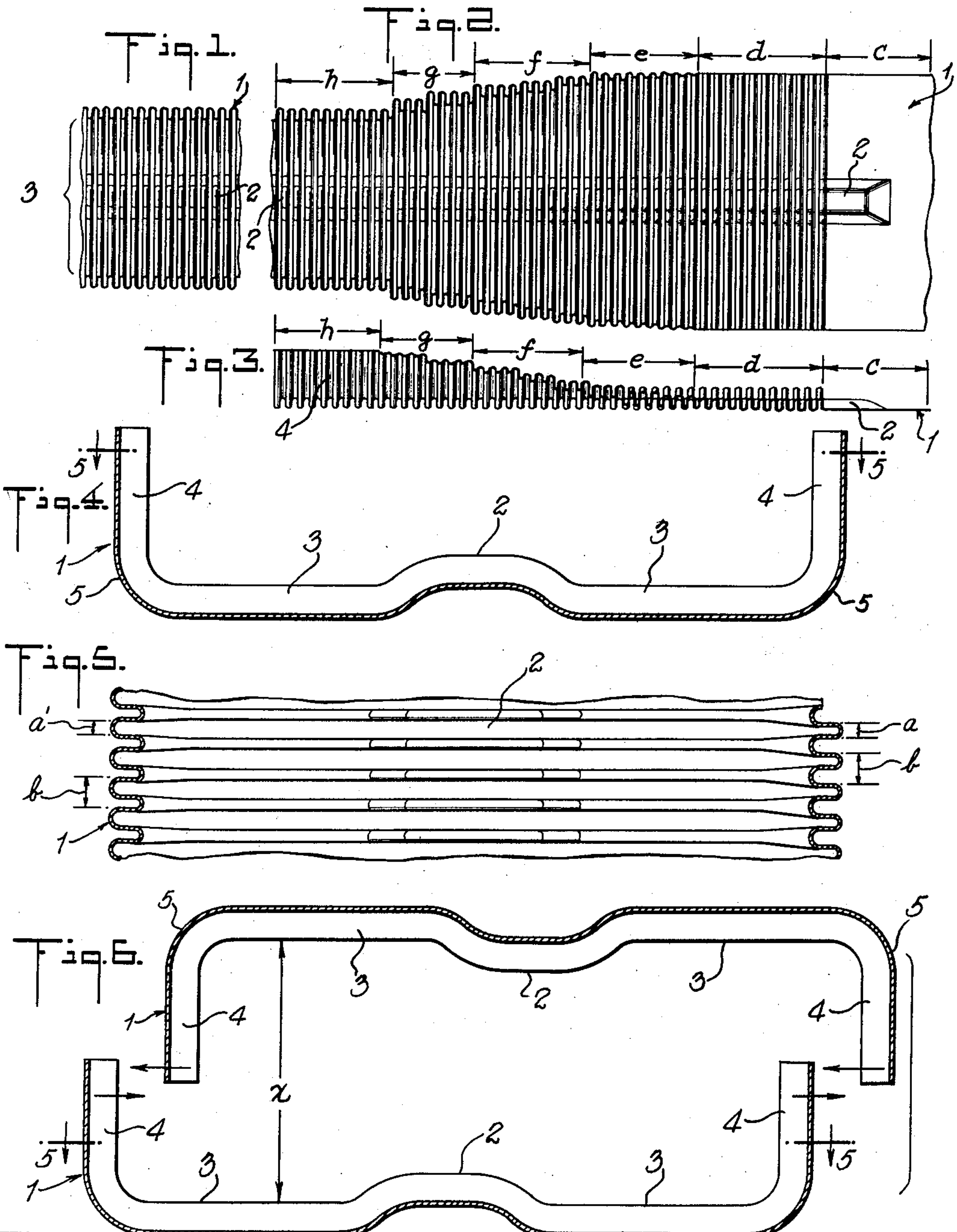
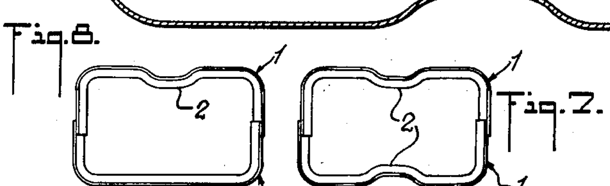
March 22, 1960 T. N. ANDERSON ET AL 2,930,007

FLEXIBLE WAVE-GUIDE TUBING

Filed May 13, 1955





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United States Patent Office 2,930,007
Patented Mar. 22, 1960

2,930,007

FLEXIBLE WAVE-GUIDE TUBING

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Application May 13, 1955, Serial No. 508,068

4 Claims. (Cl. 333—95)

This invention relates to flexible metal tubing useful as wave guides and, more particularly, to such tubing which is formed with transverse corrugations that give it flexibility and at least one longitudinally extending inner ridge that improves microwave propagation. Such tubing has various applications, but is especially useful for electrical wave propagation purposes, particularly as wave guides which interconnect microwave apparatus components.

For the purpose of conducting ultra-high frequency electrical energy, the highest degree of efficiency in conduction is achieved by employing a hollow metal conducting tube which is approximately oblong or rectangular in cross section. Such a conducting tube, if rigid, is not as well adapted as a flexible tube for use in microwave equipment, as a flexible tube can be flexed to establish connections between microwave components which may not be in alignment. Also, flexible tubing permits interconnection of components arranged according to compactness without slavish regard for connections. In such circumstances, a flexible wave guide of a given length may be used in various shapes, while each needed shape of rigid wave guide must be specially made to specific form and measurements. Therefore, flexible wave guides with transverse corrugations, as herein disclosed, provide substantial advantages over a rigid tube; and the relatively small loss in transmission efficiency of the electrical waves, due to the irregularities or corrugations of the inner walls of the wave guide, is more than offset by the advantages of flexibility.

This invention may readily be distinguished from that disclosed in the application of David Ingalls, Serial No. 402,693, which was filed January 7, 1954, now Patent No. 2,840,897, issued July 1, 1958, and assigned to the assignee of the present invention. The two inventions deal with flexible metal tubing, but the constructions are different and the methods of fabrication are different. An important improvement of the present invention resides in the provision of one or more re-entrant ridges in the wave guide as formed, this being for better microwave propagation. These ridges serve to broaden the band of frequencies which may be efficiently propagated.

Accordingly, an important object of this invention is to provide flexible tubing which is fabricated with at least one re-entrant ridge formation for the purpose of improving its microwave propagation characteristics when used as a wave guide.

Another object is to provide a flexible wave guide in which there are transverse corrugations formed with one or more re-entrant ridges, these ridges being so dimensioned and so disposed as to enable its use for the propagation of microwaves with greatly increased useful band width, but without increasing the overall dimensions of the tube itself.

Rigid wave guides having longitudinal ridges are not new, but it is believed that the combination, in a tubular, flexible wave guide, of transverse corrugations to give

flexiblity and one or more re-entrant longitudinal ridges to give broader band-width transmission, is new.

The electrical characteristics of ridged wave guides have heretofore been explained, as shown in the technical literature on this subject. Note particularly an article "Properties of Ridge Waveguide" by S. B. Cohn, Proceedings of Institute of Radio Engineers, August 1945, p. 783. Also, see "Waveguide Handbook," vol. 10, p. 399, by Marcuvitz, in the MIT Radiation Series, published by McGraw-Hill. These references are considered sufficient to render it unnecessary to explain herein the advantages of ridged wave guide construction.

A more detailed explanation of this invention will now be given, reference being had to the accompanying drawing, wherein:

Fig. 1 is a fragmentary top plan view of the outer side of a transversely corrugated and longitudinally ridged strip of relatively thin, bendable, conductive metal to be used in assembly with a mating strip to form a finished length of metal tubing having one or more, longitudinal re-entrant ridges, the said strip being generally U-shaped in transverse section.

Fig. 2 is a plan view of such a metal strip as it appears during the process of fabrication by progressive step-wise advancement through a series of forming dies.

Fig. 3 is a side elevational view of said strip as seen from the top of Fig. 2.

Fig. 4 is an enlarged, transverse sectional view of the strip shown in Fig. 1.

Fig. 5 is a fragmentary sectional view of the corrugated strip, substantially on the lines 5—5 of Figs. 4 and 6, showing certain relative dimensions of importance.

Fig. 6 is a transverse sectional view showing how two strips formed with transverse corrugations may be assembled with the folds of their corrugations in nesting inter-relationship.

Fig. 7 is a reduced-scale, cross-sectional view of the parts shown in Fig. 6, after said parts have been brought together in nesting interrelationship.

Fig. 8 is a view of the same character as Fig. 7, but illustrating a modified form of ridged, flexible tubing.

The raw material from which wave-guide tubing is fabricated, according to this invention, is a flat, thin strip 1 of bendable conductive metal of any desired length. This strip, preferably, is fed progressively through a series of reciprocating forming dies. Dies which would operate in a rolling process might be used, but the use of reciprocating dies has certain advantages, particularly in the bending of the strip material around corners so as to give it a U-shaped configuration. Therefore, the strip is advanced step-wise between pairs of such reciprocating dies and the feeding of the strip is automatically regulated so that the formation of the corrugations will be uniform and appear continuous. Fig. 1 shows in plan view the appearance of the U-shaped metal strip after its formation has been completed, that is, after it has passed through all of the dies.

It is a matter of tool design to provide a given number of corrugation formations at each stage. There may be possibly six or eight such corrugations in a pair of dies for each stage, but the actual number preferred may be more or less than that many. It is quite important, however, to space the successive stages of die sets so that the finished corrugations shall be similar. To assure such uniformity of the corrugations, successive strip portions, acted upon by the forming dies may overlap to a slight extent, if desired.

Figs. 2 and 3 show the appearance of a metal strip 1 during processing. The strip material progresses from right to left and from the first stage *c* through successive stages *d*, *e*, *f*, *g* and *h*. At stage *c* a re-entrant ridge 2 is formed. At stage *d* the corrugations are formed with uniform dimensioning completely across the strip, that is, from edge to edge of the latter. At stage e the outwardly extending folds are enlarged on one edge and reduced on the other edge as hereinafter more fully explained with reference to Fig. 5. At stage f a bending operation is started in order to turn both margins of the strip part way toward perpendicularity to the non-marginal or central part **3** is the strip. At stages g and h the marginal bending is carried further and to completion, so that side walls **4** of the U-shaped strip are formed substantially perpendicular to the central portion. During such bending, the corners are rounded as shown at **5**. Fig. 4 clearly shows the cross-sectional shape of the finished strip **1** as it issues from the forming dies. Incidentally, the series of dies are operated by synchronized strokes and the feeding of the material through them takes place when all the paired dies are open.

It has been stated above that at stage e the two edges of the outwardly extending folds are differently dimensioned, that is, at one edge they are enlarged and at the other edge they are reduced. These dimensional relationships are shown in Fig. 5, which is an enlarged cross section through the side walls of the completely formed corrugated strip **1**. The outer surfaces of the side walls of each outwardly extending corrugation at the right side of Fig. 5 are spaced apart by the distance a, and on the left side of this figure the inner surfaces of said walls of the same corrugation are spaced apart by the dimension a'. The two dimensions a and a' are about the same, and $a+a'=b$, where b represents the overall linear dimension along the strip between like outer surfaces of successive corrugations. This dimensioning of the corrugations has for its object to enable partially overlapping assembly of the two like strips **1** into a fully closed corrugated flexible tube, and to enable further processing in the form of soldering or brazing at overlapping portions.

In order that the folds of two mating strips may be assembled with their edges in overlapping relationship, or with an edge of one piece somewhat telescoped with respect to an edge of the other piece, the enlarged end portions of the folds of one piece must be brought into overlapping relationship to the reduced end portions of the folds of the other piece. The two pieces will then fit together with a satisfactory friction fit, thereby forming a two-piece tubing such as is shown in Fig. 7 in cross section. This method of assembly is shown in Fig. 6, where, in section, the upper piece is first displaced to the right side of the lower piece. Then the two pieces are brought together by relative side-to-side translational movement with the enlarged folds on the left side of the lower piece overlapping the reduced folds on the left side of the upper piece. Correspondingly, the reduced folds on the right side of the lower piece are nested within the enlarged folds on the right side of the upper piece.

A two-piece mandrel is found to be useful in assembling the two halves of the flexible tube, since it facilitates accurate and uniform degree of overlap of the mating edges. The two parts fo the mandrel may be slightly tapered and in superposed relationship, so that the small end of one part underlies and is opposed to the large end of the other part. The vertical dimension of the two mandrel parts, when assembled to function as a mandrel between the two U-shaped strips, should be the same as dimension X indicated on Fig. 6, and said mandrel parts should be longitudinally recessed to accommodate ridges **2** and to permit the hereinbefore described relative movement of the two U-shaped strips **1** while the mandrel remains in place.

After complete assembly of the mating pieces of the flexible tube, an endwise displacement of the two tapered mandrel portions, with respect to each other, will readily enable both portions to be dropped out of the tube.

Following the assembly process as above described, an operation of soldering or brazing the opposite side junctures is essential in order to secure the tube parts **1** together. This operational step, however, is not novel, but is conventional, and may be performed either before or after removal of the mandrel, if a mandrel has been employed.

It may be observed that corrugated ridged tubing, produced according to the above-described method and conforming to the tubing shown in cross section in Fig. 7, has its corrugations uniformly spaced linearly of the tubing, and each corrugation extends completely around the tube, there being a slight overlap at the two seams. The soldering or brazing does not appreciably impede flexibility. To all intents and purposes, therefore, this method of fabrication provides a finished product which is in no way inferior to a one-piece tube, the convolutions of which are conventionally spiral-wound. But it is not easy to conceive how a ridged wave guide, as shown herein, could be fabricated by the spiral winding process. It is not believed that such a process would be practical or even possible.

From the standpoint of maintaining satisfactory electrical characteristics in an improved flexible wave guide, the conducting tubing of which has one or more re-entrant ridges according to this invention, it is found that the seams at which the two mating portions are joined together do not appreciably impair its efficiency. This is possibly due to the fact that the corrugations continue across the junctures where they are overlapped, and these junctures do not cause undesirable reflections to any appreciable degree; also to the fact that the seams are located at the opposed narrower sides of the tube, which sides are relatively non-critical areas in the transmission of energy through the tube. Furthermore, the tubing is so fabricated that it can be flexed either in a longitudinal plane parallel with the broader sides of the wave guide, or in a longitudinal plane perpendicular to said broader sides. This flexibility enables convenient installation of wave guides, so fabricated, as conductors of electrical energy between components of a microwave system. The tubing itself, however, may be useful for purposes other than in flexible wave guides.

After producing the ridged flexible tubing in the manner above described, this tubing, when intended for use as a wave guide and possibly for other uses, is preferably protectively jacketed with relatively soft, rubber or rubber-like insulating material, bonded as by molding or otherwise about the metal tube.

For certain applications of my invention, it may be desired that the corrugated flexible tubing shall be formed with unlike mating portions, only one of which would be formed with a re-entrant ridge as shown in Fig. 8. In making such tubing, the forming dies to be used for producing one of the mating strips must, of course, be different from the dies used for producing the other of the mating strips. The method, in other respects, would be as hereinbefore described. In all cases of utilization of such a ridged flexible wave guide for the propagation of microwave energy, it will be appreciated by those skilled in the art that the re-entrant ridge, extending linearly of the tube, provides an extended range of band-width for efficient transmission of waves of different frequencies. The advantages of this construction will, therefore, be apparent.

It should be obvious that the inventive concept, disclosed herein, may be employed in various other ways without, however, departing from the invention as set forth in the following claims.

We claim:

1. Flexible, metal, wave-guide tubing of generally rectangular shape in cross section, comprising opposed, U-shaped, elongate parts, joined along their edges to constitute a tube, said parts having transverse corrugations, inter-nesting at said junctures; each of said corrugations extending continuously about said tube, and one of said parts having an inner corrugated ridge extending longitudinally thereof midway between said one part's edges.

2. Flexible, metal, wave-guide tubing of generally rectangular shape in cross section, comprising opposed, U-shaped, elongate parts, joined along their edges to constitute a tube, said parts having transverse corrugations, inter-nesting at said junctures; each of said corrugations extending continuously about said tube, and each of said parts having an inner corrugated ridge extending longitudinally thereof midway between said part's edges.

3. Flexible, metal, wave-guide tubing of generally rectangular shape in cross section having two opposite sides of greater width than the other two opposite sides of the tubing, all said sides having transverse corrugations rendering the tubing flexible, and each of said sides of greater width having an inner ridge extending longitudinally and centrally thereof; said ridges being spaced from each other having transverse corrugations continuous with the transverse corrugations of the sides of said tubing, said ridges and the corrugations thereof imparting a transverse rigidity to each of said sides of greater width to maintain substantially constant the cross-sectional configuration and area of said tubing when said tubing is flexed by a force applied normal to the axis thereof.

4. Flexible, metal, waveguide tubing of generally rectangular shape in cross section having two opposite sides of greater width than the other two opposite sides of the tubing, all said sides having transverse corrugations rendering the tubing flexible and one of the sides of greater width having a substantially rectangular inner ridge extending longitudinally and centrally thereof, said ridge having transverse corrugations continuous with the transverse corrugations of the sides of said tubing, said ridge and the corrugations thereof imparting a transverse rigidity to said one side to maintain substantially constant the cross-sectional configuration and area of said tubing when said tubing is flexed by a force applied normal to the axis thereof.

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