United States Patent

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[54] **HELICAL WAVEGUIDE FORMED FROM DIELECTRIC RIBBON HAVING SYMMETRICALLY DISPOSED CONDUCTIVE STRIPS ON OPPOSITE SIDES**
1 Claim, 2 Drawing Figs.

[52] **U.S. Cl.** **333/95,** 333/84
[51] **Int. Cl.** **H01p 3/12,** H01p 3/08, H01p 3/18
[50] **Field of Search** .... 333/95, 95 (A), 95 (S), 84 (M), 31, 31 (A), 98 (M), 98, 84, 3.000

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ABSTRACT: A helix waveguide structure is adapted to printed circuit techniques. In particular, the wire helix of the prior art is replaced by pairs of helices printed on opposite sides of a low loss dielectric member. The structure is advantageously fabricated by printing conductive strips on both sides of a dielectric ribbon and winding the ribbon into helix form.

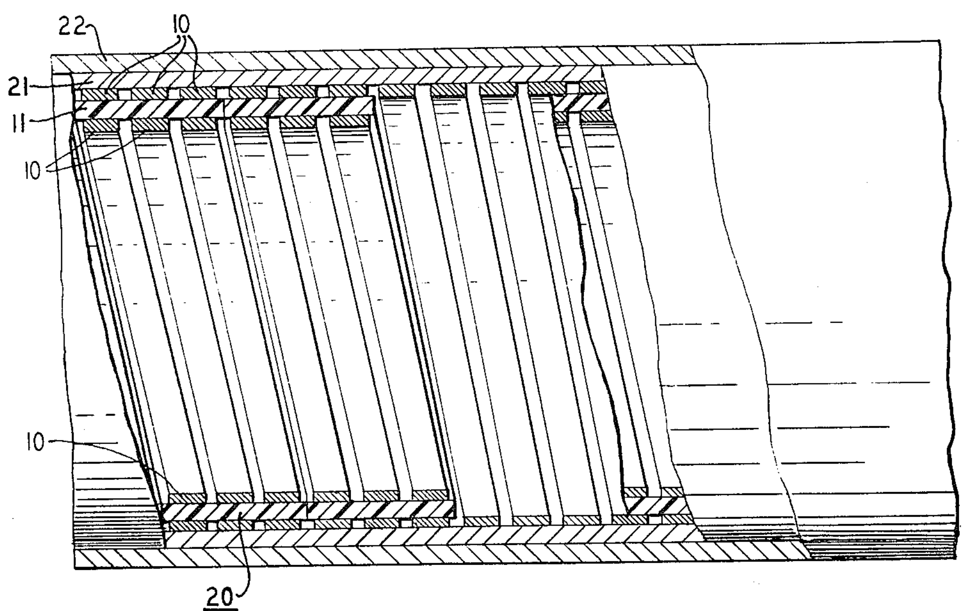

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FIG. 1

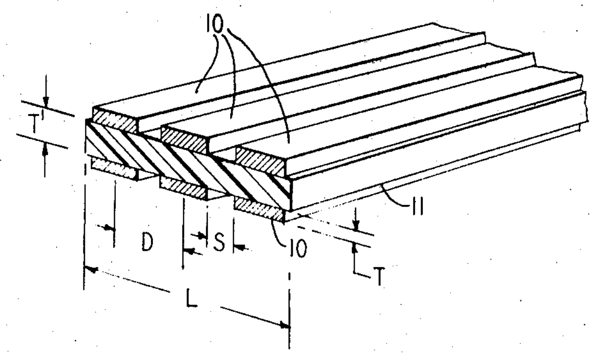
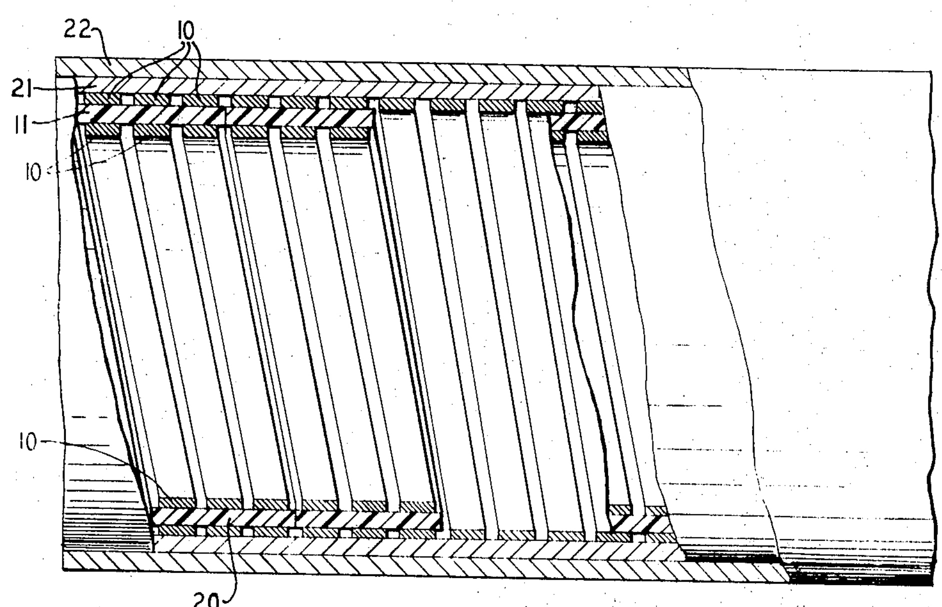


FIG. 2



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HELICAL WAVEGUIDE FORMED FROM DIELECTRIC RIBBON HAVING SYMMETRICALLY DISPOSED CONDUCTIVE STRIPS ON OPPOSITE SIDES

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 waveguides 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 waveguide, and consequently energy may be lost to other modes also capable of transmission therein. In an ideal waveguide 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 waveguide 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}, TE_{11} and TE_{12} modes.

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 practical is the helical waveguide such as is described in U.S. Pat. No. 2,848,696, issued to S. E. Miller on Aug. 19, 1958. In essence, the waveguide comprises an elongated member of insulated conducting material, such as enameled wire, would in a circular helix. The helix is typically covered with an electrically lossy material and surrounded by an outer shielding jacket, such as a steel tube, to protect it from external mechanical and electrical influences. When the inside diameter of the helix is greater than 1.22 times the free space wavelength of the lowest frequency wave to be propagated and the spacing between the centers of adjacent turns of the helix is less than 0.25 times the wavelength of the highest frequency to be propagated, the helix will propagate frequencies within this bandwidth in the circular electric TE_{01} mode. As is well known in the art, the undesired TM_{11} modes produce predominantly longitudinal wall currents and are seriously affected by the insulated separation between adjacent turns of the helix. On the other hand, the circular electric mode produces circumferential currents which are not appreciably interfered with by the helical structure. In addition, the longitudinal currents of the undesired TM_{11} modes are forced to flow through the lossy material resulting in increased attenuation for these modes. The field of the circular electric mode, on the other hand, does not penetrate through the space between adjacent conductors into the lossy material (provided the diameter of the conducting wire is comparable to or larger than the spacing between adjacent turns) because the two adjacent conductors act as a waveguide beyond cutoff. As a result of the different reactance and attenuation, the phase velocity of the TM_{11} mode in such a waveguide is significantly different from that of the TE_{01} mode, and the power transferred between the two modes in a bend is substantially reduced.

One difficulty with helical waveguides, however, is the fabrication of the helix. Typically, the helix is formed by winding a single thin strand of enameled wire on a precision ground mandrel a few inches in diameter and about 20 feet long. Since the wire is typically only a few mils in diameter, it is clear that this is a difficult way to produce the hundreds or even thousands of miles of waveguides that may be required for a waveguide communications network. For example, such thin wires of typical conducting material possess little tensile strength and can easily break while being wound under tension. Moreover, as higher frequencies are utilized, the wires become even thinner. One possible approach to simplifying the fabrication of the helix is to print a plurality of thin conducting strips on a stronger dielectric tape and then wind the tape to produce the desired helix. Unfortunately, in order to prevent significant loss to the TE_{01} mode due to penetration into the lossy layer, the conductive strips must be thicker than can be conveniently made by conventional printed circuit techniques. As has been previously explained, the conductive layers should have a thickness comparable to or greater than the spacing between adjacent strips in order to prevent loss to the TE_{01} mode. However, the minimum allowable spacing is limited by the requirement that the capacitance between adjacent strips be kept low. Consequently, in waveguides for the millimetric range, the conductor thickness should be on the order of a few mils while conventional printed circuit techniques are typically limited to conductors on the order of one mil or less.

SUMMARY OF THE INVENTION

In accordance with the present invention, a new waveguide structure has been devised to permit the use of printed circuit techniques in the fabrication of helical waveguides. In particular, the wire helix of the prior art is replaced by a double helix which can be advantageously provided by printing pluralities of pairs of thin conductive strips on opposite sides of a low loss dielectric ribbon.

BRIEF DESCRIPTION OF THE DRAWINGS

The nature of the present invention and its various features will appear more fully upon consideration of the illustrative embodiments to be described in detail in connection with the accompanying drawings in which:

FIG. 1 is a perspective view of a printed circuit tape useful in fabricating a helical waveguide in accordance with the invention; and

FIG. 2 is a partially cross-sectional view of a typical helical waveguide in accordance with the invention.

DETAILED DESCRIPTION

FIG. 1 is a perspective view of a printed circuit tape useful in fabricating a helical waveguide in accordance with the invention. It shows a plurality of thin strips **10** of conductive material such as copper disposed on opposite parallel sides of a flexible, low loss dielectric ribbon such as mylar tape. The conductive strips are substantially coextensive across the dielectric. As in the prior art the center-to-center spacing, D, between adjacent conductive strips **10** is less than one-quarter wavelength. For millimetric waves, this spacing is typically on the order of 4 mils. The spacing, S, between the edges of adjacent strips is determined by the desired capacitance and is typically on the order of a mil. The thickness, T, of the strips can be chosen for convenience of fabrication. Advantageously the strips are fabricated by printed circuited techniques and the thickness is on the order of 0.1 mil. The thickness T′ of the dielectric ribbon **11** is comparable to or larger than the spacing S but less than one-half wavelength of the highest frequency wave to be propagated. For millimetric waveguide this can be on the order of 3 mils. The length L of the dielectric tape is determined by the maximum allowable pitch angle in the helical waveguide. Typically it can be at least enough to hold two or three conducting strips.

As was previously stated, this printed circuit tape can be conveniently fabricated by using printed circuit techniques to produce the conductive strips. The tape can then be wound into a helical waveguide using substantially the same processes as used in the prior art with the tape substituted for a single strand of wire. Since the tape is stronger than a single thin strand of wire, breakage is less likely; and since the tape carries more than one conducting strip, the number of turns required to produce a given length of helix is proportionately reduced. In addition, since much thinner conductors are used, there is a saving of this material.

FIG. **2** is a partially cross-sectional view of a typical helical waveguide structure made in accordance with the invention. The waveguide comprises a helix **20** of printed circuit tape as described in FIG. **1**, an electrically lossy layer **21**, i.e. typically a material having a resistivity on the order of one ohm-centimeter, surrounding and bonded to helix **20** and an outer shielding jacket **22** to protect the helix from external mechanical and electrical influences. The conductive strips form a helical waveguide. In addition little or no TE_{01} mode energy propagates through the spaces between adjacent conductive strips. The adjacent inner diameter strips and outer diameter strips behave as a waveguide surrounding the space between them. Thus, so long as the thickness T′ is comparable to or greater than the spacing S, the TE_{01} mode energy will see the space between adjacent strips as a waveguide beyond cutoff.

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.

I claim:

1. A transmission medium for guiding wave energy in the circular electric mode of wave propagation within a given band of frequencies comprising:

an elongated dielectric ribbon member having a plurality of conductive strips symmetrically located on opposite surfaces thereof; and

said ribbon and said strips disposed in a substantially helical configuration to form a helical waveguide;

characterized in that:

said strips are conductively insulated from each other and have a center-to-center spacing of less than one-quarter wavelength of the highest frequency of said wave energy;

the thickness of said ribbon is comparable to or greater than the spacing between the edges of adjacent strips, but less than one-half wavelength of said highest frequency wave energy; and

in that an electrically lossy jacket overlays said helically wound ribbon and strips.