July 18, 1967 H. L. VILKAITIS 3,331,400

FLEXIBLE WAVEGUIDE

Filed Jan. 22, 1964

FIG. 1

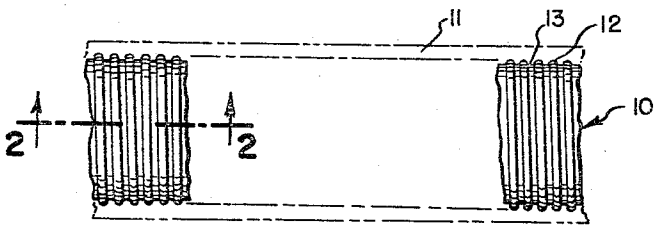


FIG. 2

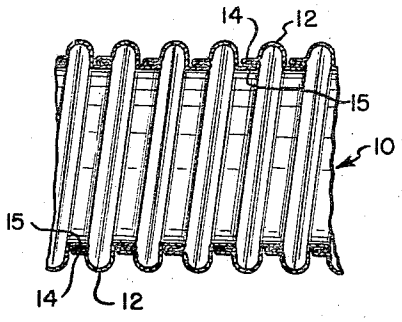


FIG. 3

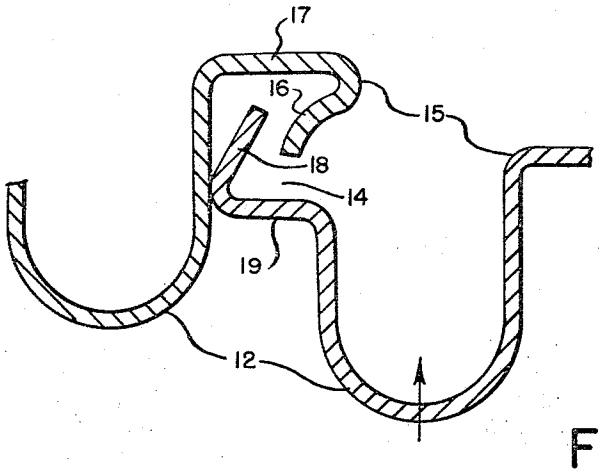


FIG. 5

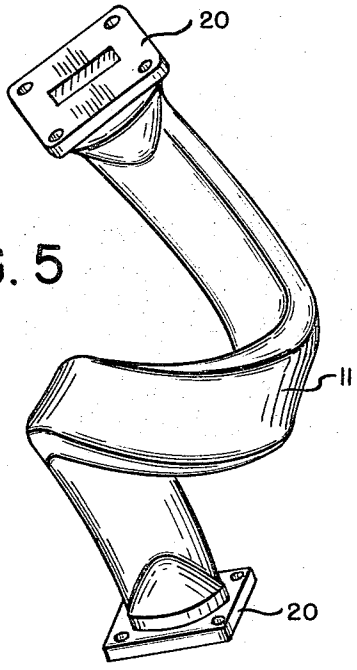
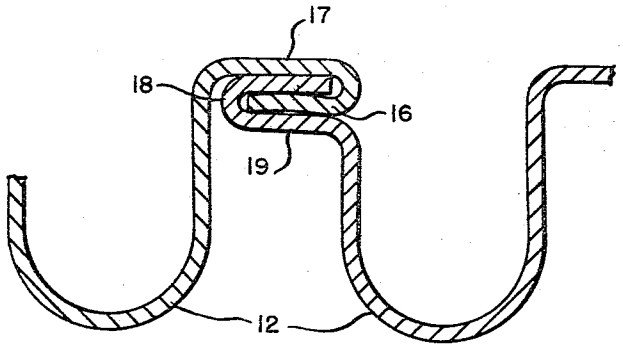


FIG. 4



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FLEXIBLE WAVEGUIDE

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This invention relates to flexible metal waveguides for the transmission of high-frequency electrical energy.

The increased use of radar and other microwave equipment in recent years has created a great need for highly flexible waveguide exhibiting both low losses and uniform electrical characteristics. In practice it is frequently desired to transmit energy from one piece of equipment to another where for mechanical reasons the transmission path cannot be a straight line and space limitations are such as to preclude a rigid waveguide connection.

Flexible waveguide of many types have or are presently being used. Among the many constructions known and used, the interlocking type is presently accepted as being one of the most versatile. This type of waveguide generally consists of a spirally wound strip of metal wherein the edge portions are folded and compressed during winding to form a continuous interlock joint having four parallel surfaces.

The flexibility exhibited by this form of waveguide is due to the relative movement of the interlocked edge portions. The degree of flexibility of a given section of waveguide is increased by increasing the distance within which the interlocked edge portions are free to slide.

Another well-known type of flexible waveguide is comprised of a series of convolutions. These convolutions may be formed circularly or spirally on the surface of a flexible metallic tube to form an integral unit or may be formed on a metallic strip that in turn is then spirally wound with its adjacent edges being interlocked.

However, as is well-known in the art, the attenuation and energy reflections in a particular waveguide increase as the uniformity and electrical conductivity of its inside surfaces decreases. Accordingly in the interlocked waveguide presently used, wherein flexibility is determined by the degree of freedom present in the interlock, the conducivity is dependent on the electrical contact maintained by the sliding edge portions of the interlock. During flexing, the point of contact in interlocked waveguide continuously changes thereby changing the attenuation per unit length. In addition, repeated flexure tends to reduce the effective contact area and correspondingly increases both the attenuation at a particular state of flexure and the variation thereof through the range of flexure.

The afore-mentioned integral convoluted waveguide exhibits generally uniform electrical characteristics and the amount by which it may be bent is dependent upon and limited by the height of the convolutions. However this structure is found to be generally unsuited for those applications wherein the waveguide must be twisted.

The convoluted waveguide with interlocked edge portions is presently wound so that the interlocks are located within the convolutions. This construction removes discontinuities from the inner surface of the waveguide to reduce the amount of reflected energy therein. However this type of waveguide requires a wire exerting sufficient force to close the interlock to be paid inside the waveguide during forming. In addition to the difficulty of manufacture, the thickness of the interlock results in a decrease in the effective depth of the convolutions thereby limiting the minimum bending radius.

The present invention is directed to a novel type of flexible waveguide which provides the electrical characteristics required for high efficiency operation while permitting a greater degree of flexure than that presently available with the afore-mentioned types of flexible waveguide.

This new flexible waveguide embodies certain features of both the interlocking and the convoluted type of construction but differs importantly in that the interlock is located between the convolutions adjacent the transmission path of the electrical energy. In addition, the interlock is formed with a crimped member therein to provide firm continuous electrical contact between adjacent edge portions throughout the range of flexure.

Also, the waveguide of the present invention exhibits mechanical characteristics exceeding those of presently known flexible waveguide. The convolutions formed are substantially independent of the dimensions of the crimped interlock thereby improving the minimum bending radius and the amount of twist per unit length.

Further features and advantages of the invention will be more readily apparent from the following description of a specific embodiment, as shown in the accompanying drawings, in which:

FIG. 1 is a side view of a portion of flexible waveguide with the outer covering removed;

FIG. 2 is an expanded sectional view taken along line 2—2 of FIG. 1;

FIG. 3 is a cross-section of an interlocked edge portion preparatory to forming;

FIG. 4 is a cross-section of a formed interlocked edge portion; and

FIG. 5 is the waveguide unit in a state of flexure.

Referring more particularly to FIGS. 1 and 2, flexible metal waveguide **10** is shown with outer covering **11**, indicated by dashed lines, removed.

The waveguide **10** is formed from a continuous spirally wound piece of metal having pre-formed convolutions **12** and flat portions **13**. Flat portions **13** comprise the interlocking edges and are more clearly shown in FIG. 2.

The cross-sectional view of FIG. 2 emphasizes the spirally wound construction of waveguide. As shown, the continuous strip of metal forming waveguide **10** has the flat portions adjacent convolution **12** folded inwardly of their respective edges to form interlocking edges **14** and **15**. Interlocking edges **14** and **15** engage one another in overlapping relationship so that the inner side of edge **15** comprises the uniform inner surface of the waveguide between convolutions.

FIG. 3 shows the position of adjacent interlocking edges **14** and **15** just prior to being interlocked. However, it is to be noted that the continuous strip of metal forming waveguide **10** prior to winding has inwardly extending lip **18** formed on edge **14** and a mating crimped portion **16** formed on edge **15**. The amount of crimp on portion **16** is advantageously predetermined so that it is substantially undisturbed during the winding operation.

During winding, the application of pressure to flange **19** of edge **14** forms the interlock as shown in FIG. 4. The pressure is dependent on the material and the amount of crimp present in portion **16** and is made sufficient to complete the seating of the interlock without unduly removing the crimp of portion **16**.

The actual winding operation advantageously takes place about a rectangular arbor or mandrel of standard waveguide size, but may be about any shape arbor according to the waveguide cross-section particularly desired. Flat portion **17** contacts and is supported by the winding arbor and, as mentioned previously, comprises that part of the interlock directly exposed to the electromagnetic energy contained in the waveguide.

The members adjacent to flat portion **17** are formed at right angles thereto, and since crimped portion **16** firmly contacts flange **19**, any discontinuities that would

otherwise appear on the inner surface of the waveguide are substantially eliminated.

As seen in FIG. 4, crimped portion **16** is securely held in the interlock and establishes electrical contact with its adjacent members, lip **18** and flange **19**, at three distinct points on the cross-section.

Since the interlock is formed at the base of convolutions **12**, said convolutions may be preformed to any particular desired height. The height of the interlock therefore does not materially affect the effective convolution height.

When waveguide **10** is subjected to a bending force in either the E or H plane dimensions, crimped portion **16** experiences no movement relative to its adjacent members **18** and **19**. Hence the same points and area of electrical contact are continuously maintained. The change in waveguide dimensions during bending is provided by convolution **12** and the individual dimensions of said convolutions effectively determine the minimum bending radii. However, as the crimped portion **16** insures continuous electrical contact and is subject to no relative movement, the waveguide characteristics are not materially altered by repeated bending.

During twisting of waveguide **10**, the large compressive and tensile forces of bending are no longer present and the amount of twist per unit length is substantially independent of the dimensions of convolution **12**. Accordingly, the construction of the interlock is such that crimped portion **16** is capable of moving relative to its adjacent members **18** and **19** in the direction of winding. This relative movement does not significantly change either the points or area of electrical contact therebetween, and hence does not substantially alter the waveguide characteristics.

When waveguide **10** is subjected to both bending and twisting forces, the convolution **12** expands and contracts in combination with the spiral movement of crimped portion **16** and provides a greater flexure range than that exhibited by flexible waveguide presently known in the art.

The following mechanical characteristics for a particular X-band embodiment of the invention indicate minimum bending radii of 1.25 and 2.25 inches in the E-plane and H-plane dimensions respectively and a twist of ±240 degrees per foot are easily attainable. The corresponding electrical characteristics showed an attenuation of 0.08 decibel per foot and a voltage standing-wave ratio (VSWR) of 1.08.

The improved electrical and mechanical properties are more readily apparent when taken in comparison with the characteristics of a similar size of the interlock flexible waveguide now used wherein the minimum bending radii were 3.37 and 7.50 inches, the maximum twist per foot was ±95 degrees, the attenuation was 0.10 decibel per foot and the VSWR was 1.15. The corresponding characteristics of convoluted waveguide having an interlock within the convolution show the minimum bending radii to be 1.37 and 2.25 inches, a maximum twist per foot of ±120 degrees, an attenuation of 0.15 decibel per foot and a VSWR of 1.10.

The above sample characteristics demonstrate the extreme flexibility of the invention and the corresponding improved electrical characteristics. FIG. 5 shows the complete waveguide unit while subjected to bending and twisting forces. As seen, mating flanges **20** are advantageously soldered to the ends of the wound strip. A flexible insulating jacket **11** surrounds waveguide **10** and may be of rubber or other suitable material to provide a flexible waveguide assembly suitable for use under varied environmental conditions.

The above discussion has described a single embodiment and it is understood that many changes in this embodiment may be made within the spirit and scope of the invention and that other embodiments utilizing the principles of the invention may be made.

I claim:

1. A flexible waveguide which comprises a strip of spirally wound material, said strip having a generally U-shaped cross-section with first and second flanges extending outwardly from the ends of the U, the outer end of said first flange forming a longitudinal recess thereon to receive the outer end of an adjacent second flange with the opening of said recess being positioned away from said adjacent second flange and the outer end of the second flange being formed to contain a lip extending into an adjacent recess with said lip having a crimp thereon to engage the walls of said adjacent recess for providing point contact, the first and second flanges forming a base interlock which defines the inner surface of the waveguide and which is located between the outwardly extending U-shaped strip.

2. A flexible waveguide which comprises a continuous strip of conducting material spirally wound about a mandrel of predetermined cross-section, said strip having a generally U-shaped cross-section with first and second outwardly extending flanges thereon, said first flange forming a longitudinal recess and said second flange having an interlocking lip formed thereon, with said interlocking lip having a crimp therein to frictionally engage the sides of said longitudinal recess and to provide point contact, the first and second flanges forming a base interlock which defines the inner surface of the waveguide and which is located between the outwardly extending U-shaped strip.

3. A flexible metal waveguide which comprises a continuous strip of conductive material, said strip having a generally U-shaped cross-section with first and second flanges outwardly extending therefrom, said first flange forming a longitudinal recess having an opening facing the center of said strip, and said second flange having a lip member for insertion in said recess, said lip member being curved to frictionally engage the upper and lower sides of said recess and to provide point contact, the first and second flanges forming a base interlock which defines the inner surface of the waveguide and which is located between the outwardly extending U-shaped strip.

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