam fail to realize such interaction and hence deliver no energy to the wave.

A principal object of the present invention, therefore, is to obtain efficient high frequency operation wherein substantially all of the electrons in the beam interact with the propagating wave and, further, interaction takes place along the entire length of the wave propagating circuit.

A related object is to obtain high power operation at high frequencies by the use of a high current electron beam.

To these ends, a feature of the present invention is the combination of a wave transmission circuit having a succession of periodically spaced discontinuities along its length and an electron gun appropriately arranged for projecting an electron beam along a path at an acute angle with the circuit for interception of the beam by the circuit along the length of the circuit. This arrangement ensures that there will be electrons flowing closely past the circuit for interacting with the traveling wave along

2

substantially the entire length of the circuit and also that all of the electrons will flow for a time closely past the circuit for interacting with the traveling wave.

In a preferred embodiment, the wave transmission circuit comprises a hollow conductive rectangular wave guide having periodically spaced corrugations along the interior surface of one of its walls. In this embodiment an electron beam is projected along a path within the interior of the hollow wave guide at an acute angle with the corrugated surface for interception by that surface. The corrugations in the wall surface of the hollow wave guide modify the electric field of a wave traveling along the wave guide so as to form longitudinal components of electric field parallel to the electron beam for interaction therewith. Such components are referred to as spatial harmonic components of the traveling wave. The strength of these spatial harmonic components decreases rapidly with distance away from the corrugated surface. By appropriately directing the electron beam into collision with the corrugated surface, however, each of the electrons in the beam passes for a time through the region of highest field strength of the spatial harmonic components, whereby maximum interaction with these components is achieved.

In traveling wave tubes utilizing electron beam interaction with spatial harmonics of a traveling wave, the electron beam can interact either with (1) the positive spatial harmonic components of a wave traveling in the same direction as the electron beam, or (2) the negative spatial harmonic components of a wave traveling in the direction opposite to that of the electron beam. The former type of interaction is referred to as forward-wave operation and the latter as backward-wave operation.

In an embodiment of the present invention suited for use in forward-wave operation, a convergent electron beam is appropriately projected for interception by a corrugated wave circuit.

In an embodiment suited for use in backward-wave operation, a divergent electron beam is appropriately projected for interception by a corrugated wave circuit.

A related feature of the present invention is the use of a wave transmission circuit whose surface is characterized by good secondary electron emissive properties. For increased efficiency of operation, such a circuit can advantageously be incorporated in each of the previously discussed illustrative embodiments. In such an arrangement, there results a substantial amount of secondary emission as the surface intercepts the high velocity electron beam. The secondary emission effect is enhanced since the beam impinges upon the surface of the circuit at an acute angle. The secondary emission forms a cloud of electrons near the surface of the circuit which exhibits a dielectric constant less than one and acts to increase the field strength in the vicinity of the circuit, thereby effecting improved efficiency of operation. Moreover, the cloud of secondary emitted electrons can be utilized as the signal wave propagating medium, eliminating the need for the series of discontinuities along the surface except as a means for launching the signal on the electron cloud.

Advantages of embodiments in accordance with the present invention are ease in construction, wide band operation, a rugged propagating circuit with good heat dissipation properties which is capable of intercepting a high current electron beam without being damaged, and, as a consequence, less stringent electron beam focusing requirements.

The above and other objects, features, and advantages of the present invention will be more fully understood from the following more detailed description taken in conjunction with the accompanying drawings, in which:

Fig. 1 shows a longitudinal section of a traveling wave tube embodiment of the present invention;

Fig. 1A is a cross-sectional view through line 1A—1A of Fig. 1;

Fig. 2 shows an enlarged view of a portion of the corrugated wave circuit of Fig. 1 and the field configuration of a wave propagating therealong;

Fig. 3 shows a longitudinal sectional view of a second embodiment of the present invention for use as a backward-wave amplifier or oscillator;

Fig. 3A is a cross-sectional view through line 3A—3A of Fig. 3;

Fig. 4 is a longitudinal sectional view of a third embodiment of the present invention for use as a forward-wave amplifier;

Fig. 4A is a cross-section taken through line 4A—4A of Fig. 4;

Fig. 8 is a longitudinal view of a modification of the forward-wave amplifier of Fig. 4;

Figs. 6 and 7 are perspective views of modifications of a fourth illustrative embodiment of the present invention wherein corrugations are provided parallel to the direction of wave propagation along the wide wall of the wave guide serving as the propagating circuit; and

Fig. 8 is a perspective view of a fifth illustrative embodiment having corrugations parallel to the direction of wave propagation along the narrow wall of the wave guide serving as the propagating circuit.

Referring more particularly to the illustrative embodiments of the various figures, Figs. 1 and 1A show a traveling wave tube 10 comprising an evacuated envelope 11, an electron gun 12 positioned at one end of the envelope, and a wave transmission circuit 13. The electron gun 12 includes an electron emissive surface 14, heater element 15, beam forming electrode 16, and accelerating electrode 17. The flared portion of the beam forming electrode controls the shape of the beam. For a parallel flow beam, as shown in the present embodiment, the angle of flare should be approximately 67.5 degrees. For a convergent or divergent beam the flare should be appropriately decreased or increased. For simplicity of drawing, support structure for the elements of the electron gun and voltage connections to the various elements have not been shown. In practice, the terminals of the heater element are connected to a suitable heater voltage source, the beam forming electrode 16 is maintained at approximately the same potential as the emissive surface 14, and electrode 17 is maintained at a suitably high positive voltage with respect to emissive surface 14 for accelerating the electrons from the emissive surface.

Transmission circuit 13 includes a section of hollow wave guide 18 having the interior surface of one wall thereof provided with corrugations 19. The depth of the corrugations is advantageously substantially less than a quarter of a wavelength at the lowest frequency of operation. With corrugation depths less than a quarter wavelength, no slot resonances occur in the frequency band of interest and the properties of the circuit do not vary appreciably even over a very broad frequency band. Wave guide 18 is sealed with a glass window 20, or other suitable wave guide seal, for maintaining the evacuated conditions in envelope 11.

The electric field of a wave propagating along wave guide 18 will be modified by the corrugated surface 19 to have longitudinal spatial field components in close proximity to the corrugated surface. Electromagnet 21 is provided to establish a magnetic field having parallel flux lines which are disposed at an acute angle with surface 19. An electron beam projected from gun 12 tends to follow along the magnetic flux lines and is intercepted by the corrugated surface, which is maintained at substantially the same direct-current potential as accelerating electrode 17. Electrons from the beam impinge upon the corrugated surface 19 along substantially its

entire length, all of the electrons of the beam finally striking the surface. This ensures that interaction between the beam and a wave propagating along the circuit will occur along the entire length of the circuit and, further, that all of the electrons of the beam will interact with the wave.

Surface 19 is characterized in that it is coated with a thin film of material having good secondary electron emissive properties, such as a silver-beryllium alloy. This results in a substantial amount of secondary emission from the corrugated surface as this surface intercepts the high velocity electron beam. The secondary emission forms a cloud of electrons near the wall surface which exhibits a dielectric constant less than one and acts to increase the field strength in the vicinity of the circuit, thereby effecting higher efficiency operation. Moreover, the cloud of secondary emitted electrons can advantageously be utilized as the signal wave propagating medium, eliminating the need for the series of corrugations along the wave guide wall surface except as a means for launching the signal on the electron cloud. Such operation is the same, in principle, as that of a double-stream amplifier as described in an article by J. R. Pierce and W. B. Hebenstreit, entitled "A New Type of High-Frequency Amplifier," vol. 28, page 33, Bell System Technical Journal (1949). In an amplifier of this type, interaction occurs between the respective wave energy associated with two distinct electron streams, wherein the two streams travel at different average velocities. It can be appreciated that one of the electron streams in such a device can be stationary while the other is moving, as in the present embodiment.

In operation, a wave propagating along the corrugated surface is amplified by the interaction between the wave and the electron beam. For backward-wave operation, wave energy is transferred via wave guide 18, from a suitable input source, to the right-hand or downstream end of transmission circuit 13 and is amplified in passing from right to left along circuit 13. The amplified wave energy is then abstracted from the left-hand or upstream end of transmission circuit 13 by wave guide 18 for transmission to a load. For forward-wave operation, wave energy from a suitable input source is applied to the upstream end of circuit 13 and is amplified in passing from left to right along the circuit. In this case the amplified wave energy is abstracted from the downstream end of circuit 13 by wave guide 18 for transmission to a load.

The field configuration of a wave passing along transmission circuit 13 is shown more clearly in Fig. 2. In order to obtain the electron beam velocity required for amplifying interaction with such a field, the following considerations must be taken into account. For shallow corrugation depth, as is preferred for broad band operation, the phase velocity of the corrugated line is approximately equal to that of an uncorrugated line, and hence approximately equal to the velocity of light. Further, the pitch of the corrugations P is small compared to the wavelength along the line. Hence, the longitudinal component of the spatially alternating electric field along the line has a periodicity of P . Thus, for synchronism with such a spatially alternating wave, the velocity of the beam must be approximately equal to Pf , where P is the pitch of the corrugations and f is the frequency of the wave to be amplified. More accurately, accounting for the velocity of the propagating wave, when the wave and the beam are in the same direction (forward-wave operation), the beam velocity must be slightly less than Pf for synchronism, whereas when the wave and the beam are oppositely directed (backward-wave operation), the beam velocity must be slightly more than Pf for synchronism.

Figs. 3 and 3A show a second embodiment of the present invention for use as a backward-wave amplifier or oscillator. Components of these figures and all suc-

ceeding figures which correspond to parts discussed with reference to Figs. 1 and 1A have been given like reference numerals. Traveling wave tube 310 of this embodiment includes an electron gun 312 and wave transmission circuit 313. The wave transmission circuit comprises a section of wave guide 318 having a corrugated surface 319 along one wall. For the reasons discussed above surface 319 is preferably coated with a silver-beryllium alloy or other material having good secondary emissive properties. Although the corrugations have a profile somewhat different from those of Fig. 1, the transmission circuit provides the same function and has substantially the same characteristics. Unlike Fig. 1, however, electron gun 312 is shaped to emit a divergent electron beam. The divergent beam impinges on the corrugated surface of circuit 313 at an acute angle, the various electrons of the beam interacting with a propagating wave along the entire length of the circuit.

In backward-wave operation, the strength of the field of a wave passing along circuit 313 is increasing from right to left because of the amplifying interaction with the beam. Such variation in field strength along the circuit requires that the electrons of the beam which strike the left-hand end of circuit 313 pass through a higher field strength region proximate the circuit before interception by the circuit than do electrons of the beam which strike the right-hand end of the circuit. Accordingly, the electrons striking the left-hand or high field strength end tend to give up a greater amount of energy and fall out of synchronism with the wave. This serves as a limitation on the level of the propagating wave to be amplified. To avoid having some electrons of the beam give up more energy than others and hence falling out of synchronism, provision is made so that the electrons which pass through the high field region travel through the region of the longitudinal field components a shorter distance before interception than electrons which pass through the low field region. In the present embodiment the divergent beam is used to accomplish this end. With the divergent beam, electrons striking the corrugated surface near its upstream end pass through the longitudinal field region proximate the surface a shorter distance than electrons which strike the downstream end of the surface. Hence, the various electrons of the beam give up substantially the same amount of energy before interception by the corrugated surface.

In operation as a backward-wave amplifier, wave energy is transferred from a signal source, shown diagrammatically as block 323, via wave guide 318 to the downstream end of circuit 313. The wave energy is amplified in passing from right to left along the circuit and the amplified wave energy is transferred via wave guide 318 to a utilization circuit 324. In operation as a backward-wave oscillator, the downstream end of wave guide 318 is advantageously terminated in its characteristic impedance to prevent reflections at this end. Energy derived from the oscillator 310 is transferred via wave guide 318 to utilization circuit 324. The present invention is similarly applicable for use in a backward-wave oscillator of the type wherein the amplified wave energy is reflected from the upstream end of the interaction circuit by a suitable reflective termination, and a predetermined portion of the reflected wave energy is abstracted by a coupling means at the downstream end of the circuit.

A third embodiment of the present invention adapted for use as a forward-wave amplifier is shown in Fig. 4. Tube 410 of this embodiment. Comprises an evacuated envelope 11, an electron gun 412, and a wave transmission circuit 413. The transmission circuit includes a section of wave guide 418 having the inner surface of one wall thereof provided with periodic discontinuities in the form of a curry-comb arrangement 419 to give rise to a spatially-alternating longitudinal electric field.

The curry-comb arrangement and the surface from which they extend are preferably coated with a material having good secondary emissive properties. Electron gun 412 is adapted to emit a convergent electron beam which impinges on the curry-comb surface of circuit 413 at an acute angle, various electrons of the beam interacting with the propagating wave along the entire length of circuit 413. Since, for forward-wave operation, the field of a wave passing along circuit 413 is increasing from left to right, electrons which reach the longitudinal field region proximate the corrugated surface at the right-hand or downstream end are required to do more work per unit length than the electrons reaching the longitudinal field region at the upstream end. With the convergent beam, however, electrons striking surface 419 near its downstream end pass through the longitudinal field region proximate the surface a shorter distance than electrons which strike the upstream end of the surface. Hence, the various electrons of the beam do substantially the same amount of work, with a consequent increase in operating efficiency.

A modification of the forward-wave tube of Fig. 4 is shown in Fig. 5. In this modification, tube 510 comprises an evacuated envelope 11, an electron gun 512, and a wave transmission circuit 513. As distinguished from tube 410, the electron gun 512 of tube 510 emits a parallel beam but surface 519 is curved so that, as in the tube of Fig. 4, electrons striking surface 519 near its downstream end pass through the longitudinal field region proximate the surface a shorter distance than electrons which strike the upstream end of the surface. Thus, also as in the tube of Fig. 4, the various electrons of the beam do substantially the same amount of work.

In operation of either of the tubes of Figs. 4 or 5 as a forward-wave amplifier, wave energy is transferred from a signal source, shown diagrammatically as block 423, via wave guide 418 to the upstream end of the curry-comb wave transmission circuit. The wave energy is amplified in passing from left to right along the circuit and the amplified wave energy is transferred via wave guide 418 to a utilization circuit 424.

Fig. 6 shows another embodiment of the present invention for use in either forward-wave or backward-wave operation. Tube 610 of this embodiment comprises an evacuated envelope 611, an electron gun 612 which is shown diagrammatically and may be of the type shown in the previous embodiments, and a wave transmission circuit 613. The wave transmission circuit 613 includes a hollow rectangular wave guide 618 having the interior surface of a wide wall 619 thereof provided with corrugations extending parallel to the axis of the wave guide. The surface of this wall is preferably coated, as shown, with a material having good secondary emissive properties. The axially extending corrugations modify the electric field of a wave passing along the wave guide to form transverse field components adjacent surface 619. Permanent magnets 621 produce a magnetic field having parallel flux lines which are disposed at an acute angle with the corrugated surface 619 and act to focus an electron beam from gun 612. The electrons of such a beam are preferably projected initially along parallel paths and follow the flux lines of the magnetic field so as to collide with surface 619, being collected thereby. The various electrons of the beam interact with a wave propagating longitudinally in either direction along circuit 613. Moreover, the interaction takes place across the entire width of the corrugated wave guide surface. Electron gun 612 and circuit 613 extend along the length of wave guide 618 a length sufficient to obtain the desired amplification. It is understood that a suitable wave guide seal is provided at both ends of circuit 613 to maintain the required evacuated conditions within envelope 611.

A modification of the embodiment of Fig. 6 is shown in Fig. 7. In this modification electron gun 712 projects a parallel electron beam which follows the magnetic flux

lines produced by electromagnets 721. The electromagnets, which replace the permanent magnets of Fig. 6, produce a magnetic field having parallel flux lines disposed at an acute angle with the corrugated wave guide wall for directing the electrons into the corrugated wall. The various electrons of the beam before interception by the corrugated wall interact with the spatial harmonic components of a wave passing along wave guide 718 for amplifying the wave. Unlike the embodiment of Fig. 6, however, effective amplification is not provided for waves passing in either direction along wave guide 718. In the present modification the interaction circuit 713 exhibits nonreciprocal properties. Such properties are attained by the use of magnetically biased elements 722 and 723 of ferrite or other gyromagnetic material. By appropriately positioning the ferrite elements, as shown, in a U-shaped wave guide 718, the magnetic focusing field from magnets 721 is advantageously used to magnetically bias the ferrite element for producing nonreciprocal attenuation of a wave along circuit 713. A wave passing in one direction along wave guide 718 in the region of circuit 713 will suffer very little attenuation because of the ferrite but will be amplified by interaction with the beam. A wave traveling in the other direction along the wave guide in the region of circuit 713, however, because of the ferrite, will suffer sufficient attenuation to cancel the amplification received and will effectively be attenuated. Moreover, by reversing the direction of magnetic field through the ferrite elements, the high attenuation direction reverses. Switch 724 serves to reverse the direction of current flow from source V_1 through the electromagnets 721, thereby reversing the direction of amplification through tube 710. In this manner tube 710 serves both as a switch to regulate the direction of easy-flow for a wave propagating through wave guide 718 and as an amplifier for amplifying the wave in the easy-flow direction. It is understood that switch 724 and direct current voltage source V_1 may be replaced by an alternative voltage source, such as a suitable pulse train, which reverses the direction of amplification and easy-flow through wave guide 718 at appropriate times in accordance with the variations in a particular signal voltage.

An alternative arrangement for obtaining nonreciprocal properties through circuit 613, of Fig. 6, is to slant the beam or the corrugations or both to be diagonally disposed with the direction of wave propagation along wave guide 618. In such an arrangement the beam velocity required for interaction with a wave in one direction along the wave guide will be different from the velocity required for interaction with a wave in the other direction. Hence, by appropriately adjusting the velocity of the beam, amplification in only one direction can be obtained. Such nonreciprocal amplification properties are often desirable to avoid amplifying undesired reflections which might lead to spurious oscillation.

A further illustrative embodiment of the present invention is shown in Fig. 8. In this embodiment tube 810 comprises an evacuated envelope 811, an electron gun 812, shown diagrammatically, and a wave transmission circuit 813. The transmission circuit includes a section of rectangular wave guide for propagating a wave polarized in a direction perpendicular to its wide wall. One narrow wall 819 of the wave guide is corrugated for modifying the electric field of the propagating wave to form a plurality of spatial components in close proximity to the corrugated surface. The corrugations along wall 819 preferably extend into the high field region of a wave propagating along wave guide 818 in a transverse mode. Such corrugations, as in the wave circuits previously discussed, are preferably coated with a material having good secondary electron emissive properties. Magnets 821 provide a focusing magnetic field having parallel flux lines disposed at an acute angle with corrugated surface 819. For ensuring interaction over the entire corrugated surface, an electron beam is projected from gun 812 to flow

along the flux lines through the region of the spatial field components and is intercepted and collected by surface 819. A wave propagating along wave guide 818 is amplified by the interaction between its spatial harmonic components and the electron beam.

It is understood that the above-described arrangements are merely illustrative of the application of the general principles of the invention. Various other arrangements may be devised by one skilled in the art without departing from the spirit and scope of the invention. In particular, the curry-comb wave circuit of Figs. 4 and 5 provides a transverse spatial field component, as well as a longitudinal spatial field component, and hence may be used in the embodiment shown in Figs. 6 and 7. Further, if desired, more than one wall of the rectangular wave guide may be provided with corrugations or other suitable discontinuities. For example, one such arrangement would be to combine the tubes of Fig. 3 and Fig. 4 to form a single tube having discontinuities along opposite walls of a wave guide. In such a case, one wall would serve to intercept a divergent beam, as shown in Fig. 3, and render backward-wave amplification, and the opposite wall would serve to intercept a convergent beam, as shown in Fig. 4, and simultaneously render forward-wave amplification. Other arrangements may be devised employing circular hollow wave guides in place of the rectangular hollow wave guides illustrated, as will be evident to one skilled in the art.

What is claimed is:

1. In apparatus which utilizes the interaction between an electron beam and an electromagnetic wave for amplifying the wave, means for propagating an electromagnetic wave along a predetermined path including a hollow wave guide, one of whose wall surfaces is characterized by a series of periodic discontinuities in the form of corrugations extending transverse to the direction of periodicity for providing a spatial harmonic electric field component of an electromagnetic wave propagating through said wave guide, said one wall surface being biased to act as a collector electrode, means for establishing a magnetic field whose flux lines form an acute angle with said wall surface, and means for projecting an electron beam for flow along said flux lines for interception by said periodic discontinuities of substantially the whole cross section of said electron beam whereby the electron beam interacts with said spatial harmonic component for amplifying the propagating wave.

2. The combination of elements in claim 1 wherein said wall surface is coated with a material having a secondary electron emission ratio greater than one whereby a cloud of electrons is formed adjacent said surface.

3. In a device which utilizes the interaction between an electron beam and a propagating electromagnetic wave to amplify the wave, a wave transmission circuit for propagating an electromagnetic wave comprising a hollow conductive wave guide, one wall of said wave guide being biased to act as a collector and having a succession of discontinuities periodically spaced along its surface for modifying the electric field of the propagating wave to form spatial harmonic components proximate said wall, said discontinuities extending transverse to the direction of periodicity, an electron source, and means for spraying said wall at an acute angle so that substantially all the electrons from said electron source impinge upon said periodic discontinuities whereby said electrons interact with said spatial harmonic components.

4. In a device which utilizes the interaction between an electron beam and a propagating electromagnetic wave to amplify the wave, a wave transmission circuit for propagating an electromagnetic wave comprising a hollow conductive wave guide having a succession of axially extending discontinuities periodically spaced apart in a direction transverse to the wave guide axis along the surface of one wall for modifying the electric field of the

propagating wave to form spatial harmonic components proximate said wall, said wall being biased to act as a collector electrode, means for forming and for projecting an electron beam in coupling relation with said spatial harmonic components along a path at an acute angle with said wall in a direction substantially transverse to the wave guide axis for gradual interception by said discontinuities of substantially the whole cross section of said electron beam.

5. In a device which utilizes the interaction between an electron beam and a propagating electromagnetic wave to amplify the wave, a wave transmission circuit for propagating an electromagnetic wave comprising a hollow conductive rectangular wave guide having a succession of axially extending corrugations periodically spaced apart in a direction transverse to the wave guide axis along the surface of one of its walls for modifying the electric field of a wave propagating along said wave guide to form spatial harmonic components proximate said one wall, said one wall being biased to act as a collector electrode and being of a material having a secondary electron emission ratio greater than one, means for forming and for projecting an electron beam in coupling relation with said spatial harmonic components along a path at an acute angle with said one wall and in a direction substantially transverse to the wave guide axis so that substantially all of the cross section of said electron beam impinges upon substantially the whole of the region of said corrugations of said one wall.

6. In a device which utilizes the interaction between an electron beam and a propagating electromagnetic wave to amplify the wave, a wave transmission circuit for propagating an electromagnetic wave comprising a hollow conductive rectangular wave guide having a succession of axially extending corrugations periodically spaced apart in a direction transverse to the wave guide axis along the surface of one of its walls for modifying the electric field of a wave propagating along said wave guide to form spatial harmonic components proximate said one wall, said one wall being biased to act as a collector electrode, a gyromagnetic member extending along said wave guide in the region of its corrugated wall surface, magnetic field producing means for magnetically biasing said member in a direction transverse to the direction of wave propagation for producing nonreciprocal wave propagating properties along the conductive wave guide in the region of its corrugated wall surface, and means for forming and for projecting an electron beam in coupling relation with said spatial harmonic components along a path at an acute angle with said one wall and in a direction substantially transverse to the wave guide axis for gradual interception of substantially all of the electrons of said beam by said corrugations of said one wall.

7. The combination of elements set forth in claim 6 including means for reversing the direction of the biasing magnetic field.

8. A traveling wave tube comprising a hollow wave guiding member, means on one surface of said wave guiding member for introducing repetitive discontinuities extending transversely of the wave guide axis to generate spatial harmonic components of electromagnetic waves in said member, and means for projecting a beam of primary electrons transversely to the direction of travel of the electromagnetic waves and at an acute angle to said one surface for collection along said one surface of substantially the whole of said beam impinging thereon.

9. A traveling wave tube comprising a hollow wave guiding member for propagating an electromagnetic wave therethrough, one inner surface of said wave guiding member having a succession of periodically arranged transverse corrugations, said one inner surface being biased to act as a collector electrode and being of a material having a secondary emission ratio greater than one, and means for forming and projecting a divergent electron beam along said wave guiding member in a direction opposite the direction of wave propagation therethrough so that substantially all of the cross section of said electron beam impinges on substantially the whole of the region of the discontinuities at an acute angle.

10. A traveling wave tube comprising a hollow wave guiding member for propagating an electromagnetic wave therethrough, one inner surface of said wave guiding member having a succession of periodically arranged transverse corrugations, said one inner surface being biased to act as a collector electrode and being of a material having a secondary emission ratio greater than one, and means for projecting a convergent electron beam along said wave guiding member in the direction of wave propagation therethrough so that substantially all of the cross section of said electron beam impinges on substantially the whole of the region of the discontinuities at an acute angle.

References Cited in the file of this patent

UNITED STATES PATENTS

2,695,929	Reverdin	Nov. 30, 1954
2,708,236	Pierce	May 10, 1955
2,796,550	Kazan	June 18, 1957
2,798,183	Sensiper	July 2, 1957

FOREIGN PATENTS

1,080,027	France	May 26, 1954
1,081,937	France	June 16, 1954