Nov. 27, 1962 H. E. M. BARLOW 3,066,269

TUBULAR WAVEGUIDES

Filed May 12, 1958 2 Sheets-Sheet 1

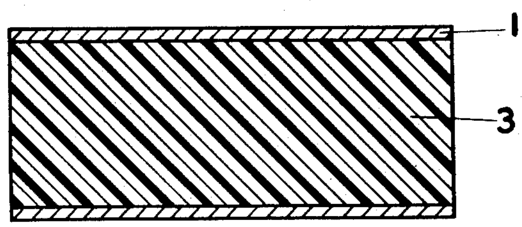

FIG. 1.

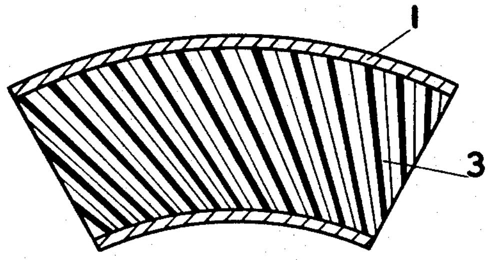

FIG. 2.

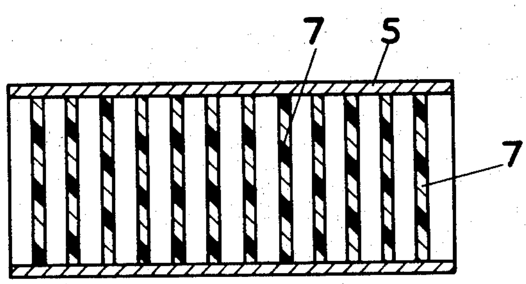

FIG. 3.

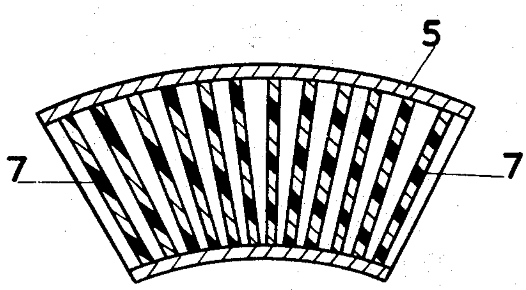

FIG. 4.

INVENTOR:

Harold Everard Monteagle Barlow,

BY Cushman, Darby & Cushman

ATTORNEYS.

Nov. 27, 1962 H. E. M. BARLOW 3,066,269

TUBULAR WAVEGUIDES

Filed May 12, 1958 2 Sheets-Sheet 2

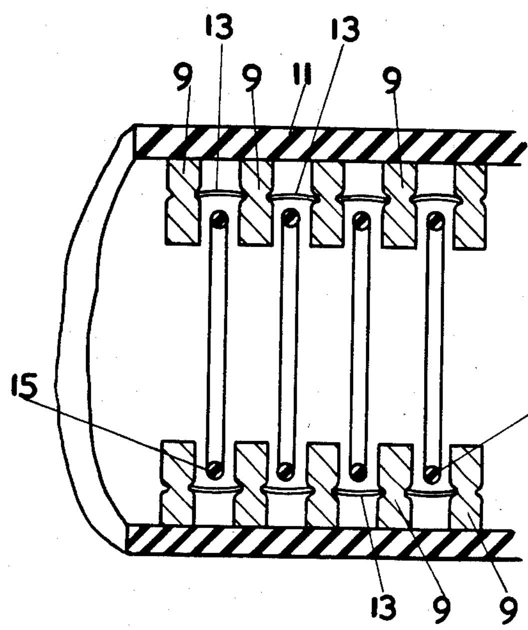

FIG. 5.

INVENTOR:

Harold Everard Monteagle Barlow,

BY Cushman, Darby & Cushman

ATTORNEYS.

United States Patent Office

3,066,269

Patented Nov. 27, 1962

3,066,269

TUBULAR WAVEGUIDES

Harold Everard Monteagle Barlow, Banstead, England

Filed May 12, 1958, Ser. No. 734,509

Claims priority, application Great Britain May 17, 1957

13 Claims. (Cl. 333—98)

This invention is concerned with tubular wave-guides suitable for the propagation of the circular H_{01} electromagnetic wave-mode.

The circular H_{01} electromagnetic wave-mode is of special interest because of its low attenuation characteristic when propagated along the inside of a hollow metal tube at a frequency well above the cut-off value. This characteristic arises from the absence of longitudinal current in the wall of the tube. Lttle difficulty is experienced when such a wave-mode is transmitted along a straight tubular wave-guide. At a frequency of 35,000 mc./s. attenuations of the order of 14 db per mile in a copper tube having an inside radius of 1.72 cms. (1.5 ins. outside diameter) are readily obtainable. This performance takes into account such variations in cross-section of the tube which are normally to be expected in commercial production and also the tolerances on longitudinal alignment that are not difficult to meet. However, in practical applications of such a wave-guide, as, for example, for a long distance communications channel, deliberate curved sections usually termed bends are inevitable and it is found that at such bends wave-modes other than the H_{01} mode tend to be set up, causing an increase in the losses.

It is an object of this invention to provide a wave-guide bend which is suitable for the propagation of the H_{01} electromagnetic wave-mode and in which the losses are reduced, as compared with such wave-guides used hitherto.

According to this invention the permittivity of the dielectric material within a curved wave-guide section or bend is varied over the cross-section of the guide and/or the surface reactance is varied around the periphery of the guide in such a manner that the wave-front represented by an equi-phase plane, of the H_{01} electromagnetic wave-mode, remains radial with respect to the centre of curvature of the bend (i.e., bent perpendicular to the longitudinal axis of the waveguide) as the wave progresses from one end of the bend to the other.

Where the permittivity of the dielectric material is varied, only a comparatively small change in its value over the cross-section of the bend is required, and the permittivity is highest in the region of the inside radius of the bend and is lowest in the region of the outside radius of the bend. For the losses to be reduced as far as possible it is important that the space within the bend is filled mostly with air and it has been found that cellular polystyrene or cellular polyethylene, which are capable of mechanical compression on the inside of the bend and mechanical expansion on the outside of the bend when the tube in which they are contained is bent to the required radius, are suitable dielectric materials. The cellular polystyrene or polyethylene may either substantially fill the bend or may be in the form of discs disposed across the cross-section of the bend and spaced apart from each other by air.

One convenient method of varying the permittivity of the dielectric material in a bend is to fill a straight tube having a length equal to that of the required bend with the cellular dielectric material and then to bend the tube and the dielectric material to the required radius of curvature. In so doing the material is compressed in the region of the inside radius of the bend and expanded in the region of the outside radius of the bend, thus increasing

the permittivity at the inside radius and decreasing it at the outside radius.

It has been found that a close approach to the required field distribution with a resulting decrease in the losses at the bend is obtained even when the guide is bent to have a radius of curvature as small as 50 to 100 times the radius of the tube.

In order to vary the surface reactance of the bend, circumferential grooves or corrugations are formed in the internal surface of a tube which is then bent to the required radius of curvature, each groove supporting an H_{011} coaxial wave-mode. There should be at least three circumferential grooves per wavelength of the circular H_{01} mode in the main guide in order to make the surface reactance effectively distributed along the length of the guide. In order to achieve this result each groove must be loaded with a high permittivity dielectric material, thus enabling the groove width and pitch to be correspondingly reduced.

When the guide is bent, the part of each groove in the region of the outside radius of the bend is increased in width and reduced in depth and the part of each groove in the region of the inside radius of the bend is reduced in width and increased in depth.

Instead of forming circumferential grooves or corrugations in the internal surface of the tube, the tube may be fabricated from a series of metal rings mounted inside a rubber tube and separated from one another by thin flexible metal spacers each slightly in compression and forming the bottom of a groove.

FIGURES 1 and 2, and FIGURES 3 and 4 of the accompanying drawings show two methods of making a curved wave-guide section or bend in which the permittivity of the dielectric material in the bend is suitably varied over the cross-section of the guide.

Referring to FIGURES 1 and 2, a tube of copper 1, having a length substantially equal to that of the bend to be produced is filled with cellular polystyrene 3 and then bent (see FIGURE 2) to the required radius of curvature. During bending the cellular polystyrene is expanded in the region of the outside radius of the bend and compressed in the region of the inside radius of the bend.

Referring to FIGURES 3 and 4, a copper tube 5, having a length substantially equal to that of the bend to be produced is provided with a number of thin discs 7 of cellular polystyrene which are spaced apart from each other at equal intervals. The tube is then bent to the required radius of curvature and during bending the discs become spaced further apart in the region of the outside radius of the bend and become closer together in the region of the inside radius of the bend.

FIGURE 5 shows, in section, a wave-guide section or bend of which the surface reactance around the periphery is automatically varied, when bent to the required radius of curvature. The guide is formed by a number of spaced rings 9 separated from each other by equal intervals and contained inside a rubber tube 11 which holds the rings in position. Each ring is spaced apart from the next by a spring metal spacer 13 and a high-permittivity dielectric loading ring 15 is placed between each pair of metal rings. When the tube so formed is bent to the required radius of curvature, the distance between two adjacent rings in the region of the outside radius of the bend is increased and that in the region of the inside radius of the bend is decreased. Thus, the section, in the region of the outside radius of the bend, is more capacitive than in the region of the inside radius of the bend. The solid dielectric material in the groove should, preferably, have a relative permittivity of about 8 with small losses and may be polythene loaded with titanium dioxide.

From the foregoing description of the several embodiments of this invention, it is now apparent that the main purpose thereof of providing a wave-guide which is suitable for the propagation of the H_{01} electromagnetic wave-mode in a rectilinear or non-rectilinear tube with losses minimized has been achieved. In each of the different embodiments, means has been provided to cause the wavefront of an equi-phase plane of the H_{01} electromagnetic wave-mode, when the tube is excited thereby by means not shown, to remain substantially radial with respect to the centre of curvature of any bend in the tube as the wavefront progresses from one end of the tube to the other. In other words, in each of the embodiments, the phase velocity of the wanted H_{01} wave-mode is specially and automatically controlled by this invention to keep the wavefront thereof radial as aforesaid, at all instants of time. To do this, of course, the phase velocity cannot remain constant around the circumference or periphery of any given cross section of the tube when bent. In each of the different embodiments, the phase velocity control means therefor causes the wave to be increased in velocity in the region of the outer radius of any bend and simultaneously decreased in velocity in the region of the inner radius of that bend. The control means modifies the wave-guide characteristic to cause the phase change coefficient of the wave propagated through the curved tube or bend to vary progressively across the full cross-section of the tube to maintain the wavefront substantially radial at all points of its path in traversing the bend of the tube. Since phase velocity is inversely proportional to the phase change coefficient, the guide is so modified that the coefficient is least at the outer radius where the phase velocity is greatest. In the embodiments of FIGURES 2 and 4, the phase velocity is so controlled because the permittivity of the dielectric material **3** and that between discs **7**, which is the same around any cross sectional periphery of the rectilinear tube sections in FIGURES 1 and 3, is varied therearound when the tube is bent as in FIGURES 2 and 4. Bending the tube in FIGURE 2 causes the dielectric near the inner radius to be compressed which in turn causes its permittivity to be increased. In an opposite manner, the bending causes the dielectric material near the outer or upper radius in FIGURE 2 to expand, thereby decreasing the permittivity of the dielectric. Because of these changes in the permittivity of the dielectric material, which are proportional to the degree of bend, the phase velocity of an H_{01} mode being propagated through the bend is automatically controlled to keep the wavefront of the mode radial.

The FIGURE 4 embodiment operates in a similar manner to control the phase velocity. The bending effected in FIGURE 4 causes the equally spaced dielectric discs **7** of FIGURE 3 to be compressed in their spacing in the region of the inner radius in FIGURE 4, and expanded in their spacing in the region of their outer radius. This decreases the permittivity near the outer radius causing the phase velocity of the H_{01} mode to be increased near the outer radius, and at the same time increases the permittivity in the region of the inner radius which causes the velocity thereat to be decreased, keeping the wavefront radial at all times.

In the embodiment of FIGURE 5 the phase velocity of the H_{01} mode is automatically controlled by automatically varying the surface reactance around the periphery of any cross section of a tube bend. In this embodiment, the phase velocity is controlled by operating on the wall of the guide, as opposed to operating on the dielectric medium within the guide as in FIGURES 1–4. When the guide of FIGURE 5 is bent to form a curved section as in FIGURE 4 for example, the distance between rings **15** in the upper grooves, i.e., near the outside radius of the bend, increases causing a larger capacitance thereabout than in the equal capacitance arrangement indicated in the rectilinear tube of FIGURE 5. At the same time, the distance between rings **15** in the inner radius decreases causing the H_{01} mode to be decreased in phase velocity at the point of distance decreased near the inner radius, to keep the wavefront radial at all instances of time during its propagation.

I claim:

1. A method of making a curved wave-guide for propagating a given mode of an electromagnetic wave comprising substantially filling a rectilinear wave-guide with cellular dielectric material, and then bending the wave-guide into a desired curve to increase the permittivity of said dielectric material in the region of the inner radius of said curve and simultaneously decrease the permittivity of said material in the region of the outer radius of said curve, whereby the phase velocity of the said given mode is automatically controlled to keep the wavefront thereof radial with respect to the centre of curvature of the said curve.

2. A method of making a curved wave-guide for propagating a given mode of an electromagnetic wave comprising inserting into a rectilinear wave-guide a plurality of cellular dielectric discs equally spaced along the length of the guide to be bent, and then bending the rectilinear wave-guide into a desired curve to decrease the intervals between said discs at the inner radius of the said curve and simultaneously increase the intervals of said discs near the outer radius of said curve, whereby the phase velocity of the said given mode is automatically controlled to keep the wavefront thereof radial with respect to the centre of curvature of the said curve.

3. A method of making a curved wave-guide for propagating a given mode of electromagnetic wave comprising loading each groove of the wall of a rectilinear wave-guide which comprises at least three circumferential grooves per wave length of the said mode with a high-permittivity dielectric material, and then bending the wave-guide to effect a desired curve and increase the capacitance in the region of the outer radius of the said curve and simultaneously decrease the capacitance in the region of the inner radius of that curve, whereby the phase velocity of the said given mode is automatically controlled to keep the wavefront thereof radial with respect to the centre of curvature of the said curve.

4. A curved wave-guide section or bend for propagating the H_{01} electromagnetic wave-mode, comprising a metallic tube and means operative on said wave-mode itself for causing an equi-phase plane thereof to remain substantially radial with respect to the centre of curvature of any bend in the tube as the wave front progresses from one end of the tube to the other, said means including means for causing the surface reactance of the tube to vary around any of its cross sectional peripheries, being more capacitive in the region of the outside radius of the bend than in the region of the inside radius of the bend.

5. A curved wave-guide section or bend as claimed in claim 4 in which the wall of the tube comprises circumferential grooves, there being at least three circumferential grooves per wavelength of the circular H_{01} wave-mode and each groove being loaded with a high-permittivity dielectric material.

6. A method of controlling the phase velocity of an electromagnetic wave in a non-rectilinear portion of a tubular wave-guide comprising varying the phase velocity of said wave in a plane substantially perpendicular to the longitudinal axis of said wave guide to maintain the front of said wave radial with respect to said axis including the step of varying the surface reactance of the said wave-guide around its circumference at a particular point along the length of the guide so that the wave is operated on only at the wall of the guide.

7. A curved wave-guide section or bend for propagating the H_{01} electromagnetic wave-mode, comprising a curved metallic tube having means for modifying the wave-guide characteristic to cause the phase change coefficient of said wave when propagated through the

curved tube to vary progressively across the full cross-section of the tube to maintain the wavefront of the wave-mode substantially radial at all points of its path in traversing the bend of said tube.

8. A curved wave-guide section or bend as in claim 7 in which said means comprises a cellular dielectric material extending over the total cross-section of the tube at at least spaced points throughout the total length of the curved tube, the cellular dielectric material having a permittivity which progressively decreases from the region of the inside radius of the curved tube to the region of the outside radius thereof.

9. A curved wave-guide section or bend as in claim 8 in which the dielectric material is selected from the group consisting of cellular polyethylene and cellular polystyrene.

10. A curved wave-guide section or bend as in claim 7 wherein said means includes means for decreasing the said phase change coefficient in the region of the outer radius of said curved tube and for increasing the said

phase change coefficient in the region of the inner radius of said tube.

11. A curved wave-guide section or bend as in claim 7 wherein said means comprises a synthetic polymer type dielectric material.

12. A curved wave-guide section or bend as in claim 11 wherein said means includes a plurality of circular members in spaced transverse planes.

13. A curved wave-guide section or bend as in claim 12 wherein said spaced circular members are respectively discs each of which fully extends across a cross-section of said tube at a point spaced from its neighbour and is composed of material selected from the group consisting of cellular polyethylene and cellular polystyrene.

References Cited in the file of this patent

UNITED STATES PATENTS

2,848,696	Miller	Aug. 19, 1958
2,865,008	Kock	Dec. 16, 1958
2,904,759	Morgan	Sept. 15, 1959