

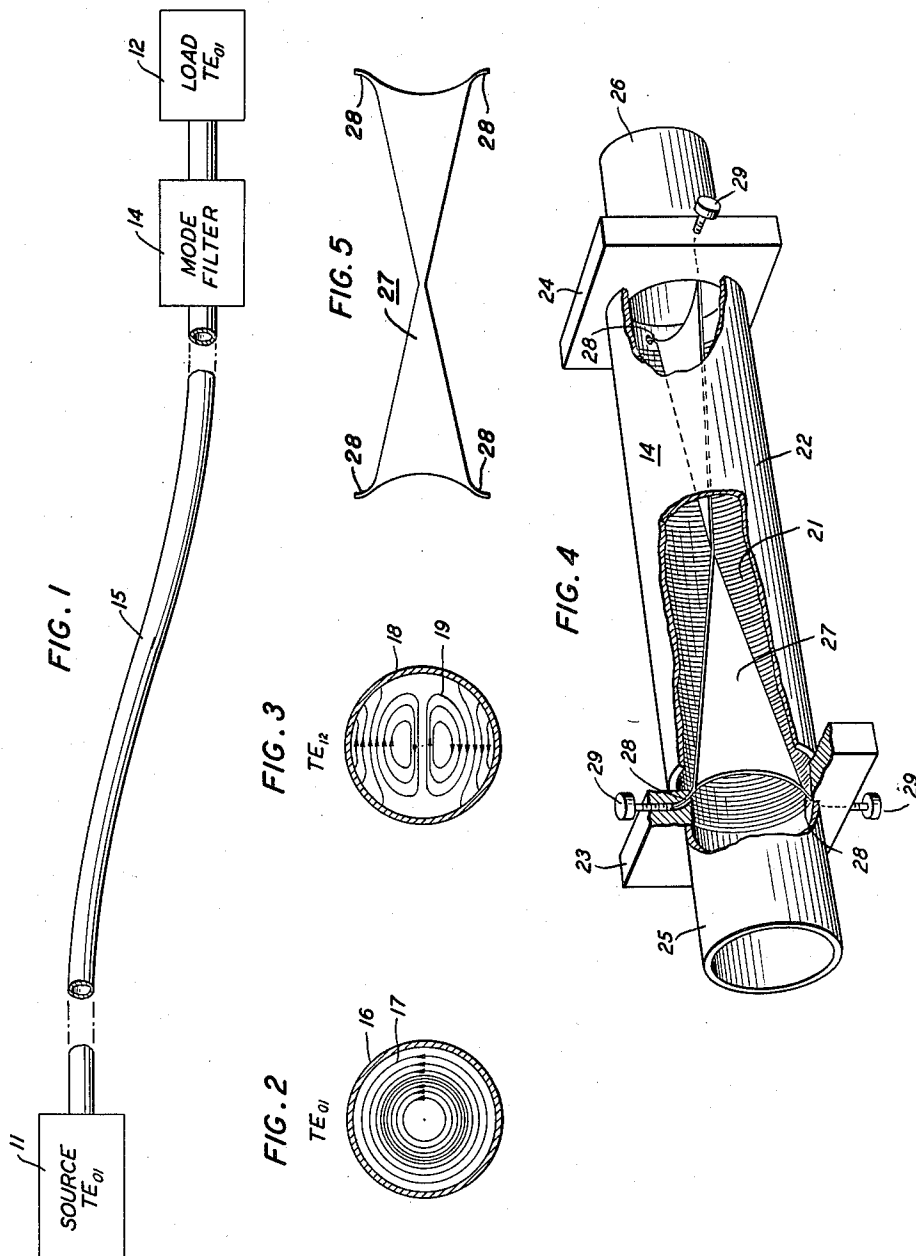
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CIRCULAR ELECTRIC WAVE TRANSMISSION

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1

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CIRCULAR ELECTRIC WAVE TRANSMISSION

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3 Claims. (Cl. 333-81)

This invention relates to circular electric wave transmission systems and, more particularly, to mode filters for passing the TE_{01} circular electric mode and substantially attenuating all other modes.

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 characteristics of this transmission mode, unlike that of most 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 cause coupling between the TE_{01} and other propagating modes. Such coupling can cause serious degradation of the TE_{01} signal and the presence of other modes may cause objectionable mismatches, and hence reflections, at the terminal equipment.

It has been found that a helically wound conductor having an internal diameter greater than 1.2 free space wavelengths, wound relatively closely, and surrounded by a dissipating jacket will propagate a properly excited circular electric TE_{01} mode with little or no attenuation while many other modes including the TM_{11} mode, will be severely attenuated. Such a wave transmission path will be hereinafter referred to as helix wave guide. While such a structure cannot present a completely continuous path for the circumferential current components of the TE_{01} wave, it has been found that if the pitch of the helix is sufficiently small, the TE_{01} mode will propagate with substantial mode purity. Forms of the helical wave guide and specific applications of the same are disclosed in the copending applications of J. R. Pierce, Serial No. 416,315, now Patent 2,848,695, granted August 19, 1958, and S. E. Miller, Serial No. 416,316, now Patent No. 2,848,696, granted August 19, 1958, both filed March 15, 1954.

The operation of the helical structures described above is based upon the discontinuous conduction path presented by the helix to the induced wall currents of all transmission modes except the TE_{01} circular electric mode. Several modes, however, such as, for example, the TE_{12} mode, like the TE_{01} circular electric mode generate relatively small longitudinal currents in the wave guide wall. The helix therefore is unable to severely attenuate these modes and they continue to propagate beyond a helical section of any reasonable length. Furthermore, the TE_{12} mode has the second lowest theoretical loss of all the round wave guide modes, its attenuation constant being only slightly over twice that of the TE_{01} mode at moderate frequencies, and hence is the mode most apt to propagate for long distances in the absence of any filtering

2

action. To substantially dissipate those modes which, like the TE_{12} mode, have small longitudinal components of wall current, it becomes necessary to operate upon the displacement currents which they generate within the wave guide. For this purpose, a filter composed of resistive elements oriented along radii of the guide would present the desired attenuation. However, the attenuating elements of the prior art have been found to be lossy to the TE_{01} circular electric mode desired to be transmitted, both because of the relative thickness of the elements required for their support and the inability to accurately locate these elements on the guide radii.

It is therefore an object of the present invention to severely attenuate those modes having small longitudinal wall current components and to transmit the circular electric mode with little or no attenuation.

It is a more specific object of the invention to accurately locate a very thin resistive element on the radii of a round wave guide used to transmit the circular electric mode.

In accordance with the present invention, it has been found that an extremely thin film of resistive material can be precisely positioned on the radii of a circular wave guide by painting or spraying such a film on a thin elastic sheet and supporting the sheet under tension within the wave guide. The elastic sheet is made of low loss material having a sufficient tensile strength to enable it to be supported under a moderate amount of tension while having an extremely small thickness. The supporting members providing the tension, which may, for example, comprise strong, thin elastic threads, also allow very precise location of the resistive film such that it falls exactly on the guide radii. Furthermore, by narrowing the transverse dimension of the sheet at the center, the sheet may be twisted ninety degrees at the center to provide loss to two perpendicular polarizations and still maintain its precise orientation.

These and other objects and features, 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 mode filter of the type provided by the present invention;

Figs. 2 and 3 illustrate the transverse electric field patterns of the TE_{01} and TE_{12} waves, respectively;

Fig. 4, partially in cross section, illustrates the construction of the mode filter in accordance with the present invention; and

Fig. 5 illustrates one form which an element of Fig. 4 may take.

Referring more specifically to Fig. 1, a guided microwave transmission system is schematically shown comprising a source 11 of electromagnetic wave energy in the circular electric mode. Source 11 is connected to a load 12 for the circular electric mode by a wave guide transmission line 15 having bends, small imperfections and obstacles much like any practical transmission system. Inserted near the end of line 15 to which load 12 is connected is a mode filter 14 to filter out components of wave energy in spurious transmission modes generated by the bends and small imperfections by which line 15 is characterized. Filter 14 completely removes or substantially reduces all of these spurious mode components and thereby prevents signal distortion and mismatch of the wave energy entering load 12. While only one filter 14 is shown, more of these filters may be employed at in-

tervals along line 15 to provide substantial TE_{01} mode purity throughout the length of the transmission path.

Fig. 2 illustrates the distribution of the electric field in a transverse section of a circular conductive wave guide 16 supporting the TE_{01} circular electric mode, the electric field components of which are represented by solid lines 17. This wave is designated the circular electric type inasmuch as the electric field consists of circular lines 17 coaxial with the guide and lying transversely thereto without any longitudinal components. The electric field intensity, represented by the closeness of lines 17, attains a maximum approximately half-way between the axis and the surface of guide 16 and drops to zero at the surface.

The configuration of the transverse electric TE_{12} mode is shown in Fig. 3 supported by round wave guide 18. The electric field is entirely transverse without any longitudinal components and substantially all of the electric field components form closed loops, such as loop 19, about two points within guide 18. Since the electric field lines cannot approach the conductive surface of guide 18 tangentially, these loops tend to move away from these walls and crowd close together at the center of guide 18. This concentration of electric field lines at the center of the guide represents a high electric field intensity at this point which is, in general, directed co-linearly along a diameter of guide 18. It is apparent that the TE_{12} mode can be supported in an infinite number of linear polarizations corresponding to the different directions which may be taken by the high intensity electric field components at the center of guide 18.

In Fig. 4 is shown in detail the mode filter 14 inserted in line 15 of Fig. 1. Filter 14 comprises a section of helically wound conductive wire 21 having a very small pitch angle and having closely spaced adjacent turns. Wire 21 is insulated such as, for example, by an enamel coating such that adjacent turns are electrically separated from each other. The turns of wire 21 in the helix are enclosed or embedded in a coating or jacket 22 of energy dissipating material such as, for example, carbon loaded polystyrene. Jacket 22, together with helically wound wire 21 is supported between flanges 23 and 24 which also support coupling stubs 25 and 26 by which filter 14 is connected to line 15 in Fig. 1. The details of the helix with its dissipating jacket and its effect on the wave energy propagated therein are more fully disclosed and described in the aforementioned copending application of S. E. Miller, Serial No. 416,316, filed March 15, 1954, now Patent 2,848,696, granted August 19, 1958.

The inside diameter of the helix formed by wire 21 is related to the diameter of the circular pipe guide which would transmit waves of the same frequency. Thus the diameter must be greater than the critical or cutoff diameter for the TE_{01} mode in a circular guide. This cutoff 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 this diameter should be made several times the cutoff diameter to decrease the attenuation afforded to the TE_{01} mode. Unfortunately, this larger diameter also allows the formation of higher order modes, among them the TE_{12} mode and other modes having small longitudinal components of wall current.

To substantially dissipate these higher order modes having small longitudinal components of wall current, a resistive film 27 is provided within turns of wire 21 between flanges 23 and 24, and extending for several wavelengths along the helix. The radial and longitudinal displacement currents of the small wall current modes such as the TE_{12} mode, represented by the high electric field concentration shown in Fig. 3, produce conduction currents in film 27 which are quickly dissipated by its resistive properties.

In accordance with the present invention, resistive film 27 comprises a thin sheet of tough elastic material to

which a coating of resistive material is attached. This elastic material has a high tensile modulus to permit sufficient tension to be applied to cause it to lie in a plane without stretching a great deal and becoming distorted, and a high enough yield point to retain its elastic behavior in the range of tensions required. More specifically, this elastic sheet should have a tensile modulus of at least 150,000 pounds per square inch and a yield point of at least 5000 pounds per square inch. One class of materials suitable for this use is polyethylene terephthalate formed by esterifying terephthalic acid and ethylene glycol and commonly known by the trade name Mylar. Besides having a tensile modulus of 500,000 pounds per square inch and a yield point of 20,000 pounds per square inch, Mylar is extremely stable chemically, being highly resistant to moisture penetration and decomposition by hydrolysis. Furthermore, Mylar can be made in the extremely thin sheets desirable for the present invention, in the range between .25 and 2 mils. A complete discussion of this class of compounds and its general physical and chemical properties may be found in an article "The Dielectric Properties of Polyethylene Terephthalate," by Reddish, Transactions of the Faraday Society, volume 46, pages 459 through 475 (1950), and one use of this material is described in "Polyethylene Terephthalate as a Capacitor Dielectric," by Wooley, Kohman and McMahon, Electrical Engineering, volume 71, pages 715 through 717, August 1952. Other film materials such as, for example, cellophane, have the required properties and are therefore equally suitable for use in the present invention. The term "Mylar" hereinafter used will also imply all other materials having the required properties.

A thin layer of resistive material such as, for example, carbon black is sprayed or painted on the Mylar sheet to provide the necessary resistive effect. Film 27 has a transverse dimension at either end which is on the order of the diameter of helix 21 but which is gradually narrowed from each end to the center such that the transverse dimension at the center is only a small fraction of the diameter of helix 21. Such a shape, developed as a plane surface, is illustrated in Fig. 5. Film 27 is then twisted ninety degrees at the center such that the two ends lie substantially in perpendicular planes. Means are provided for supporting film 27 under tension exactly on diameters of helix 21. As shown in Fig. 4, film 27 may be supported by elastic threads, such as thread 28, attached to the four corners of the film 27. These threads are passed out through small holes in flanges 23 and 24 and attached to adjustable tensioning screws 29. Screws 29 are adapted for adjusting film 27 both in position and in tension. Film 27 may, however, be supported by any other suitable means such as, for example, by extending the corners of sheet 27 itself and passing these corners out through slots in the walls of filter 14.

In operation, the mode filter illustrated in Fig. 4 freely transmits the TE_{01} circular electric mode and substantially attenuates all other modes. The conductive wall provided by turns of wire 21 interrupts the longitudinal wall current conduction path of all TM modes. These currents are forced to bridge the gaps between adjacent turns in the form of displacement currents which are quickly dissipated in jacket 22. The TE_{01} circular electric mode, however, has only circumferential wall current flow which therefore follows the turns of wire 21 and is not dissipated in jacket 22. In general, all of the TE modes except the TE_{01} circular electric modes have radial components of electric field which can induce currents in resistive film 27 and thereby be dissipated. The TE_{01} circular electric mode, however, has circular components of electric field which are everywhere perpendicular to film 27. These components therefore do not induce currents in film 27 and are not attenuated thereby. It can be seen that the mode filter shown in Fig. 4 attenuates all modes except the TE_{01} circular electric

5

mode. Furthermore, enclosing film 27 within turns of wire 21 prevents those modes which would be attenuated by either one of these elements from being converted to another mode and thereby escaping attenuation.

A principal feature of the present invention resides in the ease with which resistive film 27 may be precisely centered on diameters of helix 21, thereby insuring low loss to the circular electric mode. This film 27 may be moved to any precise location by means of screws 29 while the filter 14 is in operation and the effect on the circular electric mode can be noted. Furthermore, supporting the resistive material on a very strong thin elastic sheet allows the application of sufficient tension to remove any small irregularities in film 27 which would tend to depart from a precise coplanar location.

Another principal feature of the invention resides in the shape of film 27 which allows a single resistive film to lie in two perpendicular planes and yet be capable of precise poistioning on the guide radii. First order linearly polarized modes, such as the TE_{12} mode, can therefore be dissipated regardless of the direction of their polarization.

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 combination, a source of electromagnetic wave

6

energy in the circular electric mode, means for utilizing said energy connected to said source by a wave guide transmission line, and at least one circular electric mode filter interposed in said line, said filter comprising an elongated member of conductive material wound in a substantially helical form having adjacent turns separated from one another, an energy dissipating jacket surrounding said helix, an elastic sheet of resistive material extending longitudinally within said helix, the ends of said sheet being twisted ninety degrees with respect to each other, and means for supporting said sheet under tension radially within said helix.

2. The combination according to claim 1 in which said elastic sheet has a transverse dimension at the center substantially less than the transverse dimensions at the ends thereof, said sheet having said ends twisted ninety degrees with respect to each other.

3. The combination according to claim 1 in which said sheet is supported by means of thin elastic threads passed out through said conductive boundary.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,922,969

January 26, 1960

Harald T. Friis et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

In the grant, lines 1 and 2, name of co-inventor, for "William D. Waters" read -- William D. Warters --.

Signed and sealed this 26th day of July 1960.

(SEAL)

Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents