Sept. 27, 1966 M. P. PRACHE 3,275,955

DIELECTRIC-METAL WAVEGUIDE

Filed July 15, 1964 3 Sheets-Sheet 1

Fig. 1

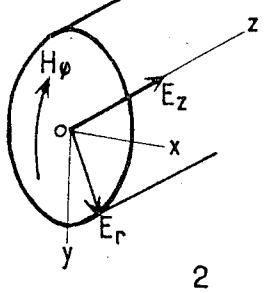


Fig. 2

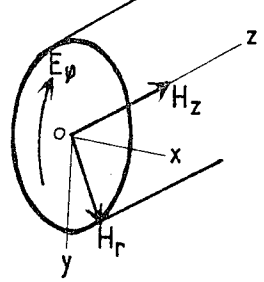


Fig. 3

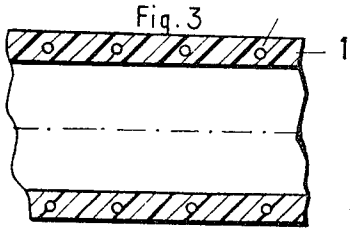


Fig. 4

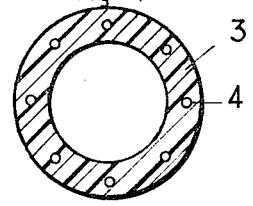


Fig. 5

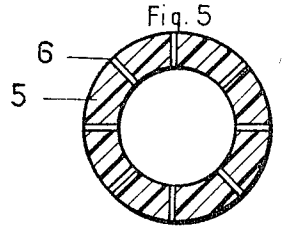
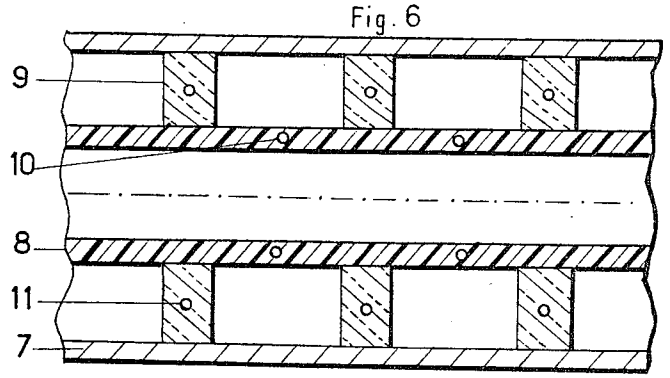


Fig. 6



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DIELECTRIC-METAL WAVEGUIDE

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Fig. 7

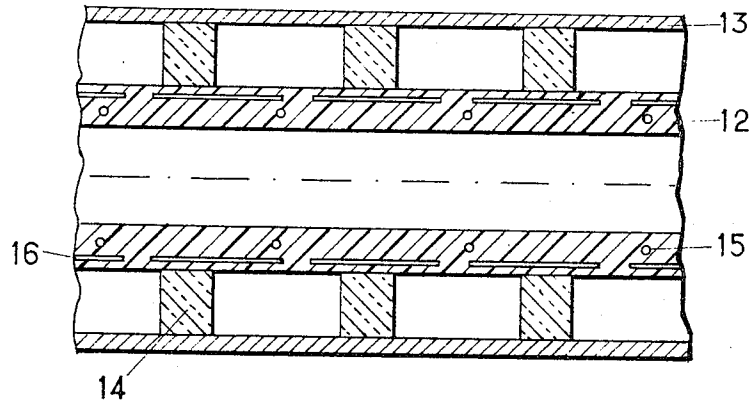
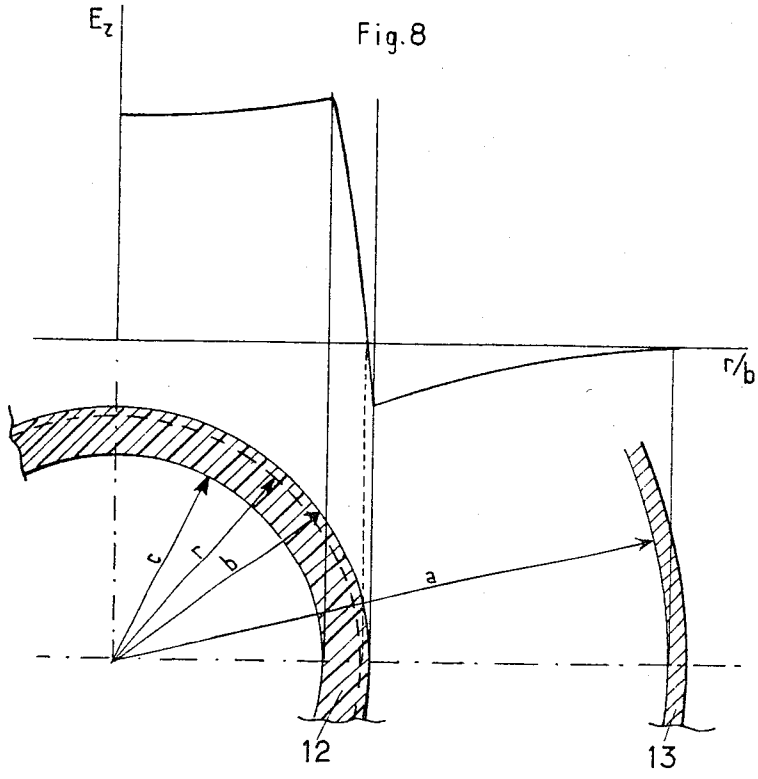


Fig. 8

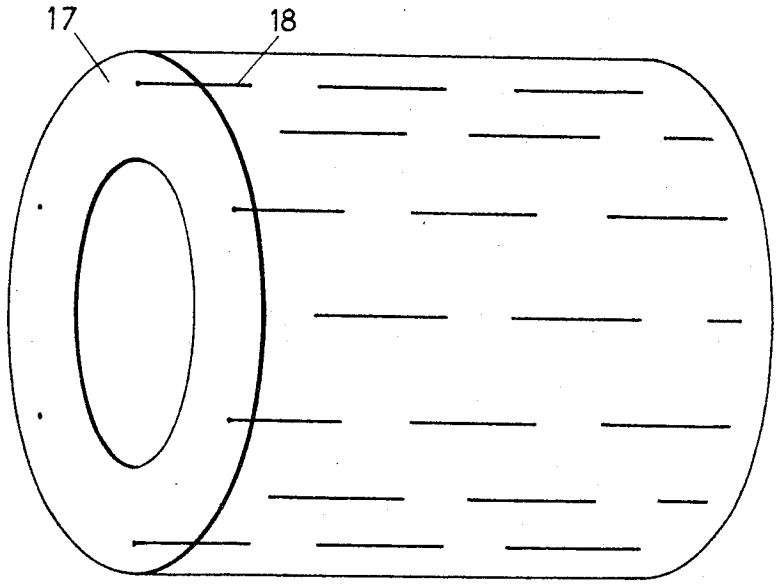


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Fig. 9



United States Patent Office 3,275,955 Patented Sept. 27, 1966

3,275,955

DIELECTRIC-METAL WAVEGUIDE

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Filed July 15, 1964, Ser. No. 382,905
Claims priority, application France, Aug. 6, 1963, 943,907; Apr. 30, 1964, 972,909
6 Claims. (Cl. 333—95)

The present invention relates to lines or circuits for the transmission of electromagnetic waves in the V.H.F. region, which waves have circular symmetry with respect to a longitudinal axis.

More precisely, the transmission circuits forming the subject of the present invention may be:

(a) Solid circular cylindrical sections or circular section tubes, made of dielectric material;

(b) Structures as defined in (a), with the addition of an outer metallic conductor tube surrounding the dielectric elements, possibly together with means for maintaining said elements in a suitable relationship with said metal tube.

It is well known that in any structure of the type defined in (a) or (b), it is possible if the frequency is sufficiently high to propagate waves of the TE or TM type.

It is also known that in such circuits, it is desirable that transmission should take place in the form of a selected one of the fundamental TE and TM modes having circular symmetry. It is therefore necessary that transmission should involve one mode only and consequently other modes which could accidentally appear must be suppressed. In other words, carrier current opeartion in telecommunications circuits requires that all the useful waves of one frequency be propagated at the same velocity. Once a mode of propagation has been selected, it is therefore the next step to eliminate all the other modes which could be propagated in the same direction at different velocities. The higher modes having circular symmetry are of no concern, since their cut-off frequencies are much higher than the cut-off frequencies of the fundamental mode; however, other modes can exist which do not have circular symmetry, the cut-off frequencies of which may be in the same order of magnitude as the cut-off frequency of the fundamental circular symmetrical mode or even lower than this.

It is an object of the present invention to permit propagation of the selected circular symmetrical TM or TE mode and to eliminate those modes which it is not desired to propagate. To this end, the fact is taken advantage of that throughout the propagation space, or at least on certain surfaces in this space, the desired modes have at least one electric field component which is zero, this same field *not* being zero for the modes which it is desired to suppress.

This property makes it possible to prevent the appearance of all those modes for which the said component is not zero. To this end, using wire conductors disposed in a suitable geometric arrangement, equipotential lines are created along which the tangential component of the electric field is necessarily zero, thus preventing the appearance of any mode for which such component is not zero while at the same time in no way interfering with the propagation of the desired mode.

The wire conductors should be sufficiently fine and well spaced from one another to ensure that the losses due to eddy currents remain low and that they do not disturb the magnetic field. If the initially straight structure is to be curved at any point, the spacing between the wires should be greater on the straight sections than on the curved ones, to allow for the increased risk that

undesired modes will appear. In certain cases, it is preferable that the wires be not continuous.

Since the wires are fine, they may be considered hereinafter, at least for the purposes of description, as having transverse dimensions which are negligible in comparison with the transverse dimensions of the circuit.

Transmission circuits exhibiting circular symmetry about a longitudinal axis, as proposed in accordance with the invention, may comprise one or more uniform, solid circular cylindrical components (or one or more cylindrical tubes), made of dielectric material exhibiting fairly high permittivity and very low loss properties, there being possibly a cylindrical metal tube arranged concentrically with respect to said tubes or solid cylinders and surrounding the same.

In accordance with the present invention, a transmission circuit is provided, for electromagnetic waves in the V.H.F. region, which exhibits circular symmetry about a longitudinal axis and is designed for the transmission of a predetermined one of the fundamental circular symmetrical TE and TM modes, said circuit comprising at least one component made of dielectric material and shaped as a circular cylinder whose axis of revolution coincides substantially with the said longitudinal axis, characterized by the use of wire conductors disposed along geometric lines arranged tangentially with respect to that electric field component of a wave propagated in the said predetermined mode, which is zero.

In another embodiment of the invention, the selected mode of propagation is the fundamental circular symmetrical TM mode for which the circular component of the electric field is zero. Consequently, the wires are circumferentially disposed in planes which are perpendicular to the longitudinal axis of the circuit and have their centers located coincidentally with said axis. In this way, the TE modes of propagation are suppressed, as also are other modes not of circular symmetrical type.

In a further embodiment of the invention, the selected mode of propagation is the fundamental circular symmetrical TE mode, for which the components of the electric field in the direction of the longitudinal axis and in the radial direction are zero. In this instance, the wires are situated either longitudinally or radially or, else, partly in one of these directions and partly in the other. In this way, the modes of propagation for which the said components are not zero, in particular the TM modes, are suppressed.

Where the transmission circuit to which the invention relates comprises a uniform solid cylindrical component, or tube, of dielectric material, at the same time as an outer metal tube, the possible mode of propagation fall into two types. The modes of the first type are of a similar nature to those which are propagated in a "dielectric cable" without metal tube, as described in the book by S. A. Schelkunoff entitled "Electromagnetic Waves," Van Nostrand, New York, 1945, the relevant passages being in paragraph 10–20, pages 425 to 428. The calculations contained in this paragraph are valid for the case in which the dielectric solid cylinder or tube is surrounded by a metal tube having the same axis of symmetry as said cylinder or tube. The modes of this first type are referred to hereinafter as "dielectrically guided modes" or "dielectric modes." The modes of the second type are described in paragraph 10–6, pages 389 to 391 of the same book by S. A. Schelkunoff and are referred to hereinafter as "metallically guided modes."

If, by way of example, we consider a transmission circuit constituted by a solid cylinder or tube of dielectric material arranged coaxially with respect to a metal tube, in which circuit the selected mode of propagation is the circular symmetrical TM dielectric mode, we can proceed

to discuss the manner in which the wires mentioned in the foregoing enable the undesired modes of propagation to be suppressed.

For the fundamental dielectric circular symmetrical TM mode, the circular component of the electric field is zero and all the modes for which this component is not zero will be suppressed by arranging in the material of the solid cylinder or the dielectric tube, metal wires, copper for example, which run circumferentially in a direction perpendicular to the longitudinal axis of the circuit, these circumferential configurations being centered on said axis. In this way, the fundamental circular symmetrical TE dielectric mode and the non-circular symmetrical modes are suppressed.

These wires also enable suppression of the "metallically guided" TE modes which may develop due to the presence of the metal tube.

However, "metallically guided" TM modes may also appear. To eliminate these, use is made of the fact that the component of the electric field in the longitudinal direction of the circuit is zero for the circular symmetrical TM dielectric mode in a certain cylindrical plane, the axis of which is coincidental with that of the solid cylindrical component or the dielectric tube, and which is located inside the dielectric material at a fixed distance from the said axis, and of the fact that the said longitudinal component of the electric field is *not* zero in this plane for the "metallically guided" TM modes, so that the latter may be suppressed by arranging at the said distance from the axis and parallel with it, a certain number of metal wires, this having no effect on propagation of the desired dielectric TM mode.

The presence of longitudinal wires and of the metal tube may lead to the formation of modes of propagation similar to those encountered in coaxial lines; however, this can be prevented by placing in the same cylindrical surface for which the longitudinal electric field component is zero, *not* continuous metal wires but short sections of metal wire arranged in longitudinal lines. These sections of wire will, preferably, be staggered longitudinally in relation to one another where two neighboring lines are considered.

The invention will be described in greater detail making reference to the case in which the transmission circuit comprises a tube of dielectric material, but it should be borne in mind that everything which is said in this relation is equally applicable to the case in which the inside radius of the tube is zero, i.e. to the case in which a uniform solid cylinder of dielectric material is used.

The detailed features and advantages of the invention will be better apparent from the following description which refers to non-limitative exemplary embodiments and from the attached figures, in which—

FIGURES 1 and 2 respectively illustrate the components of the magnetic and electric fields for the fundamental circular symmetrical TM and TE modes.

FIGURE 3 illustrates a transmission circuit of the type proposed in accordance with the invention, which is designed for the fundamental circular symmetrical TM mode and has no outer metal tube.

FIGURES 4 and 5 illustrate transmission circuits as proposed in accordance with the invention, which are designed for the fundamental circular symmetrical TE mode, and again have no outer metal tube.

FIGURE 6 illustrates a transmission circuit as proposed in accordance with the invention, in which an outer metal tube is combined with an inner dielectric tube.

FIGURE 7 illustrates another example of the transmission circuit proposed in accordance with the invention, this comprising a tube of dielectric material inserted concentrically inside a metal tube.

FIGURE 8 is a graph illustrating the variation in the longitudinal component of the electric field in the circuit of FIGURE 7, for the circular symmetrical TM dielectric mode, as a function of the distance from the axis of the circuit.

FIGURE 9 illustrates a construction of a circuit of the type proposed in accordance with the invention, in which discontinuous longitudinal wires are placed in the material of a dielectric tube.

In the following description, cylindrical coordinates will be employed, viz. z for distances measured parallel to the axis of rotation of the circuit, r for the distance of a point from said axis, ϕ for the angle of rotation about said axis; the corresponding components of the electric and magnetic fields will be designated respectively by E_z, E_r, E_ϕ and H_z, H_r, H_ϕ.

For the fundamental circular symmetrical TM modes, the components of the magnetic and electric fields which are not zero E_z, E_r, and H_ϕ, as illustrated in FIGURE 1. The component E_ϕ is zero.

For the fundamental circular symmetrical TE modes, the components of the magnetic and electric fields which are not zero are H_z, H_r and E_ϕ, as illustrated in FIGURE 2. The components E_z and E_r are zero.

In the modes of other than circular symmetrical type, none of the six components E_z E_r, E_ϕ, H_z, H_r and H_ϕ is zero.

FIGURE 3 illustrates a transmission circuit of the type proposed in accordance with the invention, comprising a tube **1** of dielectric material, which is designed for transmission of the fundamental circular symmetrical TM mode, while suppressing the unwanted circular-symmetrical and non-circular symmetrical modes. The wires **2**, made of copper for example, are arranged in circular fashion inside the dielectric material of which the tube **1** is made. The presence of the wires **2** acts to prevent the appearance of the electric field component E_ϕ, thus suppressing any modes for which this component does not happen to be zero, i.e. all the modes other than the desired circular symmetrical TM modes.

FIGURE 4 illustrates a transmission circuit of the type proposed in accordance with the invention, comprising a tube **3** of dielectric material designed for the transmission of the fundamental circular symmetrical TE mode and for the suppression of the circular symmetrical TM modes and the modes of non-circular symmetrical type. The wires **4**, made of copper for example, are disposed longitudinally in the dielectric material making up the tube **3**. The presence of the wires **4** has the effect of suppressing the E_z component of the electric field and consequently of suppressing all those modes for which this component should not be zero, i.e. all the modes other than the desired TE modes.

FIGURE 5 illustrates a transmission circuit of the type proposed in accordance with the invention, comprising a tube **5** made of dielectric material and designed for the transmission of the fundamental circular symmetrical TE mode while suppressing the circular symmetrical TM modes and the non-circular symmetrical modes. The wires **6**, made of copper for example, are disposed radially in the material of the dielectric tube. The presence of the wires **6** is such as to suppress the E_r component of the electric field and consequently to prevent the appearance of any modes for which this component should not be zero, i.e. of any modes other than the TE circular mode.

It is of course possible, where the mode of propagation selected is the fundamental TE circular symmetrical mode, to combine the arrangements of FIGURES 4 and 5.

FIGURE 6 is an example of a circuit constituted by a metal tube **7** surrounding a tube **8** of dielectric material, and by centering washers **9** made of dielectric material exhibiting low permittivity. If the selected mode of propagation is the fundamental TM circular mode, all the modes which include circular electric field components E_ϕ may be suppressed by the methods already described for the case of a dielectric tube operating on its

own, wires **10** being inserted in circular fashion in the material of the dielectric tube **8** and wires **11** being circularly disposed in the centering washers for securing the dielectric tube in the metal cylinder, these latter wires being used as required. If the selected mode were the "metallically guided" mode, it would not be necessary to provide a dielectric tube inside the metal tube and in fact any other desired means of supporting the wires would suffice.

The transmission circuit illustrated in FIGURE 7 comprises a tube **12** of dielectric material exhibiting fairly high permittivity and very low losses, which is placed inside a metal tube **13** and has its axis coincidental with that of the said tube **13**. Centering washers **14** made of dielectric material exhibiting low permittivity, are disposed between the dielectric tube and the metal tube **13**.

In the case of FIGURE 7, the mode of propagaton selected is the fundamental circular symmetrical TM dielectric mode. The higher TM dielectric modes have no effect since their cut-off frequencies are much higher than the cut-off frequency of the said fundamental TM mode. The electric field component E_ϕ is zero for the circular symmetrical TM dielectric mode. It is therefore possible to suppress those modes in which the component E_ϕ is not zero, without interfering with the propagation of the desired TM dielectric mode, by inserting in the dielectric material of the tube **12** wires **15** which are arranged circumferentially in directions perpendicular to the axis of the circuit, these circumferential configurations being centered on said axis. In this way, the circular symmetrical TE dielectric mode is suppressed as also are the non-circular symmetrical modes.

In the transmission circuit illustrated in FIGURE 7, the presence of the continuous metal tube **13** about the dielectric tube **12** may lead to the propagation of other parasitic modes, namely the "metallically guided" modes. Of these, the TE modes which have an E_ϕ component which is not zero, are suppressed due to the presence of wires **15** arranged in a circular disposition. However, these wires cannot eliminate the metallically guided TM modes for which the electromagnetic field components which are not zero are H_ϕ, E_z and E_r as with the circular symmetrical TM dielectric mode.

However, as will be demonstrated hereinafter, there exists inside the material of which the dielectric tube **12** is made, a cylindrical plane centered on the same axis as the said tube, in which the E_z component of the electric field is zero for the desired TM dielectric mode but is *not* zero for the metallically guided TM modes. It is thus possible to suppress these latter modes without interfering with the desired mode, by inserting wires longitudinally into the material of the tube **12** in the said cylindrical plane.

The presence of longitudinal wires and of the metal tube, may lead to the formation of modes of propagation similar to those appearing in coaxial lines, however, this can be prevented by placing in longitudinal lines for which the E_z component is zero, *not* continuous metal wires but instead relatively short wire sections **16**.

Thus, it is advantageous to place these short wire sections in two adjacent, parallel and longitudinally directed lines, staggering them in relation to one another in the longitudinal sense.

In FIGURE 8, in the lower left, part of a transverse section through the transmission circuit of FIGURE 7 is illustrated, this comprising a metal tube **13** of internal radius a and a dielectric tube **12** of external radius b and internal radius c. In the upper part of FIGURE 8, the variation of the longitudinal electric field component E_z for the circular symmetrical TM dielectric mode is plotted as a function of r/b, where r is the distance of a point considered from the axis of the circuit. It can be shown that the variation in E_z is on the lines illustrated in this figure and that, in particular, if the radius r increases from the value c to the value b, the E_z component changes sign and passes through zero at a specific value of r, namely r_0, which lies somewhere between the internal radius c and the external radius b of the dielectric tube **12**. Thus, there is a cylindrical plane on the same axis as the axis of the tube **12**, situated at a radius r_0 from the said axis, in which plane the component E_z is zero for the circular symmetrical TM dielectric mode. On the other hand, the component E_z is not zero for the metallically guided TM modes; it is therefore not zero at points situated at a distance of r_0 from the axis of symmetry. Consequently, it is possible to suppress these latter modes by means of sections of wire **16** disposed longitudinally at a distance r_0 from the longitudinal axis of the circuit.

Self-evidently, it is possible, within the scope of the the invention to exclusively use sections of wire which are longitudinally arranged.

The circuit illustrated in FIGURE 7 can be obtained, in the case where the wires **15** arranged in circular fashion are nearer the axis of symmetry than the wire sections **16** which are longitudinally disposed, by extruding that part of the dielectric tube which is inside the wires **15**, applying to the tube thus formed the wires **15**, extruding over that the part of the tube situated between the wires **15** and the wire sections **16**, applying to the resultant tube the wire section **16** and, finally, by extruding over that the part of the tube **12** which lies outside the wire sections **16**.

The choice of the distance of the axis of symmetry from the circularly arranged wires **15** is not absolutely fixed and these wires may of course be placed at a distance r_0 from the said axis. They can thus form a mesh with the longitudinal wire sections **16**. In this way, the construction of the circuit can be somewhat simplified and is reduced to the extrusion of that part of the tube situated inside the mesh, the application of the mesh and the extrusion of the outer part of the tube.

As already mentioned, it may sometimes be advantageous, where sections of wire disposed longitudinally on a cylindrical surface are employed, to stagger the sections in the longitudinal sense (they are placed next to one another in parallel lines). An arrangement of this sort is illustrated in FIGURE 9. A ghost view is given of the inside of a dielectric tube **17**, showing the sections of wire **18** arranged in lines parallel with the axis of the tube and staggered in relation to one another in the longitudinal sense. In order to simplify the drawing, the circularly arranged wire have not been illustrated in FIGURE 9.

In the case in which the circularly disposed wires are arranged on the cylindrical surface of radius r_0 together with the longitudinally disposed wire sections, it is of course possible to replace the complete set of wires by wires which are obliquely arranged in relation to the axis of symmetry.

What is claimed is:

1. A transmission circuit for very high frequency electromagnetic waves, adapted to the transmission of a preferred mode having a circular symmetry about a longitudinal axis of said circuit, comprised of a homogeneous cylindrical tube made of a high permittivity and low loss dielectric material inside which are embedded lengths of thin metallic wires spaced and insulated from each other and substantially oriented in a direction in which the electric field of said preferred mode has a zero component, in which said preferred mode is a fundamental circular-symmetrical TM mode and in which said wire lengths are oriented in planes substantially perpendicular to said axis and along circles having their center on said axis.

2. A transmission circuit for very high frequency electromagnetic waves, adapted to the transmission of a preferred mode having a circular symmetry about a longitudinal axis of said circuit, comprised of a homogeneous cylindrical tube made of a high permittivity and low loss dielectric material inside which are embedded lengths of

thin metallic wires spaced and insulated from each other and substantially oriented in a direction in which the electric field of said preferred mode has a zero component, in which said preferred mode is a fundamental circular-symmetrical TE mode and in which said wire lengths are oriented in radial directions passing through said axis and located in planes substantially perpendicular thereto.

3. A transmission circuit for very high frequency electromagnetic waves, adapted to the transmission of a preferred mode having a circular symmetry about a longitudinal axis of said circuit, comprised of a homogeneous cylindrical tube made of a high permittivity and low loss dielectric material inside which are embedded lengths of thin metallic wires spaced and insulated from each other and substantially oriented in a direction in which the electric field of said preferred mode has a zero component, in which said preferred mode is a fundamental circular-symmetrical TE mode and in which part of said wire lengths are oriented in a direction substantially parallel to said axis and part of said wire lengths are oriented in radial directions passing through said axis and located in planes substantially perpendicular thereto.

4. A transmission circuit adapted to the transmission of a TM circular-symmetrical mode and comprised of a cylindrical tube of a low-loss and high permittivity dielectric material surrounded by a metal tube concentrically arranged with respect to said dielectric material tube and in spaced relationship thereto and having a common revolution axis therewith, said circuit comprising insulating means for fastening said dielectric tube inside said metal tube, said dielectric tube being further provided with lengths of thin metallic wire spaced and insulated from each other and embedded in said dielectric material, in which of least part of said wire lengths are oriented

along circles having their centers on said axis and their planes substantially perpendicular thereto.

5. A transmission circuit adapted to the transmission of a TM circular-symmetrical mode and including a cylindrical tube of a low-loss and high permittivity dielectric material surrounded by a metal tube concentrically arranged with respect to said dielectric material tube and in spaced relationship thereto and having a common revolution axis therewith, said circuit comprising insulating means for fastening said dielectric tube inside said metal tube, said dielectric tube including lengths of thin metallic wire spaced and insulated from each other and embedded in said dielectric material, in which a first part of said wire lengths are oriented along circles having their centers on said axis and their planes substantially perpendicular thereto, and in which a second part of said wire lengths are composed of relatively short broken sections and are arranged along lines parallel to said axis at a distance from said axis at which the longitudinal component of the electric field of the fundamental circular-symmetrical TM wave guided by said dielectric tube is substantially zero.

6. A transmission circuit as claimed in claim 5, in which both said first and second parts of said wire lengths are located at distance from said axis substantially equal to said distance.

References Cited by the Examiner

UNITED STATES PATENTS

3,016,503	1/1962	Pierce	333—95
3,121,206	2/1964	Mandel	333—95

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