

Feb. 8, 1966

K. H. HAHNE

3,234,489

RECTANGULAR WAVEGUIDE

Filed June 4, 1963

7 Sheets-Sheet 1

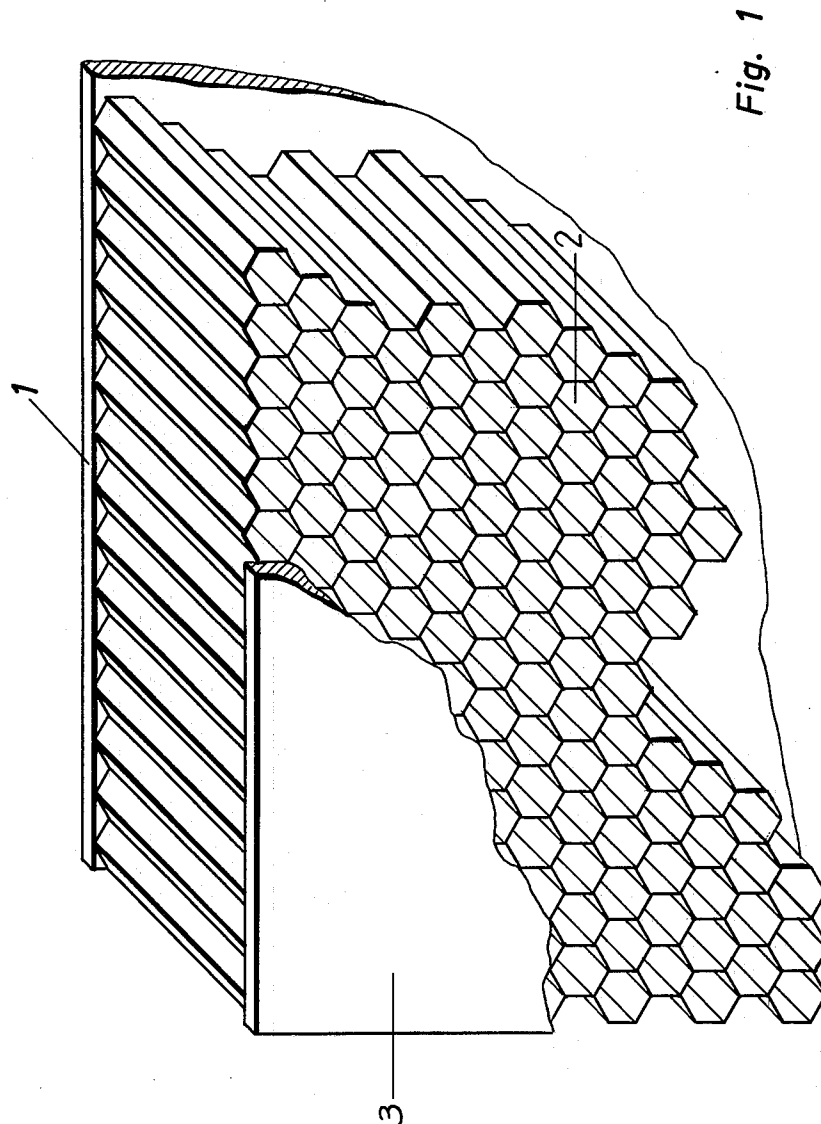


Fig. 1

Inventor
Karl Heinz Hahne
by
Michael S. Striker
M.S.

Feb. 8, 1966

K. H. HAHNE
RECTANGULAR WAVEGUIDE

3,234,489

Filed June 4, 1963

7 Sheets-Sheet 2

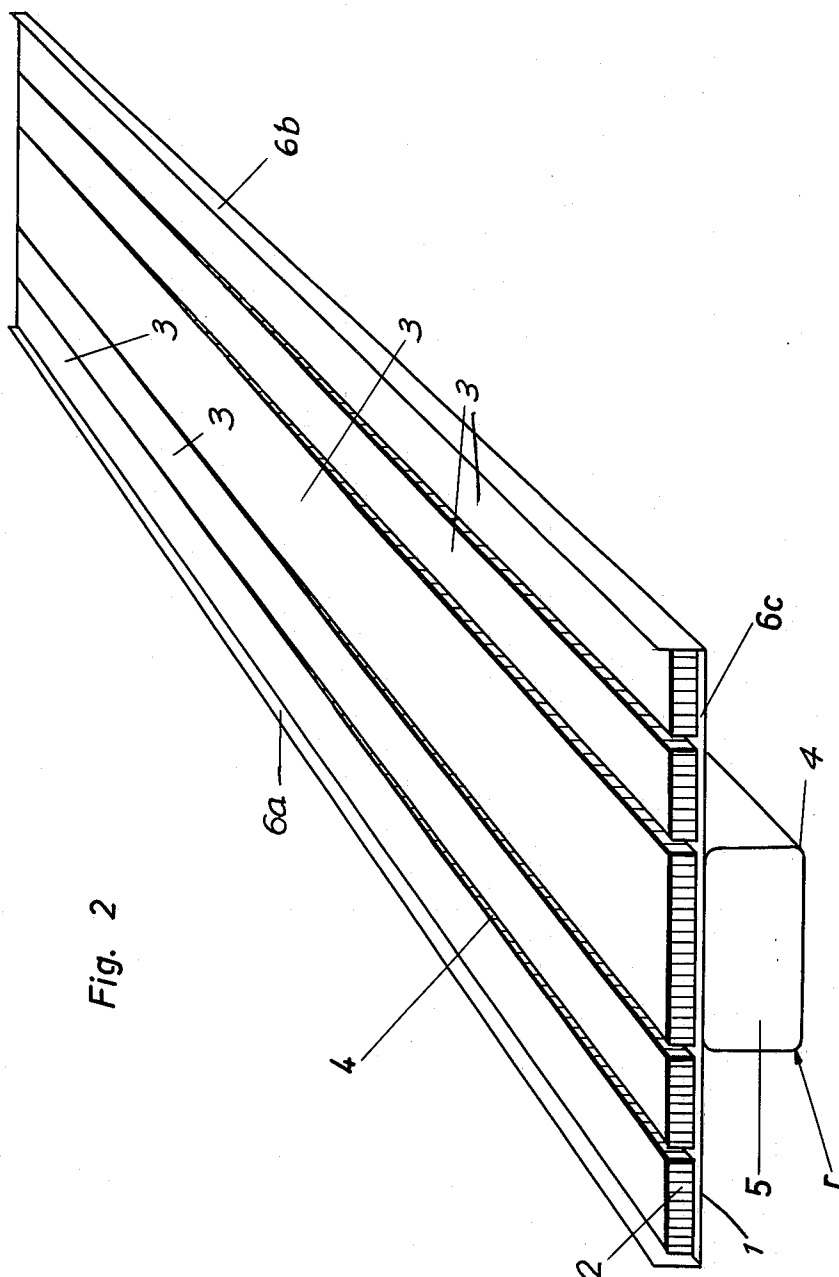


Fig. 2

Inventor
Karl Heinz Hahne
by
Michael S. Striker
R.H.

Feb. 8, 1966

K. H. HAHNE

3,234,489

RECTANGULAR WAVEGUIDE

Filed June 4, 1963

7 Sheets-Sheet 3

Fig. 4

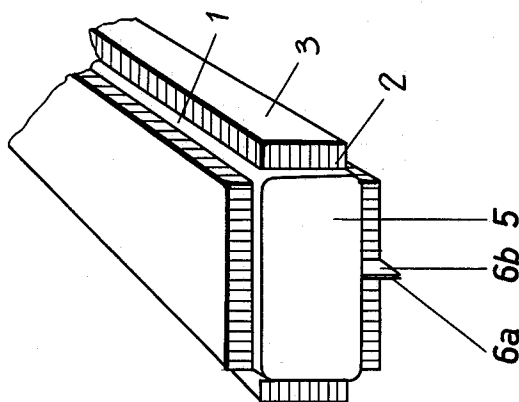
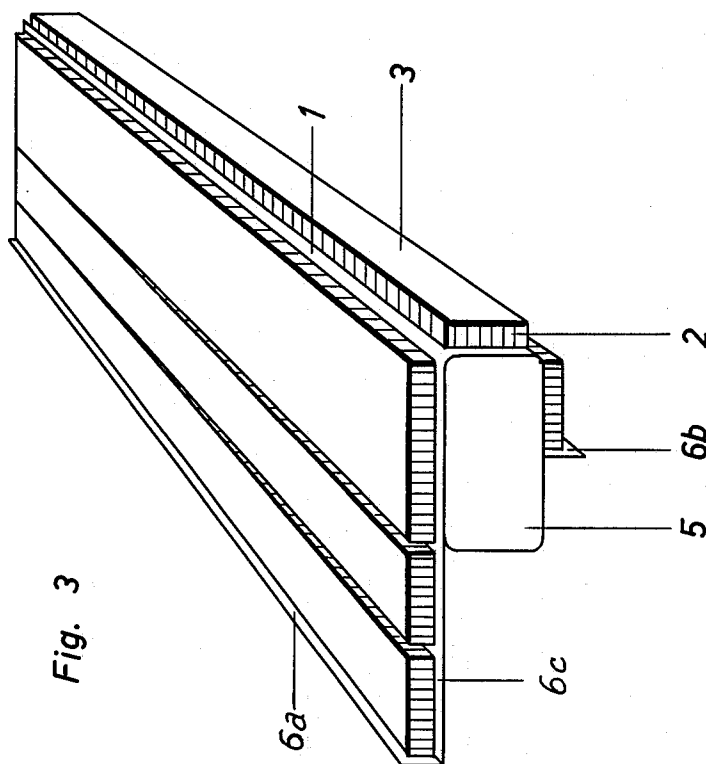


Fig. 3



Inventor
Karl Heinz Hahne
by Michael S. Striker
R.H.

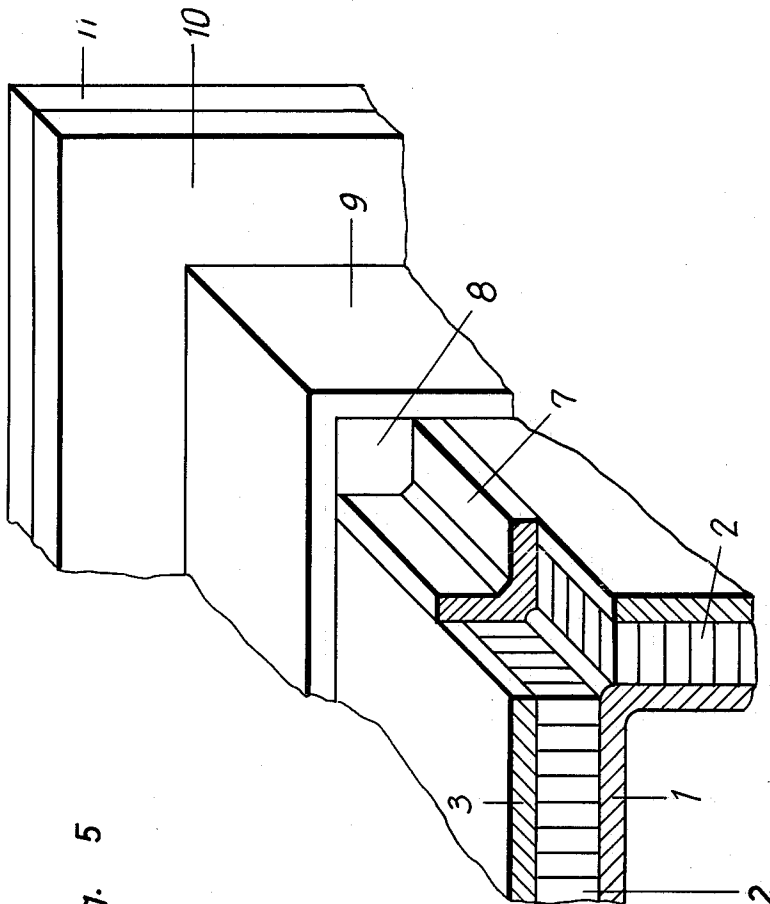
Feb. 8, 1966

K. H. HAHNE
RECTANGULAR WAVEGUIDE

3,234,489

Filed June 4, 1963

7 Sheets-Sheet 4



Feb. 8, 1966

K. H. HAHNE

3,234,489

RECTANGULAR WAVEGUIDE

Filed June 4, 1963

7 Sheets-Sheet 5

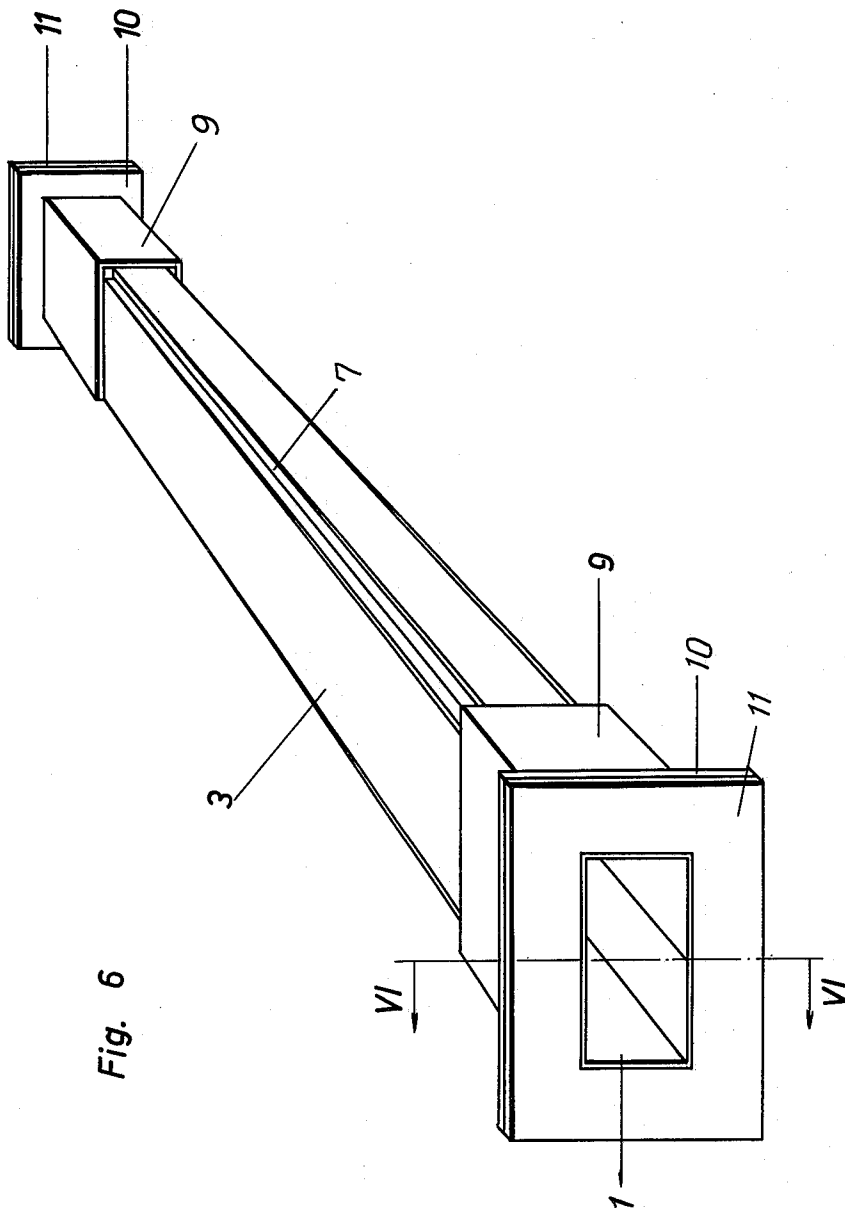


Fig. 6

Inventor
Karl Heinz Hahne
by Michael J. Striker
K.H.

Feb. 8, 1966

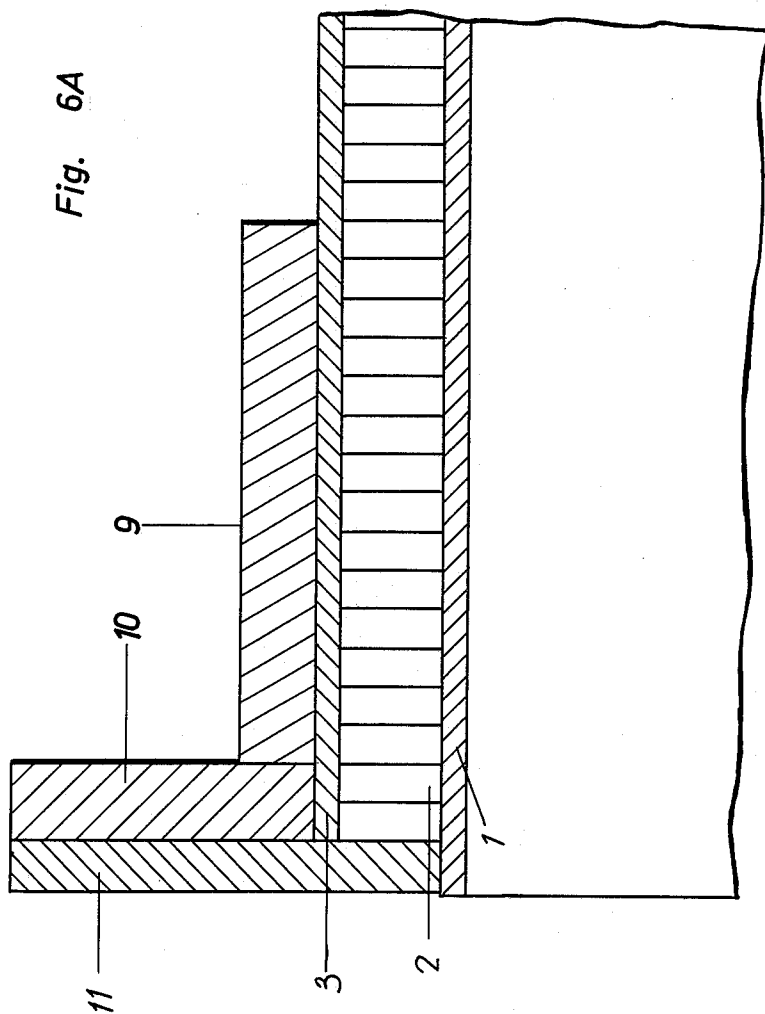
K. H. HAHNE

3,234,489

RECTANGULAR WAVEGUIDE

Filed June 4, 1963

7 Sheets-Sheet 6



Inventor
Karl Heinz Hahne
by Michael J. Striker
Attorney

Feb. 8, 1966

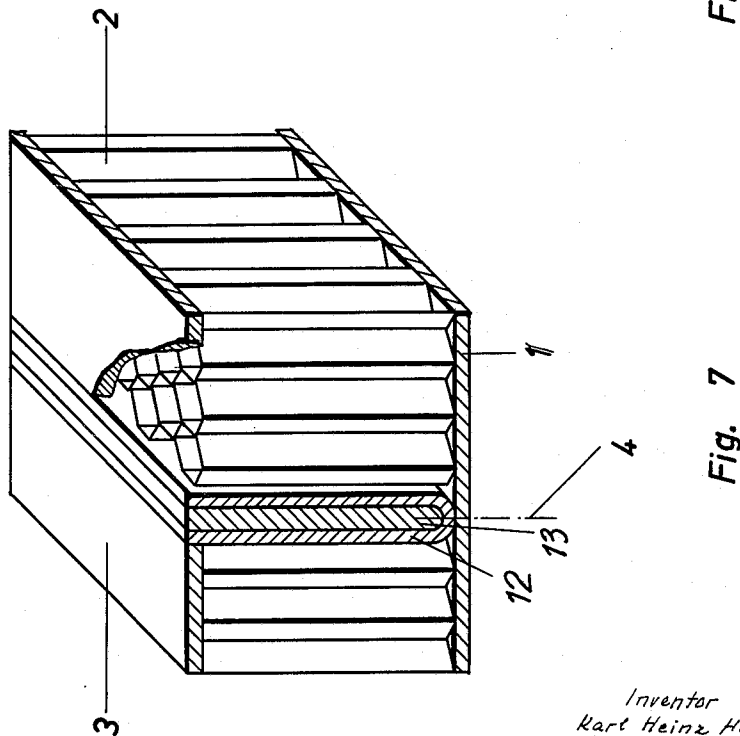
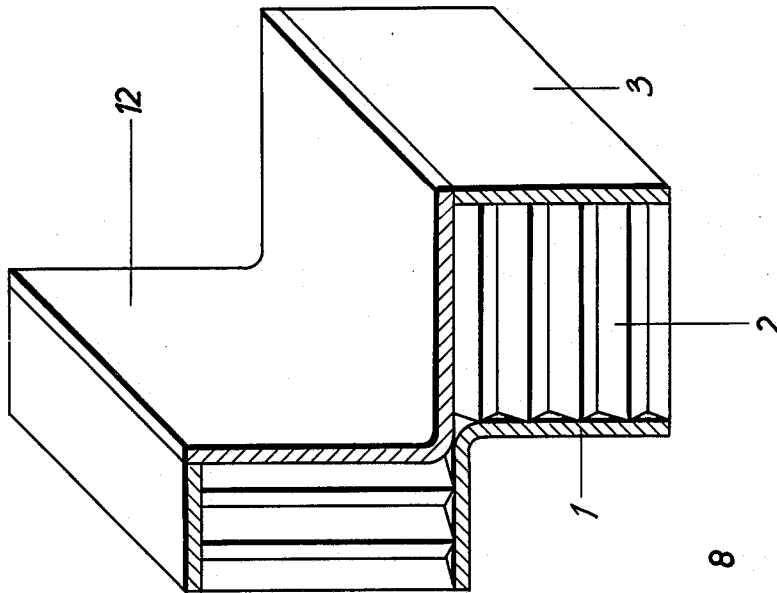
K. H. HAHNE

3,234,489

RECTANGULAR WAVEGUIDE

Filed June 4, 1963

7 Sheets-Sheet 7



Inventor
Karl Heinz Hahne

Karl Heinz Hahne

by Michael S. Striker
Attorney

RH

1

3,234,489

RECTANGULAR WAVEGUIDE

Karl Heinz Hahne, Roseberg, Blecher uber Bergisch Gladbach, Germany, assignor to Felten & Guillaume Carlswerk Aktiengesellschaft, Cologne-Muelheim, Germany

Filed June 4, 1963, Ser. No. 285,327

Claims priority, application Germany, June 16, 1962,

F 37,087

5 Claims. (Cl. 333-95)

The present invention relates to waveguides and to a process for their manufacture.

As is well known, waveguides of rectangular cross section are used to transmit electrical energy of high frequency. Such waveguides are excited at predetermined wave modi for the purpose of transmitting electrical energy. The rectangular cross section of the waveguide fulfills the requirement for the creation of the magnetic H_{10} -modus.

Such waveguides of rectangular cross section can be drawn in the form of seamless metal tubes, as long as the cross section of the waveguide is relatively small. When using a homogeneous metal, accurate tools, and uniform processing, the resulting waveguides which are sufficiently accurate are also of sufficient wall thickness to maintain their shape satisfactorily when mounted and used.

However, when rectangular waveguides of relatively large cross section are manufactured, a drawing process such as may be used for relatively small tubes can no longer be used or is simply uneconomical to be used. Such relatively large waveguides must be made out of sheet metal which is required to be bent to the required dimensions and which is required to be formed into a closed waveguide by soldering or welding.

Considerable difficulties are encountered in the manufacture of such waveguides. In order to fulfill all of the requirements with respect to dimensional stability, the sheet of metal must have a sufficient strength and thickness. As the thickness of the sheet becomes greater the bending of the sheet to the desired configuration becomes more difficult since as the forces required to shape the sheet become greater, larger and more powerful machines must be used, and the heavier and more powerful the machine, the more difficult it is to manufacture the waveguide with the required accuracy.

It is accordingly a primary object of the present invention to provide a waveguide of rectangular cross section and of relatively large dimensions which avoids all of the above drawbacks.

Thus, it is an object of the present invention to provide a waveguide of relatively large, rectangular cross section which can be manufactured with machines which are not required to exert large forces, so that as a result it is possible to manufacture the waveguide of the invention with great accuracy.

A further object of the present invention is to provide a waveguide of relatively large cross sectional area which while being stiff enough to maintain its configuration even if made in relatively long lengths nevertheless is still quite light and easily manufactured and handled.

Also, the objects of the present invention include a process for accurately and easily manufacturing the waveguide of the invention.

With the above objects in view the invention includes, in a rectangular waveguide for electromagnetic wave transmission, an inner wall means of electrically conductive sheet metal shaped to surround a predetermined rectangular cross sectional area. An outer wall means includes a plurality of outer wall layer means rigidly joined with each other and with the inner wall means, respectively, and at least one of these outer wall layer means is

2

made of a rigid, multi-cellular material, so that even in the case of large waveguide dimensions a comparatively thin inner wall means is mechanically reinforced by lightweight layers of the outer wall means.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings, in which:

FIG. 1 is a fragmentary, partly sectional elevation showing a section of a wall of a waveguide according to the invention;

FIG. 2 diagrammatically illustrates part of the process of the invention;

FIG. 3 shows a stage in the process of the invention subsequent to that illustrated in FIG. 2;

FIG. 4 illustrates a stage in the process of the invention subsequent to that of FIG. 3;

FIG. 5 is a fragmentary partly sectional perspective illustration of the completed waveguide of the invention;

FIG. 6 is a perspective illustration of a completed waveguide of the invention;

FIG. 6A is a sectional view illustrating the details of the structure at one end of the waveguide of FIG. 6, FIG. 6A being taken along the line VI—VI of FIG. 6 in the direction of the arrows;

FIG. 7 shows part of a layered material before it is formed into the waveguide of the invention; and

FIG. 8 shows the material of FIG. 7 at a stage of manufacture subsequent to that of FIG. 7.

The invention is applicable to a waveguide of rectangular cross section for transmitting electromagnetic waves, this waveguide having an inner wall made of a sheet metal which is suitably bent. The wall of the waveguide is made of a layered material of which the inner layer is made of a sheet metal of high electrical conductivity, while the other layers are made of any desired relatively stiff material e.g. of metals like aluminum or copper or of synthetic organic sheet material like polyesters, forming a cellular construction. The completed waveguide of the invention thus will retain its configuration while during manufacture relatively small forces will suffice to give the structure the desired configuration and thus the structure of the invention is manufactured with great accuracy.

Referring to FIG. 1, the wall of the waveguide of the invention includes an inner layer 1 made of a suitable, electrically conductive sheet metal carrying a reinforcing layer 2 of a honeycomb structure, and the outer layer is formed by the sheet 3. This layered wall structure can be manufactured in a known way with the upright honeycomb material fused or glued to the inner layer 1 with the use of a suitable glue like epoxy or polyester resins or other similar materials. The outer layer 3 is then glued or fused to the honeycomb layer 2. This honeycomb layer 2 is made out of strips of any suitable material for instance metals like aluminum or copper or synthetic organic sheet material, said strips being joined to each other so as to form the cellular structure illustrated in FIG. 1, these cells preferably having a hexagonal cross section. Such cellular material is well known and freely available.

The advantage of the layered construction shown in FIG. 1 resides in the fact that in spite of the relatively small thickness of the inner layer 1 and the outer layer 3, because these latter layers are rigidly joined with the upright honeycomb material a structure which is greatly resistant to bending and pressure is achieved inasmuch as the honeycomb material will have its walls stressed almost exclusively in the direction of the axis of the cells thereof.

At the same time it is of considerable significance that such a layered construction has a relatively small total weight inasmuch as the entire structure is hollow. Thus, even with bodies of considerable length, as is encountered in conventional waveguides, the danger of deformation as a result of the inherent weight of the structure itself is sharply reduced.

FIGS. 2-8 illustrate how a waveguide according to the invention may be constructed, according to one possible process of the present invention. Referring to FIG. 2 it will be seen that the initial step in the process of the invention is to provide a layered material as illustrated on an enlarged scale in FIG. 1. On a suitable support the base sheet 1 is cut in such a way that its width will equal the total width of all of the sides of the final waveguide plus additional side portions 6a and 6b used later on in the closing of the waveguide 2. On this sheet 1 the cellular layer 2 consisting e.g. of aluminum honeycomb material is placed and joined thereto with a suitable glue, for example an epoxy or polyester resin or similar material. Thus, it is possible, for example, to provide on the surface of the sheet 1 a suitable adhesive either in the form of a coating which is brushed on or in the form of a coating which is sprayed on, and on this latter coating the honeycomb layer is placed in such a way that the edge portions 6a and 6b project beyond the honeycomb layer and at each end of the sheet 1 there is a projection 6c projecting beyond the honeycomb layer 2. The adhesive is hardened by heat and pressure, the pressure being applied, for example, through a pressure plate on the honeycomb material 2 and the heating can be provided by heating the base sheet 1 as well as the pressure plate, and by providing the pressure simultaneously with the heat the honeycomb layer is rigidly joined with the sheet 1. After removing the pressure plate the outer sheet 3 can be applied to the honeycomb layer 2 and can be joined to the latter in exactly the same way. It is also possible to assemble the layers 1, 2 and 3 before joining the layer 2 to the sheet 1 and to provide the adhesive coatings between the layer 2 and the sheets 1 and 3 and then to provide heat and pressure to the entire assembly so as to fix the intermediate honeycomb layer 2 to the inner sheet 1 and outer sheet 3 simultaneously by curing the cementing material. The sheet 3 covers only the honeycomb material 2. The side edge portions 6a and 6b of the base sheet 1 are bent upwardly and are then glued to the side surfaces of the layer 2. The width of each side edge portion or flange 6a and 6b is such that these flanges extend upwardly beyond the layer 2 as is apparent from FIG. 2.

Then with the use of a suitable cutting tool, such as a small circular saw, the outer sheet 3 as well as the layer 2 are cut through so as to provide the elongated grooves 4 which extend all the way through to the sheet 1 at the places where the sheet 1 is to be bent around the shaping member 5. Because the waveguide has rounded corners, the width of each groove 4 is determined by the radius of curvature of the edges of the final waveguide tube at the corners thereof, and the width of the groove 4 is also determined by the thickness of the sheet 1. If r is the radius of curvature at each corner of the sheet 1 of the final waveguide and t is the thickness of the sheet 1, then the groove 4 must have a minimum width which is equal to

$$\frac{\pi}{2}(r+t)$$

Inasmuch as the layered construction of the invention has sufficient rigidity with sheets 1 and 3 which are of relatively small thickness, there is no particular difficulty in bending the layered construction around the core or shaping member 5. The bending of the above-described structure shown in FIG. 2 around the core 5 locates the grooves at the corners of the core and locates the flanges 6a and 6b in engagement with each other at the underside of the core 5, and these flanges are joined to each other at the underside of the core 5 with a suitable glue as a polyester

or epoxy resin or similar material. FIG. 3 shows the right side of the structure bent around the member 5 while FIG. 4 shows the left side bent around the member 5 with the flanges 6a and 6b engaging each other.

The core 5 is removed, and the resulting tubular structure is provided with end flanges as indicated in FIGS. 5 and 6. In accordance with the invention each end flange includes a pair of parts which are joined to each other, these parts being, for each end flange, a part 10 which is mechanically connected to and carried solely by the outer sheet portions 3. The other, lighter part 11 of each end flange is connected with the electrically active sheet 1 as by being glued thereto, and it is only the part 11 of each end flange which is connected with sheet 1, as is apparent also from FIG. 6A. It will be noted that the end flange 6c which projects from the honeycomb layer 2 extends into the interior periphery of the part 11 and is joined to this interior periphery to form the connection between the part 11 of each end flange and the inner sheet 1. The element 11 is then connected to the element 10 by suitable means, for instance by screwing or cementing.

Along the corners of this structure are located the angle members 7, respectively, in the manner shown in FIGS. 5 and 6, and these angle members 7 may be made of metal or a suitable plastic such as, for example, a polyester which is reinforced with glass fibers. These angle members can be glued to the exposed surfaces of the honeycomb layer 2, although this latter connection is not essential.

Each end flange 10 is fixedly connected with a relatively strong collar 9 of rectangular cross section which is slipped over and engages the sheet portions 3 and which receives in its interior the angle members 7, and in the spaces remaining between the angle member 7 and each collar 9 are located the elements 8 which fill these spaces and provide a rigid connection between the collars 9 and the end portions of the tubular assembly. Each assembly 9, 10 is fixed in position with each member 10 engaging the member 11, and the collars 9 being fastened to the exterior surfaces of the sheets 3 as well as to the edges of the elements 8 by gluing or other fastening means. As a final step member 11 which had been fastened before to the protruding parts of the inner sheet 1, is connected to the part 10 at each end of the tubular assembly. The ends of the pair of joined flanges 6a and 6b are cut back so as to provide an uninterrupted flange 6c which can extend into the plate 11 at each end of the assembly and also so as to permit each collar 9 to be slipped onto the assembly. It is also possible to form each end flange in two sections with the sections arranged in such a way that they respectively engage the flanges 6a and 6b and are joined thereto as by the use of a suitable adhesive, for example an epoxy or polyester resin or similar material. The central portions of the members 9 and 10 are formed with openings large enough to engage the entire waveguide structure by embracing sheet 3. It is only the flange elements 11 which are slipped onto the flanges 6c at the ends of the assembly and fixed to them, the flange elements 11 and flange portions 6c being joined to each other by a suitable adhesive, for example epoxy or polyester resin or similar material. The elements 10 and 11 are joined together by screws, rivets, soldering, welding, or gluing. The electrically operating elements of the assembly are in this way stressed mechanically to only a very small extent. Nevertheless with this structure the connection of each end flange with the electrically active inner sheet 1 of the assembly is achieved.

In accordance with the invention it is also possible to manufacture the assembly of the invention according to a different process. The layer of honeycomb material is conventionally supplied in the form of a stack of sheets of corresponding thickness with the individual sheets partly adhering to each other so that the assembled sheets can be pulled apart with the elongated adhering portions thereof remaining connected to each other so as to pro-

5

vide the honeycomb configuration. In other words the layer 2 originally is collapsed and can be spread so as to form from the individual sheets of the layer 2 the honeycomb construction illustrated in the drawings. In accordance with the invention, as illustrated in FIG. 7, substantially U-shaped strips 12 are arranged between and joined, as by suitable adhesive, to the edge strips of the honeycomb layer. In other words, the groups of honeycomb layers 2 at the four sides of the final construction are separated from each other by the sheet metal strips 12 which have the U-shaped construction shown in FIG. 7, these strips 12 being provided with inserts 13. Thus, there will be provided a honeycomb layer 2 as shown in FIG. 2 except that instead of grooves 4 the strips 12 with their inserts 13 are located where the grooves 4 are shown in FIG. 2. The several strips 12 are joined only at their exterior surfaces to the edge strips of the honeycomb layer. The layer 2 of this construction is arranged on the sheet 1 in the manner described above in connection with FIG. 2 and is joined thereto also in the manner described above. In this case instead of providing a single sheet 3 which is cut to form the separations aligned with the grooves 4, separate elongated strips 3 are joined to the portions of the honeycomb material 2 which extend between the strips 12 at the ends of these portions opposite from the sheet 1. Thereafter the sheet 1 is bent around the shaping member 5 in the manner described above, and the sheet metal strips 12 are deformed so as to have the configuration shown in FIG. 8, the inserts 13 simply falling out and being removed. Thus, the elements 12 take the place of the angle members 7 of FIGS. 5 and 6, with this embodiment but may of course still be reinforced by additional angle members.

The completed waveguide assembly is illustrated in FIG. 6. This construction is characterized by an extremely light weight, great mechanical strength, and great dimensional stability. In other words long assemblies having the structure shown in FIG. 6 are capable of being self-supporting without any appreciable bending and greatly resist any deformation of any type. The layered construction described above guarantees a strong resistance to bending or buckling. Where the assemblies are vertically mounted the angle members 7 or 12 and the outer sheet portions 3 absorb almost all of the tensile forces. With the above-described structure of the end flanges according to which only the separate elements 11 are joined to the inner sheet 1, this sheet 1 is able to extend all the way up to the exterior surfaces of the elements 11 without any abutting of the sheet 1 against other elements so that when several of the assemblies of FIG. 6 are joined in end-to-end relation, a smooth and reflection-free transfer from one assembly to the next is assured. The end faces of the inner base sheet 1 of such assemblies will precisely abut each other. The end flanges can be provided with bores for fixing the assemblies to each other as well as with grooves to receive sealing strips, as is well known, these details being omitted since they have nothing to do with the invention.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of waveguides differing from the types described above.

While the invention has been illustrated and described as embodied in waveguides and method for their manufacture, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are

6

intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be secured by Letters Patent is:

1. A rectangular waveguide for electromagnetic wave transmission comprising, in combination, inner wall means of electrically conductive sheet metal defining a channel of substantially rectangular cross section having four wall portions and a plurality of corresponding edge portions each located between two adjoining wall portions, said wall portions having an inner and an outer face; outer wall means composed of a plurality of elongated members each having a substantially rectangular cross section, each member extending along the outer face of a different one of said wall portions between said edge portions thereof, leaving along each of said edge portions a free space between adjacent ones of said members, each of said members consisting of an inner layer means composed of a rigid honeycomb body having a plurality of elongated cells substantially perpendicular to the plane of the respective one of said wall portions, and an outer sheet metal plate means, said outer sheet metal plate means and said inner layer means being firmly attached to each other, said inner layer means being also attached to the outer face of the respective wall portion; elongated reinforcement members fitting said free spaces and having a first portion in engagement with said inner wall means and a second portion in engagement with said outer sheet metal plate means so that even in the case of large wave guide dimensions a comparatively thin inner wall means is mechanically reinforced by light weight layers of said outer wall means and by said elongated members; and flange means attached to each end of said inner and outer wall means, each flange means including an inner portion and outer portion, the inner portion being attached to said inner wall means, the outer portion being attached to said outer wall means, and said inner and outer portions of each flange means being assembled with each other.

2. A rectangular waveguide as set forth in claim 1, wherein said elongated reinforcement members are having a substantially L-shaped cross section and wherein said reinforcement members have a pair of outer portions, each outer portion of said pair being in engagement with a different one of said outer sheet metal plate means.

3. A method of producing substantially rigid rectangular waveguides for electromagnetic wave transmission, comprising the steps of: cutting a first sheet of electrically conductive sheet metal to size sufficient to form therefrom a desired rectangular waveguide channel including longitudinal outwardly projecting flange portions; assembling by cementing said first sheet with a rigid intermediate honeycomb plate having a top and a bottom surface and consisting of a plurality of elongated cells substantially perpendicular to the bottom surface of said plate, said bottom surface being in assembled condition adjacent said first sheet; assembling said first sheet and said intermediate plate with a second sheet of sheet metal as outer layer so as to form a three-layer assembly; forming by bending said longitudinal flange portions along two opposite edges of said first sheet; cementing the lateral longitudinal edges of said intermediate layer to said longitudinal flange portions, respectively; cutting a plurality of parallel slots in said intermediate plate and outer layer, each of said slots being cut so as to have opposing side faces which are parallel to said elongated cells and transforming said intermediate plate and said outer layer into a plurality of strips extending along parallel lines along which said first sheet is to be bent for forming said desired rectangular waveguide channel; bending said first sheet along said lines into a channel of rectangular cross-section so as to cause said longitudinal flanges of said first sheet to meet; and attaching said longitudinal flanges to each other by cementing.

4. A method of producing substantially rigid rectangular waveguides for electromagnetic wave transmission, comprising the steps of: cutting a first sheet of electrically conductive sheet metal to size sufficient to form therefrom a desired rectangular waveguide channel including longitudinal outwardly projecting flange portions; assembling by cementing said first sheet with a rigid intermediate honeycomb plate having a top and a bottom surface and consisting of a plurality of elongated cells substantially perpendicular to the bottom surface of said plate, said bottom surface being in assembled condition adjacent said first sheet; assembling said first sheet and said intermediate plate with a second sheet of sheet metal as outer layer so as to form a three-layer assembly; forming by bending said longitudinal flange portions along two opposite edges of said first sheet; cementing the lateral longitudinal edges of said intermediate layer to said longitudinal flange portions, respectively; cutting a plurality of parallel slots in said intermediate plate and outer layer, each of said slots being cut so as to have opposing side faces which are parallel to said elongated cells and transforming said intermediate plate and said outer layer into a plurality of strips extending along parallel lines along which said first sheet is to be bent for forming said desired rectangular waveguide channel; bending said first sheet along said lines into a channel of rectangular cross-section so as to cause said longitudinal flanges of said first sheet to meet; attaching said longitudinal flanges to each other by cementing; reinforcing said strips where said intermediate layer has been cut along said parallel lines by inserting elongated bar members into the free corner spaces, respectively, formed along said parallel lines by said cutting of said intermediate and outer layers; fitting at each end of the thus produced waveguide a first flange onto the portion thereof formed by said strips of intermediate layer and outer layer; fitting at each end of the thus produced waveguide a second flange onto the portion thereof formed by bending said first sheet; and firmly assembling at each end of said waveguide said first and second flanges.

5. A method of producing rectangular waveguides for electromagnetic wave transmission, comprising the steps of: cutting a first sheet of electrically conductive sheet metal to size sufficient to form therefrom a desired longitudinally projecting flange portions; assembling a layer of rigid honeycomb material of a size corresponding to that of said first sheet with a plurality of U-shaped sheet metal members extending transversely of said layer along parallel lines along which said first sheet is to be bent for forming said desired waveguide channel; assembly said layer of honeycomb material and said plurality of

U-shaped members with said first sheet by placing said layer onto one surface of said first sheet and by connecting said layer to said surface; connecting a plurality of strips of sheet metal to said layer of honeycomb material at the side thereof remote from said first sheet with said strips extending between respective successive U-shaped members, respective portions of said first sheet, the layers of honeycomb material and the strips of sheet metal forming a three layer assembly of which the honeycomb material is the intermediate layer; forming by bending said longitudinal flange portions along two opposite edges of said first sheet; cementing the lateral longitudinal edges of said intermediate layer to said longitudinal flange portions; bending said first sheet along said lines into a channel of rectangular cross-section so as to cause said longitudinal flanges of said first sheet to meet while simultaneously bending said U-shaped sheet metal members into L-shaped corner reinforcements; attaching said longitudinal flanges to each other by cementing; fitting at each end of the thus produced waveguide a first flange onto the portion thereof formed by said strips of intermediate layer and said strips of sheet metal; fitting at each end of the thus produced waveguide a second flange onto the portion thereof formed by bending said first sheet; and firmly assembling at each end of said waveguide said first and second flanges.

References Cited by the Examiner

UNITED STATES PATENTS

2,381,367	8/1945	Quayle	333—95 X
2,728,479	12/1955	Wheeler	206—46 X
2,854,373	9/1958	Beach	20—92 X
2,923,902	2/1960	Pajak	333—95
2,985,075	5/1961	Knutsson-Hall.	
2,998,475	8/1961	Grimsinger.	
3,052,749	9/1962	Snapp	29—455
3,078,880	2/1963	Stephens	138—149

FOREIGN PATENTS

1,117,682	11/1961	Germany.
696,900	9/1963	Great Britain.

OTHER REFERENCES

Virgile, L. G.: Deflection of Waveguide Subjected to Internal Pressure. In IRE Transactions on Microwave Theory and Techniques, vol. MTT-5, No. 4, October 1957, pages 247-250 (page 250 relied on).

HERMAN KARL SAALBACH, *Primary Examiner.*

ELI LIEBERMAN, *Examiner.*

L. ALLAHUT, *Assistant Examiner.*