April 26, 1960 R. C. WERTMAN 2,934,674

TRAVELING-WAVE ELECTRON DISCHARGE DEVICE

Filed Feb. 7, 1956 2 Sheets-Sheet 1

Fig. 1

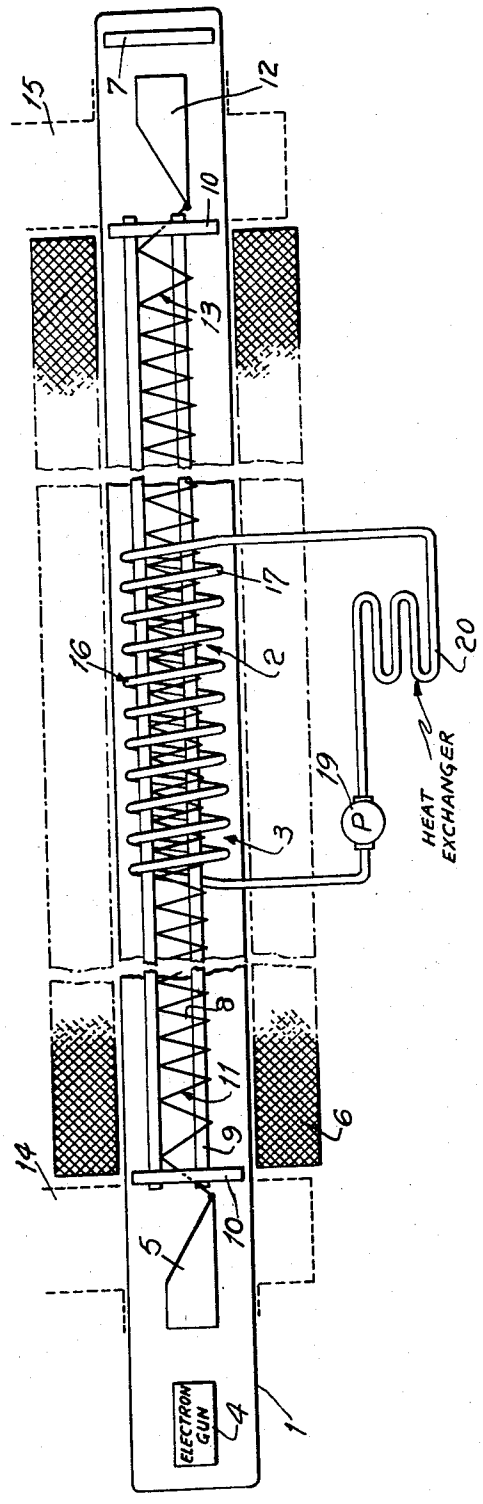
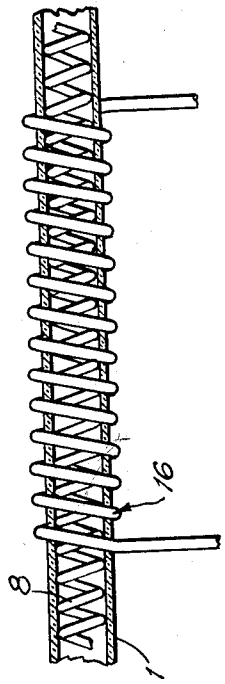


Fig. 2



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Filed Feb. 7, 1956 2 Sheets-Sheet 2

Fig. 3

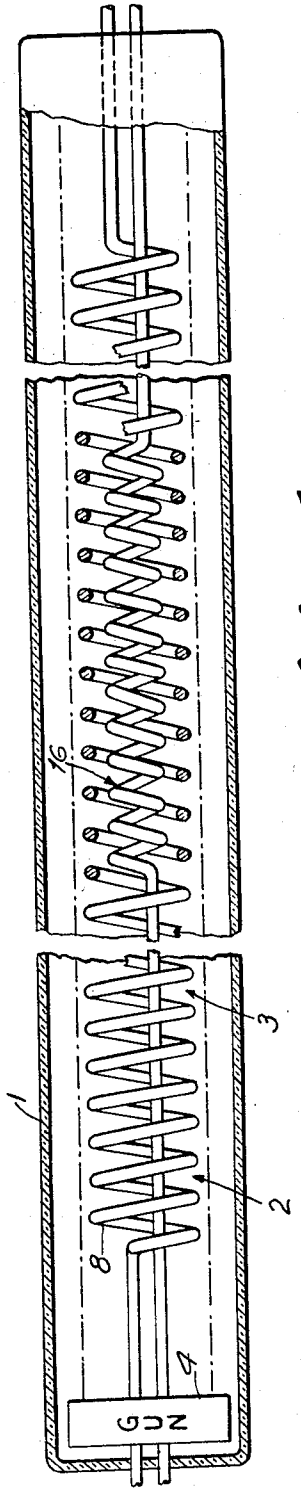
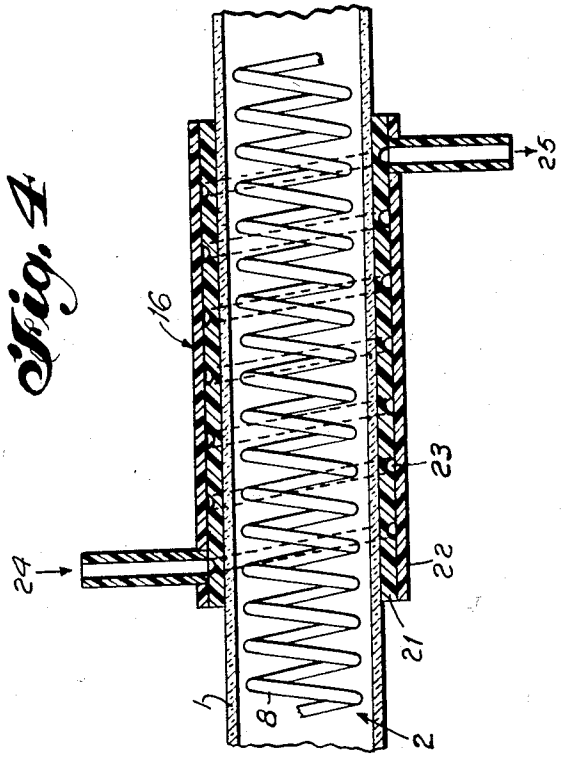


Fig. 4



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United States Patent Office 2,934,674 Patented Apr. 26, 1960

2,934,674

TRAVELING-WAVE ELECTRON DISCHARGE DEVICE

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Application February 7, 1956, Serial No. 564,022

8 Claims. (Cl. 315—39.3)

This invention relates to traveling-wave electron discharge devices and more particularly to coupled helices and a method of using them for introducing a circuit loss along the path of the radio freqency field of a traveling wave in such devices to prevent both undesired oscillations and modes of propagation therein.

The general structure and theory of operation of a traveling-wave type of electron discharge device or tube is well known, a comprehensive treatment being given in the book "Traveling-Wave Tubes," by J. R. Pierce, published by D. Van Nostrand Company, Inc., New York, 1950.

It is recognized that the useful range of amplification of a traveling-wave tube is limited by a tendency to generate self-sustaining oscillations as the amplification is increased. This effect is usually due to mismatch between the output circuit of the tube and the load circuit over all or part of the wide range of frequencies to be amplified. Because of such mismatch, energy of at least certain frequencies is reflected back toward the input end of the amplifying device. When the reflected wave is not attenuated in its travel along the helix, or other type of propagating structure, in a direction opposite to the motion of the electron stream, some energy reaching the input end of the device is reflected therefrom causing the generation of self-sustaining oscillations. Thus, the energy reflected or transmitted back to the input must be attenuated if the tube is to operate in a stable manner.

Heretofore various means have been employed to overcome this tendency of generating self-sustaining oscillations. One such means employs a body of resistive material disposed on or adjacent to the propagating structure, either in a confined location thereabout or coextensive therewith to absorb the reflected energy. Another such means employs wire-wound helices coaxial with the propagating structure and in coupled relation thereto for removal of reflected energy from the propagating structure for coupling to an appropriate termination thereof to overcome the tendency for self-sustaining oscillations. Still another such means, described in the copending application of R. H. Geiger and R. W. Wilmarth, Serial No. 464,282, filed October 25, 1954, provides a coupled-helix circuit loss by coating a dielectric sleeve coaxial with the propagating structure with a conductive film having a predetermined conductivity.

These means for overcoming the tendency for self-sustaining oscillations have greatly improved the usefulness of the traveling-wave tube, at least for certain applications. However, in attempts to obtain high power and high gain, stability of the attenuation at high temperatures, broadband attenuation characteristics and reproducibility of electrical and mechanical properties of the attenuators, it has been found that the above-mentioned types of attenuators fail to meet one or more of the above major physical and electrical properties. The lack of suitability of the above-described methods is particularly marked where high power amplification is desired. Inasmuch as the most important single factor affecting efficient performance at high power amplification is the attenuator, the ability of the attenuator to rapidly dissipate the heat generated in it at high power levels is a major factor in the tube's efficient and stable performance.

It is, therefore, an object of this invention to provide an improved means for preventing self-sustaining oscillations in a traveling-wave tube.

Another object of this invention is to provide a coupled-helix attenuator for the propagating structure of a traveling-wave tube particularly suitable for use at high power levels.

A feature of this invention is the provision of a coupled-helix circuit loss for the propagating structure of a traveling-wave tube comprising a channeled fluid-containing structure of dielectric material disposed coaxially of the propagating structure, the channel within the fluid-containing structure being in coupled relation to the electromagnetic field of the traveling-wave tube and containing therein a conductive fluid having a predetermined lossy characteristic.

An additional feature of this invention resides in the circulation of the lossy fluid through a heat-exchange system so that, in addition to providing desired attenuation, the fluid serves to remove heat generated in the attenuator in a convenient and expeditious manner.

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 diagrammatic illustration of a traveling-wave tube incorporating one form of the coupled-helix attenuator of this invention and illustrating the fluid circulation system;

Fig. 2 is an elevational view, partly in section, of another embodiment of this invention;

Fig. 3 is a diagrammatic illustration of an annular beam traveling-wave tube incorporating one form of the coupled-helix attenuator of this invention; and

Fig. 4 is a sectional view, partly in elevation, of still another embodiment of this invention.

Referring to Fig. 1, there is shown an illustrative embodiment of a traveling-wave tube adapted to be used as an amplifier at ultra-high frequencies. The arrangement shown comprises an electron beam tube including an evacuated envelope 1.. The envelope 1 may be constituted of a low-loss insulating material, such as glass or quartz, or a non-magnetic type of metal. The shape of envelope 1 may have a uniform diameter as illustrated in Fig. 1 or may include an elongated portion coextensive with the interaction section 2 and in supporting relationship with the propagating structure 3 included therein. The envelope 1 is provided at one end with means, such as a known type of electron gun 4 for producing an electron beam or stream. The electron stream emerges from the electron gun 4 and travels along a rectilinear path through an input coupler 5 and axially down the evacuated envelope 1. The electron stream is further concentrated and guided along this substantially axial path by a longitudinal magnetic field produced by magnet 6 which may be either an electromagnet or a permanent magnet. Electrode 7 serves to collect the electrons arriving at the end of envelope 1.

The propagating structure 3, which serves as a path along which the radio frequency wave may be propagated, is illustrated as including a helix 8. Helix 8 is wound with several turns per wavelength along its axis, which may preferably be of a plurality of wavelengths of the frequency being amplified. The helix is illustrated as being supported by a series of non-conductive rods 9 equally spaced about the circumference thereof and sup-

ported in an axial relationship with respect to envelope 1 by disks 10. As is known in this art, helix 8 may be supported by means of a ceramic tubing or by so shaping envelope 1 to provide an elongated portion in contact with the helix 8 for support thereof.

The helix 8 is joined at the input coupler 5 by an input matching section 11 and the output coupler 12 by the output impedance matching section 13. These matching sections are simply extensions of the helix in which the spacing between turns is increased along the circumference of the helix. Thereby, these sections act as tapered transmission lines to provide a wave transmission path of uniformly changing impedance from the relatively low impedance at the end of the couplers 5 and 12 to the relatively high impedance of the central portion of helix 8, with a minimum reflection of energy back to the signal source.

In order to utilize the device in an operable system, there is provided an incoming wave path represented by the dotted input waveguide 14 into which there is introduced the input wave signal to be amplified. An output wave path, shown as the output waveguide 15, serves to transfer the amplified output wave to a load circuit. As the electron beam and the radio frequency wave travel axially of the helix at substantially the same linear velocity, an interaction takes place whereby energy is transferred from the beam to the wave, thereby greatly amplifying the wave. As the amplified wave reaches the output end of the helix 8, it is transferred to the output waveguide 15 by means of output coupler 12. As the amplified wave reaches the impedance matching section 13, even with an extremely favorable termination, at a given band of frequencies, there will still exist reflected waves at frequencies both inside and outside the given band at the output end of the helix. This reflected wave is very little affected by the electron stream and hence will propagate back along the helix 8 toward the input end with attenuation. The reflected wave will reach the input end of the helix 8 with attenuation equal to the circuit attenuation and will in turn be reflected back toward the output end of the helix. It is obvious that where there is not enough circuit attenuation to dampen the reflected energy, this energy will result in self-sustaining oscillations. It will thus be seen that the deliberate introduction of an artificial loss within the electromagnetic field of the helix so as to provide a dissipation or removal of the reflected wave will serve to greatly increase the range of useful amplification which can be achieved with a device of this type. It is of course an essential feature of traveling-wave tube construction that this attenuation must be provided. Furthermore, where high power must be dissipated, in tubes handling powers ranging from one kilowatt to megawatts, the removal of the heat generated in the dissipation of this power becomes very difficult and troublesome.

In accordance with the principles of this invention, the artificial loss or circuit attenuation is introduced along the portion of the helix by a coupled-helix attenuator 16 appropriately disposed longitudinally along the helix 8 and in coupled relation with respect to the electromagnetic field existing about the helix. As illustrated in Fig. 1, the coupled-helix attenuator 16 is shown as a fluid-containing structure of dielectric material 17 disposed coaxially of the propagating helix 8 and in the electric field of the propagating structure. This fluid-containing structure is shown as a helix wound about the propagating helix 8. A conductive fluid having a predetermined lossy characteristic is contained in the hollowed channel of the attenuator 16. For dissipation of large amounts of power, this fluid may be circulated through the attenuator in any convenient manner; for example, a circulating pump 19 may be used to circulate the lossy fluid through the attenuator. A heat exchanger 20, cooled by air or water or in any other convenient manner, is used to remove heat from the circulating fluid. As is known in this art, in order to achieve maximum coupling, the pitch of the larger-diameter helix must be wound somewhat looser than the smaller-diameter helix, in a ratio approximately determined by the respective diameters of the helices. In addition, for proper coupling, the pitches must be disposed in opposite directions, i.e., counterwound to one another. Thus, the helical attenuator 16, as illustrated in Fig. 1, is wound about the propagating helix 8 and in a looser pitch than the winding of the propagating helix. The dielectric material 17 used for the fluid-containing structure should preferably have a low loss factor and a low dielectric constant. Where the attenuator is located within the vacuum envelope, as is the case for Fig. 1, it is preferable to form the attenuator 16 of a material such as quartz, glass or ceramic. These materials may be readily degassed and a proper vacuum obtained, which is not always the case with low-loss plastic materials. The desired properties for the conductive fluid may be readily obtained by choice of a fluid which has the desired lossy characteristic and suitable heat-transfer properties. The selection of the fluid is considered a matter of choice and may be experimentally determined by those skilled in this art. Among gases that may be used are the chlorinated fluorocarbons, commercially known as the Freons, ammonia and carbon dioxide. In general, for the fluid to be circulated, it is considered preferable to use various liquids such as alcohol, silicone oils and metallic colloidal suspensions. If a liquid such as a silicone oil, for example, is not sufficiently lossy, the degree of loss may be adjusted by the addition of colloidal graphite thereto in desired portions. The desired degree of heat transfer may, of course, also be readily controlled. As the liquid absorbs the microwave power, it will heat up; but it may readily be cooled by passing it through the heat exchanger at a desired rate and recirculating it.

In Fig. 2 is illustrated an alternative embodiment of the attenuator of this invention. In the embodiment illustrated, the propagating coil 8 is contained within the envelope 1, which is made of a dielectric material such as glass, quartz or ceramic. In this embodiment, the electromagnetic field extends outside of the envelope, and the attenuator 16 is in the form of a helical coil wound about the envelope and in coupled relation to the electromagnetic field. In general, the same considerations of coupling apply to this embodiment as were mentioned with respect to Fig. 1. Because the attenuator is located on the outside of the vacuum envelope, there is no need for degassing it. Therefore, low-loss polymeric dielectric materials, such as polystyrene, polyethylene and polytetrafluoroethylene, may be used for the attenuator 16 inasmuch as these materials are more readily shaped than corresponding glass or ceramic helices. It is, of course, apparent that maximum coupling is obtained when the two helices are as close to one another as is feasible and differ but slightly in their respective diameters.

In Fig. 3 is illustrated another embodiment of a traveling-wave tube utilizing the attenuator of this invention. In this embodiment, the propagating structure 8 and electron gun 4 are arranged so as to propagate an annular electron beam. The electromagnetic field associated with the propagating structure is essentially contained within the propagating structure. Therefore, the coupled helix 16 is of smaller diameter than the propagating helix 8 and is contained within the propagating helix. Because of its smaller diameter, the coupled helix is wound more tightly than the propagating helix. However, for a maximum transfer of energy, it is preferable that the diameter of the coupled helix approach that of the propagating helix.

In Fig. 4 is shown an additional embodiment of attenuator 16 useful for the practice of this invention. This attenuator may be somewhat more convenient to construct for certain applications. An inner dielectric cylin-

der 21 is fitted tightly in nesting relation within an outer dielectric cylinder 22. Before assembly, a series of helical channels 23 forming a continuous passageway is machined about the facing outer surface of the inner cylinder 21 or the facing inner surface of the outer cylinder 22. When the two cylinders are fitted together in a fluid-tight manner, a lossy conductive fluid may be circulated through this fluid-containing structure. The fluid enters at opening 24 and emerges at exit 25 and may be recirculated by means of a pump through a heat-exchange system, as described for Fig. 1. Where this cylindrical type of attenuator is located outside of the vacuum envelope, as shown in Fig. 4, it is preferable to shape it of a suitable low-loss plastic material. The dielectric cylinder may be also contained within the vacuum envelope, as occurs, for example, in traveling-wave tubes of the type illustrated in Fig. 1. It is then preferable to use glass or ceramic for the material forming the fluid-containing structure. In fabricating these cylinders, the same considerations with respect to pitch to obtain maximum coupling would apply as discussed with respect to Fig. 1.

The embodiments hereinabove described, in conjunction with proper construction techniques, will provide a long life and rugged type of attenuator for use in traveling-wave tubes. These traveling-wave tubes have their most useful range from 100 to 4,000 megacycles, although, where tolerances may be maintained within very close limits, this range may be extended to higher frequencies. The use of these tubes for high-power applications is of considerable importance, and the novel type of attenuator provided therein makes for tubes that may be usefully employed to dissipate powers ranging from one kilowatt up to several megawatts. By using the type of construction described, it is seen that the coupled-helix attenuator need not be located in intimate contact with the main helix of the traveling-wave tube. This arrangement reduces the possibility of mismatch on the propagating helix due to the attenuation. Also, as is illustrated in the various embodiments, the coupled-helix attenuator may be located either inside or outside the vacuum envelope. Because a flexible and controllable loss may be provided, inasmuch as the lossy liquid used and its composition is a matter of choice, levels of attenuation within close liimts may be readily achieved. Furthermore, inasmuch as the heat exchanger may be used for rapid or gradual dissipation of heat from the attenuator and this may additionally be controlled by the manner and rate in which the liquid is circulated through the heat exchanger, a simple, flexible, readily ocntrollable manner of removing heat from the attenuator and, at the same time, providing a desired degree of loss has been achieved.

While I have described above the principles of my 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 my invention as set forth in the objects thereof and in the accompanying claims.

I claim:

1. In a traveling wave electron discharge device including an elongated propagating structure having a given diameter for the propagation of radio frequency energy therealong, radio frequency energy input means coupled to one end of said propagating structure and radio frequency energy output means coupled to the other end of said propagating structure, and means for propagating a beam of electrons parallel to the axis of said propagating structure for interaction with the electromagnetic field of said energy; an attenuator disposed intermediate said input means and said output means and in spaced relation to said output means to provide said propagating structure with a substantially lossless portion adjacent said output means comprising a fluid-containing structure of dielectric material disposed in a coaxial relationship to said propagating structure and having a diameter different from said given diameter of said propagating structure, said fluid-containing structure including a channel therein disposed in said electromagnetic field, and a conductive, non-ionized fluid having a predetermined lossy characteristic contained in said channel in a predetermined energy coupling relationship with the radio frequency energy on said propagating structure to reduce said radio frequency energy traveling along said propagating structure from said input means to said output means to a predetermined useful level and to reduce said radio frequency energy reflected from said output means for travel along said propagating structure from said output means to said input means to a negligible level.

2. A device according to claim 1, wherein said fluid-containing structure has a helical form.

3. A device according to claim 1, wherein said fluid-containing structure consists of two close-fitting cylinders nested in a fluid-tight relation to one another and said channel is provided in said cylinders by a continuous helical passageway on a facing surface of at least one of said cylinders.

4. In a traveling wave electron discharge device including an elongated propagating structure having a given diameter for the propagation of radio frequency energy therealong, radio frequency energy input means coupled to one end of said propagating structure and radio frequency energy output means coupled to the other end of said structure, and means for propagating a beam of electrons parallel to the axis of said propagating structure for interaction with the electromagnetic field of said energy; an attenuator disposed intermediate said input means and said output means and in spaced relation to said output means to provide said propagating structure with a substantially lossless portion adjacent said output means comprising a fluid-containing structure of dielectric material disposed in a coaxial relationsihp to said propagating structure and having a diameter different from said given diameter of said propagating structure, said fluid-containing structure including a channel therein disposed in said electromagnetic field, and a conductive, non-ionized fluid having a predetermined lossy characteristic contained in said channel in a predetermined energy coupling relationship with the radio frequency energy on said propagating structure to reduce said radio frequency energy traveling along said propagating structure from said input means to said output means to a predetermined useful level and to reduce said radio frequency energy reflected from said output means for travel along said propagating structure from said output means to said input means to a negligible level and means for circulating said fluid in said channel and for removing heat from said fluid.

5. A device according to claim 4, wherein said fluid is selected from the gases consisting of chlorinated fluorocarbons, carbon dioxide and ammonia.

6. A device according to claim 4, wherein said fluid is selected from those conductive liquids having a predetermined lossy characteristic consisting of as major constituents silicone oils, metallic colloidal suspensions and alcohol.

7. In a traveling wave electron discharge device including a helical propagating structure having a given diameter and a given pitch direction for the propagation of radio frequency energy therealong, radio frequency energy input means coupled to one end of said propagating structure and radio frequency energy output means coupled to the other end of said propagating structure, and means for projecting a beam of electrons parallel to the axis of said propagating structure for interaction with the electromagnetic field of said energy; an attenuator disposed intermediate said input means and said output means and in spaced relation to said output means

to provide said propagating structure with a substantially lossless portion adjacent said output means comprising a fluid-containing structure of dielectric material disposed in a coaxial relationship to said propagating structure and having a diameter different from said given diameter of said propagating structure, said fluid-containing structure including a channel therein in the form of a continuous helical passageway having a pitch direction opposite to said given pitch direction of said helical propogating structure, and a conductive, non-ionized fluid having a predetermined lossy characteristic contained in said channel in energy coupling relationship with the radio frequency energy on said helical propagating structure to reduce said radio frequency energy traveling along said propagating structure from said input means to said output means to a predetermined useful level and to reduce said radio frequency energy reflected from said output means for travel along said propagating structure from said output means to said input means to a negligible level.

8. In a traveling wave electron discharge device including a helical propagating structure having a given diameter and a given pitch direction for the propagation of radio frequency energy therealong, radio frequency energy input means coupled to one end of said propagating structure and radio frequency energy output means coupled to the other end of said propagating structure, and means for projecting a beam of electrons parallel to the axis of said propagating structure for interaction with the electromagnetic field of said energy; an attenuator disposed intermediate said input means and said output means and in spaced relation to said output means to provide said propagating structure with a substantially lossless portion adjacent said output means comprising

a fluid-containing structure of dielectric material disposed in a coaxial relationship to said propagating structure and having a diameter different from said given diameter of said propagating structure, said fluid-containing structure including a channel therein in the form of a continuous helical passageway having a pitch direction opposite to said given pitch direction of said helical propagating structure, a conductive, non-ionized fluid having a predetermined lossy characteristic contained in said channel in energy coupling relationship with the radio frequency energy on said helical propagating structure to reduce said radio frequency energy traveling along said propagating structure from said input means to said output means to a predetermined useful level and to reduce said radio frequency energy reflected from said output means for travel along said propagating structure from said output means to said input means to a negligible level and means for circulating said fluid in said channel and for removing heat from said fluid.

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