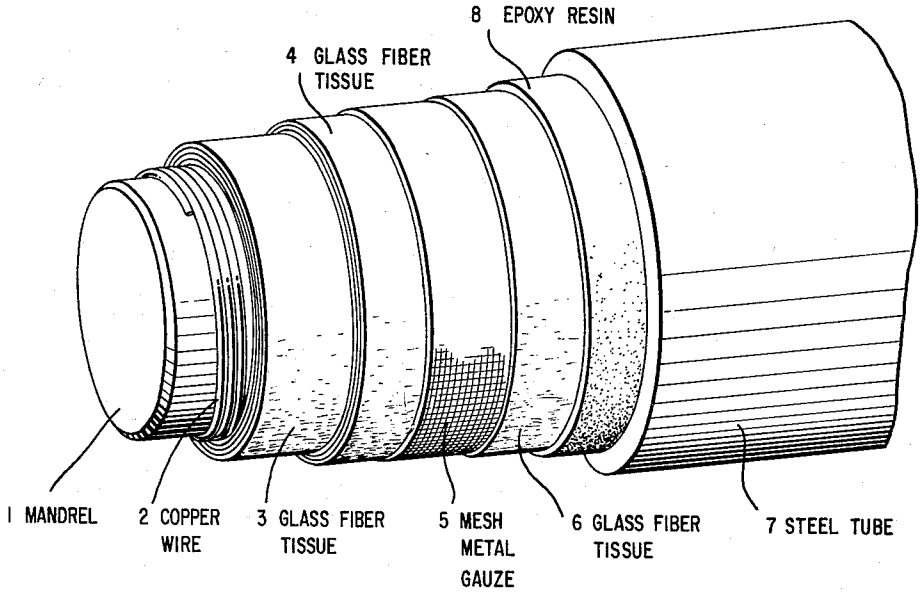
Feb. 11, 1964 P. MANDEL 3,121,206

HELICALLY WOUND CIRCULAR CROSS-SECTION WAVEGUIDES IN CONDUIT WITH EPOXY BONDING BETWEEN ELEMENTS

Filed Aug. 28, 1962

FIG. 1



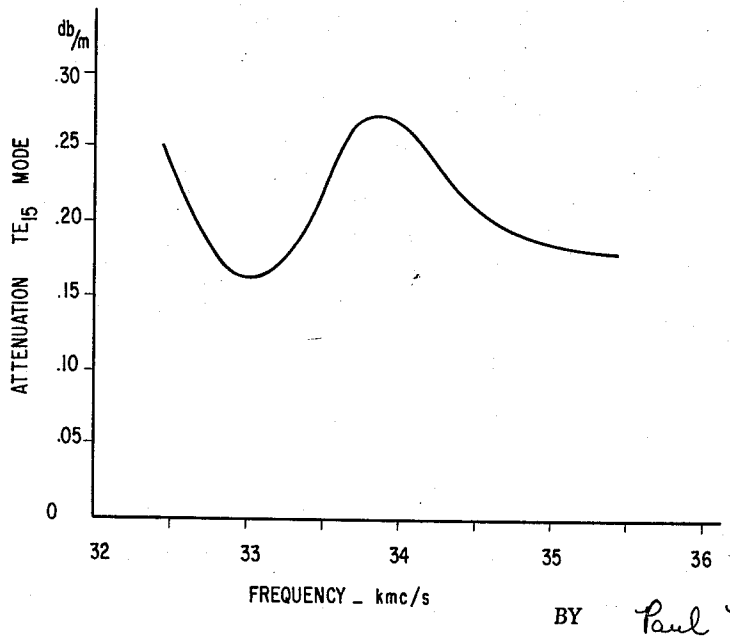


FIG. 2

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HELICALLY WOUND CIRCULAR CROSS-SECTION WAVEGUIDES IN CONDUIT WITH EPOXY BONDING BETWEEN ELEMENTS

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5 Claims. (Cl. 333—95)

This application is a continuation-in-part of my application, Serial No. 76,033, filed December 15, 1960, for "Wave Guides," now abandoned.

The present invention relates to circular cross-section waveguides, more particularly adapted to the transmission of TE_{01} waves of ultra-high frequency, and the wall of which consists of a helical winding of insulated high-conductivity metal wire.

Waveguides have been previously known which consist of a layer of wire or tape of high-conductivity metal wound in the shape of a tubular helix and externally coated by a sheathing or jacket of dielectric material which in turn is, for mechanical protection, secured inside a metallic envelope consisting, for instance, of a steel tube. The dielectric material, generally a plastic material, performs two distinct functions, that of binding together the turns of the helix so as to give the assembly a well-defined and permanent shape, and that of providing a certain amount of high-frequency energy dissipation which, thanks to the special propagation conditions of the TE_{01} wave, does not affect the latter, but is useful in eliminating certain spurious wave modes which are likely to arise from small irregularities in the internal surface of the guide or from other causes. Eventually, dissipation may be systematically increased by embedding of lossy material in the dielectric jacket.

In an embodiment of such a guide described in a paper by H. G. Unger in the U.S. review "Bell System Technical Journal," November 1958, pp. 1599–1647, it has been proposed to build the jacket from "Fiberglas," i.e. a glass fiber tissue impregnated with an epoxy resin and at least part of the fibers of which are coated with a resistive metallic oxide, to provide the required dissipation. The same author also points out that it is generally advantageous to surround the dielectric jacket by a metallic shield, provided the radial distance between the latter and the outer surface of the conducting helix be given a suitable value, substantially equal to a quarter of the radial wavelength in the dielectric material.

However, the building of a waveguide fulfilling the above-mentioned conditions is not easy in practice, since the existence of a plurality of more or less compact (or even solid) layers, and more especially that of the metal shield, make it difficult to assemble them by such a method as plastic material injection, as the injected material would not be able to freely flow through the assembly and to transform it, upon solidifying, into the desired rigid and compact structure.

An object of the present invention is a method of building the various dielectric layers and the metallic shield in such a way that they can readily be assembled, together with the tubular helix of conducting wire constituting the guide proper, by a conventional plastic material injection method. According to the invention, this result is obtained thanks to the use of a particular method of construction of the shield.

According to the present invention, there is provided a protective sheath for a waveguide including a tubular conductor formed of an elongated member of conductive material wound in a substantially helical form, comprising a dielectric jacket made of a porous insulating fabric disposed on the outer surface of said tubular conductor

and a fine mesh metal gauze shield disposed on the outer surface of said dielectric jacket, an external protective envelope in which said guide is introduced and an adhesive resin injected in the space between said external envelope and said metal shield, whereby said adhesive resin spreads through said shield and dielectric jacket to said outer surface of said conductor and ensures the compactness of the assembly.

According to a preferred embodiment of the invention, the protective envelope hereabove referred to is a metal envelope, for instance a thick and rigid steel tube.

The nature and the advantages of the invention will be better understood from the hereinafter given detailed description, made with reference to the annexed drawing, in which:

FIG. 1 is a longitudinal sectional view of a guide according to the invention, and

FIG. 2 is a curve showing the electrical transmission performance of the guide of FIG. 1.

Referring now to FIG. 1, there may be seen at 1 a cylindrical mandrel which is used in the manufacturing process of the guide and removed at the end of said process. In practice, the manufacturing of the guide takes place in comparatively short lengths, for instance 6 to 10 feet. Of course, the mandrel is an accurately machined circular cylindrical piece.

In FIG. 1, the cross-section of mandrel 1 is shown substantially actual size, while, to make the drawing clearer, the thicknesses of the various concentric layers forming the guide and its insulating covering and metal shield have been considerably enlarged, except for that of the outer protective steel tube 7, whose thickness is also shown actual size.

The helical conductor, shown at 2 in FIG. 1, consists of closely-wound turns of enameled copper wire, wound around mandrel 1.

After the layer of helically-wound copper wire layer constituting the guide proper has been wound on the whole length (or nearly that length) of mandrel 1, a covering jacket of insulating material, consisting of a plurality of layers 3, 4 of closely-wound turns of a thin tape of glass fiber tissue, is applied over the wire layer.

After several layers of the insulating material have been wound (it is preferable to use a plurality of thin layers instead of a single thicker one or a lesser number of thicker ones, since very regular and uniform overall thickness is more easily obtained in that way), the metallic shield is applied.

The metallic shield, shown at 5 in FIG. 1, consists of a layer of fine mesh metal gauze, supplied in the form of a thin and rather wide tape, which is wound in close turns over the insulating jacket. The metal gauze is made of wire with a good electrical conductivity, such as copper, or preferably of a copper alloy or bronze, for higher mechanical strength. By carefully winding such a layer of thin tape, it is also possible to secure very uniform thickness over the whole length of the mandrel.

The metallic shield having thus been wound, an extra layer of glass fiber tissue 6 is applied over said shield, and the whole assembly of mandrel 1, helical conductor 2, insulating layers 3 and 4, shield 5 and insulating layer 6 is introduced into the protective steel tube 7, inside which it is centered by spacers or any other means. An adhesive epoxy resin 8 is injected between 6 and 7, and forced by pressure to penetrate into the assembly up to the outer surface of helix 2. The injection preferably takes place from both ends of tube 7. After full impregnation, polymerization is effected in the usual way. A compact assembly is obtained, and experience shows that uniform thickness of the various layers is retained, together with good centering of each one with respect to

the others and to tube 7. On another hand, no difficulty is experienced in removing the mandrel from the assembly, since the epoxy resin does not adhere to the polished surface of the mandrel.

It has been found that it is not necessary to include dissipative material in the insulating layers located inside the shield for obtaining a waveguide having good electrical transmission properties, provided good centering of the structure is maintained, together with a suitable value of the radial distance between the outer surface of the helical conductor and the shield, as already mentioned, this value depending on the average working frequency of the wave to be transmitted and on the permittivity (dielectric constant) of the insulating layers.

A numerical example will now be given, describing a guide actually built for 35,000 megacycles per second working, and the electrical performance thereof:

(a) Mechanical Dimensions

(1) Guide dimensions:

	Millimeters
Inside diameter, helical winding	50
Copper wire diameter	0.10
Wire diameter (over enamel)	0.12
Wire winding pitch	0.12

(2) Insulating layers between guide and shield: Four layers of glass fiber tissue, each 0.08 millimeter thick, plus three layers of similar tissue, each 0.3 millimeter thick (all in the form of 20-millimeter wide tape); total thickness about 1.2 millimeter. All layers wound in close turns without overlapping. The 1.2 millimeter thickness is very close to one-fourth of a radial wavelength, for a material with a dielectric constant of about 3, as directly measured.

(3) Metallic shield: One layer fine mesh bronze wire gauze, round wire; diameter of wire 0.07 millimeter; mesh size (square) 0.16 millimeter; gauze supplied in the form of 20-millimeter wide tape.

(4) Insulating layer over metallic shield: One layer of glass fiber tape, 0.3 millimeter thick, similar to the outer layers of the insulating covering of the guide proper.

(5) Spacing for resin injection: About 3 millimeters radially.

(6) Protective envelope: Drawn seamless steel tube, inner diameter 60 millimeters, outer diameter 70 millimeters.

(b) Electrical Performance

(1) Measured attenuation of TE_{10} wave at 34,500 mc./s., 0.003 decibel per meter: This attenuation value was measured by successive reflections of short impulses in a 50-meter-long line terminated at each end by adjustable reflecting pistons. The transmitter was a magnetron, pulse-modulated by 0.02 microsecond pulses. The receiver was of the frequency-changing type, with a reflex klystron local oscillator, crystal diode mixer, 60 mc./s. bandwidth intermediate frequency amplifier, second detector and high-gain oscilloscope.

The inside of the guide was in direct communication with the atmosphere. If due account is taken of air losses (oxygen and water vapour) and of the extra attenuation introduced by the terminal coupler, the attenuation value found for the guide itself is about ten percent less than the above-given value.

(2) Attenuation of parasitic modes: The main parasitic mode is the TM_{11} mode. Its attenuation cannot, generally speaking, be measured directly, since it is too high. It is also very difficult to excite this mode alone.

The attenuation per unit length for the TM_{11} mode $\alpha(TM_{11})$ has been indirectly measured by taking advantage of a well-known relationship between its value and that of the attenuation $\alpha(TE_{15})$ of the TE_{15} mode. This relationship is the following:

$$\frac{\alpha(TM_{m,n})}{\alpha(TE_{p,q})}=\frac{U'^{2}_{p,q}-p^2}{p^2}\,\frac{1}{\sqrt{1-\left(\frac{\lambda U_{m,n}}{2\pi R}\right)^2}}\,\frac{1}{\sqrt{1-\left(\frac{\lambda U'_{p,q}}{2\pi R}\right)^2}}$$

wherein $U_{p,q}$ is the qth root of the Bessel function J_p of order p, $U'_{p,q}$ is the qth root of the derivative of the Bessel function of order p, λ the wavelength in free space and R the inside radius of the waveguide. In the particular case where $m=1$, $n=1$, $p=1$, and $q=5$:

$$U_{1,1}=3.831 \qquad U_{1,5}=16.470 \qquad U'_{1,5}=14.863$$

The attenuation of the TE_{15} mode was easily measured by a resonance method, using a one-meter-long guide sample closed at each end by a short-circuit piston. The TE_{15} wave was excited through two coupling holes respectively fed from two corresponding interconected rectangular guides, and the amplitude of the excited wave was measured from two other coupling holes, also connected with two interconnected rectangular guides. The attenuation thus measured for the TE_{15} mode was about 0.217 decibel per meter. From the aforesaid mathematical relationship, the attenuation value for the TM_{11} mode was found equal to about 45 decibels per meter.

Similar relations which hold good for the TE_{11} and TE_{12} modes gave for the latter attenuation values of 35 and 3 decibels per meter, respectively.

The TE_{15} mode attenuation curve as a function of frequency of the above-described guide is shown in FIG. 2.

What is claimed is:

1. A protective sheath for a waveguide including a tubular conductor formed of an elongated member of conductive material wound in a substantially helical form, comprising a dielectric jacket made of a porous insulating fabric disposed on the outer surface of said tubular conductor and a fine mesh metal gauze shield disposed on the outer surface of said dielectric jacket, an external protective envelope in which said guide is introduced and an adhesive resin injected in the space between said external envelope and said metal shield, whereby said adhesive resin spreads through said shield and dielectric jacket to said outer surface of said conductor and ensures the compactness of the assembly.

2. A protective sheath as claimed in claim 1, wherein said porous fabric consists of glass fiber tissue.

3. A protective sheath for a waveguide including a tubular conductor formed of an elongated member of conductive material wound in a substantially helical form, comprising a dielectric jacket made of a porous insulating fabric disposed on the outer surface of said tubular conductor and a fine mesh metal gauze shield disposed on the outer surface of said dielectric jacket, an external metal envelope in which said guide is introduced and an adhesive resin injected in the space between said external envelope and said metal shield, whereby said adhesive resin spreads through said shield and dielectric jacket to said outer surface of said conductor and ensures the compactness of the assembly.

4. A protective sheath as claimed in claim 3, wherein said porous fabric consists of glass fiber tissue.

5. A protective sheath as claimed in claim 3, wherein said metal envelope is a steel tube.

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