

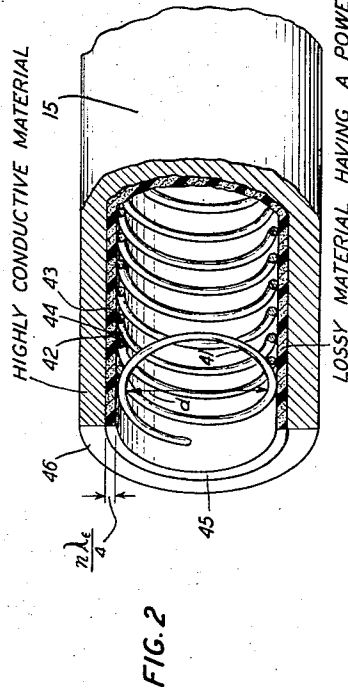
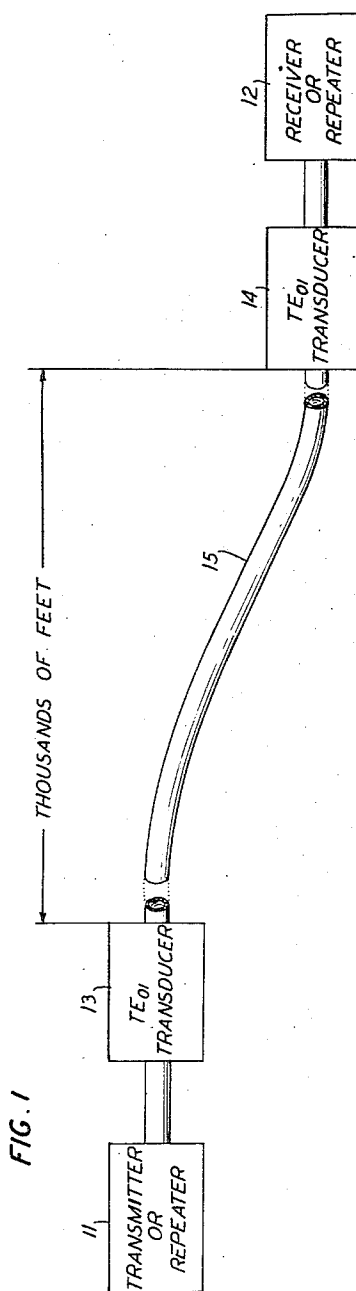
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HELIX WAVE GUIDE

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HELIX WAVE GUIDE

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

In United States Patent 2,848,696, issued August 19, 1958, to S. E. Miller, 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. Upon this wave guiding structure the TE_{01} mode has a phase constant substantially different from that of the TM_{11} and other unwanted spurious modes into which the TE_{01} mode has a tendency to degenerate. By virtue of the difference in phase constant, decoupling between the modes is provided. In order further to reduce the tendency of the TE_{01} mode to degenerate into spurious modes, the attenuation constants associated with the TE_{01} mode on the one hand and the spurious modes on the other hand may be made substantially different by surrounding the helix with a jacket of electrically dissipative material.

In general, the most satisfactory of these structures were unshielded, that is, the dissipative jacket was exposed to free space or at least separated therefrom only by a further jacket of insulating dielectric material. It was nevertheless obvious that for mechanical reasons, it might be advantageous to enclose the jacketed helix in a rigid or at least semi-rigid conductive shield. Such a shield not only would render the helix guiding path impervious to such outside influences as insects, moisture, and stray radiation from electrical sources but also would impart strength to an otherwise elastic structure. However, for reasons that were not immediately explainable it appeared that when the jacketed helix was enclosed in a surrounding conductive shield in order to obtain the mechanical advantages, the electrical performance of the helix guide was adversely affected. Long distance application of conductively shielded helix wave guide did not appear feasible.

As a result of certain analyses made by applicant, some of which are disclosed in his copending application Serial No. 679,927, filed August 23, 1957, it became apparent that performance of the transmission medium was influenced by the propagation constant of and the impedance presented to radially propagating components in the dissipative jacket and in particular that this impedance should not be too low. These radial propagation factors had been formerly overlooked, the primary emphasis being placed only on the longitudinally propagating components and their propagation constants. The new analysis supplied some explanation for the unsatisfactory performance of the conductively shielded structure. In the unshielded structure, the impedance of free space was inherently high enough that a satisfactory impedance was presented to the radial components but when a conductive shield of very low impedance was added, the impedance presented to the radial components became unsatisfactory.

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It is thus an object of the present invention not only to permit the use of conductive shielding for the mechanical advantages associated therewith but in addition to utilize the shield to improve the electrical performance of the transmission medium.

In accordance with the present invention it has been discovered that the performance of a helix wave guide could be improved by raising the impedance level seen in the helix guiding structure by radially propagating field components to a value above that inherently obtainable when the helix and its lossy jacket were surrounded by free space. In addition, it has been recognized that this increased value of impedance can be obtained by employing the previously undesirable conductive shield surrounding the lossy jacketed helix provided the power factor associated with the lossy jacket is properly chosen and the thickness of the jacket is selected so that it serves the dual function of dissipating unwanted mode currents and at the same time transforms the impedance level of the conductive shield to the proper value at the helix. Thus, in accordance with the present invention, not only do the mechanical advantages of the conductively shielded helix guide become available to the art, but also this shield is utilized to improve the electrical performance of the helix guide over that previously obtainable for the non-conductively shielded structure.

It is, therefore, another object of this invention to improve the electrical performance characteristics of a lossy jacketed transmission medium in which the conductive means comprises a helix guiding path through raising the impedance level presented to field components propagating radially in the jacket by surrounding the lossy jacket with an electromagnetically reactive shield of highly conductive material and by selecting the material comprising the lossy jacket to have an optimum thickness and a power factor within a given range.

The spacing between the helically wound conductor and the inner radius of the outer conductive pipe, i.e., the thickness of the lossy jacket, is selected to be equal to an odd number of quarter wavelengths of the radially propagating energy as measured in the dielectric jacket. In addition, the material comprising the jacket is selected to have a power factor, defined as the ratio of the imaginary part to the real part of the permittivity of the jacket material, which is less than unity but greater than one-tenth. When the above limitations are met, the radial impedance level will be of a finite value greater than that previously obtainable in unshielded structures. Optimum performance of the conductively shielded, lossy jacketed helix guide over long transmission distances will thus be obtained.

As used in this specification, the term "lossy" will be applied to a material when it has the capacity to convert electromagnetic wave energy incident thereupon into heat energy.

The term "permittivity" is understood to refer to the inductive capacity of the lossy material. When the jacket is not a pure dielectric, the permittivity becomes a complex quantity and may be expressed as $\epsilon = \epsilon' - j\epsilon''$ in which ϵ' corresponds to the classical dielectric constant of the material and ϵ'' is a frequency dependent parameter inversely proportional to the resistivity of the material. The degree of loss associated with the material is taken into account by the value of its resistivity.

The power factor of a material is understood to refer to the ratio of the imaginary part, ϵ'' , to the real part, ϵ' , of the permittivity ϵ . A pure lossless dielectric would have an infinite resistivity, a zero ϵ'' , and therefore, a zero power factor. Lossy dielectrics on the other hand have finite resistivities, an ϵ'' different from zero, and therefore, finite power factors. Thus, for example, carbon loaded paper useful in applications of the present in-

vention has a resistivity of approximately 20 an ϵ'' of approximately 2, an ϵ' equal to 4, and, therefore, a power factor of one-half.

The terms radial impedance and radial impedance level are understood to refer to the apparent resistance presented by the transmission medium to radially propagating field components associated with the unwanted modes. Thus the reactive nature of the helix, the reactive and lossy nature of the lossy jacket, and the reactive nature of the outer shield are all included in, and have an effect upon, the radial impedance.

The above and other objects, the nature of the present invention, and its various features and advantages will appear more fully upon consideration of the specific illustrative embodiment shown in the accompanying drawing and described in detail below.

In the drawing:

Fig. 1 diagrammatically illustrates a guided microwave communication system employing the circular electric wave mode and having a long distance helix wave guide section; and

Fig. 2, partially in cross section, illustrates the construction of a small section of helix guide in accordance with the present invention.

Referring more specifically to Fig. 1, a long distance guided microwave communication system is diagrammatically shown. The system is characterized as long to distinguish it from the short distances found in terminal equipment and to indicate an application of all-helix guide in a long distance communication system. The length of such a system would be measured in terms of thousands of feet and perhaps miles as opposed to several inches or a few feet in the terminal equipment. The system comprises a terminal station 11 which may be a transmitter or, if this is an intermediate station, a repeater which is to be connected to a receiver or subsequent repeater comprising terminal station 12. The energy to be transmitted between these terminal stations is to be in the circular electric or TE_{01} wave mode. It may be the case that this mode is neither produced nor utilized directly in the components of a given station and therefore the transducers 13, 14 are interposed between the stations, 11, 12 and the extremities of long distance helix guide 15. The transducers 13, 14 may be of any suitable type for converting TE_{01} wave energy to and from a dominant mode configuration. For example, they may be structures of the types disclosed in United States Patents 2,748,350, granted May 29, 1956, or 2,484,690, granted August 19, 1958, to S. E. Miller or in the copending application of E. A. J. Marcattili, Jr., Serial No. 706,459, filed December 31, 1957. It may also be the case that the TE_{01} wave mode is utilized directly in the components of the terminal stations in which case the transducers 13, 14 would be unnecessary.

Due to practical considerations, guide 15 is not completely rectilinear along its entire length. One of these considerations is that in any practical installation of helix guide, smoothly curving gentle bends are introduced since the guide has an inherent elasticity which permits the guide to deform under its own weight between supports. A second consideration is that intentional bends, or elbows, may be desirable or even necessary to follow right of ways or to turn corners. These curvatures cause the TE_{01} wave mode to tend to degenerate into spurious unwanted modes. Since in any practical long distance application of helix guide, both intentional and unintentional bends are to be expected, it is necessary that the helix guide for this application be of such construction as will produce the best over-all performance.

Such a guide is illustrated in Fig. 2 which shows in detail a short section of the helix guide 15 of Fig. 1. Guide 15 comprises a conductor 41 wound into a helix having an internal diameter d . Conductor 41 may be solid or stranded and may comprise copper alone or a

base metal such as iron or steel plated by a highly conductive metal such as copper or silver. Adjacent turns, such as the turns 42, 43 of the helix 41, are electrically insulated one from the other. This may be provided by a small air gap such as the gap 44, or the conductor 41 may have a thin coating of insulating dielectric on its surface. In all events, the pitch distance of the helix, i.e., the distance between the center of adjacent turns, should be as small as possible, consistent with the above-mentioned insulating requirement. This distance in all cases must be less than one-quarter wavelength of the energy transmitted by the helix guide, and is preferably such that the gap 44 between adjacent turns is less than the diameter of the conductor 41 forming the helix.

The space between adjacent turns of the helix 41, i.e., gap 44, is exposed to electrically dissipative or lossy material. This may be accomplished by surrounding helix 41 with a cylinder-like casing or jacket 45 of material having electrically lossy characteristics. It is neither desirable nor necessary that the material of jacket 45 extends into the space between adjacent helix turns and therefore jacket 45 preferably has a smooth internal diameter equal to the outside diameter of helix 41. In some applications it may be desirable from a mechanical point of view to overlay the outer surface of the helix with a thin lossless dielectric sleeve, as disclosed in applicant's copending application Serial No. 679,929, filed August 23, 1957.

As mentioned in an earlier portion of this specification, the presence of the electrically dissipative jacket 45 around helix 41 reduces the tendency of the transmitted TE_{01} wave energy to degenerate into unwanted modes. However, even with this tendency reduced, some power in the unwanted modes is formed and is electrically coupled through the helix into the lossy jacket. Depending upon the unwanted mode level tolerances associated with the over-all helix guide system, at least a portion of this energy in the unwanted modes is to be dissipated within the jacket. In accordance with the present invention the material of jacket 45 is chosen to have a power factor less than unity. Since the power factor is defined as the ratio of the imaginary part to the real part of the permittivity of a given dielectric, this limitation requires the magnitude of the imaginary part, ϵ'' , of the relative permittivity to be less than the magnitude of the real part, ϵ' , of its relative permittivity. Some reference sources designate the power factor associated with lossy dielectric materials as the dielectric loss tangent, and utilize for its representation the symbol $\tan \Delta$. The lowest practical value of the power factor in accordance with the present invention is 0.1. This value, however, is considerably greater than that associated with so-called low-loss or lossless dielectric materials. Helix wave guide models built in accordance with the present invention have utilized materials having a power factor of 0.5.

It should be particularly noted that optimum all-helix guide performance is not necessarily obtained by intentionally selecting a highly lossy material for the jacket 45. Since the degree of loss associated with a given material is only one parameter which influences its resistivity and thus determines the quantity ϵ'' associated with its permittivity, it is possible that a relatively low loss material would produce optimum transmission characteristics in a conductively shielded helix guide if the dielectric constant, or ϵ' , associated therewith is low enough. So far as the parameters of the material are concerned, it is essential only that the ratio of the imaginary part and the real part of its permittivity be within the desired range. No limitation upon the value of the loss associated with the material of jacket 45 is intended.

Since the power factor associated with the lossy jacket 45 is a major guiding parameter for one practicing the present invention, the material and fabrication of jacket 45 must be carefully selected. Thus, for example,

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jacket 45 may be made of a plastic or of a dielectric material such as a polyethylene in which small particles of resistive material, such as, for example, iron dust or carbon black are suspended in the proper amounts to provide the required power factor. Alternatively, jacket 45 may comprise laminated glass roving or glass tape which has been treated with tin oxide as disclosed in the copending application of G. T. Kohman et al., Serial No. 679,835, filed August 23, 1957, or with some other resistive material such as carbon. As further alternatives, carbon-loaded paper, cotton string impregnated with carbon, or alternate layers of lossy and non-lossy dielectric may be used to form the dissipative jacket. One particularly advantageous feature of jackets comprising tin oxide coated glass roving or carbon coated string is that the strands may be wound about the helix structure with a pitch which is substantially angularly related to the pitch of the helix wires. The angle between the pitch of the jacket winding and the pitch of the helix wires is, in part, determinative of the power factor associated with the jacket. Therefore, by varying the angular relationship between the pitches, the power factor may be varied. It is apparent that when the lossy jacket comprises glass roving or cotton string, it is necessary to dispose a thin dielectric sleeve, as mentioned hereinbefore, between the helix wires and the lossy jacket to prevent the protrusion of the jacket material into the interior of the helix.

Regardless of the particular type of fabrication elected for the jacket 45, it is essential, in accordance with the present invention, that its radial thickness t be an odd number of radial quarter wavelengths of the energy propagating in the jacket as measured in the jacket. That is

$$t = \frac{n\lambda_c}{4} \quad n = 1, 3, 5 \dots$$

where

$$\lambda_c = \frac{\lambda_0}{\sqrt{\epsilon - \left(\frac{\lambda_0}{\lambda_g}\right)^2}}$$

λ_0 is the free space wavelength of the propagating energy, λ_g is the guide wavelength associated with energy propagating in the helix wave guide, and ϵ is the permittivity of the jacket material.

Returning now to Fig. 2, jacket 45 is in turn surrounded by conductive shield 46. In the preferred embodiment, shield 46 comprises a conductive pipe within which the jacketed helix is disposed. Since the jacket 45 preferably has a radial thickness of only one-quarter wavelength of the energy to be propagated, the jacket itself imparts little rigidity to the helix structure. An important function of shield 46 is, therefore, mechanically to impart strength and support to the jacketed helix structure. Shield 46 may comprise, for example, copper or steel pipe. In the alternative, shield 46 may comprise overlapping metallic strips or woven braid, but in all cases the required mechanical support must be provided.

In the operation of the helix guide disclosed above, energy in the circular electric TE_{01} wave mode is excited within the helix 41 of guide 15. Ordinarily, the curvature of guide 15 and imperfections therein tend to cause degeneration of the TE_{01} mode into the TM_{11} , the TE_{12} , and other unwanted spurious modes. In accordance with the present invention this tendency has been controlled by raising the radial wall impedance presented to the unwanted modes to provide the best helix wave guide performance over long distances.

Assuming that the helix 41 were free of surrounding jackets or shields, the impedance seen by radially propagating energy would be that of free space modified slightly by the capacitive effect of the closely spaced helix wires. By surrounding the helix 41 with the lossy

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jacket the impedance presented to the radially propagating energy is lowered. The best helix guide performance in all-helix guide applications is obtained if this radial impedance is raised to a value above that previously obtainable in unshielded helix guiding structures by surrounding the jacketed helix structure with the conductive shield 46. This conductive shield participates electrically in the transmission of energy through the guide by virtue of its presentation, to radially propagating wave modes, of an impedance which affects the longitudinal propagation. Since, by virtue of its conductive nature, shield 46 presents at its surface, a zero impedance short circuit to wave energy components incident thereupon, it is essential in accordance with the present invention that this low surface impedance be transformed to a higher value as seen at the helix wires. In order to raise the shield impedance, the radial thickness of the jacket 45 is selected to be an odd number of radial quarter wavelengths of the radially propagating energy, thereby transforming the value of shield impedance in accordance with well-known principles. It is obvious that if the thickness t of the jacket 45 either substantially exceeds or falls short of the quarter wave dimension, the impedance presented by the shield 46 to radial energy components at the helix will be lower than that desired. As the radial thickness approaches a multiple of a radial half wavelength the impedance associated with the shield decreases rapidly and the shield presents a very low impedance to the unwanted mode components. Since the helix wires present a very low impedance to the circular electric wave mode, a half wavelength spacing between helix and shield would produce nearly identical longitudinal propagation constants for the TE_{01} and TM_{11} wave modes. The TE_{01} mode would then freely convert to the TM_{11} mode and the helix guide performance would revert to that obtainable in ordinary round wave guide. Since the electrical advantages to be gained by the presence of the shield would no longer be realizable under the condition of half wave spacing, it is essential that the proper quarter wave spacing be maintained.

The desired quarter wave spacing is determined by the radial wavelength of the radially propagating energy in the jacket 45. When the quarter wave spacing is attained, the impedance presented by shield 46, as modified by the impedance of the jacket 45, and the helix 41, has been raised to a value greater than that of free space, but less than infinity. A similar high impedance value would be obtained for lossy jackets having thicknesses of higher odd numbers of quarter wavelengths, but experiments have shown that a thickness of one-quarter wave is preferable. Energy in the TE_{01} wave mode is substantially unaffected by the jacket and shield since substantially the entire current associated with the TE_{01} mode is carried in the helical path 41. When the radial impedance is raised to a high value, the tendency of the TE_{01} mode to degenerate into the unwanted modes is reduced since the relative impedance seen by the two classes of modes is substantially different.

In a helix guide constructed in accordance with the principles set out hereinabove, and intended for operation at 55 kilomegacycles, the inside diameter d of the helix was 2 inches, the lossy jacket thickness was 25 mils, and the dielectric constant ϵ' associated with the jacket was 4.

In all cases, it is to be understood that the above-described arrangements are illustrative of some of the possible specific embodiments which can represent application of the principles of the invention. Numerous and varied other arrangements could 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 shielded helix wave guide for circular electric mode wave energy in which the helical member is surrounded with a mechanically rigid conductive shield, and an electrically dissipative material having a radial thick-

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ness equal to one-quarter wavelength of said energy in said material and a power factor between one-tenth and unity is interposed between and contiguous to said helix and said shield to separate said helix and shield a distance equal to said one-quarter wavelength.

2. In an electromagnetic wave energy transmission system, means for producing the circular electric mode of said wave energy, means for utilizing said circular electric wave energy, transmission means interconnecting said utilizing means and said producing means 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 and with adjacent turns insulated from one another and spaced apart a distance substantially less than one-quarter wavelength of said energy, a mechanically rigid conductive shield spaced away from and surrounding said conductive helix, and a jacket of electrically dissipative material having a power factor less than unity but greater than one-tenth and a radial thickness equal to one-quarter of the radial wavelength of said energy as measured in said jacket interposed between and in contiguous relationship with said helix and said shield so that the radial wall impedance presented to radial field components at said spaced helix wires is raised to a value greater than the impedance of free space.

3. A high frequency electromagnetic wave energy transmission line comprising a conductive means defining a low-loss transmission path having a circular cross section in planes transverse to the direction of transmission of said energy therethrough, a jacket of dielectric material having a complex permittivity whose imaginary part

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is greater than one-tenth but less than equal to its real part surrounding said conductive means throughout the entire length of said transmission line, said conductive means and said jacket being electrically coupled by a plurality of gaps in said conductive means which are regularly spaced along said line, and an electromagnetically reactive mechanically rigid shield surrounding said jacket and radially spaced away from said conductive means a distance equal to an odd number of quarter wavelengths of said energy as measured in said jacket.

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4. A long distance transmission medium for electromagnetic wave energy in the circular electric mode, said medium comprising an elongated member of conductive material wound in a substantially helical form, said helix having a diameter greater than one wavelength of said energy and having at least one turn electrically insulated from adjacent turns for every quarter wavelength of said energy along the axis of said helix, a mechanically rigid conductive shield surrounding and enclosing said helix, and a jacket of electrically dissipative material having a power factor less than unity but greater than one-tenth surrounding said helix and interposed between and in contiguous relationship with said helix and said shield, said jacket having a radial thickness equal to one-quarter wavelength of said energy as measured within said jacket so that said helix and said shield are effectively spaced said one-quarter wavelength.

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