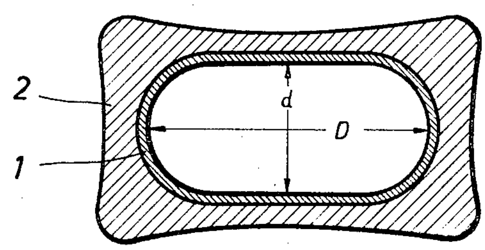

Fig. 1

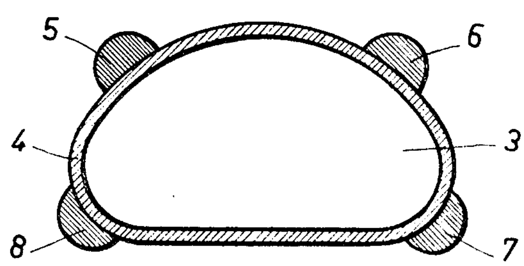

Fig. 2

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United States Patent

[11] **3,585,540**

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[73] Assignee **Telefunken Patentverwertungsgesellschaft m.b.H Ulm (Danube) Germany**
[32] Priority **July 20, 1967**
[33] **Germany**
[31] **P 16 90 288.8**

[54] **FLEXIBLE WAVEGUIDE HAVING MEANS TO REDUCE DEFORMATION OF INTERNAL CROSS SECTION**
12 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **333/95,** 138/177
[51] **Int. Cl.** **H01p 3/14**
[50] **Field of Search** .... 333/95, 95 A; 138/177, 178, 118, 137

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Assistant Examiner—Paul L. Gensler
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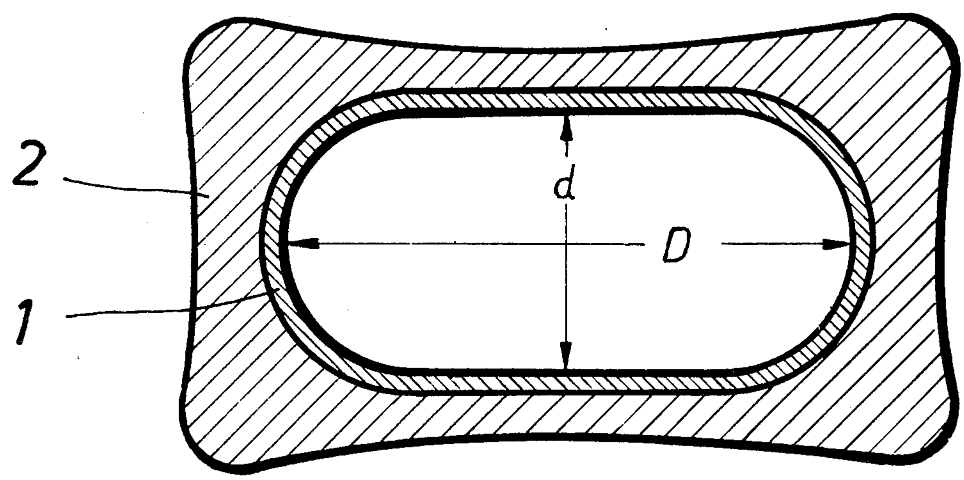
ABSTRACT: A flexible waveguide for the correct transmission of electromagnetic waves, comprising a relatively thin, seamless metal waveguide tube having a noncircular internal cross section, the edges or profile which is free of abrupt changes of direction. Means are provided, according to the invention, for imparting a rigidity to the waveguide tube which will reduce to a minimum any deformation of the internal cross section, when the waveguide is bent or twisted.



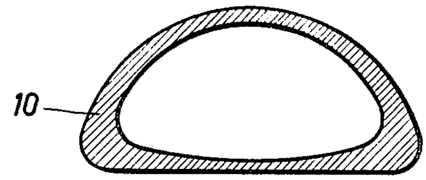


Fig. 3

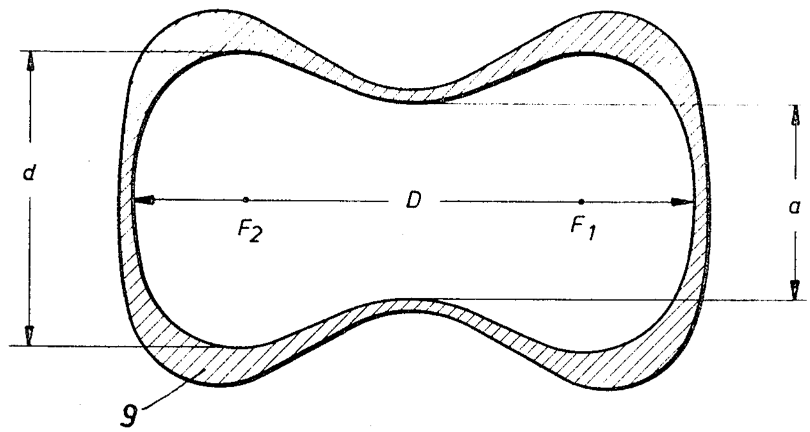


Fig. 4

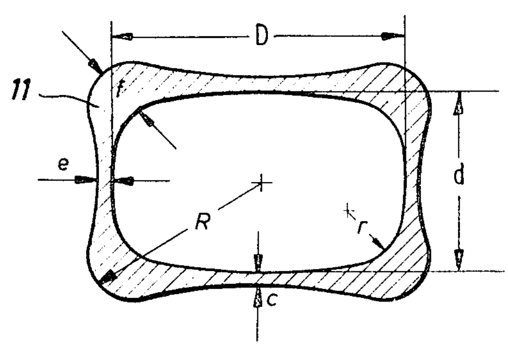


Fig. 5

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FLEXIBLE WAVEGUIDE HAVING MEANS TO REDUCE DEFORMATION OF INTERNAL CROSS SECTION

BACKGROUND OF THE INVENTION

The present invention relates to a flexible waveguide for the correct transmission of preferably linearly polarized electromagnetic waves. This waveguide possesses a noncircular effective internal cross section, the edge of which is free of abrupt changes of direction, and is formed from a relatively thin seamless metal tube.

With electromagnetic energy transmission lines which are formed from rigid rectangular or circular waveguide sections, it is necessary to employ numerous flanges to interconnect the individual sections. The use of these flanges not only increases the cost, but also produces undesirable reflections within this type of waveguide train at the various points of connection.

As is now known, it is possible to realize a practical endless waveguide train without the interposition of waveguide flanges by producing the waveguide from a corrugated metal tube. This type of energy conductor has already been on the market for some time and has proven advantageous in the construction of transmitting stations in the decimeter and the centimeter wave region.

This type of waveguide, which may be reeled on a drum, possesses an approximately elliptical cross section; compared to analogous rectangular waveguides, it exhibits a lower damping factor. However, the manufacture of these waveguides is relatively time-consuming and expensive, since, at the present, it is necessary to first provide the copper tube employed for the waveguide with a very particular corrugation and then to deform the circular cross section of the tube into an approximate ellipse.

To protect the waveguide from physical damage, the metal tube, which has been shaped in the manner described above, is provided, in addition, with a suitable dielectric protective jacket.

A waveguide constructed in this manner, however, is not unqualifiedly suited for all installations. This is especially true when it is employed as an antenna feed line at permanent microwave stations, since the ability of the waveguide to be reeled on relatively small cable drums—made possible by the corrugations—is practically not utilized at all. When the long waveguide sections are reeled on suitable drums at most only when transported from the factory to the microwave station, but after installation no longer need to be moved, the expense required for the manufacture of the elliptical corrugated tube waveguide described above is not justified. In particular, under these circumstances, the very advantage of this type of corrugated tube waveguide—that it can be reeled on a drum several hundred times without impairing its electrical characteristics—is not effectively utilized.

SUMMARY OF THE INVENTION

An object of the present invention, therefore, is to provide a new type of flexible waveguide, the electrical properties of which are as good or better than that of the waveguides known in the prior art, which waveguide may also be employed in permanent installations at reduced cost.

When a waveguide is employed as a feedline for a permanent antenna installation, it is only subjected to a bending and/or twisting when the installation is assembled. A change of waveguide position during operation of the installation will practically never occur.

The object described above, as well as other objects which will become apparent in the discussion that follows, is achieved, according to the present invention, by providing means for imparting a rigidity to the waveguide so that when it is bent or twisted the deformation of the internal cross section—which would change its electrical characteristics—is reduced to a minimum.

The present invention makes use of the knowledge of what occurs when a thin metal tube is bent. Such knowledge comes into play, for example, with the metal shields or jackets of coaxial cables.

It is a prerequisite for the employment of a thin metal tube as a waveguide, that the waveguide be dimensioned to avoid a damaging deformation of its internal cross section. There are a number of ways in which the deformation of the internal cross section may be kept to a minimum. First, it is possible to provide the outer surface of the waveguide with longitudinally extending dielectric strips. These strips make it possible to reduce the deformation of the waveguide's internal cross section, when the waveguide is bent or twisted, to such a slight degree that the waveguide may still be employed for the distortion-free and correct transmission of the electromagnetic waves.

Another possible means for imparting the necessary rigidity to the waveguide is to surround the outside surface of the waveguide tube with a dielectric jacket which, in profile, exhibits a variable thickness. The thickness of the jacket is increased at those points of the cross section of the waveguide which would be deformed to the greatest extent if the waveguide were bent.

In a preferred embodiment of the present invention the desired effect of the present invention is achieved by making the wall of the metal waveguide tube itself of variable thickness when the tube is viewed in profile. This can be realized, for example, by adding longitudinally extending metal strips to the outer surface of the waveguide to give the waveguide the desired rigidity. For technical reasons which arise in the production of the waveguide, it is practical, in this embodiment, to make the cross-sectional edge of the external surface with a continuous derivative; that is, free of abrupt changes of direction. In order to reduce the forces necessary to bend the waveguide, the thickness of the waveguide walls, preferably in the region of the principal axes, is made thinner than at the remaining points on the cross section.

The effective internal cross section of the waveguide constructed according to the present invention with a smooth internal wall, can be made with various shapes. For example, this internal cross section can be symmetrical to the principal axes of the waveguide cross section. It is possible, in addition, to make the internal cross section symmetrical with respect to only one of the principal axes. The length of the two aforementioned principal axes is always different; however, the ratio of the minor to the major principal axis is preferably made greater than 0.45.

The cross-sectional shape of the waveguide, according to the present invention should be rectangular, in the first approximation, to obtain the greatest possible bandwidth. It is possible, depending on the requirements, to arch the waveguide walls either inward or outward; that is, to make them concave or convex. For particularly broad bandwidths, the waveguide should be constructed, similar to a ridge waveguide, with at least one indentation running parallel to its longitudinal axis.

The waveguide, according to the present invention, can be advantageously produced by the seamless extrusion of a metal tube in a suitable cable-making machine. Aluminum is an especially suitable metal to use for the metal tube.

Corrugated metal tubes of copper have been used in the prior art as flexible antenna leads. The corrugation effects a physical elongation of the waveguide, however; furthermore, it leads to undesirable reflections and affects the damping.

Even when aluminum is used as the waveguide material, the waveguide constructed with the smooth wall according to the present invention produces no greater damping than the corrugated tube. An aluminum waveguide of this type has the additional advantages that it is softer and, therefore, more flexible than a copper waveguide and has a greater resistance to corrosion.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of a waveguide according to a first preferred embodiment of the present invention.

FIG. 2 is a cross-sectional view of a waveguide according to a second preferred embodiment of the present invention.

FIG. 3 is a cross-sectional view of a waveguide according to a third preferred embodiment of the present invention.

FIG. 4 is a cross-sectional view of a waveguide according to a fourth preferred embodiment of the present invention.

FIG. 5 is a cross-sectional view of a waveguide according to a fifth preferred embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, FIG. **1** shows a preferred embodiment of the present invention. In this embodiment, the wall of the waveguide tube **1** is of uniform thickness. The two principal axes of the cross section of the waveguide are designated by the letters D and *d*. In order to achieve the desired broad bandwidth, the shape of the internal cross section is made to approximately correspond to a rectangle having sharply rounded edges and outwardly curved sides.

In order to avoid undesirable variations in the internal cross section of this waveguide when it is bent or twisted, the outer surface of the waveguide tube is surrounded with dielectric jacket **2** which, unlike the waveguide tube itself, does not exhibit a constant thickness along its cross-sectional edge.

In the embodiment shown in the illustration, the thickness of the wall of the jacket is the smallest in the region of the principal axes of the waveguide. The outer contour of the dielectric jacket forms a rectangle with sharply rounded edges and with inwardly arched sides.

FIG. **2** illustrates another embodiment of the present invention, wherein the internal cross section of the waveguide is symmetrical about only a single principal axis. The wall thickness of the waveguide tube **4** is constant along the cross-sectional edge. Four metal strips **5**, **6**, **7** and **8**, are attached to the wall of the waveguide tube **4** in the region of the four "corners" thereof. Because of their shape and position, these metal strips, which extend in the longitudinal direction of the waveguide, prevent the effective internal cross section of the waveguide from changing to an undue extent when the waveguide is bent and/or twisted.

The strips **5**, **6**, **7** and **8** may, for example, be made of the same material as the waveguide tube **4** and welded onto the outer tube surface. The exact position and thickness of these longitudinal strips is dependent upon the particular cross section of the waveguide tube **4** and the material of which the tube is made.

A still further means for realizing the present invention is illustrated in FIG. **3**. The outer cross-sectional edge of the waveguide **10** forms a semicircle having rounded corners. The internal cross section of the waveguide is chosen to give the waveguide wall various thicknesses along the edge of the waveguide cross section. The walls of the waveguide thus exhibit various degrees of rigidity so that the shape of the internal cross section will be substantially retained when the waveguide is bent and/or twisted.

To achieve the desired broad bandwidth, the waveguide according to the present invention may be provided with at least one indentation extending in the longitudinal direction. The waveguide which is illustrated in cross section in FIG. 4 is constructed with two such indentations, symmetrically arranged and extending in the longitudinal direction. The resulting waveguide is similar to a ridge waveguide.

The major principal axis of the waveguide **9** of FIG. **4** is designated with the letter D. The minor axis, which also designates the distance between the two indentations, carries the letter *a*, while the distance between the nonindented portions of the waveguide is designated with the letter *d*.

The relationship of the waveguide width *d* to the separation *a* substantially determines the usable bandwidth of this type of waveguide.

In the embodiment illustrated in FIG. **4**, the wall of the waveguide is made thinner in the region of the principal axes than in the remaining regions. The wall thickness around the profile of the waveguide has a continuous derivative so that both the internal and the external edges or profiles of the wall are free of abrupt changes of direction.

The function described by the edge of the effective internal cross section is preferably made a Cassinian curve; that is, the internal cross-sectional edge may be described by the equation:

$(X^2+Y^2)^2a/2b^2(X^2-Y^2)=k^4-b^4$ where the foci F_1 and F_2 are located at (+b, **0**) and (−b, **0**), respectively, and *b* and the constant *k* are chosen such that $b<k<\sqrt{2}$ to obtain an indentation.

In the embodiments of the present invention described above the particular waveguide cross sections produce a preferred plane in which the waveguide may be bent. For many applications, however, it is advantageous if the waveguide may be bent with approximately equal ease in the planes defined by both the major as well as the minor principal axes of cross section. If the thickness of the walls is properly chosen, it is possible, according to still another embodiment of the present invention, to nearly equalize the bendability of the waveguide in these two planes.

FIG. **5** illustrates an embodiment of this type of waveguide which is equally pliable in the planes of the two principal axes of its cross section. The effective internal cross section of the waveguide takes generally the shape of a rectangle with sharply rounded edges and outwardly arched sides. The ratio of the minor principal axis of the waveguide, designated with the letter *d*, to the major principal axis, designated with the letter D, is made larger than 0.45.

The thickness of the wall of the waveguide **11** is made thinner in the region of the two principal axes than in the remaining regions which include the corners.

In the embodiment shown in FIG. **5**, the radius of curvature of the effective internal cross section, designated with the letter *r*, is equal to approximately one-fourth of the length of minor principal axis *d*. In the region of the so-called "corners" of the waveguide, the wall thickness *f* is made approximately 2 to 4 times greater than the wall thickness *e* in the region of the major principal axis of the waveguide cross section. In order to obtain a waveguide which exhibits approximately the same flexibility in the plane of the principal axis D as in the axis *d*, which runs perpendicular thereto, the wall thicknesses *e* and *c*, respectively, in the regions of these principal axes may be made suitably different. The transition between the various wall thicknesses around the cross section of the waveguide is made continuous in the illustrated embodiment.

In the waveguide cross section illustrated in FIG. **5** the four rounded outer "corners" lie on a circle with the radius R. This arrangement makes it possible to make the flanges, which are necessary to connect sections of the waveguide in the manner known in the art, as simple coupling nuts. These nuts may be made with an internal thread which engages with a corresponding external thread on the waveguide in the region of these external corners.

According to a further modification of the waveguide according to the present invention, the thickness of the wall may be increased in such a way that the outer edge of the waveguide cross section is made circular in the region of the waveguide ends. This embodiment with reinforced waveguide ends makes it particularly easy to mount the fittings.

It will be understood that the above description of the present invention is susceptible to various modifications, changes and adaptations.

We claim:

1. A flexible waveguide for the correct transmission of electromagnetic waves comprising: a seamless metal waveguide tube having a relatively thin wall of constant thickness and a noncircular internal cross section, the profile of which is continuous and free of abrupt changes of direction; and means for imparting a rigidity to said waveguide tube at selected locations such that when said waveguide is bent or twisted, the deformation of said internal cross section is reduced to a minimum, said means including a waveguide jacket made of dielectric material surrounding the outer surface of said waveguide tube, said jacket having different thicknesses in profile with the thickness being smallest in the region of the principal cross-sectional axes of said waveguide tube.

2. A flexible waveguide for the correct transmission of electromagnetic waves having a relatively thin walled seamless metal waveguide tube with a noncircular internal cross section and with the inner and outer cross-sectional profiles of said wall being continuous and free of abrupt changes in direction, said waveguide tube having two principal cross-sectional axes, the wall of said waveguide tube having different thicknesses in profile and being thinner in the region of said two axes than in the other regions thereof so that said wall imparts a rigidity to the waveguide tube such that the deformation of said internal cross section is reduced to a minimum when the waveguide is bent or twisted.

3. The waveguide defined in claim **2**, wherein said internal cross section is symmetrical with respect to said two axes.

4. The waveguide defined in claim **2**, wherein said two principal cross-sectional axes are of differing length.

5. The waveguide defined in claim **4**, wherein the ratio of the shorter to the longer of said two axes is larger than 0.45.

6. The waveguide defined in claim **2**, wherein said waveguide tube has at least one indentation extending parallel to its longitudinal axis.

7. The waveguide defined in claim **6**, wherein said inner cross-sectional profile of said wall describes a Cassinian curve.

8. The waveguide defined in claim **2**, wherein the thickness of said wall is chosen so that the bendability of said waveguide in the plane of said two principal axes is approximately equal.

9. The waveguide defined in claim **2**, wherein said waveguide tube is formed by a drawn aluminum tube.

10. A flexible waveguide for the correct transmission of electromagnetic waves having a relatively thin walled drawn aluminum waveguide tube with a noncircular internal cross section, the inner and outer cross-sectional profiles of said wall being continuous and free of abrupt changes in direction, the wall of said waveguide having a varying thickness in profile with a minimum thickness in the region of the two principal cross-sectional axes, and a maximum wall thickness in the regions therebetween, whereby undesirable deformations of said internal cross section are prevented during bending and/or twisting of said waveguide.

11. A flexible waveguide as defined in claim **2** wherein the outer cross-sectional profile of the waveguide wall is nonlinear.

12. A flexible waveguide as defined in claim **11** wherein the outer cross-sectional profile of the waveguide wall curves inwardly in the regions of said two principal cross-sectional axes.