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ELECTROMAGNETIC WAVE TRANSMISSION

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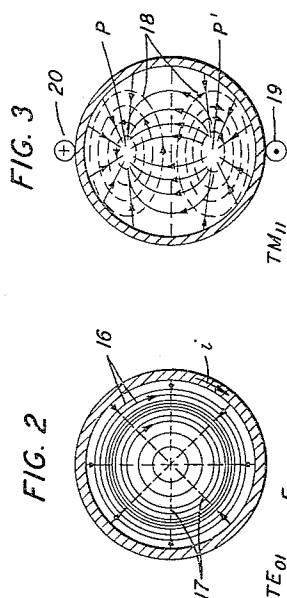
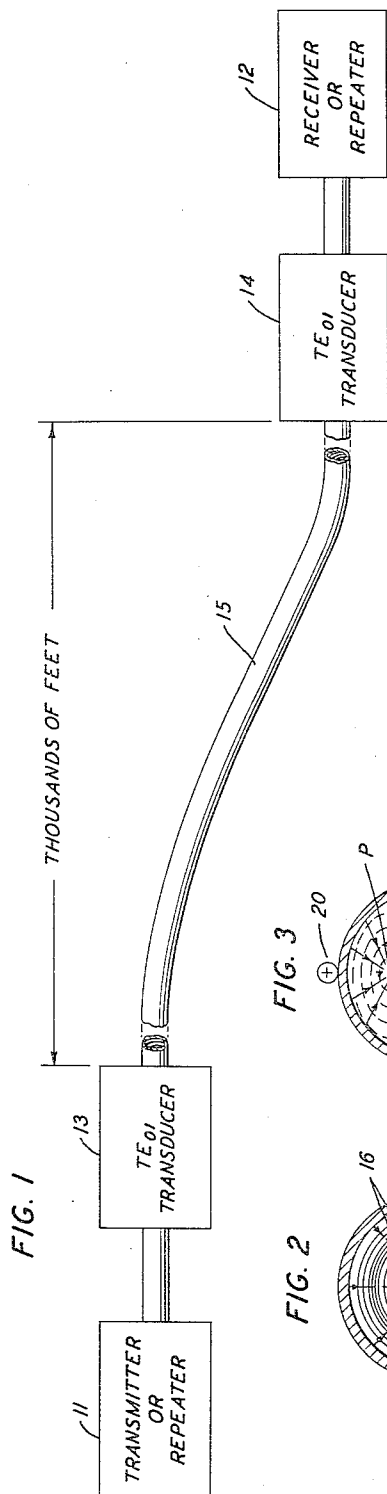


FIG. 4

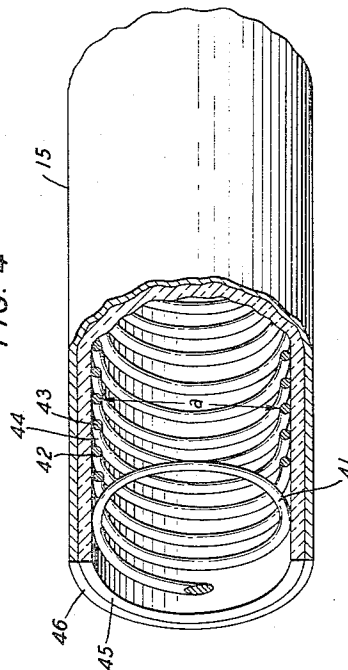
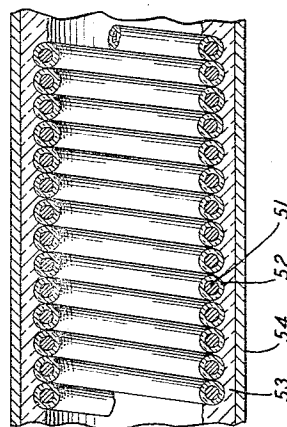


FIG. 5



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ELECTROMAGNETIC WAVE TRANSMISSION

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7 Claims. (Cl. 333—95)

This invention relates to electromagnetic wave transmission systems and, more particularly, to the transmission of the circular electric or TE_{01} mode of wave propagation over long distances in a guided wave transmission system which either through choice or inherency does not follow a perfectly straight path.

The propagation of microwave energy in the form of TE_{01} waves in circular wave guides is ideally suited for the long distance transmission of wide band signals since the attenuation characteristic of this transmission mode, unlike that of all other modes, decreases with increasing frequency. However, one difficulty with this method of transmission is that the TE_{01} mode is not the dominant mode supported in a circular wave guide, and consequently energy may be lost to other modes also capable of transmission therein. In an ideal wave guide which is perfectly straight, uniform and conducting, the propagation of TE_{01} waves therethrough is undisturbed, but slight imperfections in the guide and especially curvature of the wave-guide axis may excite waves of other modes and produce serious losses. These losses are attributed mainly to the fact that the bending of the guide produces a coupling between the desired TE_{01} and other transmission modes, mainly the TM_{11} mode.

Recognizing that the coupling between these modes may be likened to the coupling between traveling waves on coupled transmission lines in that an exchange of energy will take place between the waves when they travel together at the same phase velocity of propagation, the prior art has provided a large number of devices for negotiating bends or turns in the guides. Thus, the phase velocity of the TM_{11} mode (which is normally equal to that of the TE_{01} mode) is changed relative to that of the TE_{01} mode, to increase the relative differences in their propagation constants and to reduce the effective coupling therebetween.

Of the several prior art devices operating according to this principle, one of the most satisfactory is described as a spaced ring line. It comprises a plurality of conductive ring-shaped sections coaxially arranged, and successively spaced from each other at a uniform distance by insulating material. As will be considered in more detail hereinafter, the desired circular electric TE_{01} mode produces circumferential currents which are not appreciably interfered with by the ring structure. The undesired modes produce predominantly longitudinal currents which are seriously affected by the division of the guide into the short cylindrical sections and therefore these modes are given velocities of propagation different from the TE_{01} mode. While this structure is very satisfactory for a short section of line and may be used at a specifically contemplated bend, it is too expensive and too difficult to fabricate as a long section to be used as the transmission line itself and thus to include within its length all bends that cannot be anticipated.

It is therefore an object of the present invention to transmit circular electric mode wave energy over long distances without its degenerating into other modes.

It is a further object of the invention to provide a circular electric wave mode transmission medium which may be economically fabricated in long lengths.

In accordance with the present invention it has been found that a helical conductor of diameter greater than 1.2 free space wavelengths, wound relatively closely, will propagate a properly excited circular electric TE_{01} mode at a substantially different phase velocity from the TM_{11} mode. While such a structure cannot present a continuous path for the circumferential current components of the TE_{01} wave as was presented by the ring type line, it has been found that if the pitch of the helix is sufficiently small, the TE_{01} mode will propagate with substantial mode purity. In addition, this structure may be easily and economically wound in sections of arbitrarily long lengths.

These and other objects, the nature of the present invention, and its various features and advantages, will appear more fully upon consideration of the various specific illustrative embodiments shown in the accompanying drawings and analyzed in the following detailed description of these drawings.

In the drawings:

Fig. 1 diagrammatically illustrates a guided microwave communication system employing the circular electric wave and having a long distance transmission line of the type provided by the present invention;

Figs. 2 and 3 illustrate the transverse electric and magnetic field patterns of the TE_{01} and TM_{11} waves, respectively;

Fig. 4, partially in cross section, illustrates the construction of a small section of transmission line in accordance with the present invention; and

Fig. 5 is a cross-sectional view showing an alternative construction of a section of transmission line in accordance with the invention.

Referring more specifically to Fig. 1, a long distance guided microwave communication system is schematically shown. The system is characterized as long to distinguish it from the short distances found in terminal equipment and to define a system in which the factor of transmission attenuation becomes relatively important. 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. This system comprises a terminal station 11 which may be a transmitter, or if this is an intermediate station, a repeater 11 which is to be connected to a receiver or subsequent repeater comprising station 12. The circular electric TE_{01} mode is the mode in which energy is transmitted between stations and since this mode is not usually produced or utilized directly in the components of a station, transducers 13 and 14 are interposed between stations 11 and 12 and the long distance transmission line 15. Transducers 13 and 14 may be of any suitable well known types for converting TE_{01} wave energy to and from a dominant wave mode configuration. For example, they may be structures of the types disclosed in United States Patent 2,656,513 granted to A. P. King, October 20, 1953, or of the types disclosed in United States Patent 2,748,350, granted to S. E. Miller, May 29, 1956, or of the copending application of S. E. Miller, Serial No. 357,665, filed May 27, 1953.

Line 15 is not completely straight along its entire length since in practical installation it is substantially impossible to maintain the line along a precisely straight path over a long distance. Intentional bends may also be included in order that the line may follow right of ways or turn corners. It is these bends that produce the characteristic moding or degeneration of the TE_{01} into TM_{11} wave power. As noted above, this moding is ascribed to the fact that these waves have substantially the same phase

constants, i. e., phase velocity and wave length and, therefore, interact strongly in a manner analogous to coupled transmission lines.

Fig. 2 illustrates the distribution of the electric and magnetic fields in a transverse section of a circular conductive wave guide supporting the TE_{01} transmission mode. This wave is designated the circular electric type inasmuch as the electric field, shown by the solid lines 16, consists of circular lines coaxial with the guide and lying transversely thereto without any longitudinal components. The transverse component of the magnetic field, indicated by the dotted lines 17, forms at various points along the guide in a radial pattern. The electric field intensity attains a maximum approximately half way between the axis and surface of the guide and drops to zero at the surface. The current flow associated with the TE_{01} wave is predominantly circular around the periphery of the guide as illustrated in Fig. 2.

The configuration of the transverse TM_{11} mode is shown in Fig. 3 and is similar to that of a shield conductor pair. The magnetic field pattern is entirely transverse without any longitudinal components and is indicated by the dotted lines 18 encircling the respective poles P and P'. Since the magnetic lines must form closed paths, they tend to spread out near the center of the guide and to crowd close together at the inner surface mostly near the axis passing through P and P', thus inducing a considerable longitudinal conduction of current in the wall of the guide. The direction of this current flow is shown conventionally by the symbols 19 and 20 on Fig. 3.

Fig. 4 shows in detail a short section of the transmission line 15 of Fig. 1. Thus line 15 comprises a conductor 41 wound in a helix having an internal diameter a . Conductor 41 may be solid or stranded and may comprise a base metal such as iron or steel plated by a highly conductive material such as copper or silver. Adjacent turns such as 42 or 43 of the helix are electrically insulated from each other, and this may be provided by a small air gap such as 44. The pitch distance of the helix, i. e., the distance between the center of turns 42 and 43, and therefore the pitch angle of the helix, should be as small as consistent with the above mentioned insulating requirement. This distance in all events must be less than one quarter wavelength and is preferably such that the gap 44 between adjacent turns is less than the diameter of conductor 41.

The turns of the helix such as 42 and 43 are enclosed or embedded in a protective and supporting casing 45 of plastic or other non-conductive material. Casing 45 may either be semi-rigid, forming a more or less permanent structure, or pliable, forming a flexible one. Casing 45 may then be covered with a thin, solid, non-corrosive conductive shield 46. Shield 46 may, however, be made of spirally wound and overlapping strips, or of a woven braid of non-corrosive metal. Shield 46 serves to protect the line from outside mechanical influence such as moisture and insects and from electrical influences such as stray radiation from adjacent transmission lines.

Casing 45 may be made electrically lossy or dissipative with additional advantages, as disclosed and claimed in the copending application of S. E. Miller, Serial No. 416,316, filed March 15, 1954.

The inside diameter a of helix 41 is related to the diameter of the circular pipe guide which would transmit waves of the same frequency. Thus the diameter a must be greater than the critical or cut-off diameter for the TE_{01} mode in a circular guide. This cut-off diameter is equal to $1.22\lambda_0$, where λ_0 is the wavelength in free space of the longest wave in the transmission band. In practice a should be made several times the cut-off diameter.

In operation, the circular electric TE_{01} wave having the field pattern of Fig. 2 is excited within helix 41. A major component of the circular current i of the wave is conducted along the helical path by each turn. If the pitch of the helix is small, this component constitutes substan-

tially the entire current of the wave. A very small component of the wave is presented with a small reactance caused by the discontinuity between adjacent turns. This reactance will have the effect of changing the phase velocity of the total wave very slightly. It will not, however, appreciably affect the configuration of the TE_{01} mode. The TM_{11} mode, however, has a predominantly longitudinal current flow along the wave guiding path and will be seriously affected by the discontinuity between adjacent helix turns. At the microwave frequencies each gap constitutes a large capacitive series reactance which serves to increase the phase velocity of the TM_{11} mode considerably and thus to reduce the mode coupling and the resultant transfer of energy to the TM mode.

A principal feature of the present invention resides in the ease with which the line may be constructed in long lengths. Thus the helix 41 may be continuously wound upon one end of a rigid mandrel of diameter a . As the helix is slipped toward and off the other end the plastic casing 45 and the protective shield 46 are applied.

In Fig. 5 an alternative construction of the line is shown in which the conductor 51 from which the helix is wound is first thinly covered by a casing of non-conductive material, for example, is given an enamelled insulating layer 52. Commercially available enamelled wire may be used if desired. Thus, when the helix is wound with a pitch distance equal to twice the thickness of enamel 52, the enamel provides a uniform insulating separation between adjacent turns. Dielectric and conductive layers 53 and 54, respectively, may then be placed over the helix as described with reference to Fig. 4.

In all cases it is understood that the above described arrangements are illustrative of a small number of the many possible 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. In an electromagnetic wave transmission system, means for producing the circular electric mode of said wave energy, means for utilizing said circular electric wave energy, and means connecting said utilizing means to said producing means, said connecting means comprising an elongated member of conductive material wound in a substantially helical form, said helix having a diameter greater than one wavelength of said wave energy, said helix having adjacent turns thereof electrically insulated from each other.

2. In a high frequency electromagnetic wave transmission system, means for producing the circular electric mode of said wave energy, means for utilizing said circular electric wave energy, and a substantially cylindrical transmission medium connecting said utilizing means to said producing means, said medium being electrically conductive for direct currents from one end thereof to the other, said medium being conductively discontinuous at least once every quarter wavelength for longitudinal current components of high frequency wave energy conducted along said medium, said medium being conductively discontinuous at least once for circumferential current components of high frequency wave energy conducted along said medium.

3. In combination, a long helix of electrically conducting material having adjacent turns insulated from each other, said helix having an interior cylindrical space filled with non-conductive matter, means for exciting an electromagnetic wave having concentric circular lines of electric field within said space at one end of said helix, said wave having a wavelength less than the diameter of said cylindrical space, and means at the other end of said helix for abstracting said wave energy from said space.

4. A long distance transmission medium for electro-

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magnetic wave energy in the circular electric mode, said medium comprising an elongated member of conductive material, said member being 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 one quarter wavelength of said energy along the axis of said helix.

5. The transmission medium according to claim 4, wherein the spacing between adjacent turns of said helix is less than the dimension of said elongated member as measured parallel to the axis of said helix.

6. The transmission medium according to claim 4, wherein said helix is enclosed in a casing of non-conductive material.

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7. The transmission medium according to claim 4, wherein said helix is enclosed in a casing of non-conductive material and wherein said casing is enclosed in a shield of conductive material.

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