

Dec. 27, 1960

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2,966,643

ELECTROMAGNETIC WAVE GUIDE STRUCTURE

Filed Aug. 23, 1957

FIG. 1

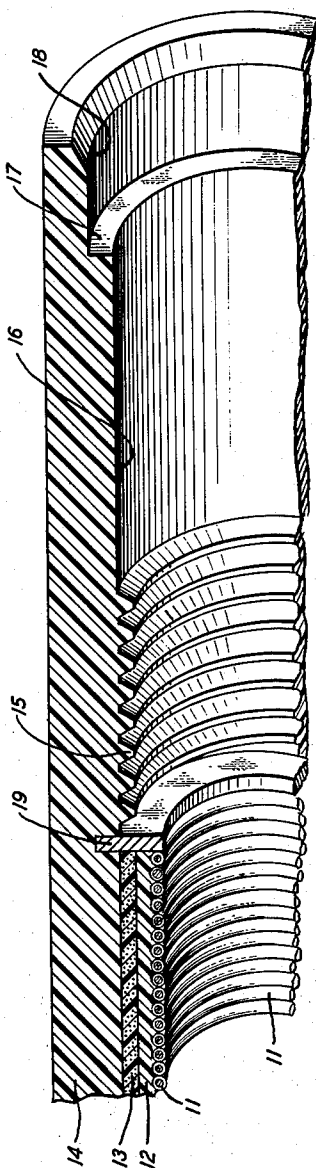
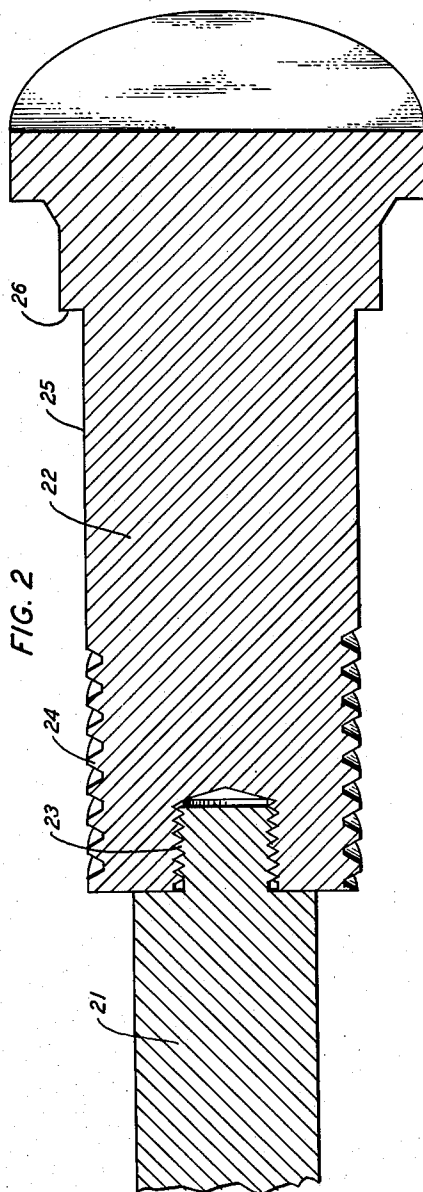


FIG. 2



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ELECTROMAGNETIC WAVE GUIDE STRUCTURE

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Filed Aug. 23, 1957, Ser. No. 679,835

4 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 copending applications of J. R. Pierce, Serial No. 416,315, filed March 15, 1954 (now Patent 2,848,695), and S. E. Miller, Serial No. 416,316, filed March 15, 1954 (now Patent 2,848,696), and in the article "Helix Wave Guide" by S. P. Morgan and J. A. Young, Jr., 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 wave-lengths 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 may have 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 and that by virtue of this difference, degeneration is reduced whether or not there is a difference in phase constant without a substantial amount of energy being actually lost in the dissipative material. The dissipative jacket is in turn surrounded by a sheath to give 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 components, particularly of the TE_{11} and TE_{12} modes.

It is, therefore, an object of the present invention to improve the helical wave guide transmission media from both an electrical and a mechanical standpoint.

Extensive research and analysis have indicated that improved and optimum operation of a helical transmission line can be obtained by providing the lossy jacket with a resistivity in the range between 1 and 10 ohm centimeters, a range substantially below that heretofore contemplated. In the structures disclosed in the above-mentioned applications and publication, the lossy jacket comprises a suitable plastic or dielectric material in which small particles of resistive material are suspended. When the resistive material is carbon or similar material, an attempt to more densely impregnate the plastic material to increase the concentration of the resistive particles and lower the resistance is unsatisfactory because it is accompanied by a physical weakening of the material substantially before a resistivity of 10 ohm centimeters can be reached. When

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a more highly conductive material such as powdered iron is used, increased concentration, which brings the resistive particles closer together, increases the capacitance therebetween and tends to increase the dielectric constant of the material to such an extent that radio frequency energy is prevented from penetrating into it for attenuation. At the other end of the resistance scale are continuous surfaces or conductive films, as opposed to isolated particles, of conductive metals and their more resistive oxides, but these all have resistivities substantially below 1 ohm centimeter.

In accordance with the invention this apparent lack of a suitable resistance material is overcome by employing as the lossy jacket strands of dielectric material that are coated with a thin metallic semiconductive or resistive film and then laminated with a suitable dielectric plastic. While the real ohmic resistance of the film so employed is much below the usable range, it will be shown that the effective resistance presented by the laminated structure to the spurious mode energy can be readily controlled by the ratio of resistive to dielectric material in the laminated structure. In particular, fibrous glass material is coated with a thin metallic oxide and then laminated with a synthetic resin such as epoxide. This structure has desirable electrical properties, is easy and economical to fabricate by commercial processes. It has the further advantage in accordance with another feature of the invention that additional layers of fibrous glass and plastic may be built as a homogeneous structure upon the lossy jacket layer to produce a protective sheath that has dimensional accuracy, that has moisture, corrosion, and deterioration resistance to a high degree, and that has a bending stiffness that can duplicate that of a connected metallic-type wave guide. In addition, a dielectric layer between the helix and the resistive jacket may be added by this construction for the purpose and in accordance with the teachings of H. G. Unger in his copending application Serial No. 679,929, filed August 23, 1957.

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 drawings and analyzed in the following detailed description thereof.

In the drawings:

Fig. 1 is a cut-away view of a small end portion of a transmission line in accordance with the invention; and

Fig. 2 is a cross-sectional view of the form upon which the structure of Fig. 1 may be made.

Referring specifically to Fig. 1, a cut-away cross-sectional view of a small 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 insulated wire closely wound in a helix. Conductor 11 may, for example, be a number 37 size, enameled or plastic insulated solid copper wire (0.005 inch overall diameter). A uniform and appropriate spacing between successive turns is provided by the insulation.

Helix 11 is surrounded by successive layers or jackets which will each be described in more detail hereinafter. Immediately surrounding helix 11 is a dielectric jacket 12 of glass fibers impregnated with a plastic or resinous material. This is followed by a lossy jacket 13 of glass fibers covered with a film of metallic oxide and similarly impregnated with plastic. Jacket 13 is in turn surrounded by an outer jacket 14 of impregnated glass fibers. 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 copper 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 is laminated the first dielectric jacket 12, the purpose, function and dimensions of which are disclosed in more detail and claimed in the copending application of H. G. Unger, Serial No. 679,929, filed August 23, 1957. In general, this jacket provides a transformation of the surface impedance that the lossy jacket 13 presents to the longitudinal currents through helix 11 and acts as an inductance in parallel with the capacitance of the helix to compensate for the shielding effect of the helix upon the spurious modes. For further details, reference is made to said copending application.

The material of jacket 12 comprises plastic reinforced with glass fibers or glass fibers impregnated with plastic. Several methods of building up this layer have each been found satisfactory. According to a first, cloth woven of glass fiber having a length similar to the length of the helix is wound over helix 11 while the plastic is applied between each layer. Alternatively, a tape woven of 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 15 to 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 handmade or 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 between 50 and 75 percent, the higher ratios of glass appearing preferable.

Several plastic materials have been found suitable for practicing the invention. A preferred embodiment employs a suitable commercially available epoxide resin of the type that may be catalytically cured to form a thermosetting polymer. For example, a suitable catalyst is usually either an amine, amide, or a combination of both. It is preferred that a fast enough catalyst be employed that the exothermic heat aids in producing the cure. However, it has been found that the reaction may be hastened without undesirable shrinkage if the exothermic cure is also accompanied by moderate external heat. Specifically, 20 parts per 100 by weight of the curing agent metaphenylene diamine has proven satisfactory. Alternatively, one of the several less expensive thermoplastic polyester resins may be employed. In

general, in practicing this portion of the invention the techniques and materials used are similar to those known to the art and used in other glass reinforced plastics. Reference is, therefore, made for further details and for alternative plastic materials to the text, "Glass Reinforced Plastics," by Phillip Morgan, published in the United States by Philosophical Library Incorporated.

Next, the resistive layer is laminated employing plastics of the types described and glass cloth, tape or roving having an electrically conducting metallic oxide coating of the kind generally known as an iridized coating applied thereto. It is known that when glass or other vitreous ceramic bodies are heated and contacted with certain metallic salts either in the form of fumes or atomized solutions thereof, a strongly adherent layer of an oxide of the metal is formed on its surface. This process is known as iridizing because the coatings thus produced are frequently iridescent due to the interference of light waves reflected from the thin oxide films. Oxide coatings that have an electrical resistance and other characteristics suitable for the present invention may be produced by using mixtures of the metal oxides 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 oxide 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 composition and thickness of the film thus formed, may be defined more clearly after the function that the resistive jacket plays in the transmission line has been examined. Thus, circular electric TE_{01} mode energy is excited within helix 11 by its connection to a solid pipe guide or other component in the system in which the helix is to be used either as a filter or as a transmission medium for circular electric wave energy. A major component of the circular current of this wave is conducted along the helical path by each turn. Since the pitch of the helix is small, this component constitutes substantially the entire current of the wave. The wave is presented with only a small reactance by the discontinuity between adjacent turns which changes the phase velocity of the wave only slightly. Very little of the total TE_{01} current will pass through the resistive material of jacket 13 and, therefore, the attenuation constant of the TE_{01} wave is also substantially unchanged.

The TM_{11} mode has a predominantly longitudinal current flow along the wave guiding path and will be seriously affected by the discontinuity between adjacent turns of helix 11. Not only is the phase constant of this mode increased by the reactance of each discontinuity, but the longitudinal currents are forced to flow through the dissipative material of jacket 13. Thus, the attenuation constant for the TM_{11} mode becomes very different from the attenuation constant for the TE_{01} mode and its degeneration into this spurious mode is reduced. With the TE_{11} and TE_{12} modes, however, there is only a limited range of values of resistivity of jacket 13 for which these modes exhibit a preference for the jacket and are subject to its attenuation to a much greater extent than the TE_{01} mode. Calculations leading to this conclusion are fully set forth in the first above-identified publication. This range includes a resistance presented to the wave energy in these modes of approximately 1 to 10 ohm centimeters.

Now it is a particular feature of the present invention that as a result of the laminated nature of jacket 13 the resistance presented to the wave energy is not the same as the measurable resistance of the metallic films upon the glass. The latter will therefore be referred to as

"the ohmic resistivity" and the resistance presented to the wave as the "effective resistivity." By laminating the resistive films with dielectric material in accordance with the invention, it is possible to use a material having an "ohmic resistivity" that is more than a thousand times lower than the required "effective resistivity." Thus, metallic and metallic oxide films can be used with the further advantage that the dielectric constant of the composite material remains low as opposed to the high dielectric constant of a composite material including isolated metallic particles.

To illustrate these principles, the parameters of a preferred embodiment may be given by way of example. It is desired to produce an "effective resistivity" in the order of 2 ohm centimeters having a dielectric constant in the order of 10. This is done by winding 0.005 inch thick laminations (the thickness of the glass fibers material) having a metallic oxide coating applied thereto of material having an "ohmic resistivity" of approximately 0.002 ohm centimeters to a total thickness of 0.04 inch. The metallic oxide coating in such an embodiment may be in the order of 3,000 angstroms in thickness which gives it a surface resistivity of approximately 50 ohms per square. Equivalent parameters for other embodiments may be determined empirically or they may be calculated using the equations derived for multilayer transmission line structures by E. I. Hawthorne in an article "Electromagnetic Shielding With Transparent Coated Glass" appearing in the Proceedings of the Institute of Radio Engineers, vol. 42, page 548, March 1954.

Having thus constructed lossy jacket 13, the transmission line in accordance with the invention 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 roving of glass fibers and tape of glass fibers in these portions and to employ a resin having some resiliency and ductility to prevent chipping of these parts through use. Therefore, in accordance with a preferred embodiment of the invention, 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, a substantially homogeneous, closely bounded 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 insure uniform serpentine deformation of the entire line in the event of thermal 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 the standard 2 inch inside diameter wave guide.

The completed guide is then cured according to standard plastic handling processes while mandrel 21 con-

tinues 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 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 mode, said medium comprising an elongated member of conductive material wound in a substantially helical form with adjacent turns electrically insulated from each other, a first jacket surrounding said helix for presenting an effective resistivity of a given value to wave energy having current components parallel to the axis of said helix, said jacket comprising glass fibers coated by an iridized film of metallic oxide, said film having a value of ohmic resistivity substantially lower than said given value, said coated fibers being bound together in a laminated structure by a plastic material, a second jacket surrounding said first jacket comprising further glass fibers being bound together in a laminated structure by a plastic material.

2. In combination with the medium of claim 1, a section of conductive metallic walled wave guide connected to one end of said medium, the laminated jackets of said medium having a total thickness sufficiently greater than the thickness of the metallic wall of said wave guide section so that said medium has a bending stiffness substantially equal to the bending stiffness of said wave guide section.

3. A 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 with adjacent turns electrically insulated from each other, and a jacket surrounding said helix for presenting an effective resistivity of a given value to wave energy having current components parallel to the axis of said helix, said jacket comprising fibers of glass with iridized coatings of metallic oxide, said iridized coatings having values of ohmic resistivity substantially lower than said given value of effective resistivity and being separated in a laminated construction by dielectric material at least a part of which comprises a plastic material impregnating said glass fibers the amount of separation raising the value of effective resistivity presented to said component to said given value.

4. The medium according to claim 3 wherein said fibers of glass are woven into fabric and wherein said fabric is wound about the axis of said helix.

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