July 30, 1957 D. INGALLS ET AL 2,800,705

METHOD FOR MAKING TWISTED FLEXIBLE WAVE GUIDES

Original Filed April 8, 1950 2 Sheets-Sheet 1

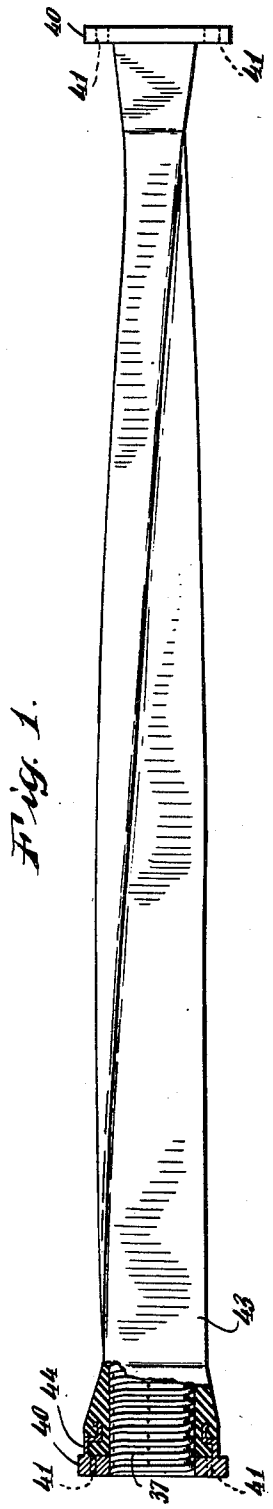


Fig. 1.

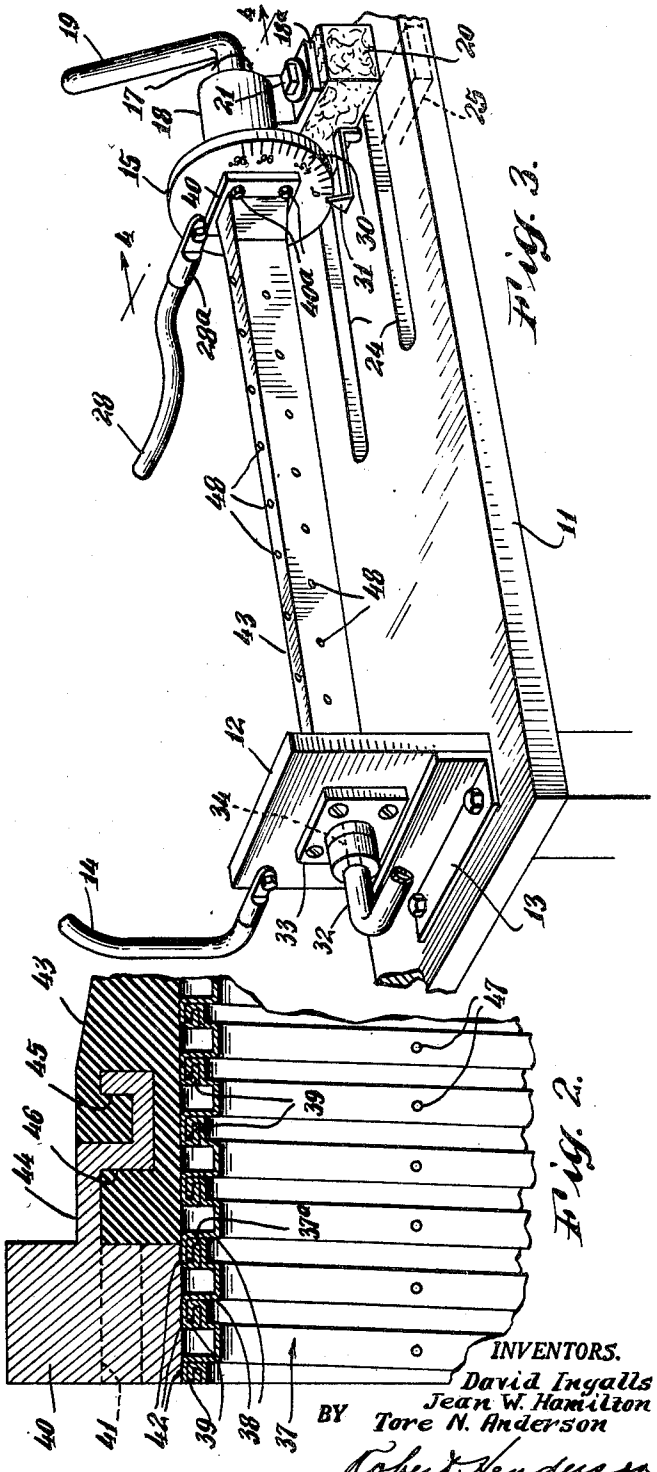


Fig. 3.



Fig. 2.

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Fig. 5.

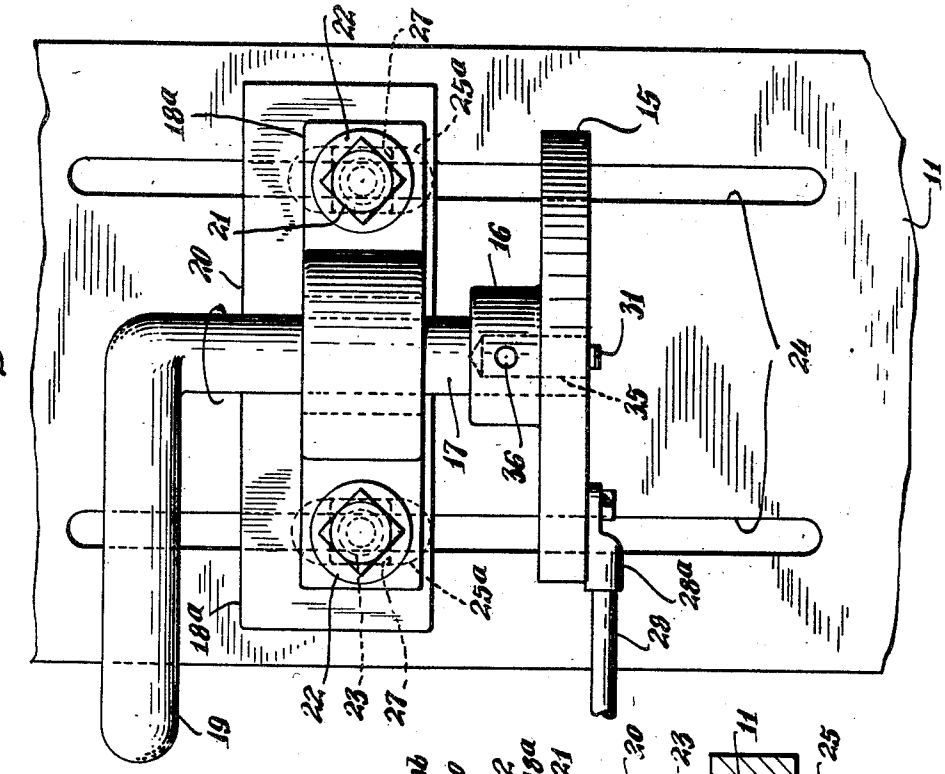
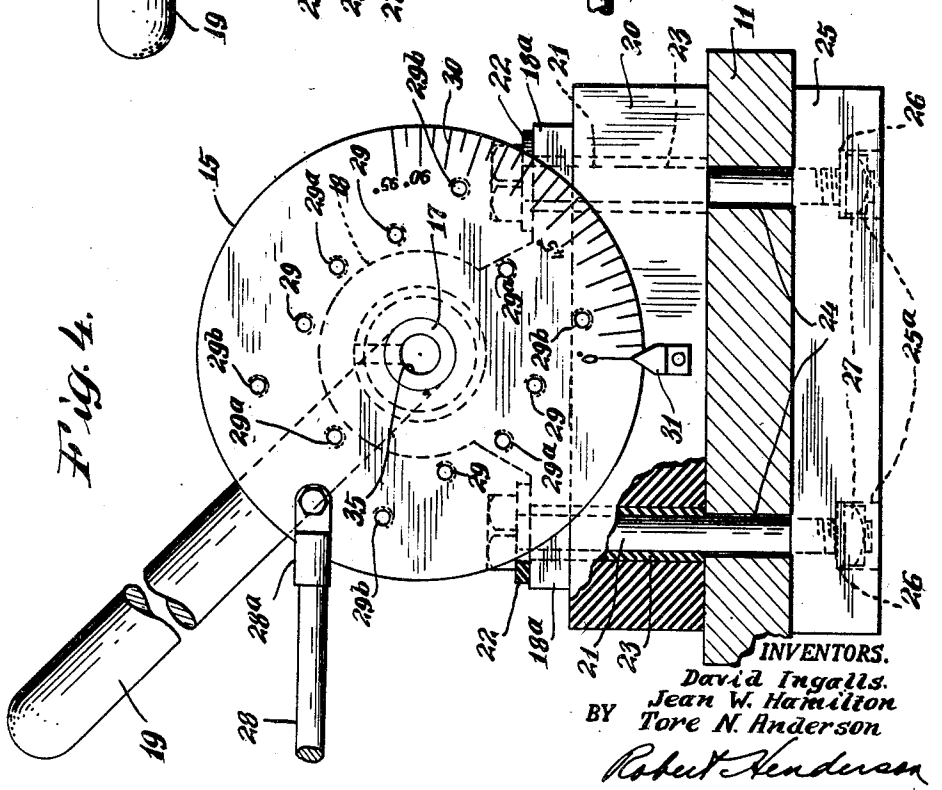


Fig. 4.



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# METHOD FOR MAKING TWISTED FLEXIBLE WAVE GUIDES

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7 Claims. (Cl. 29—155.5)

This application is a division of copending application filed by us under date of April 8, 1950, and under Serial No. 154,796, now abandoned, and is being filed pursuant to a requirement for division made by the examiner and sustained by the examiner of classification during the prosecution of said application.

This invention relates to novel methods for making flexible wave guides such as are employed to transmit microwaves between various components of radar apparatus and television or other electrical equipment.

Wave guides have been made flexible principally to enable them to be bent to facilitate their installation in the equipment of which they form an electrical impulse conducting part. One form of flexible wave guide, which has been found in practice to be highly efficient conductively and in other respects, includes a conducting core of generally rectangular cross-section which is formed by winding thin, strip, conducting metal spirally on a rectangular mandrel, the strip being ridged longitudinally to form transversely extending convolutions in the core so that it may be bent to facilitate its installation. The edges of the strip are soldered to enhance the conductivity of the wave guide, but this limits the flexing of the wave guide to bending thereof and excludes the possibility of twisting it. Such wave guides are usually made in straight or untwisted form, but in some installations a twisted wave guide may be very useful in establishing a desired connection.

An important object of the present invention is the provision of simple and effective methods by which such twisted, flexible wave guides may be manufactured.

The foregoing and other objects are accomplished by the present invention which, for illustrative purposes, is shown in some particularity in the accompanying drawings without, however, limiting the invention to such particular illustrated structures.

In the drawings:

Figure 1 is a side elevation of a twisted flexible wave guide, manufactured according to the present invention, one end of the wave guide being cut away to show a portion of it in transverse section.

Fig. 2 is a greatly enlarged fragmentary view of the upper portion of the wave guide shown in section in Fig. 1.

Fig. 3 is a perspective view of apparatus, according to this invention, for converting a non-twisted wave guide into the form of a twisted wave guide; this apparatus also being suitable for practicing the method hereinafter described as a part of the present invention.

Fig. 4 is a vertical sectional view of the waveguide twisting apparatus on the line 4—4 of Fig. 3.

Fig. 5 is a top plan view of the right end of the apparatus shown in Fig. 3.

Wave-guide twisting apparatus according to the present invention may be of various designs, but Figs. 3–5, inclusive, of the drawings illustrate a preferred embodiment of twisting apparatus within the invention.



In the illustrative embodiment shown in the drawings, a rectangular base plate **11** has a metal end plate **12** fixed upon one end thereof in upright position by any suitable means, as, for example, by an angle bracket **13**; and the plate **12** is connected by an electrically conductive cable **14** in a relatively low voltage electric circuit of high amperage.

Toward the other end of the base plate a metal, rotatable end plate **15** is mounted thereon in a vertical position extending in a plane parallel to the plane of the opposite end plate **12**. The plate **15** has a coaxial cylindrical extension **16** fixed at its outer end and the said extension, in turn, has fixed thereto a coaxial shaft **17** extending horizontally through a bearing **18** whereby to be supported in the latter for rotation. The shaft **17** is provided at its outer end with a handle which may be in the form of an operating lever **19** by which the shaft and its integrally associated parts, particularly the plate **15**, may be rotated.

The bearing **18** is supported upon a block **20** of suitable insulating material, as, for example, Micarta or the like. The block **20** rests upon the top of the base plate **11**, and the bearing **18** and said block are fastened down upon the base plate by headed bolts **21** which, by means of insulating washers **22** and cylindrical insulating sleeves **23**, are effectively insulated from the bearing **18**. The bolts **21** extend downwardly through suitable bolt holes in mounting lugs **18***a* of the bearing, and in the block **20**, thence through longitudinal slots **24** formed in the base plate **11** and through suitable bolt holes in a clamping crosspiece **25** engaging the underside of the base plate **11**; and washers **26** and nuts **27**, the latter of which are threaded onto the lower ends of the bolts **21**, serve to hold the several mentioned parts in assembled relation upon the base plate. The nuts **27** may advantageously be square and seat witihn elongate bottom recesses **25***a* in the crosspiece **25**; the said recesses, preferably, being narrower than the diagonal dimension of the nuts **27** and wider than the latter's side-to-side dimension so that the nuts cannot turn materially in said recesses.

By loosening the bolte **21**, the block **20** and the rotatable plate assembly which it carries may be shifted longitudinally of the base plate **11** so that the apparatus can be adjusted for twisting wave guides of different lengths.

A flexible, electrically conductive cable **28** is suitably bolted at its connecting lug **28***a* to the end plate **15**, and serves as a means of connecting the latter in the previously mentioned low voltage-high amperage electrical circuit. As the plate **15**, in normal operation of the device, need never be rotated more than approximately 95°, the cable **28** preferably is sufficiently flexible and possessed of sufficient freedom of movement as not to materially oppose rotation of the plate **15**. In addition, the lug **28***a* may be pivotally connected to the plate **15**, if desired, thereby enhancing the freedom of rotation of the latter.

As best seen in Fig. 4, the plate **15** is provided with plural sets **29**, **29***a* and **29***b* of threaded holes to enable wave-guide connection flanges of various sizes and bolthole arrangements to be bolted to said plate. Although the opposed side of plate **12** is not visible, nevertheless, that side of plate **12** is similarly provided with plural sets of such threaded holes. Also, although not an essential feature of the invention, the plate **15** may advantageously be provided with graduation marks **30** with suitable indicia applied thereto indicating up to about 95° rotation of the plate; and a pointer **31**, suitably fixed to the block **20**, may have an indicating portion thereof overlying the graduation marks **30**.

Another advantageous feature of this device, but one which, nevertheless, may be omitted while still utilizing

a substantial phase of the present inventive concept, resides in means by which a cooling fluid, preferably air or carbon dioxide, may be introduced into a twisted wave guide in the apparatus in order to cool it immediately upon the completion of the forming of the twist therein. Such means may comprise a pipe or tube **32**, suitably connected, for example, to a source of compressed air, and connected by a flange **33** to the plate **12** in alignment with a bore **34** in the latter through which compressed air may be introduced from said pipe onto the interior of a wave guide bolted to the plate **12**. As best seen from Figs. 4 and 5, the plate **15** may also be formed with a bore **35** which extends coaxially through the plate **15** and into the cylindrical extension **16**; and an open radial bore **36**, formed in the latter and communicating at its inner end with the bore **35**, may be provided to serve as a discharge passage for carrying off, to free air, the compressed air introduced into the wave guide for cooling purposes. If a liquid, such as water, is used as a cooling medium, suitable flexible piping or tubing should be connected to the discharge end of the bore **36** to carry off the liquid to a suitable container or to waste.

Although the apparatus hereinbefore described is suitable for twisting wave guides of various types, nevertheless, one type of wave guide which may be twisted by this machine is illustrated in Figs. 1, 2 and 3 of the drawings. The wave guide includes a flexible, electrically-conductive core **37** which is formed by winding longitudinally-grooved, thin, flexible metal strip, upon a mandrel of rectangular cross-section, in such fashion that adjacent edges of successive turns of the strip material enter into interlocking relationship as at **37***a* and are rolled down at such interlocking edges as the strip is spirally wound upon the mandrel; and the mentioned longitudinal grooves are such that the metal core is spirally convoluted as indicated at **38**. As the strip material is wound upon the mandrel to form the core, a thread of solder and suitable soldering flux is also wound with the strip and melted so that the spiral seam joining adjacent turns of the strip includes such bonding solder as at **39**, as a means of sealing and strengthening the seam and enhancing the electrical conductivity of the core. Because of the fact that the core is of thin material and is convoluted as described, it may be bent, but because the spiral seam is soldered, the core cannot be twisted.

As such flexible wave guides may be most economically made in straight or untwisted form, a wave guide is first made with a straight or untwisted core **37**. Connecting flanges **40** preferably are soldered upon the ends of the core as at **42**, the solder preferably extending completely around the core in order to provide an air-tight connection between the core and the flanges. Then, a jacket **43** of flexible rubber, synthetic rubber, or other suitable moldable rubber-like material, is molded upon the core to completely envelop the latter and to extend into a firm bonding engagement with axial extensions **44** of the flanges **40**. The flanges **40**, and particularly their extensions **44**, are preferably treated with a suitable bonding composition such as bonding rubber or other suitable adhesive, or the flange and its extension may be otherwise treated for the purpose of assuring a firm bonding of the jacket material with the flanges **40** and their extensions **44**. It has been found advantageous also to form the extension **44** with an outer peripheral groove **45** and/or an inner peripheral groove **46**, into which groove or grooves the jacket material will flow and become firmly bonded during its molding to form air-tight connections thereat between the flanges and the jacket.

When the wave guide is made with the expectation that it may carry air therein under considerable pressure to enhance its conductive qualities, some or all of the convolutions of the core **37** may have apertures **47** formed therein so that the compressed air will not deform the core by bulging it outwardly, but instead the air will find its way through the openings **47** to the area between the core and the jacket **43** so that the air pressure imposed upon the inner surface of the core will be substantially balanced by the pressure of the air on the outer surface thereof. Under this arrangement, the jacket **43** functions as the means for containing the air pressure.

Let us now assume that we have a flexible wave guide of the character just described in its untwisted form, in which the solder **39** has previously been heated and then permitted to cool to effect soldering of the core in the manner already described, and that it is desired to twist that wave guide so that the opposite end flanges **40** thereof are disposed at an angle of about 90° relatively to each other when the wave guide is in its unflexed or unbent condition. In order to use the described apparatus for such twisting, the bolts **21** are loosened, permitting the block **20** with all the structure which it supports to be adjusted along the slots **24** to such a position that the opposing faces of the plates **12** and **15** are spaced apart preferably slightly more than the normal length of the wave guide to be twisted. The block **20** is then locked in its mentioned adjusted position by tightening the bolts **21**.

The untwisted wave guide is then fastened in place by bolting one end flange **40** to the inner face of plate **12** and its other flange **40** to the inner face of plate **15**. This is accomplished by the use of machine bolts **40***a* or equivalent bolts, pegs, studs or the like, which may be passed through bolt holes **41** in the flanges **40** and threaded into the threaded holes **29**, constituting a set of such holes which correspond to the holes **41** in the flanges of the wave guide. The tightening of the machine bolts **40***a* will have the effect of slightly stretching the wave guide.

After the wave guide has thus been fastened to the plates **12** and **15**, the electric circuit, including the cables **14** and **28** and the plates **12** and **15** and now including the core **37** of the wave guide, is closed by suitable switch means (not shown), thereby establishing an electric potential between the plates **12** and **15** of about five or six volts and a current flow through the core **37** which should be of about 150 to 200 amperes if the wave guide is of relatively small cross-section or of considerably greater amperage if the wave guide is of relatively large cross-section. Upon closing of the described electric circuit, the operator may manually urge, but not force, the handle **19** in a direction (indicated by directional arrows) which would cause twisting of the wave guide such as would tend slightly to unwind the several convolutions of its core.

The twisting, however, cannot take place until the solder **39** at the spiral seam of the core becomes softened after a relatively short duration of flow of the electric current. As soon as such softening occurs, the handle **19** will yield to the pressure being applied thereto by the operator, whereupon the operator further manipulates the handle to rotate the plate **15** to an extent several degrees greater than the twist desired to be imposed upon the wave guide. In this manipulation, the operator may be guided by the position of the graduation marks **30** in relation to the pointer **31**.

As soon as the softening of the solder takes place, also, the operator opens the described electric circuit, but the heat generated by the electric circuit through the core **37** is sustained for a sufficient time to permit completion of the twisting of the wave guide. After the desired twist has been given to the wave guide, the operator holds the handle **19** in its turned position, to hold the twist until the solder has cooled sufficiently to reharden within the spiral seam of the core and thereby render the twist permanent.

The rubber or rubber-like jacket material may possibly be more or less harmed if the solder softening heat is sustained for too long a period of time, although, ordinarily, the danger of this is not very great and the harm would not be serious. Nevertheless, to avoid this danger and assure a high quality product, it may be of

some advantage for the operator to introduce a quenching or cooling medium such as compressed air into the interior of the wave guide by opening a suitable valve (not shown) in the pipe or tubing **32** as soon as the wave guide has been given its desired twist. The radial bore **36** and possibly also the bore **35** may preferably be of smaller diameter than the bore **34**, thus offering some resistance to the passage of air from the interior of the wave guide during the cooling part of the process. The compressed air accelerates the rehardening of the solder and shortens the period during which the heat is maintained in the core **37**, thereby speeding up the operation of the apparatus and minimizing the possibility of damage to the jacket **43**.

The operator, while holding the handle **19** in the position to which it has been rotated to give the wave guide the desired twist, can know when the solder has rehardened by noting when the handle no longer reflects any tendency of the wave guide to return to its untwisted condition. After rehardening of the solder has occurred, the handle **19** may be released and the machine bolts **40***a* removed, whereafter the wave guide in its permanently twisted form may be removed from the device. Then, the handle **19** may be turned back to bring the zero graduation mark on the plate **15** back into register with the pointer **31**. In this position of the plate **15**, the several sets of threaded holes **29**, **29***a*, **29***b* therein are directly opposite to corresponding holes in plate **12**, so that the two said plates are positioned to receive another straight wave guide for twisting.

It will be perceived that, when the core **37** is heated interiorly for softening the solder by means such as, for example, the electrical heating means hereinbefore described, it is entirely feasible to employ the described means for quenching or cooling the wave guide. In contrast, if obvious means such as an oven arrangement were employed for heating the wave guide to soften the solder, it would be very difficult, to say the least, and probably impossible, to quench or cool the wave guide in such manner as to prevent material damage to the rubber-like jacket. In any event, any use of oven heating or like means would necessarily involve handling of the wave guide after heating and before quenching or cooling. Such extra handling is unnecessary with the present invention.

The heat communicated from the core **37** to the jacket **43**, during the described twisting process, may cause the jacket material to throw off gas. The volume of gas thus generated, ordinarily, would be of relatively small volume; yet that which is thrown off at the inside of the jacket might cause a slight temporary bulging of the latter. However, upon dissipation of the heat, the gases within the jacket may to some extent re-enter the jacket material or may gradually leak away. Any remaining gases would be of relatively small volume and would not have any material effect upon the finished wave guide or its functions. Of course, if the core of the wave guide were provided with the apertures **47**, the generated gas would escape inwardly through such apertures and out of the ends of the wave guide to free air. However, if such apertures are not provided in the core and if it is desired to provide a positive avenue of escape for such gas, vents or perforations **48** may be formed in the jacket of the wave guide before the latter is heated and twisted. If the finished twisted wave guide is to be used as a pressurized wave guide, the apertures **48** may be filled, after the escape of gas from the wave guide, by vulcanizing or bonding into the latter apertures a composition similar to that of which the jacket **43** is formed or some other impervious resilient composition which will form a good bond with the jacket material so that the fillings of the apertures **48** will not become dislodged.

Although the fundamental features and certain desirable supplemental features of the wave-guide twisting apparatus according to this invention have been hereinbefore described, nevertheless, certain further refinements or variations of that apparatus may be included if desired. For example, a torque spring could be associated with the handle **19** in a coaxial position relatively to the shaft **17** to impose a torque upon said handle during the passage of heating current through the core. The effect of using such a spring would be that, immediately upon softening of the solder, the torque spring would automatically turn the handle **19** angularly to give the desired twist to the wave guide, suitable means being employed, of course, to limit the angular rotation of the plate **15** to approximately the number of degrees desired in the twist. Also, the handle **19** could be associated with electrical switch means controlling the described heating circuit that, immediately upon said handle turning to twist the wave guide, when the solder softens, the handle would operate the switch means to open the electric circuit. The handle could also be associated with suitable valve means for opening the latter to inject the compressed air or other cooling medium into the wave guide.

Other means than those hereinbefore described can be employed for heating the solder to soften it. Thus, electric induction heating may be employed, or the apparatus may be connected by suitable ducts to a source of highly heated air for softening the solder. Regardless of what particular heating means are employed, the heat developed, preferably, should be precisely controlled so that it is transmitted to the core only sufficiently to soften the solder.

Under certain heating conditions, the solder may have a tendency to flow inwardly, thereby leaving undesirable solder deposits on the inner surface of the wave guide and possibly tending to weaken the spiral seam of the core **37**. To overcome this tendency, the apparatus may be so designed and driven, if desired, that plates **12** and **15** with a wave guide held therebetween, in its twisted condition, may be held in their twisting relationship and, while thus held, may be rotated rapidly in unison while the core is heated; the centrifugal force developed by such rotation adequately opposing any such tendency of the solder to flow inwardly.

Where a desired twisted wave guide is not required to have the described jacket, the solder at the seam need not necessarily be heated and allowed to set while the core is in its straight or untwisted form. In that situation, the straight, unjacketed wave guide may be twisted and held in its twisted form in the manner hereinbefore described, and, while it is thus held, the solder may be heated and softened for the first time and then be permitted to cool and harden to render the twist permanent.

The references herein to several possible variations of this invention have been made to afford a thorough understanding thereof without intending to limit the invention to those variations. Obviously, the present inventive concept may be utilized in various other ways than those hereinbefore described or mentioned, without departing from the invention as set forth in the following claims.

What we claim is:

1. A method of making a twisted, flexible wave guide comprising the steps of forming a conductive core by spirally winding, on a mandrel of oblong cross-section, a strip of relatively thin, flexible, electrically-conductive material, with adjacent turns of the strip in seaming engagement, and, at the same time, associating bonding material with said seam, removing said core from the mandrel, twisting said core and holding it twisted, and, while it is thus held, effecting a physical change in said bonding material to condition it to effect a bond at said seam and thereby hold the core in its twisted condition.

2. A method of making a twisted, flexible wave guide from a straight, flexible wave guide having a hollow, cross-sectionally oblong, internally unsupported conductive core of spirally wound conductive metal the turns of which are joined by a spiral, soldered seam, the said

method comprising heating the solder to soften it at the spiral seam, twisting the core and holding it twisted, and permitting the solder to cool and harden while the core is thus held.

3. A method of making a twisted, flexible wave guide according to claim 2, further characterized in that the wave guide is rotated rapidly about its longitudinal axis while it is thus held twisted and while the solder is soft in order to oppose inward flow of the soft solder.

4. A method of making a twisted, flexible wave guide comprising the steps of forming a conductive core by spirally winding a strip of longitudinally-ridged, relatively thin, flexible, electrically-conductive metal, on a mandrel of oblong cross-section, with adjacent turns of the strip in seaming engagement, soldering said seam, applying a flexible jacket about the core, heating the core by means effective interiorly of the jacket to heat and soften the solder, twisting the jacketed core while maintaining the solder in its heated, softened condition, and holding the core twisted and permitting the solder to cool and set while the core is thus held; the method further including the step of removing the conductive core from the mandrel prior to said twisting of the core.

5. A method of making a twisted, flexible wave guide comprising the steps of forming a conductive core by spirally winding a strip of longitudinally-ridged, relatively thin, flexible, electrically-conductive metal, on a mandrel of oblong cross-section, with adjacent turns of the strip in seaming engagement, applying solder to said seam, applying a flexible jacket about the core, heating the solder



to soften it, twisting the jacketed core while the solder is soft and holding it twisted, and permitting the solder to cool and set while the core is held twisted; the method further including the step of removing the conductive core from the mandrel prior to said twisting of the core.

6. A method of making a twisted, flexible wave guide according to claim 5, further comprising perforating the core to permit escape of gases from the jacket material.

7. A method of making a twisted, flexible wave guide according to claim 6, further comprising plugging the perforations after setting of the solder to prevent further escape of fluid from within the jacket.

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