

Nov. 5, 1963

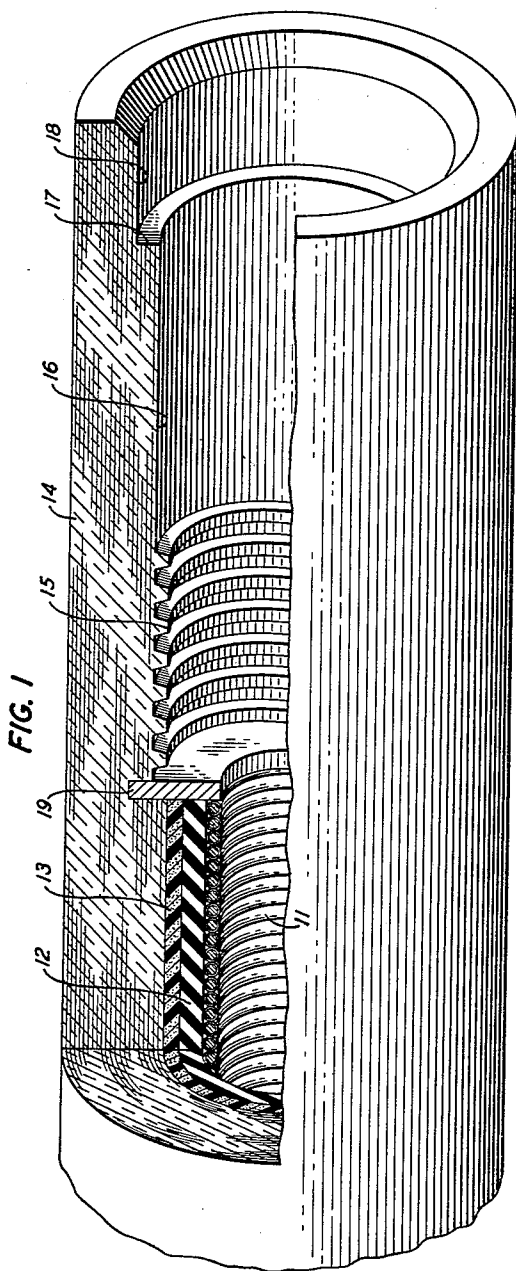
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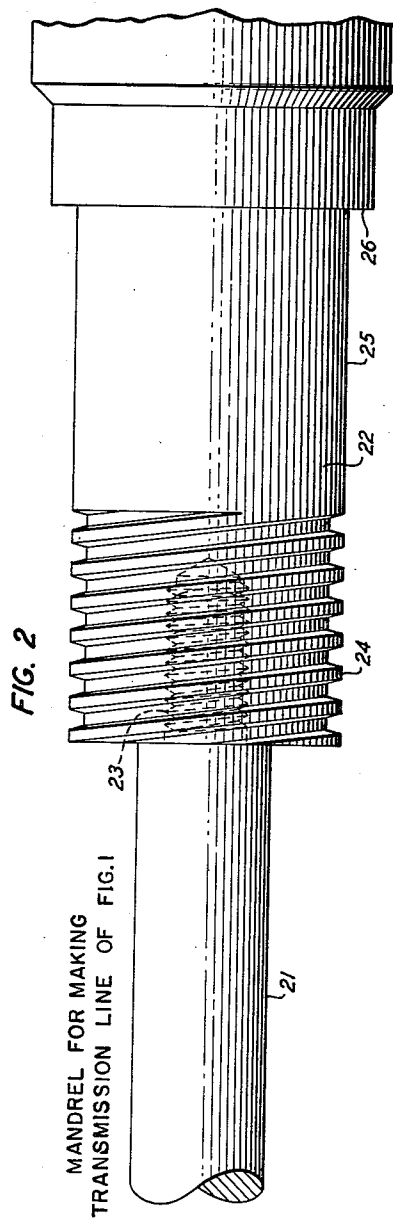
UNWANTED MODE ABSORBING CIRCULAR WAVE GUIDE HAVING
CIRCUMFERENTIAL GAPS COUPLED, BY INTERMEDIATE
DIELECTRIC, TO EXTERNAL DISSIPATIVE SHEATH

Filed Aug. 23, 1957

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TRANSMISSION LINE ——— FOR CONNECTION TO NEXT SECTION



MANDREL FOR MAKING
TRANSMISSION LINE OF FIG. 1

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FIG. 3A

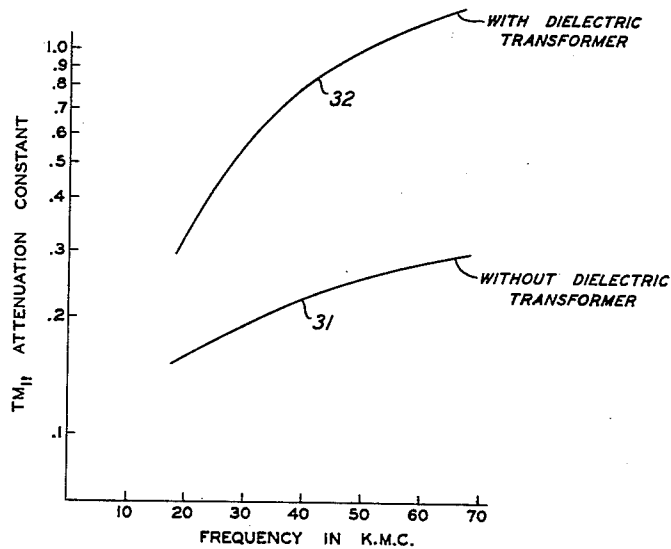
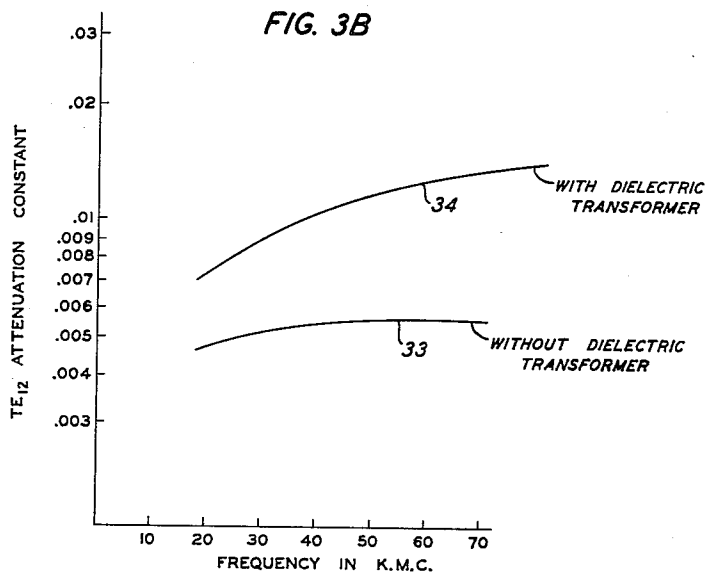


FIG. 3B



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UNWANTED MODE ABSORBING CIRCULAR WAVE GUIDE HAVING CIRCUMFERENTIAL GAPS COUPLED, BY INTERMEDIATE DIELECTRIC, TO EXTERNAL DISSIPATIVE SHEATH**Hans-Georg Unger, Lincroft, N.J., assignor to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York**

Filed Aug. 23, 1957, Ser. No. 679,929

7 Claims. (Cl. 333-95)

This invention relates to electromagnetic wave transmission systems and, more particularly, to an improved form of transmission line for the circular electric or TE_{01} mode of wave propagation.

In the compending applications of J. R. Pierce, Serial No. 416,315, and S. E. Miller, Serial No. 416,316, both filed March 15, 1954, now United States Patents 2,848,695 and 2,848,696 respectively, both issued August 19, 1958, and in the article "Helix Wave Guide" by S. P. Morgan and J. A. Young in the Bell System Technical Journal, November 1956, pages 1347-1384, it is disclosed that a closely wound helical conductor of diameter greater than 1.2 free space wavelengths of the transmitted energy is a transmission medium suitable for propagating a properly excited circular electric TE_{01} mode. It is shown that such a medium greatly minimizes the inherent tendency of this mode to degenerate into spurious modes, particularly the TM_{11} mode and to a lesser extent the TE_{11} and TE_{12} modes. In particular, it is shown that upon this wave guiding structure the TE_{01} mode has a substantially different phase constant from the TM_{11} mode, thereby providing decoupling between these modes. Furthermore, the helix is surrounded by a jacket of electrically dissipative material which introduces a large difference in the attenuation constants presented to the spurious modes and the TE_{01} mode. By virtue of this difference, degeneration is further reduced without a substantial amount of energy being actually lost in the dissipative material. The dissipative jacket is in turn surrounded by a sheath to provide mechanical strength and protection to the structure.

Such a transmission medium is ideally suited for long distance transmission of wide band signals since the attenuation of the TE_{01} mode decreases with increasing frequency. Used in long lengths, the helical wave guide serves to negotiate both accidentally and intentionally introduced bends and turns. Used in shorter lengths, the helical guide serves as a filter to purify the TE_{01} energy and to remove spurious mode components, particularly of the TE_{11} and TE_{12} modes.

Since it is the magnitude of the difference in attenuation and phase constants between the desired and the unwanted modes that determines the efficiency of the helix wave guide, it is desirable to make this difference as large as possible. In the past, it has been found that the obtainable difference in these constants between the TE_{01} wave mode on the one hand and the higher order spurious modes on the other was limited to values not sufficiently great for various applications. The reason for this limitation lies in two factors. First, lossy jacket materials which have desirable mechanical properties do not always present an electrical impedance to the longitudinal helix currents associated with the unwanted modes conducive to optimum attenuation. Second, the finite size and spacing of the helix wires themselves create a capacitive grid between the propagating spurious mode wave energy within the wave guide and the external lossy jacket, thereby partly shielding the jacket from the wave energy and permitting only partial penetration of the unwanted wave modes into the absorbing jacket.

It has been priorly thought that, in order to obtain

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optimum performance of the lossy jacketed helix wave guide, the electrically dissipative material of the jacket should be in closest proximity possible to the longitudinal currents flowing in the helix structure and associated with the unwanted modes. However, in accordance with the present invention, it has been found that a separation between helix wires and lossy jacket causes an increase in attenuation constant of the unwanted modes and therefore reduces conversion losses in the helix type wave guide.

It is, therefore, an object of this invention to increase the difference in attenuation constants between those associated with the TE_{01} wave mode and those associated with higher order spurious wave modes in a helix wave guide.

It is a more specific object to transform to a more suitable value the surface impedance presented by the lossy jacket of a helix wave guide to longitudinal currents at the helix.

A further object is to compensate the capacitive energy shielding effect of the helix wires.

In accordance with the invention, impedance-transforming radial transmission line means are inserted between the metallic helix wires and the outer lossy jacket of a helical transmission line. In the preferred embodiment, the transformer means takes the form of an insulating layer of dielectric material. Such a dielectric transformer presents an inductive reactance to the interior of the wave guide which acts in parallel with the helix wire capacitance. By proper proportioning of the composition and thickness of this layer the capacitive shielding effect of the helix wires may be compensated. At the same time, the dielectric transformer serves to change the surface impedance of the lossy jacket as seen from the wave guide interior to a more favorable value as far as attenuation of the unwanted modes is concerned.

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

In the drawing:

FIG. 1 is a cut away view of the end portion of a transmission line in accordance with the invention;

FIG. 2 is a perspective view of the form upon which the structure of FIG. 1 may be made; and

FIGS. 3A and 3B are graphs illustrating the performance of the invention.

Referring more specifically to FIG. 1, a cut away cross sectional view of a section of transmission line contemplated for use in a circular electric mode wave transmission system is shown as an illustrative embodiment of the present invention. This line comprises an elongated conductive member 11 of relatively fine wire closely wound in a helix. Conductor 11 may, for example, be an enameled or plastic insulated solid copper wire. Adjacent turns of the helix wires are electrically insulated from each other, and this may be provided by a small air gap or by an insulating coating on the wire itself. The pitch distance of the helix, i.e., the distance between centers of adjacent turns, and therefore the pitch angle of the helix should be as small as is consistent with the insulating requirement. This distance in all events must be less than one-quarter wavelength and is preferably such that the gap between adjacent turns is less than the diameter of conductor 11.

Helix 11 is surrounded by successive annuli or jackets which will each be described in more detail hereinafter. In accordance with the invention, immediately surrounding helix 11 is transformer jacket 12 which may comprise any insulating dielectric of moderate dielectric

constant. This is followed by a lossy jacket 13, which is in turn surrounded by an outer jacket 14. The right-hand portion of jacket 14 includes a connector comprising an internally threaded region 15 for connecting to an adjoining section of wave guide, an internally smooth portion 16 of larger diameter which facilitates thread alignment when inserting the adjoining section, and a larger diameter section 18 forming a seat 17 to receive a suitable washer for sealing with the adjoining section. A conductive ring 19 between helix 11 and threaded portion 15 that has an inside diameter equal to the inside diameter of helix 11 terminates the ends of the helix and forms a conductive abutting surface for the adjoining wave guide.

FIG. 2 shows the mandrel upon which the structure of FIG. 1 is formed. Portion 21 represents a smoothly polished member upon which helix 11 is wound and portion 22 represents a typical one of a pair of end molds suitably fastened by threads 23 to either end of portion 21. Portion 22 includes an externally screw threaded portion 24, a smooth portion 25 and a seat forming portion 26. Such a mandrel of the desired length together with its end molds is mounted for axial rotation between the chucks of a suitable winding machine after rings 19 have been located in place.

After a suitable mold release agent has been applied to mandrel 21 and end mold 22, the mandrel is rotated and helix 11 is closely wound between rings 19. It may be wound with a single strand, or it may be wound with a plurality of strands being simultaneously fed in parallel.

Over this helix, dielectric impedance transforming jacket 12 is formed in accordance with the present invention. As indicated in the principal embodiment, this transformer is formed by laminating thin layers of a dielectric material. The dielectric jacket acts much like a short radial transmission line, transforming the impedance of the lossy jacket presented to the longitudinal currents through helix 11 to a more favorable value so far as attenuation of spurious modes is concerned. Stated differently, in the absence of the dielectric jacket, the admittance of the lossy jacket as seen from the helix interior has a low inductive component. At the same time, adjacent turns of the helix wires themselves act as parallel plate capacitors and present a capacitive reactance which tends to shield the spurious mode wave energy from the lossy jacket and to prevent its absorption therein. The impedance transforming effect of dielectric jacket 12 serves to increase the inductive component of the lossy jacket admittance. This inductive component acts in parallel with the helix wire capacitance and eliminates its shielding effect, thereby permitting more complete penetration and absorption of the spurious mode wave energy into the lossy jacket than previously attainable.

Dielectric jacket 12 is preferably a material of low to medium dielectric constant. In addition, for best operation of the device over a broad frequency band, the electrical thickness of the layer should be less than one-quarter wavelength of the highest operating frequency to be transmitted.

As stated hereinabove, the spacing between adjacent turns of helix 11 is always less than one-quarter wavelength. For practical operation of the helix wave guide, the spacing of the helix wires is kept as small as possible and is usually considerably less than $\lambda/4$. In the same manner, for practical operation, the thickness of the dielectric jacket would be considerably greater than the helix wire spacing. That is to say, a helix wave guide employing insulated wire for the helix element wound in such a manner as to have adjacent turns in continuous contact with each other may be said to have a dielectric layer on its outer surface of a thickness equal to half the spacing of the helix wires. Such a thickness of dielectric jacket, however, is insufficient to provide the desired impedance transformation of the present inven-

tion. An additional sleeve or jacket of dielectric material, concentrically located on the outer surface of wires 11, is thus necessary. In practice, it has been found desirable to use a dielectric sleeve having a radial thickness of from 4-10 mils when practicing the invention in a two inch inside diameter helix wave guide.

While the material of transformer 12 may be any insulating dielectric of moderate dielectric constant, it is preferable that in addition to the proper electrical properties, it have desirable mechanical properties as well. For example, as disclosed and claimed in the copending application of G. T. Kohman et al. Serial No. 679,835 filed August 23, 1957, now United States Patent 2,966,643, issued December 27, 1960, it is pointed out that a particularly suitable material for such a structure may conveniently comprise glass fibers, reinforced plastic, or glass fibers impregnated with plastic. Several methods of building up such layers are disclosed in said copending Kohman et al. application. According to a first cloth of woven glass fibers having a length similar to the length of the helix is wound over helix 11 while the plastic is applied between each turn. Alternatively, a woven tape of woven glass fibers may be spirally wound down and back a plurality of times along the helix. Similarly, glass fiber roving comprising a loosely twisted cord containing in the order of 50 glass fibers is spirally wound down and back many times until the required thickness is built up. In the case of roving, the loosely twisted fibers tend to flatten out so that each turn increases the layer by only the thickness of a few fibers. In the case of tape or roving, the material may first be passed through a container of fluid plastic before winding or the plastic may otherwise be suitably applied between turns. The use of woven cloth appears preferable for custom made short lengths while the use of tape or roving appears preferable for use with commercial winding machines. In either case the glass content of the glass lamination should be held at a high uniform value, perhaps of the order of between 50 and 75 percent, the higher ratios of glass appearing preferable. Several plastic materials have been found suitable for the above purposes. A preferred embodiment employs a suitable commercially available epoxide resin of the type that may be catalytically cured to form a thermosetting polymer.

FIGS. 3A and 3B illustrate, in graphical form, the increase in attenuation constants of unwanted TM_{11} and TE_{12} wave mode energy afforded by the invention. In particular FIG. 3A shows the attenuation constant for the TM_{11} wave mode as a function of frequency for a helix wave guide both with and without a dielectric transformer. The particular wave guide used to obtain the curves had a two-inch diameter while the dielectric transformer in accordance with the invention was 6 mils thick and had a dielectric constant of 4. In FIG. 3A, curve 31 shows the helix wave guide attenuation constant for the TM_{11} wave mode in the helix wire-lossy jacket structure. In such a structure the lossy jacket is contiguous to the helix itself. Curve 32 illustrates the helix wave guide attenuation constant for the TM_{11} wave mode in the helix wire-dielectric transformer-lossy jacket structure in accordance with the invention. It is clear that the introduction of dielectric jacket 12 in FIG. 1 substantially increases the obtainable TM_{11} wave mode attenuation. For both the illustrated cases, that is with and without the dielectric sleeve, the TE_{01} wave mode attenuation constant is very small, of the order of 3×10^{-6} . From this value for the TE_{01} mode attenuation constant and from FIG. 3A, it may be seen that, at 55 kilomegacycles for example, the increase in the difference in attenuation constants between the TE_{01} and TM_{11} wave modes provided by the invention is over 400 percent.

FIG. 3B shows, for the TE_{12} wave mode, the attenuation constant as a function of frequency for a helix wave guide with and without the dielectric transformer. Structures identical to those described above in conjunction

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with FIG. 3A were utilized to obtain the curves of FIG. 3B. Curve 33 illustrates the TE_{12} attenuation constant of the plain helix wire-lossy jacket structure. Curve 34 illustrates the same quantity for the helix wire-dielectric transformer-lossy jacket structure in accordance with the invention. Again, as in the case of the TM_{11} wave mode previously considered, the TE_{01} wave mode attenuation constant is of the order of 3×10^{-6} . From this value and from FIG. 3B, it may be seen that at 55 kilomega-

cycles, for example, the increase in attenuation constants between the TE_{01} and TE_{12} wave modes provided by the invention is over 200 percent.

It should be noted that this substantial increase in attenuation constant difference between the desired TE_{01} and unwanted spurious modes, of which TM_{11} and TE_{12} are among the most troublesome, arises from a physical separation of the energy propagating helix and the energy absorbing lossy jacket.

Referring again to FIG. 2 and to the method of construction of the helix wave guide embodiment of the present invention over dielectric jacket 12, resistive layer 13 is formed. In some applications of the helix wave guide, homogeneous materials having isotropic electrical properties have been utilized for this layer. Oftentimes, however, these solid materials have mechanical properties unsuitable for some applications. As disclosed in the above-mentioned Kohman et al. application, a suitable material for this structure is laminated treated glass fibers. The resistive layer is laminated employing plastics suitable for lamination purposes and glass cloth, tape or roving having an electrically conducting metallic oxide coating of the kind generally known as an iridized coating applied thereto. Oxide coatings that have an electrical resistance and other characteristics suitable for the lossy jacket may be produced by using mixtures of the metal oxides of tin, titanium, cadmium, indium and antimony. In particular, the combination of the oxides of tin plus small quantities of the oxides of titanium and antimony have been found satisfactory. The selection and amount of the other materials combined with the tin together with the thickness of the film, control the electrical surface resistivity of the film. In general, the application of these materials to glass from a tetrachloride solution is discussed in more detail in United States Patent 2,564,707 granted August 21, 1951, to J. M. Mochel and in the copending applications referred to therein.

The transmission line is completed by adding the protective sheath 14 and the connectors at each end thereof. Portions of the connector comprising threaded portion 15, aligning portion 16 and seat portion 17-18 are formed by being filled in and built up to the outside diameter of ring 19 in a wound or laminated construction by a process similar to that described for dielectric jacket 12. It is preferable to employ glass fiber roving and tape in these portions and to employ a resin having some resiliency and ductility to prevent chipping of these parts through use. An epoxide resin cured by a mixture of 10 parts per 100 metaphenylene diamine and 32 parts per 100 polyamide may be employed.

Finally, the structure of sheath 14 is wound over resistive jacket 13 and over the formed threads and seats of parts 15, 16, 17 and 18. Except for its greater thickness, sheath 14 may be identical to dielectric jacket 12. If preferred, somewhat larger fibers of glass may be used however. Because of the identical mechanical nature of jackets 12, 13 and 14, as described in the principal embodiment of the invention, a substantially homogeneous, closely bonded structure is obtained. Thus, the thickness of sheath 14 is built up so that the total thickness of the laminated structure has a bending stiffness comparable to that of the solid wall metallic wave guide employed in the same system. Such structural uniformity through the line is necessary to ensure uniform serpentine deformation of the entire line in the event of ther-

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mal expansion. Otherwise, a concentrated bend would occur at the weakest point introducing undesirable mode conversion. In a particular embodiment, a wall $\frac{5}{8}$ inch thick provides a sufficiently large structural moment of inertia to offset the greater modulus of elasticity of the copper in a standard 2 inch inside diameter wave guide.

The completed guide is then cured according to standard plastic handling processes while mandrel 21 continues to rotate. Slight elevations in temperature have been found permissible to hasten the curing. End molds 22 may then be removed and mandrel 21 withdrawn.

In all cases it is understood that the above-described arrangement is illustrative of one of the many possible specific embodiments that represent application of the principles of the invention. Numerous and varied other arrangements can readily be devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A transmission medium for electromagnetic wave energy in the circular electric wave mode comprising an elongated member of conductive material wound in a substantially helical form with adjacent turns electrically insulated from each other, dielectric spacing means having a low value of electrical dissipation and a minimum radial thickness substantially greater than one-half the separation between adjacent turns of the helical member but less than one-quarter wavelength of said energy at the operating frequency surrounding said helix, and a sleeve of electrically lossy material having a value of electrical dissipation considerably greater than said low value surrounding said means.

2. The medium according to claim 1 in which said means comprise a dielectric sleeve.

3. A transmission medium for circular electric mode wave energy within a given frequency range comprising an elongated member of conductive material wound in a substantially helical form with a helix diameter greater than 1.2 free space wavelengths of said energy with adjacent helix turns spaced apart a distance substantially less than one-quarter wavelength of said energy but electrically insulated from one another, a jacket of electrically dissipative dielectric material surrounding said helix and spaced away therefrom a distance substantially greater than one-half the spacing between adjacent helix turns, and a sleeve of dielectric material having a low value of electrical dissipation interposed between and contiguous to said helix and said jacket, said sleeve presenting an inductive reactance to radially propagating wave energy within said frequency range.

4. A transmission medium for wave energy in the circular electric wave mode within a given frequency range comprising an elongated member of conductive material wound in a substantially helical form with adjacent turns electrically insulated from each other, dielectric means for dissipating wave energy having current components parallel to the axis of said helically wound member surrounding said helix, and a sleeve of dielectric material exhibiting low electrical dissipation interposed between and contiguous to said helical member and said dielectric dissipating means to separate said dissipating means and said helical member a given distance substantially greater than one-half the spacing between adjacent helix turns, said sleeve presenting an inductive reactance to radially propagating wave energy within said frequency range.

5. The transmission medium according to claim 4 in which said given distance is less than one-quarter wavelength of the energy to be transmitted.

6. A transmission medium for wave energy in the circular electric wave mode comprising a conductive means defining a low-loss transmission path having a circular cross section in planes transverse to the transmission direction of said energy therethrough, a jacket of electrically lossy dielectric material surrounding said conductive means throughout its length, said conductive

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means and said lossy jacket being electrically coupled by a plurality of regularly spaced gaps in said conductive means, and means for spacing said jacket from said means comprising a substantially lossless dielectric sleeve interposed between and contiguous to said jacket and said means with a radial thickness substantially greater than one-half the longitudinal extent of said gaps between adjacent conductive portions of said conductive means but less than one-quarter wavelength of said energy.

7. A transmission medium for wave energy in the circular electric wave mode comprising a conductive means defining a low-loss transmission path having a circular cross-section in planes transverse to the transmission direction of said energy therethrough, a jacket of electrically lossy dielectric material surrounding said conductive means throughout its length, said conductive means and said jacket being electrically coupled by a plurality of regularly spaced gaps in said conductive means, and impedance transformer means interposed be-

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tween and contiguous to said jacket and said conductive means for matching the impedance of said jacket to said low-loss transmission path, said transformer means consisting of a dielectric sleeve.

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