Oct. 5, 1965 R. S. WASHECKA 3,210,695

WAVEGUIDE ASSEMBLED FROM FOUR THIN SHEETS AND STRENGTHENED BY EXTERNAL REINFORCEMENT, AND ITS METHOD OF MANUFACTURE

Filed Dec. 5, 1960 2 Sheets-Sheet 1

Fig. 1

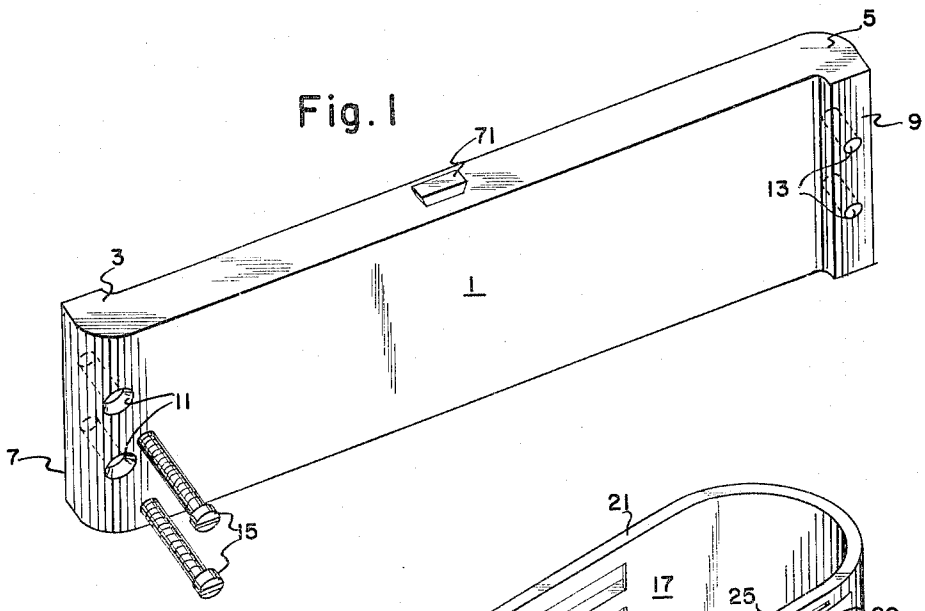


Fig. 2A

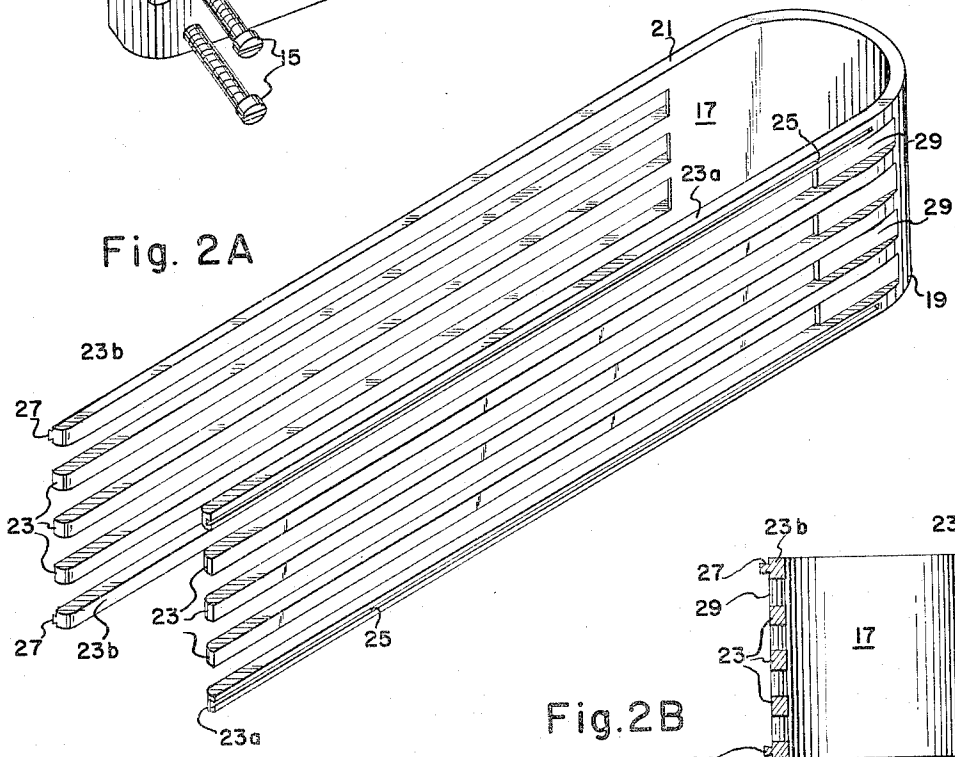


Fig. 2B

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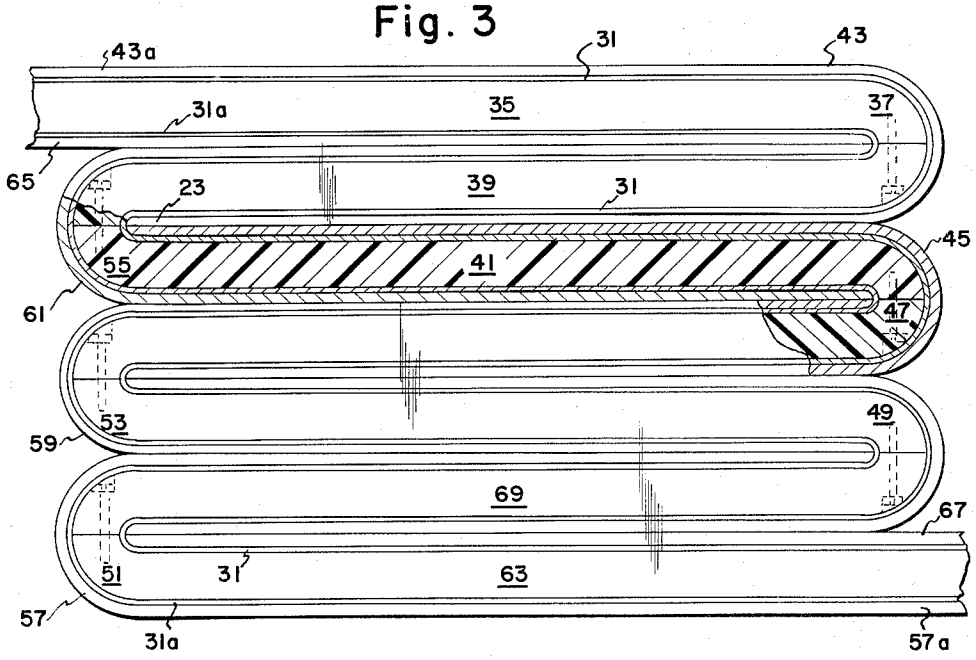
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Fig. 3



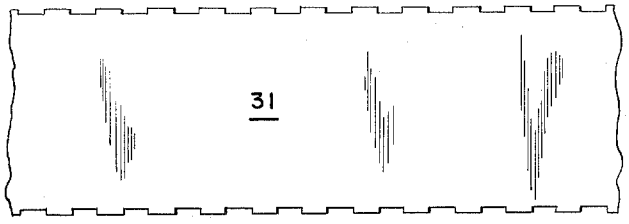


Fig. 4 A

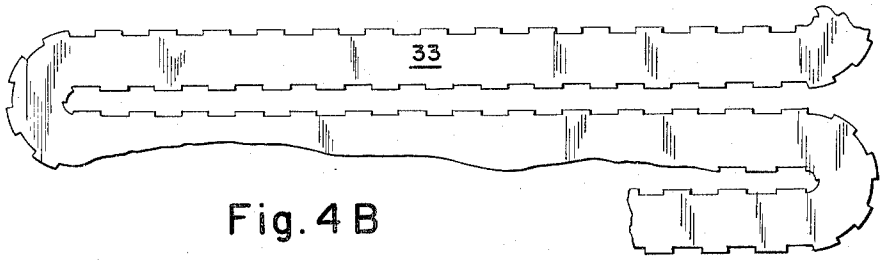


Fig. 4 B

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WAVEGUIDE ASSEMBLED FROM FOUR THIN SHEETS AND STRENGTHENED BY EXTERNAL REINFORCEMENT, AND ITS METHOD OF MANUFACTURE

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4 Claims. (Cl. 333—31)

This invention relates to waveguides and, more specifically, to a method of manufacturing waveguide sections of light weight.

Heretofore, extrusion processes have been generally employed in the manufacturing of waveguide sections. Due to (1) the difficulty and, also, the objectionable cost of extruding a very thin-walled hollow structure and (2) the necessity of providing sufficient rigidity to a waveguide section, the wall thicknesses of waveguide sections have been excessive. The excessive thickness of the walls of a waveguide section adds nothing to the electrical properties thereof but, rather, results in numerous disadvantages. These disadvantages are directly attributable to the weight of the individual waveguide sections. For example, in microwave systems wherein dipole antenna arrays are employed, the large combined weight of the numerous components of such arrays, including waveguide plumbing, is always unattractive; in some instances, it may preclude the use of the dipole array. Even where an antenna dipole array is employed as a ground installation, the weight disadvantage may be serious in view of the added difficulty of transporting the antenna and installing it at remote locations and, also, the increase in requirements for strength of the supporting structure and the motive power for varying the azimuth and/or elevation of the antenna. And the weight disadvantage might be such as to preclude the advantageous use of the antenna on other than the largest types ships and aircrafts, either of the military or commercial types.

This invention is directed, therefore, to overcoming these weight disadvantages through a practical manufacturing method whereby particular components of such microwave systems, i.e., waveguide sections or plumbing, are of light weight and can be manufactured at a substantially reduced cost. The resulting benefits are numerous. For example, the reduction in weight of waveguide section components allows for a substantial reduction in transportation costs from the manufacturing location to the assembly location, greater ease in handling of the individual waveguide sections during the assembly process, a reduction in the cost and complexity of the mounting on which the assembled antenna dipole array is to be supported and rotated, etc.

This invention contemplates a manufacturing method whereby a waveguide section, which may have a serpentine or other tortuous conformation, is manufactured of thin-rolled metal sheets of conductive material in lieu of extruded materials. The metal sheets so provided are cut in precise form to constitute the narrow and wide walls, respectively, of the waveguide section. The metal sheets constituting, for example, the wide walls of the waveguide section are cut to form flexible strips; the metal sheets constituting the narrow walls of the waveguide section are cut in accordance with the contour of the desired waveguide section. The metal strips constituting the wide walls of the waveguide section are rigidly held against the opposite faces of an inner form by means of U-shaped clips to form the contour of the desired waveguide section. Thereupon, one of the metal sheets constituting one narrow wall of the waveguide section is placed in position and dip-brazed to the aforementioned wide walls to provide joints of proper electrical conductivity. Lightweight material, e.g. polyurethane foam, is then injected into recesses in the U-shaped clips exterior to the wide walls between loops of the waveguide section to provide structural rigidity. When the injected material has set, the inner form is removed and the other of the metal sheets constituting a narrow wall of the waveguide section is positioned and dip-brazed whereby a hollow waveguide section results. The remaining U-shaped clip is thereupon removed.

A waveguide section of precise assembly results wherein structural rigidity is provided by the lightweight material sandwiched between the loops of the waveguide section and, also, the metal sheets constituting one pair of walls which effectively overcome the resiliency of the metal strips constituting the other pair of walls of such section. Further structural rigidity, if required, may be provided the waveguide section by additional laminations on either side of the sandwiched material.

This invention recognizes that the fields inside a waveguide section induce currents that flow on the inner surface of the walls in accordance with the well-known laws of skin effect, i.e. the depth of penetration is inversely proportional to the square root of the signal frequency. At the very high frequencies with which the waveguide sections are employed, this penetration is very small and the portion of the walls in excess thereof provides only shielding. Therefore, recognizing this fact, the thickness of the walls of the waveguide section are determined so as to provide only that degree of shielding desired for the signal frequencies to be directed along the waveguide section.

The manufacturing method in accordance with the principles of this invention will become evident upon a consideration of the description hereinafter set forth in conjunction with the accompanying drawings wherein:

FIGURES 1 and 2A, respectively, illustrate the basic structures which, when assembled, comprise an inner form and the U-shaped clips, respectively, which cooperate to rigidly position thin precut metal strips of conductive material constituting, for example, the wide walls of a serpentine waveguide section during the assembly process. FIGURE 2B is a front view of the U-shaped clip illustrated in FIGURE 2A.

FIGURE 3 shows the structures illustrated in FIGURE 1 and FIGURES 2A and 2B relatively positioned and containing thin metal strips of conductive material to form the wide walls of the tortuous waveguide section.

FIGURES 4A and 4B, respectively, illustrate the design of the metal sheets of conductive material constituting the walls of the serpentine waveguide section.

The invention is hereinafter described with respect to the manufacture of a serpentine waveguide section of type commonly used in microwave systems. However, the techniques now to be described can, with certain modifications evident to those skilled in the art, be employed in the manufacture of numerous configurations of waveguide sections, i.e. straight runs, bends, twists, etc.

Referring now to FIGURE 1, an inner form assembly may comprise any number of elongated S-shaped solid members **1**, which may be of plastic, wood, metal, etc. having extremities **3** and **5** of predetermined curvature. The extremities **3** and **5**, as illustrated, each extend at right angle curves oppositely from the member **1**. The faces **7** and **9** of the extremities **3** and **5**, respectively, are parallel with the respective surfaces of the member **1**.

A pair of unthreaded bores **11** extend from the face **7** and through the extremity **3** to the far surface of the member **1**. The unthreaded bores **11** are properly countersunk, as illustrated, on the surface of the member **1**. Correspondingly positioned in the other extremity **5** of the

member 1 are the threaded bores 13. However, the threaded bores 13 need not extend to the opposite surface of the member 1 but are of sufficient depth to fully engage an assembly screw 15 directed from a corresponding bore 11 of a next adjacent member 1, as shown in FIGURE 3.

As shown in FIGURE 3, when a number of members 1 are rigidly positioned by the assembly screws 15, they form a continuous, serpentine structure. By determining the thickness and, also, the contours of the individual members 1, an assembly of such members provides a convenient inner form about which the individual metal sheets comprising the respective walls of the serpentine waveguide section may be joined.

FIGURE 2A illustrates a resilient clip 17 having legs 19 and 21 for rigidly positioning thin, precut metal strips, hereinafter described, constituting opposite walls of a serpentine waveguide section on the inner form assembly, hereinafter detailed. The legs 19 and 21 of the clip 17 are divided into a plurality of parallel fingers 23 having rounded ends. To effect an interlocking of adjacent clips 17, dovetailed channels 25 are provided in particular ones of the fingers 23, e.g. fingers 23*a*, of the leg 19 for receiving dovetailed tongues 27 provided corresponding fingers 23, e.g. fingers 23*b*, of the leg 21 of an adjacent clip 17.

Each of the clips 17 is dimensioned to accommodate the extremities 3 and 5, respectively, of adjacently assembled members 1; further, the legs 19 and 21, respectively, of a pair of interlocked clips 17 are dimensioned to extend fully between a pair of assembled members 1 with sufficient clearance for the thin, metal sheet which constitutes one of the walls of the waveguide section.

That portion of the clip 17, designated as 29, at which the fingers 23 join the main body are recessed. Accordingly, when adjacent clips 17 are interlocked and positioned on a pair of assembled members 1, as illustrated in FIGURE 3, access may be had to the area between the fingers 23 of adjacent clips.

Thin metal sheets are precisely cut into a pair of strips 31, as illustrated in FIGURE 4A, to constitute, for example, the wide walls of the waveguide section. The longitudinal edges of the strips 31 may be notched, as illustrated, to interlock with correspondingly notched edges of the narrow walls of the waveguide section. Other thin metal sheets, illustrated in FIGURE 4B, are precisely cut in accordance with the desired contour of the waveguide section to form a pair of strips 33 which constitute the narrow walls of the waveguide section. The edges of the strips 35 are also notched to complement the notches of the strips 31.

According to the process, therefore, an assembly of members 1 provides an inner form which has the same contour, e.g., serpentine, as the desired waveguide section. This assembly is effected by means of the assembly screws 15 as illustrated in FIGURE 3.

To assemble the serpentine waveguide section, one of the metal strips 31 is placed against the top surface of the uppermost member 35 of the inner form assembly and brought over the first right-side loop 37 and partially into the opening formed between the second and third members 39 and 41. When the strip 31 is positioned, a clip 43 having an elongated leg 43*a*, hereinafter discussed, is forced over the strip 31 and onto the first right-side loop 37 of the inner form assembly. A forcing of a clip 43 onto the first right-side loop 37 drives the strip 31 further into and along the opening between the second and third members 39 and 41 of the inner form assembly. The curvature of the free ends of the fingers 23, as illustrated in FIGURE 2A, facilitates the travel of the thin strip 31 into the opening without danger of crimping. When the first clip 43 has been placed in position, a portion of metal strip 31 is securely held against the outside surfaces of the first and second members 35 and 39 of the inner form assembly; further, the lower edges of the notches of the strip 31, as illustrated in FIGURE 4A, are substantially flush with the upper and lower surfaces of the members 35 and 39.

The above procedure is repeated with a second clip 45 to bring the strip 31 around the second loop 47. As the second clip 45 is pushed over the second loop 47, it is interlocked with the first positioned clip 43 by means of the tongues 27 of the clip 45 and the channels 25 of the clip 43. (See FIGURE 2.) The respective fingers 23 of the first and second positioned clips 43 and 45 are, therefore, aligned.

The procedure is continued until the one metal strip 31 is firmly positioned over the remaining loop 49 and other loops which may be provided and into the openings between them.

When the one metal strip 31 has been thus positioned, the second metal strip, hereinafter designated 31*a*, is similarly positioned and restrained on the left-side loops 51, 53 and 55, illustrated in FIGURE 3, by additional clips 57, 59 and 61, respectively. At this time, the positioning of the second strip 31*a* is begun at the bottom surface of the lowermost member 63 of the inner form assembly and brought over the first left-side loop 51. In placing the second strip 31*a*, which is notched in the same fashion as the first strip 31 already positioned, care is exercised to properly align the respective notches for reasons which will become evident.

As illustrated in FIGURE 3, the uppermost and lowermost members 35 and 63 of the inner form assembly are not provided with curved ends 3. Rather, the corresponding extremities of the members 35 and 63 may continue at any angle, herein illustrated as a straight angle, to the terminals of the waveguide section. Accordingly, to effect a proper positioning of the strips 31*a* and 31 with respect to the members 35 and 63, respectively, a pair of flat elongated structures 65 and 67, having the same cross-sectional size and shape as the leg 19 of the clip illustrated in FIGURE 2A, are inserted and interlocked with the respective clips 61 and 49 located within the openings provided between the members 35 and 39 and the members 69 and 63, respectively. In addition, the legs 43*a* and 57*a* of the clips 43 and 57 positioned over loops 37 and 51, respectively, are extended to rigidly position the particular strips 31 and 31*a* along the respective straight extremities of these members, as illustrated.

The two strips 31 and 31*a* are held firmly in position by the inner form assembly and the clips 43, 45, etc. and, also, the elongated structures 65 and 67 to form the wide walls of the waveguide section of desired contour.

One of the pair of metal sheets 33 forming one narrow wall of the waveguide section, as shown in FIGURE 4B, is now positioned. The sheet 33 is formed, for example, by stamping, to conform to the desired contour of the waveguide section. When the one sheet 33 is positioned on the rigidly positioned strips 31 and 31*a*, the respective notches fit into the cuts provided between the notches of the other. The strips 31 and 31*a* and the one sheet 33 are now conveniently supported and dip-brazed or covered by a hot metal spray to form a joint along the corners of waveguide section of proper electrical conductivity.

While the inner form assembly is positioned within the three walls of the waveguide section so formed, a lightweight material is injected under pressure between the waveguide section loops to provide structural rigidity. For example, this lightweight material may be polyurethane foam which, when allowed to set, forms a rigid, sponge-like structure supporting the adjacent wide walls of the waveguide section loop in fixed relationship. The polyurethane foam is injected at the recesses 29 provided in each of the clips 43, 45, etc. The polyurethane foam is forced through the recesses 29 between the fingers 23, 23a and 23b of adjacent interlocked clips against the outer faces of the strips 31 and 31*a*.

When the polyurethane foam has set, the strips **31** and **31***a* are maintained thereby in fixed relationship. The inner from assembly of members **35**, **39**, **41**, etc. is now removed. For this purpose, for example, a second dovetailed tongue **71** may be provided each of the members as illustrated in FIGURE 1. The dovetail extensions **71**, correspondingly situated on each of the members **1**, may be engaged and the inner form assembly removed as a unit by pulling with equal force on each of the members.

When the inner form assembly has been removed, a second one of the metal sheets **33** is positioned to form the other narrow wall of the waveguide section. The strips **31** and **31***a* are supported in fixed relationship by the polyurethane foam. As before, the second sheet **33** is positioned such that the notches interfit with the notches of the strips **31** and **31***a*. When positioned, the second sheet **33** is dip-brazed or sprayed with hot metal to form a joint with the strips **31** and **31***a* of proper electrical conductivity.

When the second narrow wall of the waveguide section has thus been joined, the clips **43**, **45**, etc. and, also, the structures **65** and **67** are removed. Rigidity is provided at this time by the polyurethane foam which is sandwiched between opposing walls or loops of the resulting waveguide section. Although resulting waveguide section is very light, it is relatively strong and can be employed without further reinforcement, if reasonable care is exercised in its handling and installation.

If, however, greater rigidity against vibration is desired, and, also, to safeguard the assembled waveguide section from stresses imposed by wind and other elements, additional laminations, not shown, light, rigid metal sheets may be positioned on either or both flat sides of the wave guide section. Polyurethane foam may then be inserted under pressure between the laminations so provided and the narrow walls, i.e. the metal sheets **33**, of the waveguide section. It will be understood waveguide sections of limited lengths can be assembled and terminated with proper flanges, not shown, for further assembly with other waveguide sections to increase the over-all length of the system. Also, if the resultant waveguide section is to be employed in conjunction with antenna dipole arrays, dipole connectors may be brazed along the waveguide section at selected points.

I claim:

1. A waveguide comprising a pair of spaced parallel lateral walls of smooth surfaced, thin, easily bendable sheet metal arranged in a succession of parallel loops disposed in zig zag relation, a pair of spaced flat top and bottom walls of thin sheet metal of generally convolute peripheral contour secured, respectively, in parallel relation on top and bottom edge portions of said lateral walls to provide with said lateral walls, in effect, a metal shell in the form of a succession of convolute loops, and a rigid mass of dielectric material confined between opposed outer surface portions of the lateral walls of said shell and arranged and adapted to rigidly support said shell walls in effective operative relation.

2. A waveguide as claimed in claim **1** and wherein the top and bottom edges of said lateral walls and the peripheral edges of said top and bottom walls are of crenelate contour and the crenelations of said top and bottom edges of said lateral walls are interfitted with and are secured respectively to the crenelations of said top and bottom walls.

3. A method of manufacturing a tortuous waveguide section comprising the steps of providing an inner form having a contour corresponding to the desired waveguide section, rigidly positioning flexible metal strips along opposite faces of said inner form by means of external clips, joining a first metal sheet of the same contour as said inner form to said flexible metal sheets along joints of proper conductivity, injecting a foam adhesive through interstices provided in said external clip between opposing faces of at least one of said flexible metal strips, allowing said adhesive to set into rigid condition, removing said inner form from between said flexible metal strips, joining a second metal sheet of predetermined design to said flexible metal strips along joints of proper conductivity, and removing said external clips.

4. A method of manufacturing a waveguide section comprising the steps of providing a structure in accordance with the desired contour of said waveguide section, fixedly positioning a pair of precut metal strips on opposite faces of said structure, joining a first metal sheet precut in accordance with the contour of the desired waveguide section to said first mentioned metal strips, sandwiching reinforcing means between oppositely disposed outer face portions of any one of said metal sheets constituting a loop to support said face portions in fixed spatial relationship, removing said structure, and joining a second metal sheet precut in accordance with the contour of the waveguide section to said first mentioned metal strips.

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