United States Patent [19]

Alsberg

[11] **3,779,805**

[45] **Dec. 18, 1973**

[54] **METHOD OF MAKING WAVEGUIDE MODE FILTER**

[75] Inventor: **Dietrich Anselm Alsberg,** Berkeley Heights, N.J.

[73] Assignee: **Bell Telephone Laboratories, Incorporated,** Murray Hill, N.J.

[22] Filed: **May 19, 1971**

[21] Appl. No.: **144,748**

[52] **U.S. Cl.** ..... **117/212,** 117/8, 117/43, 117/95, 117/213, 333/98 M

[51] **Int. Cl.** **B44d 1/02,** B44d 1/18

[58] **Field of Search** ..... 117/212 117/213, 117/8, 117/95, 117/43, 333/98 M

[56] **References Cited**

UNITED STATES PATENTS

3,016,502	1/1962	Unger	333/98 M
3,598,636	8/1971	Honeycutt, Jr.	117/95
3,305,666	2/1967	Zaromb	117/8

FOREIGN PATENTS OR APPLICATIONS

867,496	5/1961	Great Britain	333/98 M
603,119	6/1948	Great Britain	333/98 M

Primary Examiner—Alfred L. Leavitt
Assistant Examiner—Kenneth P. Glynn
Attorney—W. L. Keefauver and Edwin B. Cave

[57] **ABSTRACT**

A waveguide mode filter comprising a dielectric-lined waveguide having a series of electrically lossy vanes in the lining parallel to the waveguide axis dissipates longitudinal and radial current components produced by unwanted modes and thereby suppresses such modes. A method of forming the vanes includes the steps of flooding the dielectric-lined waveguide interior with a solution containing lossy particles, drawing a cutting head through the waveguide to slice the dielectric lining so that the solution flows into the incisions and is trapped therein, and drawing a wiper through the waveguide to remove the excess solution.

13 Claims, 5 Drawing Figures

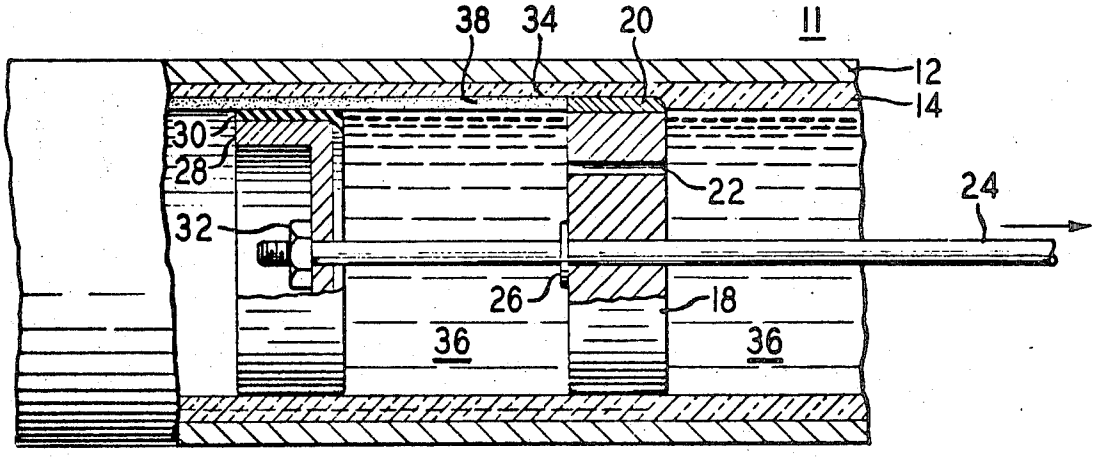


FIG. 1

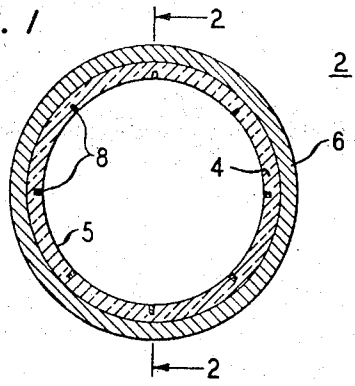


FIG. 4

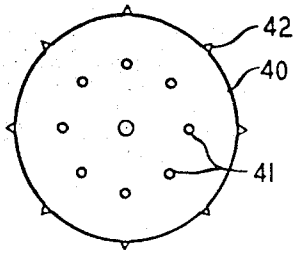


FIG. 2

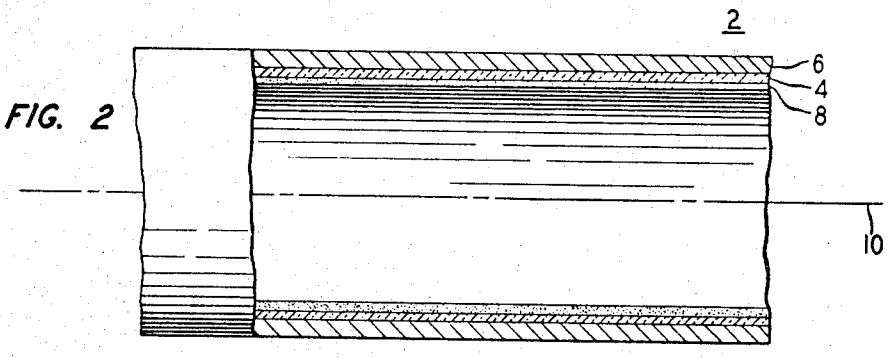


FIG. 3

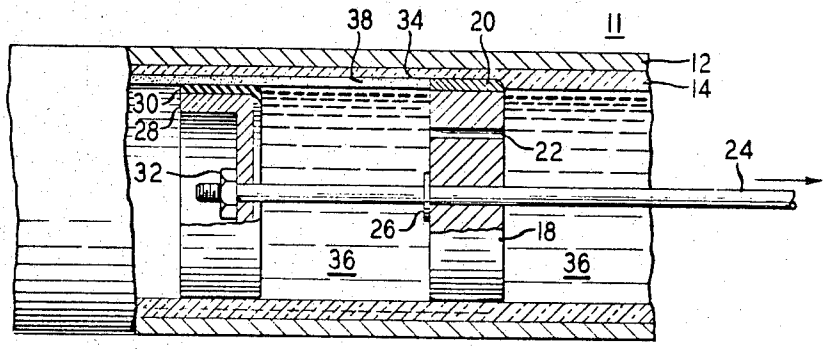
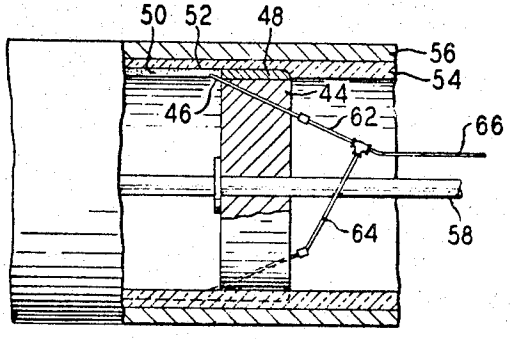


FIG. 5



METHOD OF MAKING WAVEGUIDE MODE FILTER

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to waveguide mode filters and in particular to filters utilizing electrical lossy vanes to separate wave modes and to a method of forming such vanes in a dielectric-lined waveguide.

2. Description of the Prior Art

The TE_{01} circular wave mode is known to be well suited for long distance transmission of high-frequency broadband signals because the attenuation of this mode decreases with increasing frequency. However, waveguides which are large enough to transmit the TE_{01} wave mode can also support other unwanted modes. Conversion and reconversion of energy between the TE_{01} mode and other modes has a deleterious effect on the quality of the transmission. Consequently much effort has been directed toward finding ways of preventing the conversion of the TE_{01} mode into other unwanted modes and removing or filtering these unwanted modes from the waveguide system.

Waveguides containing a thin dielectric lining have been effective in reducing the conversion of the TE_{01} mode into spurious modes by increasing the differences in phase constants between these modes. Dielectric-lined waveguide is relatively easy and economical to manufacture because the process usually involves placing a lining in a preformed metallic tube which can be made relatively accurately.

Helix waveguide is an effective means of removing or filtering certain unwanted modes from a waveguide transmission system. However, helix waveguide is relatively difficult and expensive to manufacture. Helix waveguide is normally formed by an inside-out process involving winding a helix on a mandrel and subsequent encasement in a desired tube. The helix waveguide thus obtained is normally not as straight and accurate as dielectric-lined waveguide which utilizes performed steel tubing.

Therefore an object of this invention is to simplify waveguide mode filters to permit their fabrication by relatively easy processes such as used in the manufacture of dielectric-lined waveguide.

The use of resistive or dissipative vane structures inserted in the waveguide interior provides one alternative to helix waveguide as a mode filter. Such vane structures can be used alone or in conjunction with other filtering means including helix waveguide. However, all of the presently known resistive vane structures require relatively difficult manufacturing steps and involve the use of separate structures which add to the cost of a waveguide transmission system. Another limitation is the increased reflection of energy from the discrete structure within the waveguide interior. Still another limitation is the difficulty which would be encountered in cleaning the waveguide containing such a discrete structure after a failure allowing ingress of water and the like.

Accordingly, a further object of this invention is to eliminate the necessity of discrete structures in mode filter designs utilizing resistive or dissipative vanes.

SUMMARY OF THE INVENTION

The foregoing objects and others are achieved in accordance with the principles of this invention by a waveguide mode filter which utilizes resistive vanes formed in the lining of a dielectric-lined waveguide. Thin vanes of resistive or lossy material are disposed in the dielectric lining along radii of the waveguide and in a direction parallel to the longitudinal axis of the waveguide. The vanes dissipate longitudinal and radial currents and thus suppress unwanted modes having electric field components which produce such currents. The TE_{01} mode is not effected by such vanes.

The lossy vanes can be formed in the dielectric lining by flooding the interior of the waveguide with a solution containing lossy particles and drawing a cutting head through the waveguide to form incisions in the lining into which flows the solution. The excess solution is then removed leaving a very thin lossy vane within the lining while the lining maintains its smooth and continuous inner surface.

BRIEF DESCRIPTION OF THE DRAWING

The invention will be more fully comprehended from the following detailed description and accompanying drawing in which:

FIG. 1 is a transverse cross-sectional view of a mode filter comprising resistive vanes in accordance with the principles of the invention;

FIG. 2 is a sectional view along direction 2—2 of FIG. 1;

FIG. 3 is a schematic sectional representation of apparatus for forming resistive vanes in the dielectric lining of a waveguide;

FIG. 4 is a transverse view of the cutting head utilized in FIG. 3; and

FIG. 5 is a schematic sectional representation of another embodiment of a cutting head for forming resistive vanes by using injection nozzles.

DETAILED DESCRIPTION

Referring now to FIG. 1 there is shown a mode filter section 2 comprising a modified dielectric-lined waveguide which operates on the principle that dissipation of electric currents generated by unwanted modes eliminates or suppresses such modes. The desired TE_{01} mode has no longitudinal or radial current components. Furthermore, the circular or tangential electric field of the TE_{01} mode essentially disappears at the inner surface 5 of dielectric lining 4 and there are no radial or longitudinal current components related to the TE_{01} mode within lining 4. Hence dissipative or resistive vanes 8 within lining 4 oriented to suppress longitudinal or radial current components will attenuate many unwanted modes but will not appreciably affect the desired TE_{01} mode. In the illustrative embodiment vanes 8 lie along radii of mode filter section 2 and extend in directions parallel to the longitudinal axis 10 of section 2 as shown more clearly in FIG. 2. With this orientation vanes 8 present substantial resistive paths in both the longitudinal and radial directions and a negligible resistive path in the tangential direction.

Vanes 8 lie within dielectric lining 4 and terminate at the inner surface 5 thereof so that filter section 2 has a smooth continuous inner surface. Thus section 2 can be readily cleaned by rodding and swabbing similar to methods used for cleaning cable conduit in the event of a failure which allows ingress of water. Vanes 8 will normally extend only part way into lining 4 and will not contact the outer conductive shield or tube 6. The thickness of vanes 8 is exaggerated in FIG. 1.

FIG. 3 illustrates the apparatus and method for forming resistive vanes in a dielectric lining. Outer conductive tube **12** contains an appropriate dielectric lining **14** therein to form a standard dielectric-lined waveguide section **11.** The interior of lining **14** is flooded by a solution **36** containing lossy particles therein. One example of a suitable solution is epoxy containing small carbon particles suspended therein. Such a solution has the advantage of containing no solvents which must be evaporated during subsequent curing. Another suitable solution is a colloidal graphite suspension available commercially under the trademark AQUADAG. Still another suitable solution is that comprising an organic adhesive in solution, such as that available commercially under the trademark HYDROPOL, containing suspended resistive particles such as carbon. Unlike the epoxy solution, these latter two solutions contain solvents which must subsequently be evaporated during curing. A cutting head **18** containing a plurality of cutters **20** around its periphery is drawn through the interor of flooded lining **14.** The outer diameter of head **18** is smaller than the inner diameter of lining **14.** However, cutters **20** extend from the periphery of head **18** so that cutters **20** are forced into lining **14** thereby forming incisions or slices **34** in lining **14** as head **18** is moved therethrough. Cutters **20** advantageously can be resiliently mounted in head **18** so that the depth of incisions **34** remains substantially constant regardless of curvatures or like variations in lining **14.** Cutters **20** also can be adjustably mounted in head **18** to permit desired changes in the depth of incisions **34** from one filter section **11** to another. Head **18** contains openings **22** which allow movement of solution **36** therethrough as head **18** is moved through lining **14.**

As cutters **20** slice lining **14,** solution **36** flows into incisions **34** while the incisions are held open by the cutters. As head **18** is moved forward, incisions **34** tend to close behind cutters **20** thereby squeezing out the excess solution **36** and leaving a thin lining of trapped solution which solidifies or cures to form a resistive vane **38.** If a solution containing a solvent which must be evaporated has been used, the curing of such solution can be quickened by circulating a dry gas through the waveguide or by utilizing vacuum drying techniques known in the art. This drying step is advantageously performed immediately after the waveguide interior is wiped or cleaned as is explained in the following paragraph. As previously mentioned, if the epoxy solution is used, no drying or solvent removal step is required.

Cutting head **18** is followed by a wiper **28** which forces all excess solution **36** along the interior of lining **14.** Wiping surface **30** on wiper **28** comprises a resilient cleaning material which ensures that all of solution **36** is removed from the inner surface of lining **14.** Head **18** and wiper **28** advantageously can be mounted on a common pulling rod **24** by standard fastening hardware **26** and **32,** respectively.

The embodiment of a cutting head **40** detailed in FIG. **4** shows cutters **42** mounted at 45° intervals around the periphery thereof and openings **41** therethrough. Such a cutting head design would produce a filter section having resistive vanes oriented as shown in FIG. **1.** Different numbers and angular spacings of cutters **42** could of course be utilized depending upon the amount of unwanted mode power expected to be generated and consequently the number of vanes required to remove or dissipate such power. If a large number of vanes is desired, a tandem arrangement of cutting heads containing staggered or offset cutters advantageously can be utilized rather than utilizing a single cutting head with many closely spaced cutters. Such a tandem arrangement prevents the stresses on a particular cutting head from becoming excessive.

An alternative method of forming resistive vanes in the dielectric lining is illustrated in FIG. **5.** This method involves apparatus identical to that shown in FIG. **3** except for a modification of the cutting head **44.** Cutting head **44** includes small jets or nozzles **46** through the body thereof which exit at the trailing edge of each cutter **48.** Nozzles **46** are connected via lines or pipes **62, 64,** and **66** to a supply of solution, not shown, which is under pressure. Nozzles **46** inject a small stream of solution into incisions **52** as they are formed in lining **54** by cutters **48,** thereby creating lossy vanes **50.** In this method the interior of lining **54** need not be flooded with the solution. However the wiping or cleaning step may still be required unless the amount of solution injected is accurately controlled.

Although the invention has been described with respect to a filter section for passing the TE_{01} wave mode and removing other unwanted modes the principles thereof can be utilized in a filter for removing the TE_{01} mode. For example if the lossy vanes are oriented transverse to the longitudinal axis, modes having radial and tangential current components would be suppressed. These suppressed modes would include the TE_{01} mode which has tangential current components. Such vanes could be formed by utilizing circumferential cutters around cutting head **18.** Head **18** would then be stepped by discrete intervals along lining **14** while the cutters were withdrawn from contact. The cutters would then be extended and head **18** rotated to form transverse incisions in lining **14.** A filter for removing the TE_{01} mode might find application in testing apparatus and the like.

A major advantage of the foregoing methods of making mode filter sections is that such methods are compatible with the processes for making ordinary dielectric-lined waveguide. The proposed methods essentially comprise steps added to the basic dielectric-lined waveguide manufacturing process. Thus economies of large scale production can be realized in the basic process itself. The filter sections can be unique units each of which is relatively heavily loaded with dissipative vanes. Alternatively, a very light loading of vanes could be utilized in all the dielectric lined waveguide so that the entire waveguide transmission system is comprised of substantially identical sections each of which provides a small amount of mode filtering.

While the invention has been described with reference to specific embodiments thereof, it is to be understood that various modifications thereto might be made by those skilled in the art without departing from the spirit and scope thereof.

What is claimed is:

1. A method of making a mode filter for passing the TE_{01} wave mode and suppressing wave modes having longitudinal and radial current components comprising the steps of:

forming a dielectric lining around the inner surface of a conductive pipe;

flooding the interior of said lining with a solution containing particles of electrically lossy material;

making incisions in said lining so that said solution can flow therein, said incisions extending radially in said lining and in the direction of the longitudinal axis of said pipe; and

removing the excess of said solution from said interior of said lining so as to leave a thin layer of said solution in said incisions thereby to form lossy members in said lining which present substantial resistive paths to said longitudinal and said radial current components and a negligible resistive path to tangential current components.

2. The method of claim **1** wherein said step of making incisions includes the steps of:

mounting a plurality of cutters around the periphery of a mounting means; and

drawing said mounting means through said lining so that said cutters slice said lining to form said incisions, said cutters holding said incisions open to permit said solution to flow therein adjacent said cutters, said incisions closing when said cutters are removed thereby squeezing excess solution therefrom.

3. The method of claim **2** wherein said cutters are resiliently mounted within said mounting means so that the depth of said incisions remains constant regardless of variations such as curvatures in said lining, and said cutters are adjustably mounted so that said depth of said incisions can be varied.

4. The method of claim **2** wherein said mounting means includes openings therethrough for allowing movement of said solution through said mounting means as said mounting means moves within said lining.

5. The method of claim **1** wherein said solution comprises an epoxy containing carbon particles.

6. The method of claim **1** including the step of drying said interior of said lining subsequent to said removing step so that removal of solvents from said solution within said incisions is effected.

7. The method of claim **6** wherein said solution comprises a colloidal graphite suspension.

8. The method of claim **6** wherein said solution comprises an organic adhesive in solution containing carbon particles therein.

9. The method of claim **1** wherein said removing step comprises drawing a wiper through said lining, said wiper including a resilient wiping surface which contacts the inner surface of said lining around the entire periphery thereof so that said excess solution is removed from said lining.

10. The method of claim **1** wherein said lossy members have edges terminating at the inner surface of said lining so that said lining and said members present a substantially smooth and continuous surface.

11. A method of forming a mode filter section from a waveguide containing a dielectric lining, comprising the steps of:

flooding the interior of said lining with a solution containing particles of lossy material;

forcing a plurality of cutters into said lining to form incisions therein so that said solution flows into said incisions;

removing said cutters so that said incisions close thereby trapping a thin layer of said solution to form lossy members within said lining; and

removing the excess of said solution from said interior.

12. A method of forming a mode filter section from a waveguide containing a dielectric lining comprising the steps of:

making incisions in said lining extending radially in said lining and in the direction of the longitudinal axis of said waveguide;

filling said incisions with a lossy material; and

removing the excess of said material from said interior of said lining so as to leave a thin layer of said material in said incisions which present substantial resistive paths to longitudinal and radial current components and a negligible resistive path to tangential current components.

13. The method of claim **12** wherein said filling step comprises injecting a solution containing particles of lossy material into said incisions under pressure.

* * * * *