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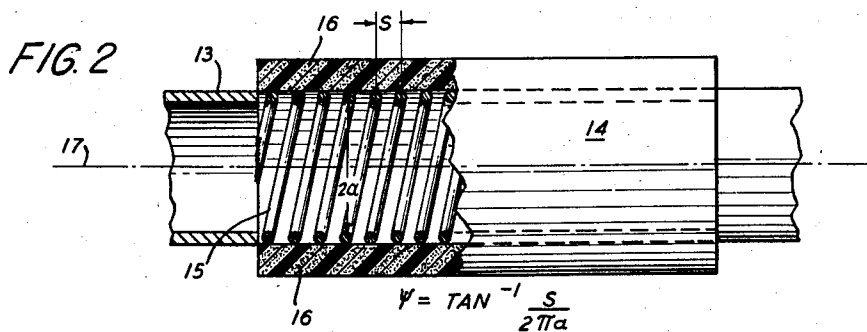
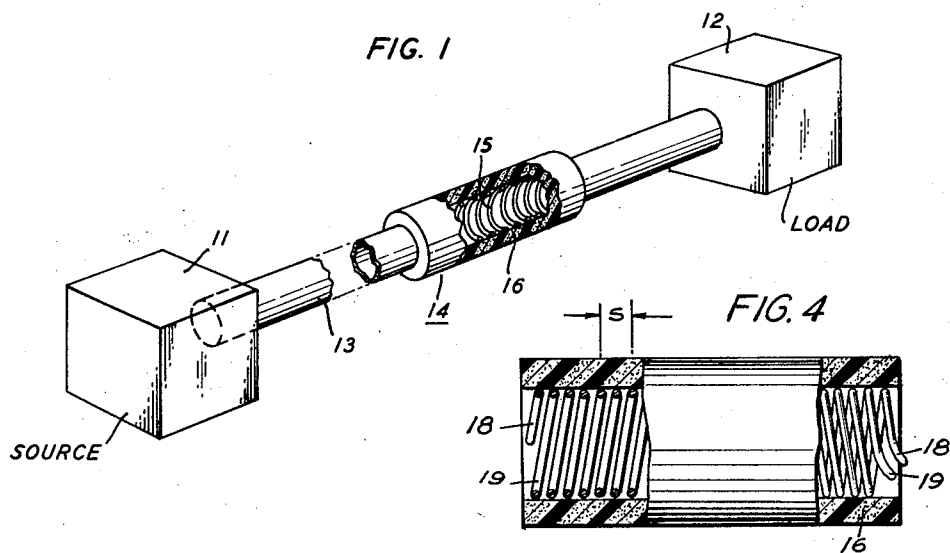


FIG. 3

MODE	ψ	ν	a/λ_0
TE ₁₁	22.1°	.801	.366
TE ₂₁	24.5°	.820	.593
TE ₃₁	25.8°	.829	.807
TE ₁₂	10.0°	.727	1.17

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1

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HELICAL WAVE GUIDES

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This invention relates to electromagnetic wave transmission systems employing a wave guide of circular cross section and, more particularly, to mode and polarization selective elements for use in such systems.

It is an object of the present invention freely transmit a given round guide mode of electromagnetic wave energy and to substantially attenuate all other modes.

It is another object of the invention to freely transmit a given sense of circular polarization of a round wave guide mode of electromagnetic wave energy and to substantially attenuate the opposite sense of circular polarization.

It has been known that electromagnetic waves propagating in a conductively bounded transmission medium of circular cross section induce conduction currents in the cylindrical conductive boundary. Waves of the transverse electric type, that is, waves having electric vectors which are everywhere perpendicular to the direction of propagation, are characterized by the fact that the induced wall currents in general have both longitudinal and transverse components, the longitudinal component being parallel to the axis of propagation and the transverse component being perpendicular thereto. The resultant direction of wall current flow is therefore at some angle to the axis of propagation, this angle corresponding to the proportion between the longitudinal and transverse components. Furthermore, each such mode has a unique and different direction of wall current flow, depending upon the particular field configuration associated with that mode.

In accordance with the present invention, an anisotropic conducting boundary is provided for a circular wave guiding path such that unattenuated wall current conduction takes place only at one specific angle and substantial dissipation is introduced into currents flowing at all other angles. More particularly, it has been found that a wave guiding structure having a helically wound conductive boundary will provide a substantially lossless transmission path for the mode having a direction of wall current flow which lies along the helical windings. At the same time, all other modes, having different directions of wall current flow, will "see" as discontinuous wave conduction path and will bridge these discontinuities between windings in the form of displacement currents. These displacement currents can be dissipated in a lossy sheath or jacket surrounding the helix. The wave guiding structure thus provided acts as a mode filter in that it will preferentially propagate only one mode and will severely attenuate all other modes. Furthermore, the sheathed helical wave guide is capable of distinguishing between opposite senses of circular polarization of electromagnetic wave energy. It will freely propagate only that sense of circular polarization corresponding to the circular sense of the helical winding and will dissipate wave energy having the opposite sense of circular polarization. This helical structure can therefore be used as a filter for one sense of circular polarization or as a transducer from linearly polarized to cir-

2

cularly polarized waves. The linearly polarized waves here referred to are those waves whose electric field vector at a point at all times lies along a fixed line and merely varies in amplitude with the progression of time.

- 5 On the other hand, in the circularly polarized wave, the electric field vector at a point describes a circle in the plane of the cross section as time progresses and does not change in amplitude. The latter should not be confused with the circular electric or circular magnetic waves which
- 10 have no direction of polarization. It is well known that a linearly polarized wave can be considered as two circularly polarized waves of the same frequency but of opposite circular polarizations.

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

In the drawings:

- 20 Fig. 1 is a perspective view of a wave transmission system employing a helical filter in accordance with the principles of the invention;

Fig. 2 is a partially cut away view of the helical filter shown in Fig. 1;

- 25 Fig. 3 is a table of the helix pitch angles and diameter ratios required to freely pass certain of the lower order modes; and

Fig. 4 is a partially cut away view of a multifilar helical filter in accordance with the principles of the invention.

- 30 Referring more particularly to Fig. 1, there is shown as a specific illustrative embodiment of the invention an electromagnetic wave transmission system comprising a source 11 of microwave energy in some given transverse
- 35 electric mode, preferably the dominant TE_{11} mode for the round pipe wave guide, and having a given sense of circular polarization. Source 11 may, for example, supply TE_{11} mode energy in the clockwise or right hand sense of circular polarization, as viewed along the direction of
- 40 propagation, corresponding to the direction of rotation of a right hand screw when advancing in the direction of propagation. Source 11 is connected to load 12 by means of wave guide transmission path 13 of substantially circular cross section. Source 11 and load 12 are
- 45 adapted for the right hand sense of circular polarization of the dominant mode while transmission path 13 represents the type of transmission line having bends, joints, slight physical imperfections, and deliberately inserted components, any of which tend to introduce multimoding and asymmetrical reactance effects to the energy transmitted therealong. As is well known, these effects convert
- 50 portions of the normally right hand circularly polarized dominant mode wave into other spurious modes and into the opposite left hand sense of circular polarization, resulting in elliptically polarized wave components. To prevent undue reflections from load 12, these spurious modes and polarizations must be eliminated in some manner prior to entering load 12.

In accordance with the present invention, the spurious modes and polarizations introduced by path 13 are eliminated from the output thereof by a filter 14 comprising a helically wound conductor 15 surrounded and supported by a lossy jacket 16. The walls of filter 14 will conduct electrical currents in only one direction, corresponding to the direction of the helical windings, and will dissipate modes and polarizations having different directions of wall current flow. The operation of the filter may be better understood upon consideration of Fig. 2 which shows filter 14 separated from the system shown in Fig. 1.

- 70 Referring therefore to Fig. 2, the axis 17 designates the axis of propagation of wave energy in filter 14. As shown in Fig. 2, the helix formed by conductor 15 has

3

an inner diameter of "2a" and a helical pitch angle of "ψ," where the pitch angle is defined by

$$\tan^{-1} \frac{s}{2\pi a}$$

where s is the spacing between turns. Jacket 16 is composed of highly dissipating material for attenuating the displacement currents existing between adjacent turns of wire 15. Jacket 16 may, for example, comprise a dielectric material such as polystyrene or Teflon in which carbon particles are embedded. Conductor 15 has a diameter which is small compared to the wavelength of the energy in filter 14 and adjacent turns of conductor 15 are closely spaced but electrically separated from one another. Conductor 15 may, for example, be an enamel-covered copper wire which is closely wound to form the helix. To arrive at the proper pitch angle "ψ," a multifilar winding as shown in Fig. 4, comprising a plurality of insulated conductive wires i.e., 18 and 19, may be used instead of single conductor 15 of Fig. 2, for it is evident that as the pitch increases, the space between adjacent turns will increase, thus exposing the preferred mode to the dissipative jacket 16. This may be avoided, however, by using a multifilar winding. It is then possible to use the large pitch angle called for by the mode to be propagated and still satisfy the other two requirements of an efficient filter, namely that the diameter of conductor 15 be small compared to the wavelength of the energy of the preferred mode to be transmitted through the filter and that adjacent turns of conductor be closely spaced. Thus, in Fig. 4, the space s between adjacent turns of winding 18 is filled in by a turn of wire 19, thus providing a low loss path for the wall currents associated with the preferred mode.

It can be shown from the characteristic equations for a helical wave guide such as that shown in Fig. 2 that the attenuation constant of such a geometry for a transverse electric TE_{nm} mode is approximately given by

$$\alpha = K \frac{\nu^2}{a\sqrt{1-\nu^2}} \cdot \frac{p^2}{p^2-n^2} \cdot \frac{\left(\tan \psi \pm \frac{n}{p} \sqrt{\frac{1-\nu^2}{\nu^2}}\right)^2}{1+\tan^2 \psi} \quad (1)$$

where:

α=the attenuation constant of the helix,
K=a constant depending upon the properties of lossy jacket 16,
a=the inner radius of filter 14,
ν=λ₀/λ_c=the ratio of free-space wavelength λ₀ to cut-off wavelength λ_c of the waves in filter 14,
p=the mth zero of the derivative of the Bessel function of order n,
m=the number of the mode,
n=the order of the mode,
ψ=the pitch angle of the helix,

and the plus sign denotes that sense of circular polarization of the transverse electric wave opposite to the sense of the helical winding of conductor 15, while the minus sign denotes that sense of circular polarization the same as the sense of the helical winding.

It can be seen from a consideration of Equation 1 that the attenuation constant of a helical wave guide can be made substantially equal to zero when the numerator of the quantity on the right hand side of the equal sign is made to equal zero. This condition is attained when the bracketed quantity is zero, which occurs when the sense of the helical winding is the same as the sense of the circular polarization of the waves transmitted there-through and the helix pitch angle is given by

$$\psi = \tan^{-1} \left[\frac{n}{p} \frac{\sqrt{1-\nu^2}}{\nu} \right] \quad (2)$$

A helix having the above-defined pitch angle will theoretically have zero attenuation (assuming infinite conductivity of the helix) for the TE_{mn} mode having a

4

sense of circular polarization corresponding to the sense of the helical winding. In this case, the wall currents of this mode lie exactly along the helical windings and suffer little or no wall attenuation loss. On the other hand, all of the other modes having wall currents which do not lie along the helix will be attenuated as displacement currents in lossy jacket 16. The transverse electric modes having a sense of circular polarization opposite to the sense of the helical winding will also have wall current components which do not lie along helically wound conductor 15 and will also be attenuated by lossy jacket 16. Furthermore, for a particular frequency of operation this loss to the opposite sense of circular polarization can be made a maximum. More particularly, when

$$\nu^2 = \frac{\sqrt{n^4 + 14n^2p^2 + p^4} + p^2 - 5n^2}{4(p^2 - n^2)} \quad (3)$$

the opposite sense of circular polarization is most severely attenuated. The table in Fig. 3 of the drawings illustrates the values of "ψ" and "ν" which will satisfy both Equation 2 and Equation 3 for the different modes. Also given is the value of a/λ₀ corresponding to the particular values of "ν." In view of the preceding explanation, it can be seen that a sheathed helix can be designed to pass any transverse electric mode in any desired sense of circular polarization merely by choosing the proper parameters. All other modes and polarizations will be severely attenuated. For example, a helix has been constructed for the dominant TE₁₁ mode which will transmit one sense of circular polarization of this mode with less than a .1 decibel loss while attenuating the opposite sense of polarization more than 25 decibels.

As is evident from the foregoing comments, the structure shown in Fig. 1 as filter 14 may also be used as a transducer from linearly polarized to circularly polarized waves. A properly constructed helix of sufficient length will completely absorb the undesired circularly polarized component, leaving only the desired sense of polarization.

In all cases it is understood that the above-described arrangements are illustrative of a small number of the many possible specific illustrative embodiments which can represent applications of the principles of the invention. Numerous and various 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 wave energy components having at least one sense of circular polarization, means for utilizing a component of said energy in a given sense of circular polarization, filtering means connecting said utilizing means to said producing means for selectively transmitting said wave energy in said given sense of circular polarization and attenuating all other modes and polarizations said filtering means comprising a plurality of elongated members of insulated conductive material wound in a substantially helical form, said members being substantially aligned with the direction of wall current flow for said given sense of circular polarization whereby said given polarization is freely transmitted, and energy dissipating means surrounding said helix whereby said other modes and polarizations are attenuated.
2. The combination in claim 1 wherein the distance between and the diameter of said conductive members are small compared to a wavelength of said wave energy in said given sense of circular polarization.
3. In an electromagnetic wave transmission system, means for producing wave energy components having at least one sense of circular polarization, means for utilizing a component of said energy in a given sense of circular polarization, filtering means connecting said utilizing means to said producing means for selectively transmitting

5

ting said wave energy in said given sense of circular polarization comprising a helically wound conductive member surrounded by an electrically dissipating sheath, said member having the same sense of winding as said given sense of circular polarization, and in which said member has a pitch angle and diameter for a given frequency given by

$$\tan \psi = \frac{n \sqrt{1 - \nu^2}}{p \nu}$$

$$\nu^2 = \frac{\sqrt{n^4 + 14n^2 p^2 + p^4 + p^2 - 5n^2}}{4(p^2 - n^2)}$$

where ψ is equal to said pitch angle, n being the order

6

of the mode of said wave energy, p being the m th zero of the derivation of the Bessel function of order n , and ν being the ratio of the free-space wavelength to the cut-off wavelength of the frequency of said wave energy.

References Cited in the file of this patent

UNITED STATES PATENTS

2,720,609	Bruck et al. -----	Oct. 11, 1955
2,746,018	Sichak -----	May 15, 1956
2,779,006	Albersheim -----	Jan. 22, 1957
2,848,696	Miller -----	Aug. 19, 1958

FOREIGN PATENTS

504,140	Canada -----	July 6, 1954
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