July 7, 1959 A. K. WING, JR., ET AL 2,894,168

DIRECTIONAL POWER DIVIDERS

Filed Nov. 20, 1953 2 Sheets-Sheet 1

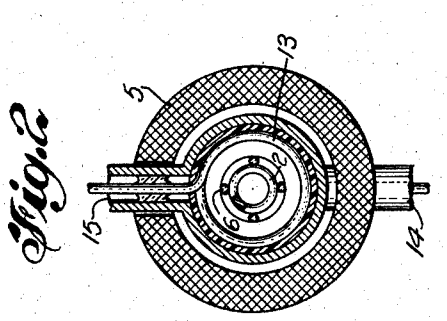


Fig. 2

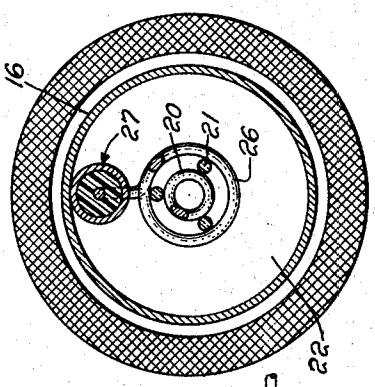


Fig. 4

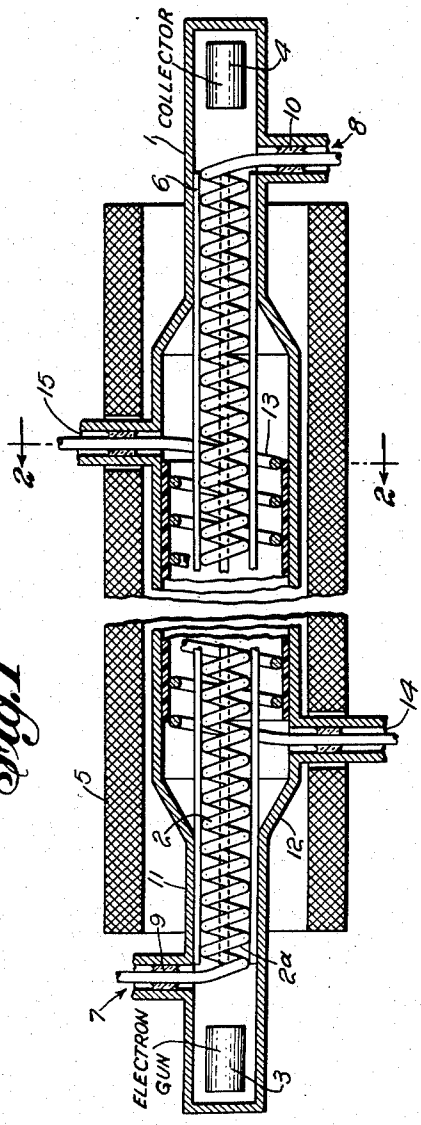


Fig. 1

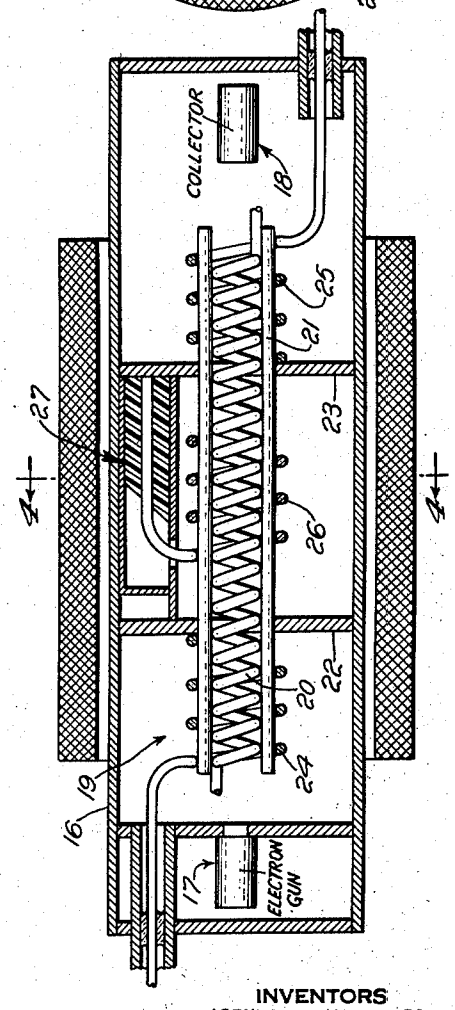


Fig. 3

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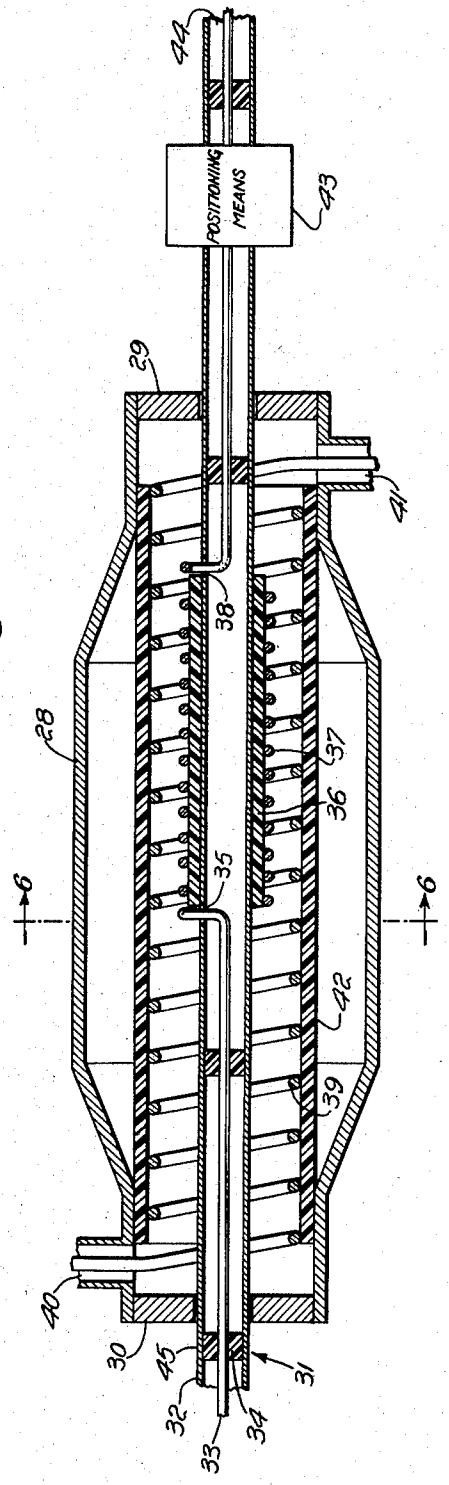


Fig. 5

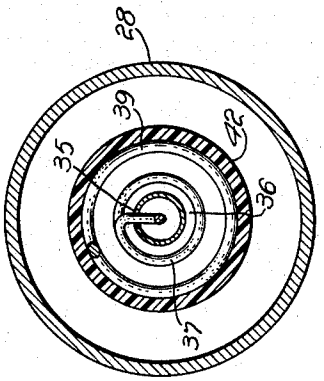


Fig. 6

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DIRECTIONAL POWER DIVIDERS

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Application November 20, 1953, Serial No. 393,404

3 Claims. (Cl. 315—3.6)

This invention relates to radio frequency directional power dividers and more particularly to coupled helical radio frequency transmission lines employed as broadband directional power dividers.

Wave guide type power dividers including rectangular waveguides and coaxial lines are well known in the art as means for providing calibrated pickup probes, directional couplers, bifurcated lines, and branched lines useful in monitoring transmitted radio frequency energy, mixing signals and so forth employing the normal radio frequency "plumbing" in the UHF and microwave frequency ranges. While these devices are satisfactory for their intended uses in these frequency ranges they tend to be physically large and limited to some extent in bandwidth capabilities. This latter disadvantage becomes rather important to those working in the traveling wave electron discharge device field, since it is desirable to be able to handle microwave energies which are inherently broader in bandwidth than the bandwidth handling capabilities of the usual waveguide type power dividers.

It is well known that helical radio frequency transmission lines, as employed in traveling wave electron discharge devices for the propagating structure therein, have a low phase velocity as compared to waveguide type radio frequency transmission lines. This inherent low phase velocity means that for a given electrical length, in terms of wavelengths or electrical phase, helical line radio frequency circuit elements are physically smaller and more compact than corresponding circuit elements formed with waveguide transmission lines. It is further known that helical radio frequency circuits may be made to have an extremely broadband frequency handling capability.

Therefore, an object of this invention is to provide compact, broadband directional power dividers suitable for employment in connection with traveling wave electron discharge device techniques.

Another object of this invention is to provide coupled helical radio frequency transmission lines for employment as broadband directional power dividers.

Still another object of this invention is the provision of a main wave propagating structure and a second wave propagating structure in coaxial, coupled relation to said main propagating structure, both of said structures being enclosed within an envelope to form a traveling wave device having directional power dividing properties.

A feature of this invention is the provision of a coupler structure coaxial of the main wave propagating structure of the type employed in a traveling wave electron discharge device enabling the monitoring of the energy flowing in said main propagating structure.

Another feature of this invention is the provision of a main wave propagating structure, a coupler device coaxial of said propagating structure and positioning means associated with said coupler device to position said coupler axially with respect to said propagating structure enabling the achievement of an energy wave phase shift.

Still another feature of this invention is the provision

of a phase shifting device including a main wave propagating structure having a helical configuration and a coupler helix coaxial of said propagating structure wherein the helical configuration of said coupler is a continuation of the center conductor of a coaxial line disposed on the axis of said propagating structure and means to position said coupler helix longitudinally with respect to said wave propagating structure to achieve a phase shift in the energy coupled from said wave propagating structure.

Further features of this invention include the provision of a coupler helix associated with each extremity and the central position of the wave propagating structure of a traveling wave electron discharge device. The coupler helices at the extremities are employed to couple radio frequency energy into and out of the wave propagating structure respectively, while the coupler helix in the central position thereof, due to its directional properties, is utilized to suppress reflected waves on said propagating structure.

The above-mentioned and other features and objects of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a longitudinal sectional view of a traveling wave electron discharge device illustrating an embodiment following the principles of this invention;

Fig. 2 is a cross-sectional view taken along line 2—2 of Fig. 1;

Fig. 3 is a longitudinal sectional view of a traveling wave electron discharge device illustrating another embodiment in accordance with this invention;

Fig. 4 is a cross-sectional view taken along line 4—4 of Fig. 3;

Fig. 5 is a longitudinal sectional view of a phase shifting device in accordance with this invention; and

Fig. 6 is a cross-sectional view taken along line 6—6 of Fig. 5.

Referring to Figs. 1 and 2, there is illustrated a traveling wave electron discharge device comprising essentially an outer non-magnetic metallic conductive envelope or shell 1 surrounding a helical type wave propagating structure 2. At one end of envelope 1 is located a suitable electron gun 3 for furnishing a concentrated stream of electrons which pass axially through the interior of helical conductor 2 for collection at a collector electrode 4 disposed at the opposite end of envelope 1. The electron gun 3 and collector 4 may take any of the known configurations having electrical properties suitable for this application. The various electrode potentials and means for applying them have received extensive treatment in the prior art and as a result are omitted in the drawings of this application to simplify the figures thereof to more clearly illustrate the structural details for achieving the desired directional power dividers in accordance with the principles of this invention.

The traveling wave electron discharge device is shown to have associated therewith a means 5 for producing a magnetic field whose lines of flux are parallel to the longitudinal axis of the tube for focusing and confining the electron beam parallel to the axis of the tube to enhance the interaction between the electron stream and broadband radio frequency energy conducted along the helical path of conductor 2. Means 5 may be a solenoid so configured that the desired magnetic field is developed or it may comprise a permanent magnet type electron-optical device for development of the desired axial magnetic field.

Wave propagating structure 2 is illustrated as being supported by dielectric rods 6 appropriately positioned about the circumference thereof to maintain structure 2 in a rigid, non-movable condition. Structure 2 is further

illustrated as having an input terminal 7 disposed adjacent the electron gun 3 for launching broadband radio frequency energy onto the wave propagating structure 2. As the radio frequency energy is conducted along helix 2, interaction with the electron stream occurs and the amplified energy is conducted from helix 2 to output terminal 8 disposed adjacent said collector 4. Input terminal 7 and output terminal 8 are provided with glass beads 9 and 10, respectively, to assure a vacuum tight envelope 2.

As is known, the characteristic impedance of a helical propagating structure, such as structure 2, is of the order of several hundred ohms while radio frequency transmission lines of the coaxial type may be of the order of 50 ohms, therefore, it is necessary to provide matching sections at both the input and output portions of the traveling wave discharge device capable of matching the 50 ohm transmission lines 7 and 8 to the input and output respectively of the helical propagating structure 2. Such a matching structure is described in detail in the copending application, Serial Number 346,086, filed April 1, 1953 in the name of J. H. Bryant, entitled "Radio Frequency Matching Devices," now U.S. Patent No. 2,803,777. The matching structure disclosed therein includes a conducting surface 11 included as a portion of the envelope in close proximity to the helically wound structure 2*a*, an extension of the main propagating structure 2. The detailed description of this arrangement is covered in the above-mentioned copending application, but it is well to point out here that the close proximity of conducting surface 11 and helix 2*a* provide an impedance of approximately 50 ohms, for coupling to the 50 ohm radio frequency transmission line 7. The impendance transfer between the 50 ohm impedance level and the several hundred ohm impedance level of the main propagating structure is provided by gradually increasing the diameter of the conducting cylinder as illustrated at 12. The output matching section is substantially identical to the input section just described and provides the desired impedance match between the radio frequency transmission lines and the helical propagating structure as fully described in the above-identified copending application.

In accordance with the principles of this invention, a coupler helix 13 is provided in a coaxial relation with wave propagating structure 2 having energy input and output means as indicated at 14 and 15. By proper termination and utilization of terminals 14 and 15, and the interacting relationship existing between the fields of the coupling helix 13 and the main propagating structure 2, it is possible to provide a number of circuit elements such as directional couplers, power monitors, phase shifters, terminations and matching elements.

Considering just the propagating structure 2 and the coupling helix 13 with their associated input and output terminals such as indicated at 7 and 8, 14 and 15 respectively, the general arrangement for directional radio frequency power dividers may be discussed. Assume that a quantity of radio frequency power is fed into terminal 7 of propagating structure 2 and assume that terminals 14, 15, and 8 are terminated in matched loads. Due to the coupling relationship existing between propagating structure 2 and coupling helix 13, a portion of this radio frequency power will appear at terminal 15 of the coupler helix with the remainder of the power, neglecting losses in the propagating structure, appearing at terminal 8 of propagating structure 2. Due to the electromagnetic field interaction between the propagating structure and couplin helix 13, no power will appear at terminal 14 of the coupler helix. The converse statement may also be made; namely, power fed into terminal 8 of the main helical propagating structure 2 would appear at terminals 7 and 14, with no power appearing at terminal 15.

In the embodiment of Fig. 1 and the remaining figures, cognizance must be taken of the pitch direction, that is, the direction of relative winding of main and coupler helices. For some applications, the direction will be the same for both helices and for other applications the two helices should have opposite pitch directions, depending on factors which include primarily the degree of coupling. The proper choice of the pitch direction to use for each helix for a given application may be arrived at any one qualified in microwave circuits and electromagnetic theory. However, it should be kept in mind that the degree of interaction for coupling between the two helices depend upon the ratio of radii and the phase velocities of the two helices. To gain insight into the merits of pitch direction for the two helices, it may practically be said that if the two coupled helices have the same pitch direction, the coupling is magnetic only, while for helices wound in the opposite direction the coupling is both electric and magnetic. For maximum interchange of power between two helices per unit axial distance, the helices should be wound in opposite direction, that is, having opposite pitch direction. There may be situations, however, where one may wish to couple power gradually and will use the same pitch direction for both helices: For example, it might occur that with opposite pitch direction the axial distance for practically complete power transfer would be so short that their end effects would become objectionable.

The embodiment illustrated in Fig. 1 incorporated in an active traveling wave discharge device illustrates a power monitor therefor. For this application, the coupling between the main propagating structure 2 and the coupler helix 13 is relatively weak, with one percent or less of power on helix 2 appearing at terminal 15 of the coupler helix 13 so that the main helix is undisturbed for all practical purposes and enables the observation by means of metering the power handling capabilities of the propagating structure 2. It may be well to state at this time that this power monitoring arrangement of the voltage divider of this invention is not limited to an active traveling wave device but may be incorporated wherever there is need to measure the power handled by a passive helical structure capable of being in a coaxial arrangement with a coupling helix substantially as described herein.

Figs. 3 and 4 illustrate a traveling wave device again illustrated to be a traveling wave electron discharge device employing as circuit elements therein, coaxially coupled helices following the principles of this invention and performing in a novel manner certain desired functions heretofore achieved by complicated arrangements for power transfer and reduction of troublesome reflected wave energy along the propagating structure.

The traveling wave device of Figs. 3 and 4 essentially comprise an outer envelope 16 including therein an electron gun 17 for production of an electron beam for propagation along the axis of envelope 16 to a collector assembly 18 at the opposite end of envelope 16. Intermediate electron gun 17 and collector 18 is disposed an interaction region 19 including a helically wound wave propagating structure 20 appropriately supported by dielectric rods 21 disposed to be maintained in rigid relationship by aid of annular baffles 22 and 23.

As is common in all traveling wave electron discharge devices, it is desired to couple at the electron gun end of the interaction region 19, a radio frequency wave for passage along structure 20 whereby the desired interaction with the electron beam emitted from electron gun 17 is achieved to realize the desired amplification prior to extraction of the energy from structure 20 at the collector end thereof. Heretofore, it has been the practice to incorporate complicated and delicate impedance matching structures necessitating the proper configuration of various elements closely associated to the ends of the propagating structure 20. In accordance with the principles of this invention, there is provided a coaxial arrangement of coupling helix 24 at the electron gun end of propagating structure 20 for coupling radio frequency

energy to the main propagating structure. At the output or collector end of propagating structure 20, there is similarly provided a coupler helix 25 which is in a coupled relation with structure 20 for removing therefrom the amplified radio frequency wave. This arrangement for coupling radio frequency energy into and out of the propagating structure 20 is possible since the coupling between a main helix and a coupler helix as herein disclosed will be relatively broadband, an essential feature for the proper operation of a traveling wave electron discharge device.

The action of transmitting a radio frequency wave down the propagating structure 20 establishes, as is known, waves traveling in the reverse direction on structure 20 due to reflections at the output end of structure 20. This reflection of wave energy is undesired and will cause an unwanted oscillation to be sustained therein. Various schemes have been incorporated in a traveling wave tube to reduce this troublesome reflection, such as the application of a lossy material to the propagating structure itself or to the means supporting the propagating structure in a rigid arrangement. It has been discovered that since the coupling arrangement described herein has directional properties, such a coupler may be employed to suppress the reflected wave on the helix of a traveling wave tube. This is illustrated in Figs. 3 and 4 by coupler helix 26 disposed intermediate input and output couplers 24 and 25. In this arrangement, the coupler helix 26 is wound in such a direction as to couple to the reflected wave, with the power from the reflected wave being fed to the terminated coaxial line as indicated at 27. Thus, the coupling of helix 26 to the propagating structure 20 provides a novel means of substantially eliminating the troublesome reflected waves known to occur within a traveling wave electron discharge device.

Referring to Figs. 5 and 6 there is illustrated therein another embodiment utilizing the principles of coupled helices hereinabove described with particular reference to an active traveling wave electron discharge device. The embodiment of Figs. 5 and 6 illustrate an application of coupled helices to a passive arrangement operating to control the desired phase relation of energies coupled from a main propagating structure. For instance, a proper phase relation is required of the energy in the feedback path of an oscillator with respect to the oscillatory energy, such as described in the copending application in the name of J. H. Bryant, Serial No. 384,553, filed October 7, 1953, now U.S. Patent No. 2,829,252.

The coupled helix phase shifter of Figs. 5 and 6 includes an outer conducting cylinder 28 configured to provide input and output matching sections as described in connection with Fig. 1 and as disclosed in copending application, Serial No. 346,086, now U.S. Patent No. 2,803,777. Cylinder 28 is closed at both ends by annular discs 29 and 30 through which extends a coaxial transmission line 31 having an outer conductor 32 and an inner conductor 33. Inner conductor 33 is appropriately spaced from outer conductor 32 by dielectric spacers as indicated by 34.

Inner conductor 33 is caused to emerge from outer conductor 32 through aperture 35 therein, and is wound in a helical manner about outer conductor 32 but separated therefrom by dielectric spacer 36 to form a coupler helix 37. After achieving the necessary turns to form coupler helix 37 the inner conductor is returned through aperture 38, such that an inner and outer conductor relationship is again established.

Coaxial to coupler helix 37 is disposed the main propagating structure 39 of helical form having radio frequency input and output means 40 and 41, respectively, illustrated herein to be of the coaxial type, but may, of course, assume the configuration illustrated in Fig. 3. Main helix 39 is separated from the conducting surface 28 by dielectric rods or a cylindrical sleeve 42 to maintain said structure 39 in a rigid condition and also to electrically insulate structure 39 from conducting surface 28.

The coupling helix 37 which is actually the continuation of the center conductor 33 of the coaxial line 31 is caused to be positioned on the longitudinal axis with respect to the main helix 39 by positioning means 43. Positioning means 43 may comprise in its simplest form a manual movement by hand to achieve the desired phase shift caused by the relative position of the coupler helix 37 along the longitudinal axis of propagating structure 39. Another form of positioning means 43 may be a rack and pinion arrangement to appropriately position the coupler helix with respect to the main helix to achieve a desired phase shift in the energy coupled to the coupling helix 37, the output thereof utilized in an appropriate manner such as sustaining oscillations in an oscillatory system.

The means for matching from the center coaxial line 33 to the coupling helix 37 where the center conductor 33 becomes the coupling helix 37 is based on the principles described in copending application, Serial No. 346,086, now U.S. Patent No. 2,803,777. As the center conductor 33 emerges from the aperture 35, the helix radius, or the outer conductor 32, may be tapered to obtain a smooth impedance transition between the 50 ohm coaxial line to the coupling helix.

Radio frequency energy coupled into terminal 40 and propagated along structure 39 to terminal 41 will interact with coupler helix 37 such that a certain amount of power will be extracted from structure 39, the phase angle of which will depend upon the axial position of coupler helix 37 relative to the longitudinal distance along structure 39, said appropriately phased signal energy being coupled from terminal 44 of coaxial line 31 for application to that device for which a phase corrected signal is desired to be utilized. Of course, energy may be launched onto structure 39 at terminal 41 and the appropriately phased signal is removed from the phase shifter at terminal 45 due to the directional relationship as disclosed hereinabove.

While we have described above the principles of our invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of our invention as set forth in the objects thereof and in the accompanying claims.

We claim:

1. In a traveling wave electron discharge device having a housing, an electron gun disposed in the forward end of said housing for projecting a beam of electrons along a given path toward the rearward end thereof, and a helical wave propagating structure disposed within said housing coaxially of said given path for interaction between the wave energy and the electrons of said beam, helical input means disposed within said housing coaxially of and in coupled relation with the forward end of said propagating structure for launching wave energy into said propagating structure, helical output means disposed within said housing coaxially of and in coupled relation with the rearward end of said propagating structure for removal of the interacted wave energy from said propagating structure, and directional coupling means disposed within said housing intermediate to and distinct from said input and output means in coaxial coupled relation with said propagating structure for removal of reflected energy from the field of the wave energy traveling on said propagating structure.

2. A directional power divider comprising a housing, a convoluted wave propagating structure for the propagation of broadband radio frequency energy therealong disposed within said housing, input means coupling radio frequency energy to said propagating structure, output means coupling radio frequency energy from said propagating structure, and directional coupling means disposed within said housing intermediate said input means and said output means and coaxially of said propagating

structure for removal of energy therefrom, said input and output means each including a helical wound conductor disposed within said housing coaxially of the appropriate extremity of said propagating structure and in predetermined coupled relation therewith.

3. In a traveling wave electron discharge device having a housing, an electron gun disposed in the forward end of said housing for projecting a beam of electrons along a given path toward the rearward end thereof, and a helical wave propagating structure disposed within said housing coaxially of said given path for interaction between the wave energy and the electrons of said beam, input means disposed within said housing at the forward end of said propagating structure for launching wave energy into said propagating structure, output means disposed within said housing in the rearward end of said propagating structure for removal of the interacted wave energy from said propagating structure, and directional coupling means disposed within said housing coaxially of said propagating structure intermediate said input and

output means for removal of energy from the field of the wave energy traveling on said propagating structure, said input and output means each including a helical coil disposed coaxially of said forward end and said rearward end, respectively, of said propagating structure and in predetermined coupled relation therewith.

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