

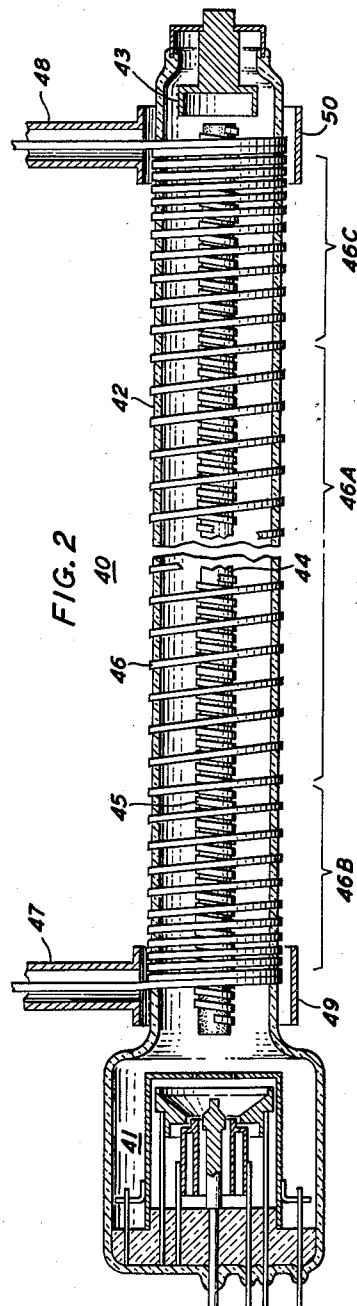
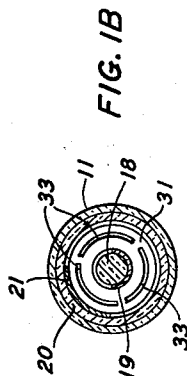
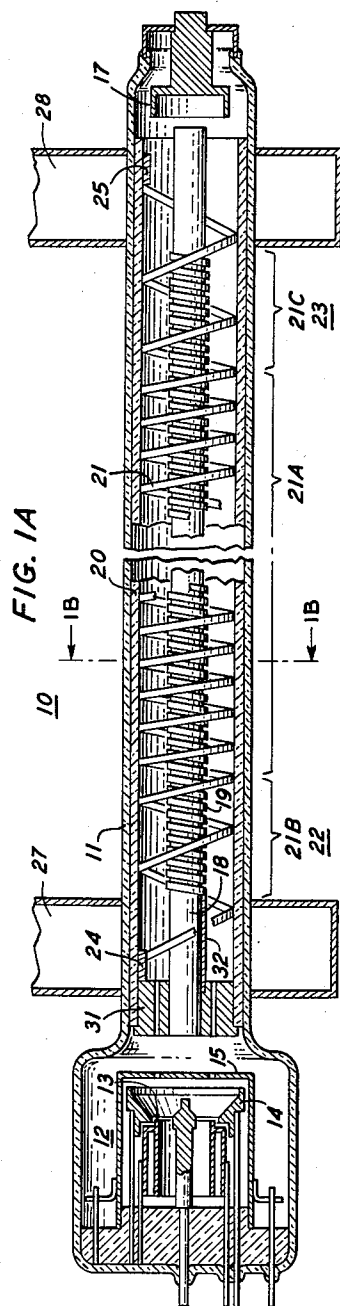
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TRAVELING WAVE TUBE

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TRAVELING WAVE TUBE

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9 Claims. (Cl. 315—3.6)

This invention relates to microwave apparatus which utilizes the interaction between a traveling electromagnetic wave and an electron beam over a distance of a plurality of operating wavelengths. Devices of this kind are now generally described as traveling wave tubes.

In a traveling wave tube, a slow wave interaction circuit is employed to propagate a traveling electromagnetic wave and an electron beam is projected longitudinally past the circuit for interaction with electric field components of the wave. The instant invention relates more particularly to a traveling wave tube which employs as the interaction circuit a pair of coaxial conductive helices of different diameters, the sense of the windings of the two helices being opposite.

In the most common form of traveling wave amplifier the slow wave circuit is designed to establish longitudinal electric field components of the traveling wave with which the electrons interact. In operation the electrons are displaced longitudinally into regions of slightly different longitudinal fields by the action of the longitudinal field, whereby they give energy up to the wave and the wave is amplified. An interaction circuit comprising a pair of coaxial helices as described above is found to be well suited for such operation provided the two helices are excited so that at corresponding axial positions the excitation on the two helices is substantially in the same phase. A mode of propagation of this kind in the circuit is known as the "in-phase" mode. In its first aspect, the invention relates to an arrangement for coupling to and from a traveling wave tube which uses a wave circuit of this form.

Another less common type of traveling wave tube, of which illustrative embodiments are described in United States Patent 2,801,361, issued July 30, 1957, to J. R. Pierce, utilizes a slow wave circuit particularly designed to establish strong transverse electric field components of the traveling wave for interaction with the longitudinally flowing electrons. In general, it is true that if the electric field of a slow traveling wave is purely transverse over a plane or cylindrical surface, it must also have a longitudinal component at regions removed from this surface. In such a transverse field traveling wave tube, it is characteristic of the mode of operation that the transverse fields set up by a slow traveling wave displace the electrons flowing longitudinally in such a surface of pure transverse field transversely into regions of longitudinal electric field, and the displaced electrons then interact with the longitudinal electric field and as a result give up energy to the slow traveling wave whereby it is amplified.

It is characteristic in a transverse field type travelling wave tube that if in the absence of a signal the electrons are confined to the plane or cylindrical surface of purely transverse field where the longitudinal field is zero, fluctuations in current density or velocity of the electrons will produce no noise power in the circuit. Accordingly, by properly focusing and collimating an elec-

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tron beam for traveling along such a plane or surface in the absence of a signal, it is possible to make the noise figure of the tube very small.

However, a serious difficulty hitherto in such transverse field tubes has been the realization therein of the required surface along which the electric field of a traveling wave will be substantially purely transverse. An interaction circuit comprising a pair of coaxial helices as described above is found to have particular promise for such operation provided that the excitation be such that at corresponding axial positions it be exactly out of phase on the two helices. Such a mode of propagation on the helices is known as the "out-of-phase" mode. With such a circuit there will exist in the interspace between the two helices a cylindrical surface along which the electric field of a wave traveling therealong is substantially purely transverse as desired. In its second aspect, the invention relates to a transverse field traveling wave amplifier which incorporates a circuit of this kind.

In practice it has proven difficult hitherto to excite a pair of coaxial helices as described in only a single one of its two possible modes, i. e., a pure mode, since the usual coupling arrangements thereto result in the excitation of a mixture of the two modes. Such dual excitation makes it impossible to realize the full advantages of each type of operation. In a transverse field amplifier, it results in a higher signal-to-noise ratio and in a longitudinal field amplifier it makes for reduced efficiency.

Because of these considerations, a specific object of the invention is to provide a coupling arrangement to a pair of coaxial helices as described which results in excitation of only a single one of its two possible modes.

It is in accordance with the invention to utilize in a transverse field tube a pair of concentric helices which have relatively similar phase retardation characteristics over the intermediate portions of their lengths, but in which along corresponding axial positions of the end portions the phase velocity characteristic of one decreases gradually relative to that of the other. In such an arrangement, a signal wave applied to the input end of the one helix establishes along the intermediate portion of the interaction circuit a transverse electric field of the desired pattern. Moreover, by such an arrangement, at the output end, the transverse electric mode wave traveling along the interaction circuit is transferred substantially completely to the one helix from which it can readily be abstracted.

It is also in accordance with the invention to utilize in a longitudinal mode tube a pair of concentric helices which have relatively similar phase retardation characteristics over the intermediate portions of their lengths but in which along corresponding axial positions of the end portions the phase retardation characteristics of one increases gradually relative to that of the other and the signal wave is applied to and abstracted from the ends of the one helix.

The invention will be better understood from the following more detailed description taken in conjunction with the accompanying drawings in which:

Fig. 1A shows in longitudinal sectional view as an illustrative embodiment of one aspect of the invention a longitudinal field concentric helix traveling wave tube;

Fig. 1B represents a transverse section of the tube shown in Fig. 1A taken along the line 1B—1B; and

Fig. 2 shows in longitudinal sectional view as an illustrative embodiment of a second aspect of the invention a transverse field concentric helix traveling wave tube.

Referring now more particularly to the drawings, in the traveling wave tube 10 shown in Figs. 1A and 1B, the various tube elements are enclosed in an evacuated envelope 11 which, for example, is of glass. Housed at

one end of the tube in the electron gun 12 which serves as the source of an annular cylindrical electron beam. The electron gun 12 is of a design well known to workers in the art and includes an electron-emissive annular cathode 13, a beam forming electrode 14, an accelerating anode 15 and various support and spacer elements. Lead-in connections provide the desired operating voltages to the various gun elements. At the opposite end of the tube, a collector electrode 17 in target relation with the cathode 13 serves to collect the spent electrons.

Axially disposed along the tube is the center support rod 18, of a suitable dielectric material such as quartz, about which is wound the inner conductive helix 19, which advantageously can be of the ribbon, or tape, type wound flat. The inner helix advantageously has a pitch which is uniform along its length. The two ends of the inner helix are advantageously terminated to be substantially reflectionless. Supported by the walls of the envelope 11 is a tubular cylindrical support member 20, of a suitable dielectric material such as quartz, within which in turn is supported the outer conductive helix 21, for example, also of ribbon type wound flat.

The outer helix 21 advantageously is wound in a direction opposite to that of the inner helix 19. The pitch of the outer helix 21 is uniform along an intermediate portion 21A of the helix length a plurality of operating wavelengths long and is such to provide in the absence of the inner helix a characteristic phase velocity to waves propagating therealong which is substantially equal to the characteristic phase velocity of waves propagating along the uniform pitch inner helix 19 in the absence of the outer helix. It is usually unnecessary that such phase velocities be exactly equal although any appreciable difference results in reduced coupling. This intermediate portion of the circuit is the region of the principal interaction with the electron flow and for this reason preferably has a uniform phase velocity characteristic. When very high output levels are desired, it may be advantageous to reduce the phase velocity characteristic at the output end of this intermediate portion of the interaction circuit to match the reduced average velocity of the beam. Restated in somewhat different language, in the tube depicted the retardation characteristics of the inner and outer helices viewed alone are substantially identical with one another along the intermediate portions of the two helices. However, in accordance with a characteristic feature of this aspect of the present invention, the pitch of the outer helix 21 increases gradually with distance out towards its two ends 21B, 21C to provide therealong a phase velocity characteristic which exceeds that of the inner helix at corresponding axial positions by a growing amount. These end regions 22, 23 along which the phase velocity characteristics of the two helices are dissimilar serve as the energy exchange regions between the two helices. In practice, these regions may be longer than indicated in the drawing.

At the electron source or input end, the corresponding energy exchange region 22 serves to convert the wave propagating solely on the outer helix 21 to a wave propagating in a longitudinal electric mode along the two helices.

At the collector or output end, the corresponding energy exchange region 23 serves to convert the longitudinal mode wave traveling along the two helices into a wave propagating solely on the outer helix from which it can be abstracted conveniently for utilization.

It is to be understood that what is important is to achieve a relative change of the correct sign in the phase retardation characteristics of the two lines at corresponding axial positions over the energy exchange regions 22, 23. For example, it is possible to achieve the desired effect at each end by keeping the pitch of the outer helix 21 uniform over the energy exchange region and decreasing the pitch of the inner helix 19 with distance out towards the end over the energy exchange region, or

even by varying the pitch of both helices simultaneously so long as the pitch of the outer helix increases with respect to the inner helix with distance out towards the end.

The input and output connections between the two ends of the outer helix and external transmission lines can be made in any of the ways known to workers in the art for coupling to a helix. In the illustrative embodiment depicted, at each end the outer helix is connected to one of the two coupling strips 24, 25. The input coupling strip 24 is supported in field coupling relation within the hollow rectangular waveguide 27 which has its narrow side walls apertured for passage there-through of the tube. The input waveguide 27 is coupled to a source of signal energy which produces a mode of propagation therein having an electric field vector parallel to the coupling strip 24. A corresponding wave is thus generated along the coupling strip and imparted to the outer helix 21 for travel along the interaction circuit. The region of increased pitch 21A of the outer helix 21 adjacent the input coupling strip 24 provided for effecting the energy exchange with the inner helix 19 also serves inherently to improve the match between the relatively high impedance of the coupling strip 24 and the relatively low impedance of the outer helix 21. It is this consideration which makes it advantageous in this embodiment to vary over the energy exchange region the pitch of the outer helix 21 to which the coupling connection to an external transmission line is to be made. It is characteristic of the coupling arrangement described that the desired excitation is achieved without the need for passing through the tube envelope any conductor carrying radio frequency currents. This is of considerable practical importance.

The output coupling strip 25 is shown coupled in an analogous manner to the output waveguide 28.

The outer helix 21 advantageously is extended at its two ends somewhat beyond the length of the inner helix 19 to provide an isolated single helix region at each end to be coupled by way of the coupling strips to the input and output waveguides. It is feasible to extend the inner helix 19 to be coextensive with the full length of the outer helix 21.

It is to be understood that other arrangements can be utilized to couple the ends of the outer helix to external transmission lines. In particular, each end of the outer helix 21 can be connected to the inner conductor of a coaxial transmission line, the outer conductor of which can be connected to a shield surrounding a portion of the helix 21.

The two helices 19, 21 are advantageously maintained at the same positive D.-C. potential relative to that of the cathode 13 to provide a purely longitudinal accelerating electrostatic field to the electrons traveling through the interspace. To this end, a cylindrical conductive sleeve 31 is provided at the input end of the wave circuit which fits between the central support rod 18 and the outer support member 20. The sleeve 31 connects to the inner helix 19 by way of extension arm 32 and to the outer helix 21 by way of the coupling strip 24. The sleeve 31 is thereafter connected by suitable lead-in conductors, not shown, to a suitable voltage supply which provides the accelerating voltage. The accelerating voltage is chosen to provide a longitudinal velocity to the electrons suitable for interaction with the traveling in phase wave.

The sleeve 31 also serves another function. It is provided with three narrow openings 33 as shown in Fig. 1B which serve as the path of flow of the annular beam there-through. These openings are aligned with the cathode 14 and the cylindrical potential surface in the interspace between the inner and outer helices 19 and 21 corresponding to that of substantially pure longitudinal field. This potential surface lies approximately midway between the cylindrical surfaces defined by the two helices. Accordingly, the sleeve 31 serves to intercept the electrons which

are not properly aligned with this surface and which, accordingly, would set up noise on the circuit.

To keep the annular beam cylindrical in its flow, with a minimum of spurious transverse components which would displace the beam from the potential surface of pure longitudinal field, it is important to provide some focusing action on the beam. Various arrangements are known to workers in the art for this purpose. Typically the tube may be immersed in a longitudinal uniform magnetic field. In the interest of simplicity, no focusing equipment has been shown here.

It is also usually desirable to make the circuit lossy, at least in the backward direction, to minimize the effect of reflections of wave energy at the output coupling connection.

The general principles of providing selective energy exchanges between coupled transmission lines by utilizing variations in the retardation characteristics of at least one of the coupled lines over the energy exchange region are described in a copending application Serial No. 465,578, filed October 29, 1954, by J. S. Cook. It is there pointed out that to excite selectively the faster in-phase mode characteristic of a pair of coupled helices of this kind, the helix having initially the faster characteristic phase velocity should be supplied with the input wave, and alternatively to excite the slower out-of-phase mode the helix having the slower phase velocity should be supplied with the input wave. In further accord with such principles, it is advantageous for achieving the desired energy exchange to make the coupling region at least several "beat" wavelengths long. As is described more fully in United States Patent 2,811,673, issued October 29, 1957, of R. Kompfner, a wave traveling along one of two coupled helices having substantially the same phase velocity characteristic propagates with a velocity only slightly different from that of the wave on an identical uncoupled helix, but its amplitude now varies sinusoidally both with distance and time, exhibiting a phenomenon which is there called "spatially beating" and which is characterized by a "beat" wavelength. In the practice of the present invention, the length of the energy exchange regions necessary to divide the energy equally between the two helices may be shortened if in addition to varying the phase retardation characteristics therealong, there is also varied in an appropriate manner the coupling between the two helices as by varying the separation therebetween. The general principles of such arrangements are set forth in a copending application Serial No. 465,579, filed October 29, 1954, by A. G. Fox. By this expedient there is made possible a shortening of tube length at the expense of an increase in complexity of fabrication.

It may in some instances be desirable to maintain the characteristic impedance of the inner and outer helices substantially uniform and equal to one another over the coupling region while at the same time providing the desired relative change in retardation characteristics. Various arrangements for this purpose will be obvious to workers in the art. Typically, the impedance of the outer helix may be kept uniform over the energy exchange region 21B by surrounding it with a conductive cylinder.

It is also possible to introduce an input wave into the interaction circuit by exciting the inner helix from an external transmission line. For example, the inner helix may be connected to the inner conductor of a coaxial transmission line which connects to the signal source. In such a case, the relative pitches of the two helices over the input energy exchange region should be such that the retardation characteristic of the inner helix increases relative to that of the outer helix with distance towards the end. At the output end, wave energy can be abstracted from the tube by coupling to the inner helix in an analogous manner. Moreover, it is possible to couple the external transmission line to the inner helix at one end and to the outer helix at the other end provided appropriate modifications are made.

It is characteristic of the tapered coupling regions of the kind described that had the retardation characteristic of the outer helix been decreased gradually from a high value at its point of signal excitation to a smaller value at the point where its retardation characteristic becomes equal to that of the inner helix, the signal power would have instead been divided equally and out-of-phase between the two helices at corresponding axial positions along the intermediate portion of equal retardation characteristics. Accordingly, a substantially pure transverse electric field of the traveling wave would be established in the interspace between the two helices.

Fig. 2 illustrates a tube 40 which utilizes as the interaction circuit a pair of concentric helices excited to set up a traveling electromagnetic wave which has a transverse electric field vector for interaction with the electron flow. An electron gun 41 which provides an annular beam of electrons is housed at one end of the tube envelope 42 and a collector 43 at the opposite end of the tube serves to collect the spent electrons. A center rod 44 of insulating material serves as the support for the inner helix 45 of the concentric pair. The pitch of the inner helix 45 is uniform along its length. Supported by the outer surface of the envelope is the outer helix 46 of the concentric pair. The outer helix 46 advantageously has an intermediate region 46A a plurality of operating wavelengths long of uniform pitch along which its characteristic phase velocity is substantially equal to that of the inner helix and end portions 46B and 46C which serve as the energy exchange regions. In such portions the pitch decreases with distance towards its end to a value which results in a characteristic phase velocity considerably slower than that along the inner helix. At its two ends, the outer helix is electrically connected to the inner conductors of coupling coaxial connectors 47 and 48. The outer conductors of the coaxial connectors are connected to conductive shields 49, 50 which surround a few end turns of the outer helix. The inner helix is extended at each end beyond the end of the outer helix where it is made substantially reflectionless by a resistive termination formed by spraying lossy material 51 on the support rod 44. As discussed above in connection with the longitudinal field tube of Fig. 1, it may be desirable in some instances that such phase velocity may be desirable in some instances that such velocity characteristics though uniform need not be exactly equal for the two helices. The velocity of the beam is adjusted by a suitable D.-C. accelerating potential on the helices to have a velocity therepast substantially equal to that of the traveling out-of-phase wave. In some instances, it may be desirable to coat the inner surface of the tube envelope with a thin layer of stannic oxide and apply the accelerating potential thereto. In the interest of simplicity, a showing of the lead-in conductors by which the accelerating potentials are applied to the helices has been omitted here.

By an arrangement of this kind, input wave energy supplied from the coaxial connector 47 is applied initially to the outer helix. Then, by reason of the presence of the input energy exchange region corresponding to the end region 46B of the outer helix 46, the input wave energy is divided equally and out-of-phase with the inner helix 45. That the waves on the inner and outer helices are equal and out-of-phase at corresponding axial positions will serve to provide a substantially pure transverse electric field in the interspace region between the two helices. Interaction with such a substantially pure transverse electric field makes possible enhanced efficiency as described above. At the output end, the effect of the presence of the output energy exchange region corresponding to the end region 46C of the helix 46 is that the power on the two helices is combined into the outer helix 46 from which it is transferred to the output coaxial connector 48.

In operation, the annular electron beam projected from

the electron gun is made to flow longitudinally through the interspace region in field coupling relation with the transverse electric field. To this end, it will generally be desirable to provide focusing of some kind for maintaining the electron flow cylindrical in its passage through the interspace region. Such focusing can be provided, for example, by a longitudinal magnetic field. It also will usually be desirable to use a cylindrical sleeve such as sleeve 31 of Fig. 1A to properly align the electrons with the cylindrical surface between the two helices corresponding to that of substantially pure transverse field. Additionally, it is usually desirable to increase the loss in the backward direction in the circuit both to minimize the effects of reflections and to insure stability against backward wave oscillators when the operation is at high power levels.

Moreover, as in the previously described embodiment, since only relative retardation characteristics along the energy exchange regions are important, it is possible for achieving the desired effect to vary the pitch of the outer helix while keeping the pitch of the inner helix uniform or to vary the pitch of each of the two helices over the energy exchange regions.

Alternatively, external transmission line connection may be made to an end of the inner helix 44, which necessitates a reversal in sign of the change in relative retardation characteristics over the corresponding energy exchange region.

Moreover, it is unnecessary in a longitudinal mode tube of the kind shown in Fig. 1 to project the electron beam in the interspace between the two concentric helices. In particular, it is feasible to utilize a solid electron beam projected axially through both helices.

It is to be understood that the various illustrative embodiments which have been described are merely illustrative of the general principles of the invention. Various modifications thereof may be devised by a worker skilled in the art without departing from the spirit and scope of the present invention.

What is claimed is:

1. In combination, means forming an electron beam, an interaction circuit for propagating a traveling wave in field coupling relation with said beam comprising a first pair of coaxial counterwound helices, and means for establishing a normal mode on said first pair of helices comprising a second pair of helices which form an extension of the first pair of helices and means for launching a traveling wave entirely on only one of said second pair of helices for subsequent division of the wave energy between said first pair of helices.

2. In combination, means for providing an electron beam, a first helix of substantially uniform pitch coaxial with the electron beam, a second helix coaxial with said first helix and having coupled to the first helix an intermediate portion of substantially uniform pitch and an end portion of at least several turns in which its pitch varies with distance in from its end and an external transmission line disposed for launching a traveling wave substantially entirely in only one of said two helices for subsequent division of the wave energy between the pair of helices for establishing a normal mode on the two coupled helices.

3. In a transverse field traveling wave tube, means for providing an annular electron beam, a first helix coaxial with the electron beam, a second helix coaxial with said first helix and having coupled to the first helix a major intermediate portion of substantially uniform pitch and an end portion of at least several turns in which its pitch varies with distance in from its end to its substantially uniform value, one of the two helices being within the beam and the other without the beam, and an external transmission line disposed for launching a traveling wave substantially entirely on only one of said two helices for

subsequent division of the wave energy between the two helices for establishing an out-of-phase mode on the two helices.

4. In a transverse field traveling wave tube, means for providing an annular electron beam, a first helix of substantially uniform pitch coaxial with and enclosed by the electron beam, a second helix coaxial with said first helix and surrounding the electron beam and having coupled to the first helix a major intermediate portion of substantially uniform pitch and an end portion of at least several turns in which its pitch increases with distance in from its end to its substantially uniform value, and a transmission line coupled to said second helix for launching a traveling wave substantially entirely on said second helix for subsequent division of the wave energy between the two helices for establishing a normal mode on the coupled helices.

5. A transverse field traveling wave tube according to claim 4 which further includes an envelope which encloses the first and second helices and excludes the transmission line.

6. In a traveling wave tube, means for providing an electron beam, a first helix of substantially uniform pitch coaxial with the electron beam and a second helix coaxial with said first helix and having coupled to the first helix an intermediate portion of substantially uniform pitch and an end portion of at least several turns in which its pitch decreases with distance in from its end to a substantially uniform value, and a transmission line disposed for launching a traveling wave substantially entirely on only said second helix for division of the wave energy between the two helices.

7. A traveling wave tube according to claim 6 characterized in that the second helix surrounds the first helix and the transmission line is coupled to said second helix for launching the traveling wave thereon for subsequently establishing an in-phase mode on the coupled helices.

8. In combination, means forming an electron beam and means for propagating a traveling wave in field coupling relation with the beam comprising a coupled pair of counterwound coaxial helices of different diameters characterized in that along a substantial intermediate common portion of the axis the difference in characteristic phase velocities of the two helices is substantially uniform therealong and along a common end region corresponding to at least several turns of each helix the difference in characteristic phase velocities of the two helices varies with distance toward the end from said substantially uniform value to a substantially different value, and means for launching a traveling wave entirely on only one of the two helices for subsequent division of the wave energy between the pair of helices.

9. In combination, means forming an electron beam and means for propagating the traveling wave in coupling relation with the beam comprising a coupled pair of counterwound coaxial helices of different diameters characterized in that along a substantial common intermediate portion of their axis the two helices have substantially equal characteristic phase velocities therealong and along an end portion corresponding to at least several turns of each helix the difference in characteristic phase velocities of the two helices varies with distance toward the end from substantially zero to a significant value, and means for launching a traveling wave entirely on only one of the two coaxial helices for subsequent division of the wave energy between said pair of helices.

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