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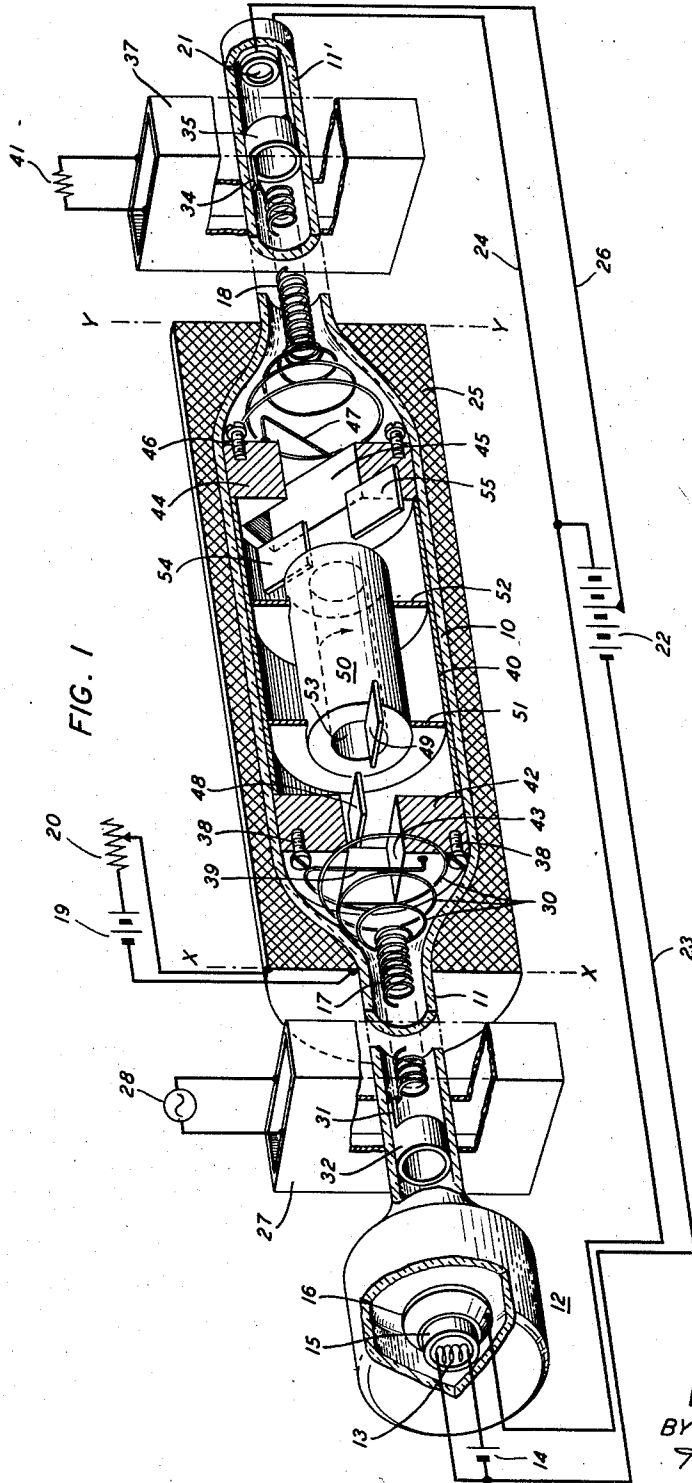
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2,849,642

TRAVELING WAVE AMPLIFIER

Filed June 17, 1953

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 2

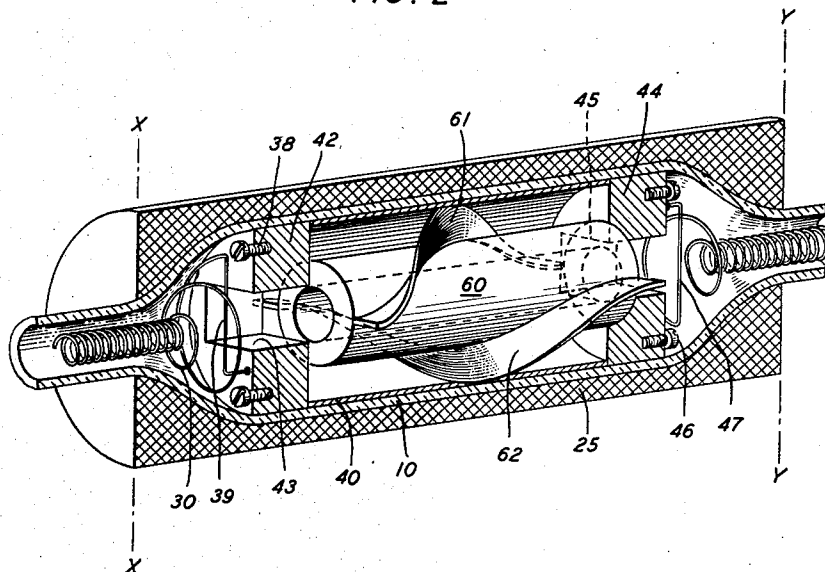
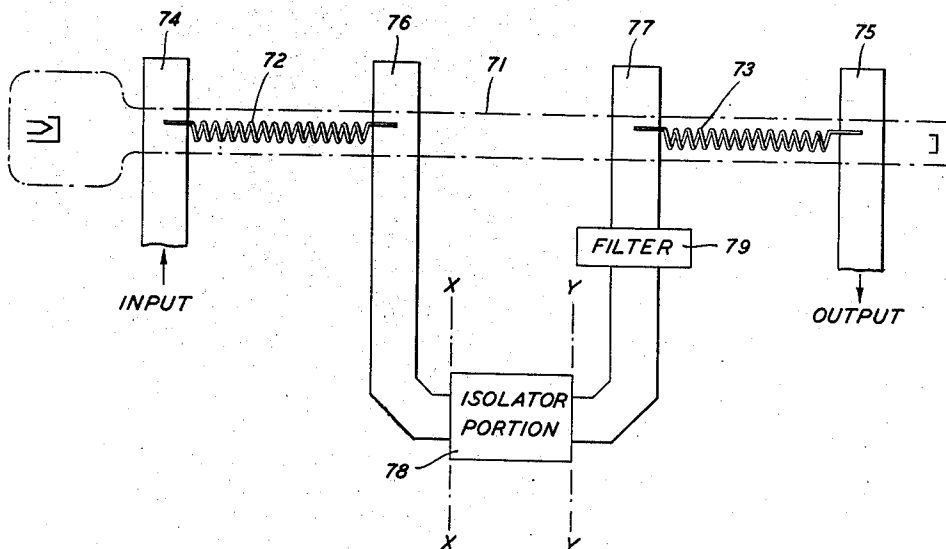


FIG. 3



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1

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TRAVELING WAVE AMPLIFIER

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Application June 17, 1953, Serial No. 362,310

4 Claims. (Cl. 315—3.6)

This invention relates to devices for amplifying high frequency electromagnetic waves and, more particularly, to traveling wave tube devices in which amplification is had through interaction between an electron stream and the high frequency electric field associated with the waves to be amplified along the transmission path of the waves.

One object of the invention is to increase the maximum power output and the efficiency to be obtained from the traveling wave tubes.

The conventional traveling wave tube includes a cathode for supplying electrons, gun electrodes for focusing the electrons and projecting them as a beam down the tube, and a collector electrode. Surrounding the beam path is an electric wave-guiding means which in one of the more common forms of traveling wave tubes comprises a helical wire. To the upstream and downstream extremities of the helix are coupled respective input and output circuits, usually comprising wave-guide circuit means, for introducing signals to be amplified and for delivering the amplified signal. As the signal propagates along the helix, its electromagnetic field interacts with the electrode beam in such manner that the beam becomes modulated and the signal grows in strength.

In these traveling wave tubes it has been extremely difficult to secure accurate impedance matches between the guiding means and the signal input and output circuits over the broad frequency range in which a traveling wave tube operates. Components of the radio frequency signal tend to be reflected back and forth along the guiding means. Since the components traveling in the direction of the electron flow are amplified, the reflections may produce oscillation of the tube and result in tube instability. Further, if such components are reflected back to the input end of the traveling wave tube circuit out of phase with the incoming signal wave, the wave is degraded resulting in what has been termed long line impedance effects. In the past, instability and long line impedance effects have been effectively reduced by inserting loss or attenuation into the traveling wave circuit either concentrated at one point along the guiding means or distributed in a certain way along its length. These techniques are fully disclosed in the copending applications of J. R. Pierce, application Serial No. 640,597, filed January 11, 1946, which issued April 28, 1953 as United States Patent 2,636,948, and C. C. Cutler application Serial No. 168,202, filed June 15, 1950. In general, the effect of this loss was to attenuate the backward traveling waves below the point of operation and instability. However, this desirable effect was also accompanied by impaired amplification of the forward traveling wave as a result of the consequent resistance loss which in turn resulted in reducing the maximum power output and the efficiency of the traveling wave tube.

It is, therefore, a further object of the invention to avoid the traveling wave tube oscillations without incurring heavy resistance losses for the forward traveling wave along the guiding means.

2

In accordance with one feature of the present invention, the guiding means helix is divided into at least two sections in the upstream and downstream portions of the beam path, respectively. Between these sections is interposed an isolator or a one way transmission device comprising a Faraday-effect or antireciprocal rotating element with associated polarization-selective connections. Thus, infinite attenuation is introduced to the reflected backward traveling wave without introducing substantial attenuation to the amplified forward traveling wave. It is thus possible to substantially reduce the amount of distributed loss that must be located along the resulting two sections in order to prevent oscillations and, therefore, to reduce the total amount of attenuation suffered by the forward traveling wave.

Certain features of the combination to be disclosed are claimed in the copending application of G. H. Robertson, Serial No. 409,806, filed February 12, 1954, which issued July 2, 1957, as United States Patent 2,798,203. Related features are disclosed and claimed in the copending application of R. Kompfner and H. Suhl, Serial No. 362,177, filed June 17, 1953.

These and other objects, the nature of the present invention, and its various features and advantages, will appear more fully upon consideration of the various specific illustrative embodiments shown in the accompanying drawing and analyzed in the following detailed description of these drawings.

In the drawings:

Fig. 1 is a perspective view of a traveling wave tube device having a two section helix and including an isolator portion interposed between the two sections in accordance with the first specific embodiment of the invention;

Fig. 2 illustrates a second embodiment of the invention by showing in perspective view a modified isolator portion which may replace the isolator components of Fig. 1 between the cross-sections $x-x$ and $y-y$ thereof; and

Fig. 3 illustrates schematically a third embodiment of the invention in which an isolator, such as the isolator portion of Figs. 1 or 2, may be connected externally to a traveling wave tube.

Referring now particularly to Fig. 1, there is shown an illustrative embodiment of a conventional traveling wave tube amplifying device to be used as an amplifier for ultra-high frequencies modified in accordance with the present invention. The arrangement shown comprises an electron beam tube including an evacuated envelope having in the order named from left to right an enlarged electrode portion 12, an elongated portion 11, an enlarged isolator portion 10 and a second elongated portion 11'. The envelope is constituted of a low loss insulating material such as quartz or glass which in practice may be constructed in sections to be later fused or otherwise joined together.

The electrode portion 12 is provided with a means such as a known type of electron gun for producing an electron beam. The combination shown comprises a heater 13, which is supplied with energy by a source 14, a cathode 15 connected to the circuit of the heater 13, and a focusing electrode 16 having a configuration which provides field patterns suitable to accelerate and focus the electron stream when the electrode is biased to a suitable potential. The electron stream is further concentrated and guided along an axial path by a longitudinal magnetic field formed by a coil 25 which is energized by a source 19 through a rheostat 20. The strong magnetic field formed by the coil 25 serves also to prevent the deviation of the electron stream from the desired path by an outside magnetic influence and as a magnetizing field for certain other components to be

described in detail hereinafter. An anode 21 serves to collect the electrons arriving at the end of the envelope 11'.

In the operation of the device, the focusing electrode 16 is maintained at a potential of the order of 1,500 to 2,000 volts above that of the cathode 15 by a potential source conventionally represented as a battery 22. A conductor 23 serves to connect the negative pole of the potential source 22 to the cathode 15 while a conductor 24 serves to connect a positive pole to the focusing anode 16 and to the helix 17-18. The collector anode 21 is connected through a conductor 26 to apply a positive potential somewhat lower than that of electrode 16 for the purpose of decelerating the electron stream before it strikes anode 21. This is by no means essential to the operation of the device and the collector may be maintained at a higher potential.

Surrounding the beam path is an electric wave-guiding means. In one of the more common forms of conventional traveling wave tube, this means comprises a helical wire extending between an input circuit and an output circuit and maintained at the direct current potential of the focusing electrode. According to the present invention, the usual helix is divided into two portions, an upstream section 17 and a downstream section 18, located respectively in envelope portions 11 and 11'. As conventionally employed in the traveling wave tube art, the terms "upstream" and "downstream" have reference to the direction of the flow of the electron stream in the beam, "upstream" indicating proximity to the electron gun and "downstream" indicating proximity to the anode. The input end of section 17 is coupled to an input circuit, conventionally represented on Fig. 1 as a wave guide 27 of rectangular cross-section which is coupled to a source 28 of signal waves to be amplified. Envelope 11 is inserted transversely through guide 27, coupling between the guide and helix 17 being achieved by means of an input coupling strip 31 connected to the end of helix 17. There is provided a cylindrical metallic section 32 which supports the input coupling strip and cooperates with input guide 27 to form an open-circuited transmission line.

Thus, when guide 27 is excited so as to produce a mode of wave propagation having an electric field parallel to input coupling strip 31, a corresponding wave is generated along the coupling strip and imparted to helix 17. The wave then travels along the circumference of helix 17 at a speed approximating that of light but at a linear velocity along the axis of the helix which is smaller in proportion to the ratio of the distance between turns to the circumference per turn of the helix. In usual practice the diameter of the helix is a small fraction of a wavelength to provide interaction by inductive coupling between the wave propagating along helix 17 and the electron beam. Initially, this produces waves of charge density and velocity in the electron stream. As the wave and the electron stream travel along the axis of the helix, the wave on the helix travels at a different velocity from the electrons forming the modulated electron stream, and the electrons impart energy to the wave in a manner which increases the amplitude of the wave at a rapidly increasing rate.

The downstream end of helix 17 is terminated in a transformer means 42 for converting the amplified wave on helix 17 into a linearly polarized wave. Numerous devices may serve to perform this conversion function, but as one specific example, transformer 42 may be a cylindrical metallic member substantially one-quarter wavelength thick having a rectangular iris 43 extending through the center. Iris 43 should have a wide dimension of substantially one-half wavelength and a narrow dimension approximately one-half of the wide dimension in order to accept and support plane polarized dominant mode waves for which the electric vector, which deter-

mines the plane of polarization of the wave, is parallel to the short side of the iris.

In order to make the physical connection from the small diameter of helix 17 to the relatively larger dimensions of iris 43 and to improve the impedance match therebetween, the last several turns 30 of helix 17 are increased in pitch, and increased in diameter from the small diameter of helix 17 to a diameter approximately equal to the wide dimension of iris 43. The end 39 of helix 17 is brought into a plane parallel to the transverse plane of iris 43, parallel to the narrow dimension thereof, and sufficiently to one side of the center of the wide dimension of the iris so as not to obstruct the passage of the electron beam. End 39 is fastened to the upstream face of transformer 42 at a position to one side of the iris. To further improve the impedance match between helix 17 and transformer 42, a plurality of longitudinally extending tuning probes 38 are located on the upstream face of transformer 42 around iris 43. By adjusting the lengths of probes 38 and the pitch and diameter of turns 30, the amplified traveling wave of helix 17 may be made to excite a linearly polarized wave in iris 43. Numerous other means for obtaining a connection and impedance match between helix 17 and transformer 42 may, of course, be employed.

Turning for the movement of the downstream section of helix 18, the arrangement is seen to be very similar to the upstream section 17. Helix 18 commences at transformer 44 which is similar to transformer 42 except that the iris 45 of transformer 44 is inclined at an angle of 45 degrees clockwise as viewed from the input end with respect to iris 43 of transformer 42. Linearly polarized waves in iris 45, therefore, excite an electromagnetic wave upon turn 47 of helix 18 which continues propagation to the output end of helix 18. Tuning probes 46 are located on the downstream face of transformer 44 to improve the impedance match of transformer 44 to helix 18. The wave receives further amplification during its travel along helix 18 where it is coupled by output coupling strip 34, supported by a cylindrical section 35 to output wave guide 37. The output wave guide 37 is coupled to a load circuit 41 for receiving and utilizing the amplified waves.

Interposed between the upstream section 17 and the downstream section 18 and, more particularly, between transformer 42 and transformer 44 is a one-way transmission device or isolator which allows unimpeded flow of the electron stream between the helix sections, which couples the forward traveling wave on helix 17 to helix 18, but which introduces substantial attenuation to a backward traveling wave on helix 18. Connected to transformer 42 and extending within envelope 10 is a metallic cylindrical sleeve 40 which acts as an electromagnetic wave guide of circular cross-section for linearly polarized waves. Positioned in the end of guide 40 adjacent transformer 42 is a polarization-selective attenuator comprising resistive vanes 48 and 49. Vanes 48 and 49 are diametrically disposed in guide 40 in a plane perpendicular to the electric polarization in iris 43 so as to absorb and dissipate waves having a polarization perpendicular to the plane of polarization of waves in iris 43. Vanes 48 and 49 extend from the wall of guide 40 for a distance slightly less than the radius of guide 40 so as to leave a space for free passage of the electron beam between the internal edges of vanes 48 and 49. Positioned in the end of guide 40 adjacent transformer 44 are a second pair of resistive vanes 54 and 55 diametrically disposed in guide 40 in a plane perpendicular to the electric polarization in iris 45, i. e., a plane displaced 45 degrees clockwise from the plane of vanes 48 and 49. Except for the angle of disposition, vanes 54 and 55 are identical to vanes 48 and 49. They may each comprise a thin sheet of low dielectric material, for example, polystyrene coated with a film of resistive material, for example, carbon black or may consist solely of carbon or

other resistive material. Thus, a wave polarized perpendicular to the plane of any vane will suffer only negligible attenuation, while a wave polarized parallel to the plane of the vane will induce currents in the resistive material and will be dissipated thereby.

Interposed between vanes 48—49 and 54—55 in the path of the electromagnetic wave passing therebetween in guide 40 is suitable means of the type which produces an antireciprocal or Faraday-effect rotation of the plane of polarization of these waves such that an incident wave impressed upon a first side of the rotator emerges on the second side polarized at a different angle from the original wave, and an incident wave impressed upon the second side emerges upon the first side with an additional rotation of the same angle. As illustrated by way of example in Fig. 1, this means comprises a cylindrical ferromagnetic element 50 supported axially in guide 40 by supporting rings 51 and 52 of dielectric material. Element 50 is provided with an axial hole 53 to allow passage of the electron beam.

Element 50 may be made of any of the several ferromagnetic materials which each comprise an iron oxide with a small quantity of a bivalent metal such as nickel, magnesium, zinc, manganese, or other similar material, in which the other metals combine with the iron oxide in a spinel structure. This material is known as a ferromagnetic spinel or a ferrite. As a specific example, element 50 may be made of nickel-zinc ferrite prepared in the manner described in an article "The Microwave Gyrotor," in the Bell System Technical Journal, January 1952 by C. L. Hogan and in his copending application for patent Serial No. 252,432, filed October 22, 1951, which issued May 29, 1956 as United States Patent 2,748,353. As there disclosed, this material has been found to operate satisfactorily as a directionally selective Faraday-effect rotator of polarized electromagnetic waves when placed in the presence of a longitudinal magnetizing field of strength below that required to produce ferromagnetic resonance in the material. The magnitude of rotation is approximately directly proportional to the length of the material traversed by the waves and to the intensity of magnetization of the material.

For the purposes of illustration, the magnetic field produced by coil 25 is also utilized to provide the necessary longitudinal magnetic field for element 50. The polarity of this field is such that the direction of rotation of a wave propagated from left to right through element 50 (as indicated by the arrow on the element) is clockwise in the same sense as the angle between vanes 48—49 and vanes 54—55. It should be noted, however, that element 50 may be magnetized to the proper strength alternatively by a separate solenoid, by a permanent magnet structure or may be permanently magnetized if desired.

Element 50 is adjusted to produce a 45 degree rotation of the plane of polarization for a single passage of electromagnetic wave energy. Since element 50 is subjected to this same intensity of magnetization as required for the electron beam portion of the tube, the above-described rotation is most readily obtained by choosing the length of the material comprising the element. However, if a separate magnetic field is provided for element 50, the intensity of the field may also be adjusted.

Thus, the forward traveling amplified wave of helix 17 is converted into a linearly polarized wave in iris 43 of transformer 42 and applied to guide 40. This wave travels past vanes 48 and 49 unaffected thereby inasmuch as the plane of the vanes is perpendicular to the polarization of the wave, to element 50. Element 50 rotates the wave 45 degrees in a clockwise direction, as indicated by the arrow on element 50 in the drawing. This brings the wave into a polarization perpendicular to the plane of vanes 54 and 55 past which the wave travels unaffected into iris 45 of transformer 44. The wave is then applied to helix 18 along which it travels, receiving further amplification. The wave reaches a

maximum amplitude at the output end of helix 18 and is transferred to output wave guide 37 by means of coupling strip 34. Should any component of this wave be reflected back from transformer 44 into guide 40, it would be rotated 45 degrees by element 50 in the direction of the arrow thereon, bringing the polarization of this component into the plane of vanes 48 and 49 to be dissipated by vanes 48 and 49.

A backward traveling wave on helix 18, however, excites a linearly polarized wave in iris 45 of transformer 44 polarized parallel to the narrow dimension of iris 45. This backward traveling wave travels past vanes 54 and 55 unaffected thereby inasmuch as the plane of the vanes is perpendicular to the polarization of the wave, to element 50. Element 50 rotates the wave 45 degrees in the direction of the arrow bringing the wave into the plane of vanes 48 and 49 by which it is dissipated. Should any component of the wave fail to be dissipated in vanes 48 and 49, it will be reflected in the forward direction by transformer 42 (since the polarization of these components is perpendicular to the wave polarization accepted by iris 43). The reflected components will be rotated 45 degrees by element 50 bringing them into the plane of the vanes 54 and 55 by which they will be dissipated. This results in substantially infinite attenuation to a backward traveling wave, while a forward traveling wave has been effectively coupled from helix 17 to helix 18. Thus, the input and output circuits of the amplifier are effectively isolated and the limitations imposed by disturbances due to reflections therebetween are avoided.

Should it be found necessary to add a small amount of attenuation either to helix section 17 or helix section 18 to prevent local reflections and oscillations resulting therefrom, this may be done by the techniques of the above-mentioned copending applications of Pierce and Cutler, for example by plating with low loss material a portion of the turns of helix 17 or helix 18.

Referring now to Fig. 2, a modification of the isolator portion of the traveling wave tube amplifier of Fig. 1 is shown. The isolator portion of Fig. 2 may be substituted for that portion of Fig. 1 between the sections $x-x$ and $y-y$. In so far as the components of the isolator of Fig. 2 are the same as corresponding components of Fig. 1, similar reference numerals have been employed. The modification will be seen to reside first in the fact that irises 43 and 45 of transformers 42 and 44, respectively, need no longer be aligned at the specific angle of 45 degrees. By way of illustration they are now aligned to receive wave energy of similar polarization. Axially located within guide 40 is an elongated cylinder 60 of ferromagnetic material which is similar to element 50 of Fig. 1 except that the angle of rotation may be any angle greater than 45 degrees so long as the polarization in iris 43 is rotated into the polarization of iris 45. In the particular embodiment illustrated in Fig. 2, this rotation is 180 degrees.

Cylinder 60 is supported in its axial position by two thin spiral vanes 61 and 62 of resistive material. Vanes 61 and 62 are provided with equal smooth helical twists of constant pitch so that they remain on opposite sides of element 60 and in the same diametrical plane with each other in any cross-section along their length. They commence in the end of guide 40 adjacent transformer 42 in a plane normal to the electric polarization supported by iris 43 and end in the end of guide 40 adjacent transformer 44 in a plane normal to the electric polarization supported by iris 45. Vanes 61 and 62 like vanes 48—49 and 54—55 of Fig. 1 may be constructed of thin sheets of low dielectric material coated with a film of resistive material or they may be made entirely of resistive material. In either event, the resistances of vanes 61 and 62 should be sufficiently high that their tendency to distort the wave field and shift the wave polarization by acting as guiding structures is small.

Thus, the polarization of a vertically polarized wave

introduced into guide 40 by iris 43 will be normal to the plane of vanes 61 and 62 upon the first encounter of the waves with the vanes and will be rotated by element 60 during passage down guide 40 so that the polarity of the wave remains normal to the plane of the vanes at every point along their length. The rotated waves emerge at the right in the proper polarization for acceptance by iris 45. For this passage, therefore, a minimum of wave energy will be dissipated in vanes 61 and 62.

The backward traveling wave introduced by iris 45 into guide 40 will be initially polarized normal to vanes 61 and 62 at their downstream ends. As this wave propagates in an upstream direction along guide 40, element 60 progressively rotates the polarization of the wave so that an increasingly larger component of the wave is brought into the plane of the vanes 61 and 62 to be dissipated thereby. When the wave has propagated such a distance that its total rotation is 45 degrees, the entire wave will have been brought into the plane of vanes 61 and 62 and an opportunity presented for the wave to be completely dissipated in vanes 61 and 62. Successive opportunities for dissipation are presented as any remaining wave components continue propagation in the upstream direction since each time this wave is rotated through a full 45 degrees, all components thereof are passed through the plane of the resistive material.

The arrangement disclosed in Fig. 2 of the present application is related to certain devices disclosed in the copending application of A. G. Fox, Serial No. 362,243, filed June 17, 1953, which issued August 6, 1957, as United States Patent 2,802,184.

In the above-described arrangements, in each case the isolator portion between the sections $x-x$ and $y-y$ of the discharge device has been included within the evacuated envelope 10. However, it is within the scope of the present invention to locate the isolator portion outside of the tube enclosure itself. Such an arrangement is illustrated schematically in Fig. 3. Thus, Fig. 3 shows schematically a traveling wave tube amplifier 71 having an upstream section of helix 72 and a downstream section 73. An input wave guide 74 is shown connected to the input end of helix 72 and an output wave guide 75 is connected to the output end of helix 73. Guides 74 and 75 and their connections to the respective helices may be identical to that of guides 27 and 37 of Fig. 1 described in detail above. The downstream end of helix 72 is coupled to guide 76 which may be identical to guide 75 and the upstream end of helix 73 is coupled to guide 77 which may be identical to guide 74. The other ends of guides 76 and 77 are coupled through a one-way transmission device 78 which may be substantially similar to the isolator portion between sections $x-x$ and $y-y$ of either Fig. 1 or Fig. 2. In other words, guides 76 and 77 of Fig. 3 serve the functions of transformers 42 and 44 of Fig. 1, i. e., to couple to and from the traveling wave on the helix, to convert the helical wave to and from a linearly polarized wave, and to apply the linearly polarized wave to the components of the isolator portion, now, however, located away from the tube. The electron beam of tube 71 passes straight through from helix 72 to helix 73 and does not need to pass through the components of the isolator. The arrangement of Fig. 3 also affords the possibility of including a band pass filter 79 in one or both of guides 76 and 77. If the filter 79 has a constant impedance over all frequencies within the band when viewed from the tube, it will prevent wave oscillations of the tube outside of the operating band.

In all cases, it is understood that the above-described arrangements are simply illustrative of a small number of the many possible specific embodiments which can represent applications of the principles of the invention. Numerous and varied other arrangements can readily be devised by those skilled in the art without departing from the spirit and scope of the invention. For example, the

extended wave path can be divided into more than two sections and a unidirectional transmission element inserted intermediate each pair of adjacent sections. Additionally, each section can be other than a section of helix circuit. Any of the various forms of wave propagating circuits useful for interaction with an electron beam known to workers in the art can be employed, for example, filter sections such as can be formed by coupled cavity resonators.

What is claimed is:

1. A wave amplifying device enclosed within a sealed envelope comprising a transmission path including a conductor in the form of an elongated helix, an input coupling circuit for said helix for exciting said helix with traveling electromagnetic waves, means for projecting a stream of electrons lengthwise of the helix and in the space occupied by the field of said helix, means for supporting linearly polarized electromagnetic wave energy in a plurality of polarizations including mutually perpendicular polarizations, said means being interposed in a center region of said path with adjacent portions of said helix extending on either side thereof, transition means at each end of said interposed means for coupling between said waves on an adjacent portion of said helix and waves of a predetermined linear polarization in each end of said interposed means, means for rotating wave energy propagated from one end to the other end of said interposed means from the predetermined polarization in said one end into the predetermined polarization in said other end, said rotation being antireciprocal, and means included in said interposed means for attenuating wave energy of one predetermined polarization to a substantially smaller degree than wave energy polarized perpendicular to said one predetermined polarization, said one predetermined polarization of said attenuating means being substantially parallel to the polarization of waves passing said attenuating means in the direction of said electron stream flow and thereby also perpendicular to some polarization of waves passing said attenuating means in a direction counter to said electron flow.

2. The combination according to claim 1, wherein said attenuating means comprises a vane of resistive material in at least one of said ends of said interposed means in a plane perpendicular to said one predetermined polarization in that end.

3. The combination according to claim 1, wherein said attenuating means comprises a vane of resistive material commencing in said one end of said interposed means in a plane perpendicular to said polarization in said one end and spiraling into a plane perpendicular to said polarization in said other end.

4. In combination, a traveling wave type amplifying device enclosed within a sealed envelope including a beam propagation path and a helical wire constituting a wave propagation path, said wave path extending from the upstream end to the downstream end of said beam path, a pair of transformer means coupled to said helix along the center region of said beam path, one of said means adapted to couple to and from waves on an upstream section of said helix, the other of said means adapted to couple to and from waves on a downstream section of said helix, and a one direction transmission structure interconnecting both said transformer means for isolating said upstream section from said downstream section for waves propagating in one direction along said helix, said structure including means for producing an anti-reciprocal rotation of the electric polarization of wave energy coupled by said transformer means, and resistive material located in a plane substantially parallel to the electric polarization of said rotated energy propagating in said one direction.

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