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H. T. FRIIS ET AL

3,018,452

HELIX WAVE GUIDE

Filed Dec. 29, 1959

FIG. 1

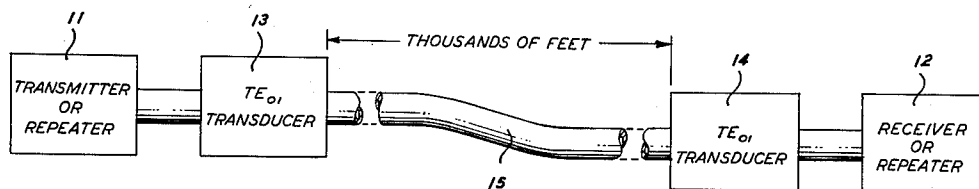


FIG. 2

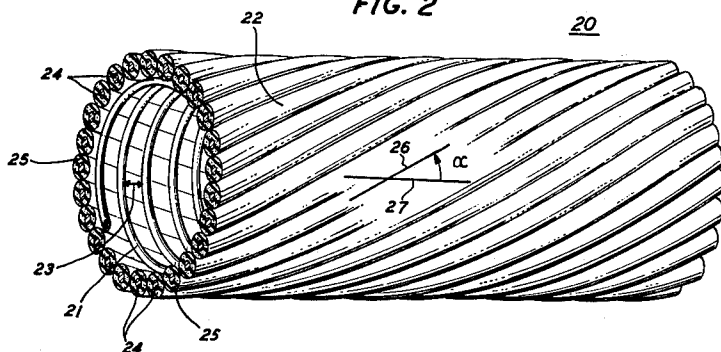
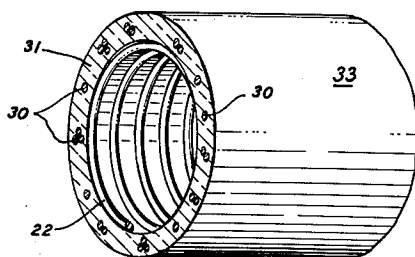


FIG. 3



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HELIX WAVE GUIDE

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5 Claims. (Cl. 333—95)

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

United States Patent 2,848,696, issued August 19, 1958,
to S. E. Miller, discloses that a closely wound helical
conductor of diameter greater than 1.2 free space wave-
lengths of the transmitted energy is a transmission medium
suitable for propagating a properly excited TE_{01} mode.
Upon this wave guiding structure the TE_{01} mode produces
wall currents which are circumferentially directed and
which are satisfactorily supported by the small pitch helix
even though no continuously conductive circumferential
path is provided. At the same time, the unwanted modes
into which the TE_{01} mode has a tendency to degenerate
produce wall currents which are directed in a longitudinal
direction parallel to the guide axis. The dielectric gaps
between adjacent helix turns, across which these currents
must pass, affect the production and propagation of the
unwanted modes. Generally, on the helix guide the
 TE_{01} mode has a phase constant substantially different
from that of the TM_{11} and other unwanted spurious modes.
By virtue of this difference in phase constant, decoupling
between the modes is provided. Additionally, the helix
may be surrounded with a jacket of electrically dissipative
material to increase the attenuation constant difference
between the TE_{01} mode and the unwanted modes and
thereby further to reduce the tendency of the TE_{01} mode
to convert to spurious wave forms.

Such a transmission medium is ideally suited for long
distance transmission of wide band signals since attenua-
tion of power in the TE_{01} mode decreases with increasing
frequency. Used in long lengths, the helix type wave
guide serves to negotiate both accidentally and intention-
ally introduced bends and turns with relatively low con-
version loss. Used in shorter lengths, the helix guide
acts as a filter to purify the TE_{01} energy by attenuating
spurious mode components, particularly of the TM_{11} and
 TE_{12} modes.

Since an increase in the magnitude of the difference
in phase constants and attenuation constants presented by
the guiding structure to the desired mode on the one hand
and to the undesired modes on the other hand increases
the efficiency of the helix guide by reducing mode conver-
sion, it is desirable to increase this difference as much as
possible. For certain applications of the helix guide
however the maximum difference in the propagation con-
stant components is less than that desired. Therefore the
electrical performance of the helix guide falls below the
desired level. Several reasons may be advanced for this
limitation. First, the surface impedance presented to
the unwanted mode currents by the dielectric jacket sur-
rounding the helix is oftentimes of an undesirable value.
Second, the finite size and spacing of the adjacent helix
wires create a capacitive grid between the propagating
spurious mode wave energy within the guide and the
external dielectric jacket, thereby partially shielding the
jacket from the wave energy and permitting only partial
penetration of the undesired currents into the jacket.
Third, the dielectric constants of available lossy jacket
materials are generally too high for effective guide per-
formance.

In the copending application of H. G. Unger, Serial

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No. 679,929, filed August 23, 1957, it is disclosed that
a dielectric separation between helix wires and lossy
jacket in a radial direction introduces an inductive effect
which may be used to compensate for the capacitance
of the wire separation and to transform the impedance
presented to unwanted mode currents by the jacket to a
more desirable value. In the copending application, the
compensating medium takes the form of an isotropic
insulating layer of dielectric material of low to moderate
dielectric constant. Such a medium favorably affects the
propagation characteristics of the helix guide by changing
the impedance presented by the lossy jacket to the longi-
tudinal gap currents associated with the unwanted wave
modes. Since the theory of mode discrimination in the
helix guide rests upon the provision of a substantially
continuous conductive path for TE_{01} mode wall currents
and a substantially discontinuous conductive path for
unwanted mode wall currents, the use of an insulating
medium as a dielectric impedance transformer does not
offend widely held concepts.

However, as disclosed in the copending application
of J. R. Pierce Serial No. 862,665, filed December 29,
1959, it has been discovered that the performance of a
helix type wave guide may be improved by surround-
ing the helix with a jacket exhibiting anisotropic conduc-
tivity with maximum conductivity in a direction parallel
to the guide axis. This is so even though the significant
characteristic difference between the wanted and unwanted
wave modes on a helix guide is the existence of longitudinal
currents of the latter modes at the helix wall.

It is one object of the present invention to improve
helix guide performance by the introduction of longitudinal
conductivity in an improved manner into the media sur-
rounding the helix winding.

As disclosed in the Pierce application, a helix guide
is overlaid with longitudinally extending conductors
which in turn are surrounded by an isotropic dielectric
jacket which may be electrically lossy. In the fabrication
of such a structure difficulty may be encountered in posi-
tioning the longitudinal conductors prior to and during
application of the surrounding medium.

It is, therefore, a further object of the present inven-
tion to facilitate fabrication of a helix wave guide which
includes an anisotropically conductive jacket surround-
ing the helix winding.

It is a more specific object of the invention to introduce
the anisotropic conductivity as an integral part of the
winding procedure used in fabrication of the surround-
ing jacket.

In accordance with the invention, a conductor which
is closely wound in a helical form with a diameter at
least equal to 1.2 free space wavelengths of the energy
to be transmitted is provided with a composite external
jacket comprising both dielectric media and conductive
media. The conductive media are anisotropic in na-
ture; that is, the conductive path provided in a direction
parallel to the axis of the helix is substantially continuous
for currents flowing in that direction while the conduc-
tive path provided in a circumferential direction around
such axis is substantially discontinuous for currents flow-
ing in that direction. As used in this specification "anis-
otropic conductivity" will be understood to refer to a
heterogeneous anisotropy which produces an inductive ef-
fect. That is, the anisotropy arises from discrete con-
ductive and dielectric regions disposed in alternate re-
lation circumferentially about the helix, each such alter-
nate region extending substantially longitudinally over the
extent of the modified guide section. Such an anisotropi-
cally conductive jacket, by providing an inductive effect,
improves the helix guide performance.

According to a preferred embodiment of the present
invention, the desired longitudinal conductivity is pro-

vided by conductors coated with electrically lossy material which overlay the exterior surface of the helix winding and are wound thereupon with a wide circular pitch. Since the single surrounding jacket includes both conductive and dielectric properties, its application as an integral part of the winding procedure eliminates problems of conductor positioning present in the prior art. The resultant anisotropically conducting jacket serves to transform the impedance of its surrounding media to a value conducive to maximum effect upon the propagating unwanted wave modes and at the same time to compensate the inherent capacitive shielding effect of the helix wire grid.

A feature of the invention is the mechanical strength imparted to the dielectric jacket by the presence of the metallic conductors throughout its extent.

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

In the drawing:

FIG. 1 diagrammatically illustrates a guided microwave communication system employing TE_{01} waves and including a long distance helix wave guide section;

FIG. 2 is a perspective view of a section of helix guide including an anisotropically conductive jacket in accordance with the invention; and

FIG. 3 is a perspective view of an alternate helix guide structure having substantial longitudinal conductivity in the outer jacket.

Referring more particularly to FIG. 1, a long distance guided microwave communication system is shown in diagrammatic form. 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 in the 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 2,848,690 granted August 19, 1958, to S. E. Miller or in the copending application of E. A. J. Marcatili, Jr., Serial No. 706,459, filed December 31, 1957, now Patent No. 2,963,663, issued December 6, 1960. 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.

FIG. 2 is a perspective view of a helix guide structure 20 in accordance with the present invention which may be used as long distance guide section 15 in FIG. 1. Guide 20 comprises elongated conductive member 21 of relatively fine wire wound in a circular helix, surrounded by a jacket 22. Conductor 21 may be a solid or stranded copper wire or it may comprise a metal such as iron or steel plated with a highly conductive metal such as copper or silver. Adjacent turns of the helix are electrically insulated from each other, and the insulation may be provided by small air gaps 23, as shown, or the adjacent turns may touch, insulation being provided by an enamel or plastic coating on the conductor itself. The

pitch distance and pitch angle of the helix, i.e., the distance between the centers of adjacent turns is preferably as small as is consistent with the insulating requirement. This distance must in all events be less than one-quarter wavelength and is preferably such that gaps 23 have a width which is less than the diameter of conductor 21.

Surrounding helically-wound conductor 21 is jacket 22 comprising a plurality of conductors 24 each covered with a coating 25 of electrically lossy material. The term "lossy" is understood to refer to a material which is capable of converting into heat energy substantial amounts of electromagnetic wave energy incident thereon. Conductors 24 are preferably metallic and may comprise material similar to that of helical conductor 21. Lossy coatings 25 provide the attenuating mechanism for unwanted modes propagating within jacket 22. As a specific example, jacket 22 may comprise copper wires which are coated with carbon impregnated paper pulp. Alternatively the metallic wire may be coated with carbon loaded plastics, or any other similar lossy material. Since the conductors 24 should be insulated from one another, coatings 25 should possess dielectric insulating properties in addition to their loss properties.

As shown in FIG. 2 the jacket 22 comprises a plurality of coated conductors wound about the helical conductor 21 with a wide circular pitch; that is, the direction of the central axis of a given one of conductors 24, indicated by line 26, is related by a small angle α to the direction of the central axis of the guide itself, indicated by line 27. In the theory, α should be of the order of one or two degrees. However, the inductive effect produced by the conductors varies as cosine α and therefore, in practice α could be increased to twenty-six degrees with a consequent reduction of only ten percent in inductive effect. Jacket 22 thus exhibits a substantial conductivity in a direction parallel to the axis of guide 20 but substantially zero conductivity in a circumferential direction.

One particular advantage of this coated conductor type anisotropic jacket lies in its ease of fabrication. Manufacture of guide 20 is facilitated since loss and anisotropic conductivity are imparted to the guide together as jacket 22 is formed by simultaneous winding of the coated conductors about the helix. As illustrated in FIG. 2 jacket 22 comprises only one layer of coated conductors. The attenuating properties of the jacket may be increased without detracting from over-all guide performance by disposing a plurality of layers of such conductors over the inner helix.

In the typical operation of a helix guide as shown in FIG. 2, and incorporated into FIG. 1, wave energy principally in the TE_{01} mode but with a finite unwanted mode level enters at one end of guide section 15 and is propagated therealong. The circumferential wall currents set up by the TE_{01} mode are carried by the helical conductor 21 whereas the longitudinal wall currents set up by unwanted modes are exposed through gaps 23 to the surrounding jacket 22 in which these currents set up radially propagating waves. The longitudinal conductivity of jacket 22 causes it to appear as an inductive reactance to the radially propagating modes, thereby compensating for the capacitance of the helical conductor and causing the jacket impedance to assume a value conducive to nearly complete coupling of the energy represented by these modes into the jacket 25. The wave energy within jacket 25 is then absorbed by the loss mechanism within the jacket. When the desired impedance match is attained, wave energy in the TE_{01} mode in guide 15 does not easily convert to TM_{11} and other unwanted modes since both the attenuation and phase constant differences between the desired and undesired modes are nonzero. This result follows from the axiom that the tendency to mode conversion is minimized by maximizing the propagation constant differences between the wanted and unwanted modes.

FIG. 3 is a perspective view of an alternate embodi-

ment of the helix guide shown in FIG. 2. As disclosed in the copending application of G. T. Kohman et al., Serial No. 679,835, filed August 23, 1957, now Patent No. 2,966,643, issued December 27, 1960, the jacket which surrounds the central helix of a helix type wave guide may comprise successive laminated wrappings of resin impregnated Fiberglas. In FIG. 3 conductors 30 are randomly distributed within the Fiberglas laminations 31 which surround the helically wound conductor 32. Helix 32 and the Fiberglas portion of jacket 31 are proportioned as disclosed in the above-mentioned Kohman et al. application. Conductors 30 are randomly distributed throughout the laminations as the wrapping process associated with the building up of jacket 31 proceeds. Conductors 30 may extend longitudinally parallel to the axis of the helix guide 33, or they may be wound on with wide circular pitch, as in FIG. 2. In either case the presence of conductors 30 within jacket 31 imparts longitudinal conductivity to the jacket which substantially improves the electrical transmission characteristics of the guide 33.

In all cases it is understood that the above-described arrangements are merely illustrative of the many specific embodiments which can represent applications 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 the form of a helix having a longitudinal axis with adjacent turns of said helix electrically insulated from each other, and means exhibiting anisotropic conductivity comprising a layer of lossy coated conductors overlaying the outer surface of said helix.

2. In an electromagnetic wave energy transmission system, the combination of means for launching the circular electric mode of said wave energy, means for receiving said circular electric wave energy, and means for interconnecting said launching means and said receiving means comprising a conductor wound into a helix with insulated adjacent turns having a given pitch and a plurality of lossy coated conductors wound about said helix with a pitch different from said given pitch.

3. A transmission medium for wave energy of the circular electric family comprising an elongated member of insulated conductive material wound in the form of a helix having a longitudinal axis, and a jacket surrounding said helix comprising a plurality of electrically lossy coated conductive wires wrapped around said helix with a wide circular pitch.

4. A high frequency electromagnetic wave energy transmission line comprising conductive means defining a low-loss transmission path having a circular cross section in planes transverse to the direction of transmission of said energy therealong, and a medium comprising conductors coated with electrically lossy material wound about said conductive means with wide circular pitch, said medium and said conductive means being electrically coupled through a plurality of regularly spaced apertures in said conductive means.

5. In combination, a conductive helix proportioned for the transmission of circular electric mode wave energy, and an anisotropically conductive layer comprising electrically lossy coated conductors wound about said helix to produce greater conductivity in a direction parallel to the longitudinal axis of said helix than in a circumferential direction about said axis.

References Cited in the file of this patent

UNITED STATES PATENTS

2,934,724 Wild et al. ----- Apr. 26, 1960