United States Patent [19]

Ajoika et al.

[11] **3,761,845**

[45] **Sept. 25, 1973**

[54] **FABRICATION METHOD AND APPARATUS USING FERRITE FOR SHIFTING PHASE OF AN ELECTROMAGNETIC WAVE**

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[73] Assignee: **Hughes Aircraft Corporation,** Culver City, Calif.

[22] Filed: **July 27, 1972**

[21] Appl. No.: **275,841**

[52] **U.S. Cl.** ..... **333/24.1,** 29/600, 333/98 R

[51] **Int. Cl.** **H01p 1/32**

[58] **Field of Search** ..... 333/10, 24 G, 24.1, 333/24.2, 31 A; 29/600

[56] **References Cited**

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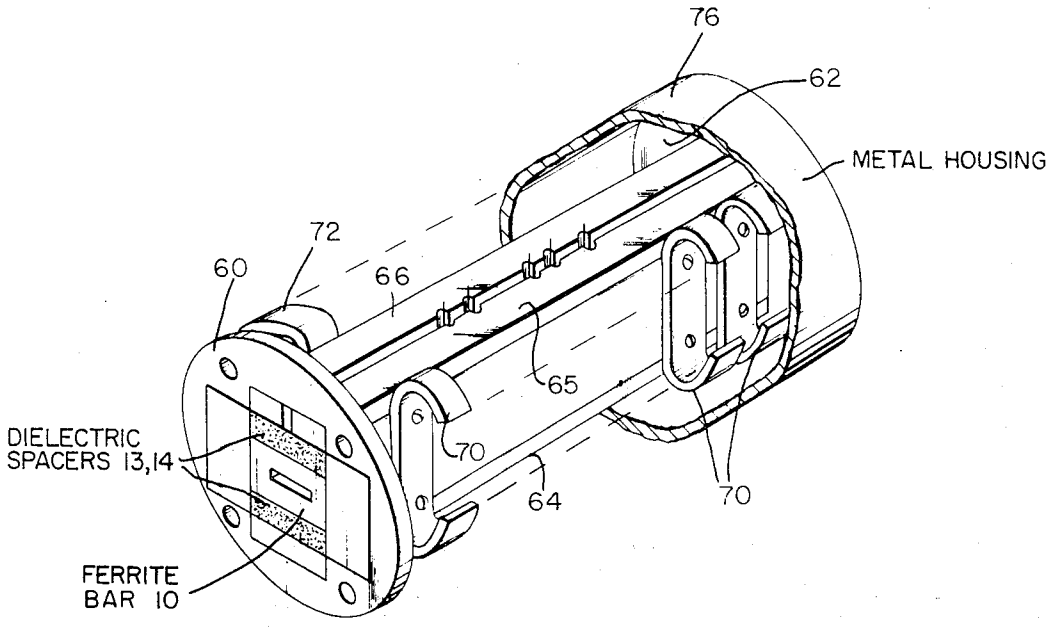
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Primary Examiner—Paul L. Gensler
Attorney—W. H. MacAllister, Jr. et al.

[57] **ABSTRACT**

The present invention relates to an apparatus and method of manufacture of a simple and inexpensive ferrite phase shifter. It is economical to have the ferrite bar with its concommitant longitudinal rectangular hole for the high dielectric constant insert to be fired in the desired shape but it is rather difficult to hold the high tolerance of flatness required to fit the precision waveguide housing normally used. The "as fired" ferrite bars are often slightly warped or have a slight twist and likewise the hole generally follows the distortions of the entire ferrite bar, i.e., the hole is not perfectly straight. From the electrical point of view, a slight warpage in the bar is not in itself detrimental. It is undesirable only because it cannot be accurately fitted to the waveguide housing. These and other problems are circumvented by wrapping a metallic foil around a composite structure comprised of the ferrite bar and side spacers of low dielectric constant to form the phase shifter.

3 Claims, 13 Drawing Figures



5 Sheets-Sheet 1

Fig. 1.

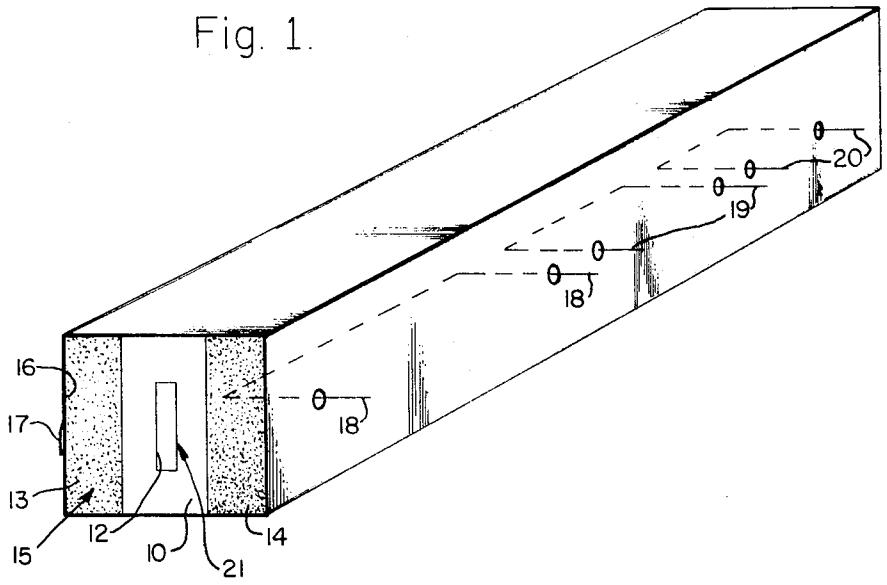


Fig. 2.

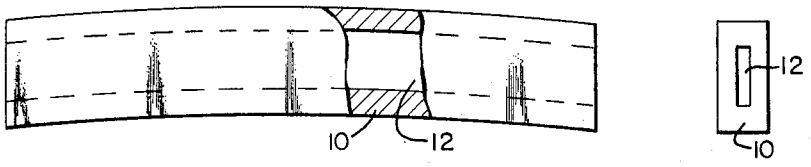


Fig. 3.

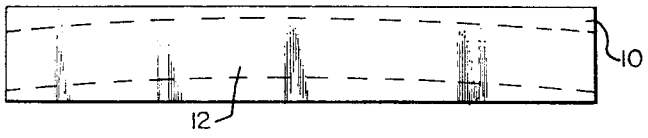
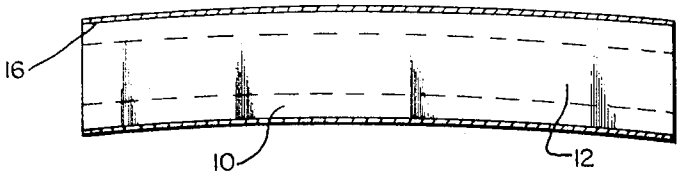


Fig. 4.



5 Sheets-Sheet 2

Fig. 5.

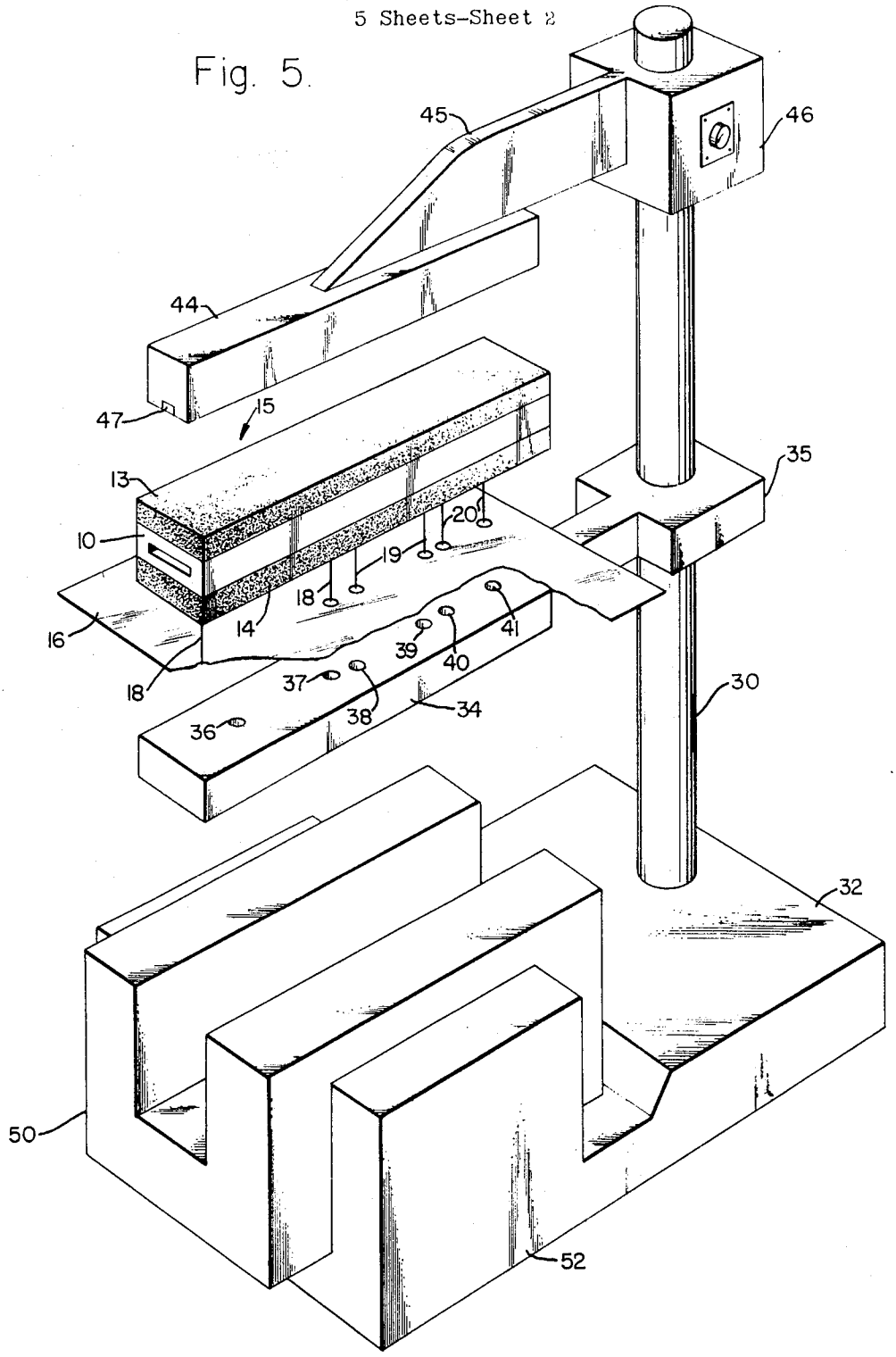


Fig. 6.

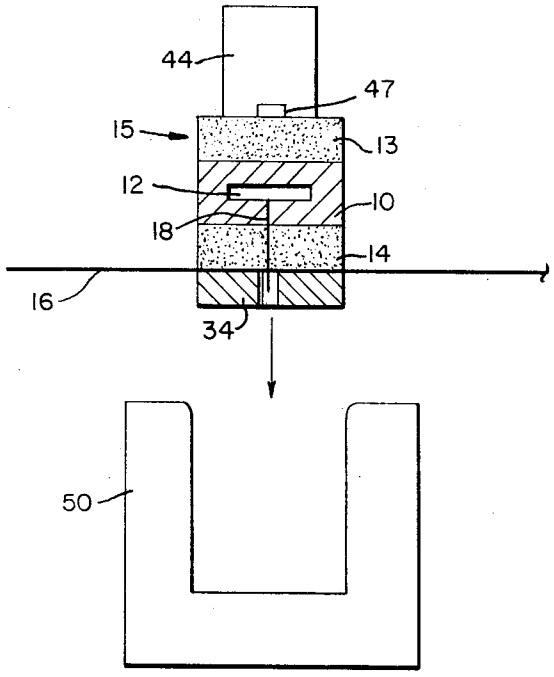


Fig. 7.

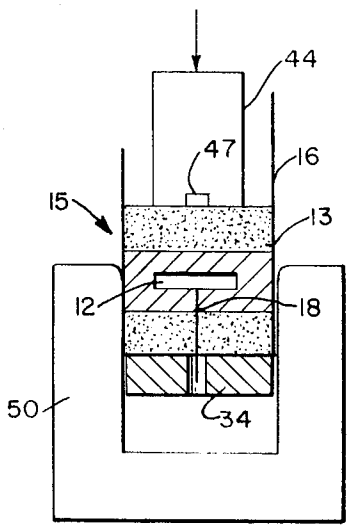


Fig. 8.

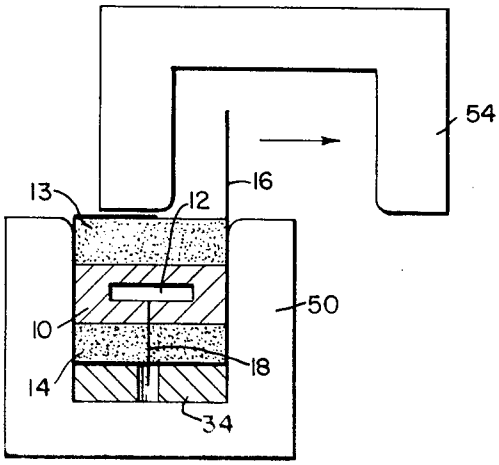


Fig. 9.

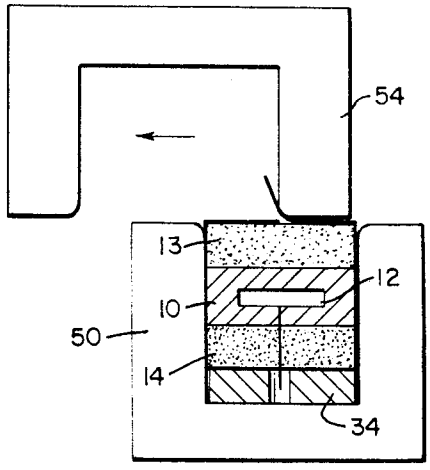


Fig. 10.

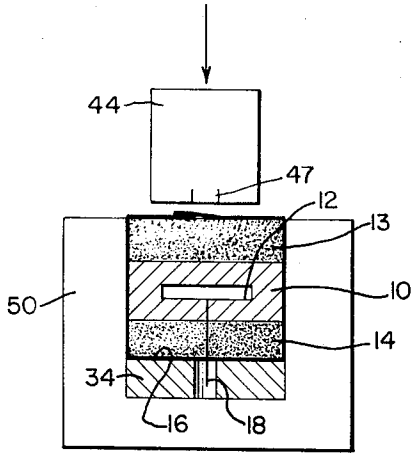


Fig. 11.

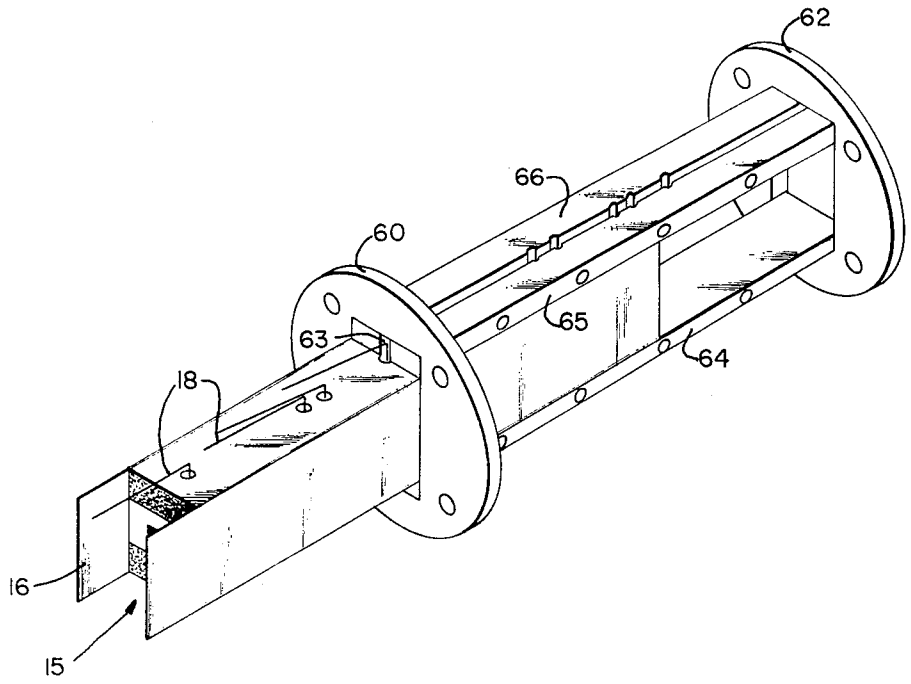


Fig. 12.

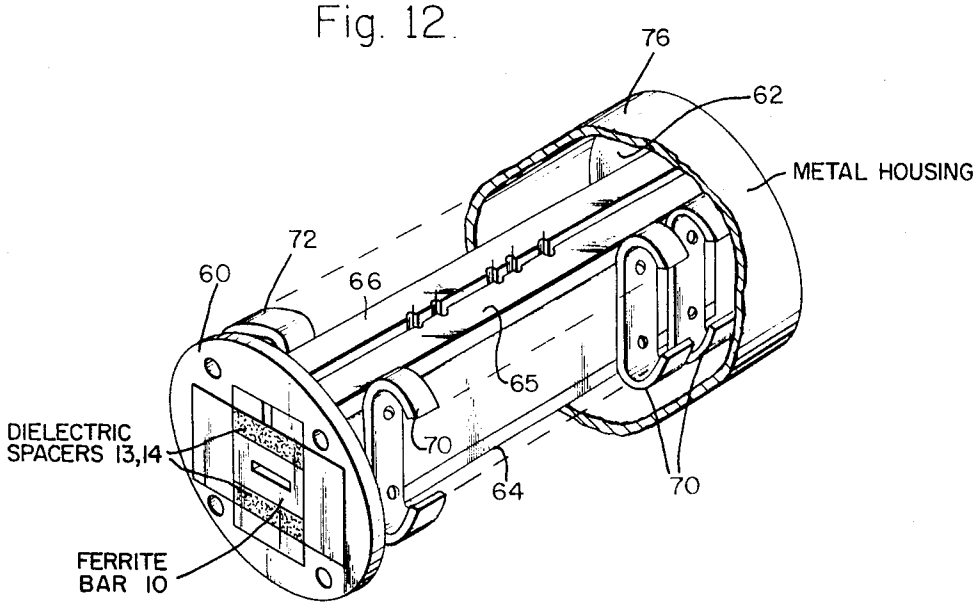
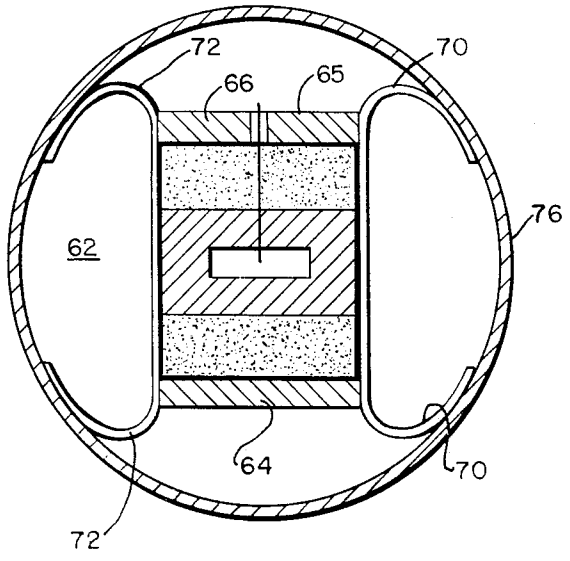

76
62
METAL HOUSING
72
60
66
65
DIELECTRIC
SPACERS 13,14
70
64
70
FERRITE
BAR 10

Fig. 13.


72
70
66
65
62
76
64
70
72

FABRICATION METHOD AND APPARATUS USING FERRITE FOR SHIFTING PHASE OF AN ELECTROMAGNETIC WAVE

BACKGROUND OF THE INVENTION

It is the present practice to implement a ferrite phase shifter by accurately fitting a ferrite bar inside a waveguide. It is well known that the most critical tolerance in waveguide ferrite phase shifters is the contact between the waveguide and ferrite surface. Typically, "air gaps" between the ferrite and waveguide of greater than 0.0005 inches can cause the generation of undesirable higher order modes which cause radio frequency loss resonances to occur. In the past, the intimate contact was assured by extremely accurate grinding of the ferrite surfaces to maintain perfect flatness fo the top and bottom surfaces that must contact the waveguide. Also, the waveguide itself must be accurately ground to mate with the ferrite bar. If the waveguide housing is too loose, loss resonances can occur and if it is too tight undesirable magnetostriction effects can occur. This accurate grinding and accurate fitting of the ferrite bar to the waveguide is costly in production. In addition, the assembly process is rather difficult.

Thus, summarizing, the ferrite bar must be accurately ground to high dimensional tolerance and flatness. This is not only costly but may cause the hole in the bar, which is "fired in" and bends with the bar, to be off center rendering the unit useless. Next, the waveguide holder must be machined accurately to mate with the ferrite bar without being too tight to cause magnetostriction effects. Lastly, the assembly of the phase shifter is difficult. This is especially true in threading the drive wires without breakage or without causing short circuits to the waveguide walls during insertion of the ferrite bar into the waveguide.

SUMMARY OF THE INVENTION

In accordance with the present invention, an economical ferrite phase shifter is provided by wrapping a metallic foil around a composite structure comprised of the ferrite bar and two side spacers of low dielectric constant. The side spacers are of such a width that the entire structure has the same cross section as the desired waveguide housing. The composite structure is glued together with low loss glue. When this structure is wrapped with foil, the foil becomes the waveguide. Since the foil is resilient, it can follow the contour of the "as fired" ferrite bar even if it is slightly warped or twisted. Thus intimate contact of waveguide and ferrite is assured. The wrapped device is then inserted in a holding device which protects the phase shifter and provides means for attaching to other waveguides.

The net result in that accurate grinding of the ferrite and the accurately machined waveguide are eliminated—both of which are very costly. In addition, there will be less attrition in ferrite bars because of the obvious possibility of cracking, chipping, or contaminating the ferrite bar during the grinding process. Also, since the hole in the ferrite usually follows the outer contour of the "as fired" ferrite it can remain centered at all cross sections whereas if the outer surface is ground flat, the hole will become off-center at various cross-sections making the bar useless. Another advantage of the foil wrapping technique is that the difficulty of threading the drive wires through the holes in a precision waveguide is eliminated. In the foil wrapped method, the drive wires are all simultaneously inserted in matching holes in the falt foil before the wrapping operation. This has the further advantage that the wires make the foil and ferrite bar "self jigging" in that the proper alignment of the flat foil and ferrite bar is automatically assured.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a perspective view of the device of the present invention without protective and connecting apparatus;

FIGS. **2–4** illustrate the disadvantages of grinding versus the use of foil;

FIG. **5** illustrates apparatus for implementing a process for fabricating the device of FIG. **1**;

FIGS. **6–10** illustrate the process for fabricating the device of FIG. **1**;

FIG. **11** shows the device of FIG. **1** being inserted in a protective device;

FIG. **12** illustrates a perspective view of the device of FIG. **1** in a protective and connecting apparatus; and

FIG. **13** shows a cross-sectional view of the device of FIG. **12**.

DESCRIPTION

Referring to FIG. **1** of the drawings, there is shown the essential portions of the ferrite phase shifter of the present invention from the standpoint of electronic operation. In particular, a ferrite bar **10** of rectangular cross-section extends for the entire length of the phase shifter. The ferrite bar **10** is "fired" with a rectangular hole **12** which runs lengthwise therethrough and is centrally disposed with the longer axis thereof coinciding with the longer axis of the cross-section of bar **10** and the shorter axis coinciding with the short axis of the bar **10.** The ferrite of bar **10** is of a type that is commercially available and has a relative dielectric constant that is of the order of **16.** Low dielectric spacer bars **13, 14** each of a width equal to that of ferrite bar **10** are disposed coextensively on both sides thereof and glued in place with low loss glue. Spacer bars **13, 14** are preferably of equal thickness to form a composite bar **15** having cross-sectional dimensions equal to the desired inside dimensions of waveguide to be used along the ferrite phase shifter. The low dielectric spacer bars **13,14** are fabricated from commercially available dielectric foam having a dielectric constant of the order of **2.** By having a low dielectric constant is meant that the dielectric constant is low compared to the dielectric constant of the ferrite bar **10** which has a constant of the order of sixteen. An alternative configuration would be to make the low dielectric spacer bars **13,14** hollow so that the composite dielectric constant would approach that of air. The waveguide about composite bar **15** is provided by a sheet of foil **16** of a width equal to that of the length thereof and wrapped thereabout and joined along the center of a broad side of low dielectric spacer bar **13** by means of a soft solder joint **17.** Drive wires **18,19,20** are disposed through the opposite side of composite bar **15** and foil **16** to the rectangular hole **12** and extend for predetermined portions therealong. The ratio 4:2:1 is typical for the lengths of the drive wires. The rectangular hole **12** is then filled with a commercially available high dielectric core **21** which has a relative dielectric constant of the order of 30. It has been found that the dielectric core **21** may have a

dielectric constant that ranges from a constant greater than that of ferrite bar **10** to a constant of the order of **38.** By "high" is meant that the dielectric constant of core **21** is high compared to the dielectric constant of the ferrite bar **10** which is of the order of 16. The method of constructing the foregoing portions of the ferrite phase shifter is described in connection with FIGS. **5** through **10.**

Referring to FIG. **2** there are shown side and end views of a ferrite bar **10** having a "fired in" rectangular hole **12** that is warped. From the electrical point of view, a slight warpage of the bar **10** is not in itself detrimental. It is bad only because it cannot be accurately fitted to the waveguide housing. Also, when the outer surfaces of the ferrite bar **10** are ground flat, the center hole **12,** which cannot be straightened, often becomes sufficiently off-center (at various cross-sections) to render the bar **10** electrically useless as evident in FIG. **3.** The present method of fabricating a ferrite phase shifter does not require grinding in the manner shown in FIG. **3** but rather utilizes a sheet of foil **16** which follows the contour of the "as fired" ferrite bar **10** as shown in FIG. **4.** The rectangular hole **12** remains centered along the length of bar **10** whereby warppage does not detrimentally affect the electronic performance of the ferrite phase shifter. It is to be understood, of course, that the ferrite bar **10** is not intentionally warped or twisted but may become that way during the manufacturing processes.

Referring to FIG. **5** there is shown an exploded view of apparatus for implementing a method for assembling the ferrite phase shifter of FIG. **1.** In particular, the apparatus of FIG. **5** includes a vertical traverse rod **30** supported by a stand **32.** A support block **34** is attached to the vertical traverse rod **30** by means of a slidable bracket **35.** Support block **34** includes holes **34–41** that are placed to accommodate the drive wires **18,19,20** and has a substrate area that is exactly coextensive with the broad side of ferrite bar **10** and the low dielectric spacer bars **13,14,** i.e., the composite bar **15.** The sheet of foil **16** which is preferably aluminum or copper initially has a width sufficient to wrap around the composite bar **15** with a slight overlap along the center of low dielectric spacer bar **13.** The overlapped portions of the sheet of foil **16** are pre-tinned so that they may be subsequently soldered together. Further, the sheet of foil **16** is pre-cut with the edges along the broad sides of the low dielectric spacer bars **13,14** coextensive with the edges thereof and the edges along the remaining sides of composite bar **15** cut to extend longer than the bar **15.** Holes are punched along the center of the sheet of foil **16** to coincide with the holes in low dielectric spacer bar **14** for the drive wires **18,19** and **20.**

The pre-cut punched sheet of foil **16** is then placed over the support block **34** with the holes therethrough coinciding with corresponding holes **36–41.** The drive wires **18,19,20** are threaded through appropriate holes in composite bar **15** along rectangular hole **12.** The threaded composite bar **15** with the drive wires **18,19,20** down, as shown in the drawing, is then placed over the sheet of foil **16** coextensive with the support block **34** and with the drive wire **18** extending through holes **36,37;** the drive wire **19** extending through holes **38,39;** and the drive wire **20** extending through holes **40,41.**

A pressure device **44** having a flat under-surface of an area that is the same lenth but somewhat narrower than the top surface of composite bar **15,** as shown in FIG. **5** of the drawings, is supported on top of composite bar **15** by means of a bracket **45** which, in turn, is attached to a slidable mounting **46** on the vertical traverse rod **30.** A heating element **47** is disposed along the center of the underside of pressure device **44** flush with the surface thereof. Directly below the support block **34** is placed a nylon or teflon U-shaped forming block **50** which is held in place by means of a vise **52** which is attached to the stand **32.** The channel of the U-shaped forming block **50** has a depth equal to the vertical dimension of support block **34** and composite bar **15,** as shown in FIG. **5.** Further, the corners of forming block **50** at the top of the channel are rounded to provide a guide for the insertion of the support block **34,** sheet of foil **16** and composite bar **15,** as will be hereinafter explained.

FIGS. **6–10** illustrate cross-sectional views of the apparatus of FIG. **5** during the process of forming the ferrite phase shifter in the form shown in FIG. **1.** Referring to FIG. **6** the pressure device **44** is dropped down into actual contact with the composite bar **15** which rests over the support block **34** with the pre-cut pre-tinned sheet of copper foil **16** inbetween. The support block **34** along with composite bar **15** and pressure device **44** is moved directly over the channel of the U-shaped forming block **50** and lowered to the bottom thereof as shown in FIG. **7** of the drawings. This operation folds the sheet of foil **16** over both sides of the composite bar **15** leaving the exposed surface thereof flush with the top surface of forming block **50.**

Proceeding to FIG. **8,** an inverted nylon or teflon U-shaped forming block **54** is used to finish wrapping the sheet of foil **16** about the composite bar **15.** The channel depth of U-shaped forming block **54** is not critical but should be greater than the height of the unfolded sheet of foil **16** above the top surface of block **50.** The inner edges of the block **54** are rounded so as to avoid shearing the sheet of foil **16.** The left side of forming block **54** is then placed over the left side of forming block **50,** as shown in the drawing, and is then pulled to the right while applying moderate pressure. The direction of forming block **54** is then reversed, as shown in FIG. **9,** and the remaining portion of the sheet of foil **16** wrapped around the composite bar **15.** Next, as shown in FIG. **10,** the pressure device **44** is positioned over the wrapped composite bar **15** and the heating element **47** energized sufficient to melt the solder of the pre-tinned surface and then de-energized to allow the solder to solidify while holding the sheet of foil **16** in position. The wrapped composite bar **15** may now be removed from the forming block **50.**

The foil wrapped ferrite phase shifter of FIGS. **1** and **10** is not practicable for use in an electronic system in the state shown as it is too fragile and has no way of coupling from and to waveguide in the system. A housing for protecting the ferrite phase shifter and at the same time providing a means to couple to external waveguide is described in connection with FIGS. **11, 12** and **13.** Referring to FIG. **11** waveguide flanges **60,62** are spaced a distance apart exactly equal to that of the composite bar **15.** Each of the flanges **60,62** includes a square and/or rectangular aperture of a size to just receive the foil wrapped composite bar **15.** In addition, one of the flanges **60** or **62** such as flange **60** includes a notch **63** in the center of the side designed to be adjacent the low dielectric spacer bar **14** to allow for pas-

sage of the drive wires **18,19,20** when the foil wrapped composite bar of FIG. **10** is slid through the flange **60.** The flanges **60,62** are connected by a flat metal bar **64** which extends between and is flush with the respective opposite edges of the apertures therein. In addition, flat metal bars **65,66** extend between flanges **60,62** on both sides of the notch **63** and are flush with the sides of the apertures therein opposite from the flat metal bar **64.** The foil wrapped composite bar **15** with the drive wires **18,19,20** may now be slid inbetween the flat metal bar **64** and the flat metal bars **65,66** with the drive wires **18-20** passing through the notch **63.** It is, of course, possible to assemble the flange **60** onto the flat metal bars **64,65,66** last so that notch **63** is not required.

Referring now to FIGS. **12,13** ears of the sheet of foil **16** extending out from the composite bar **15** are folded back on the flat surface of the flanges **60,62** and conductively attached thereto. A series of phosphor bronze finger springs **70,72** with wrap-around ends are now connected across the flat metal bars **64,65** and across the flat metal bars **64,66,** respectively. A cylindrical metal housing **76** of an inside diameter equal to the diameter of the flanges **60,62** is then disposed about the ferrite phase shifter from the flange **60** to the flange **62** whereby the springs **70,72** support the foil wrapped composite bar **15** along the entire length thereof. In actual operation, it may be desirable to circulate coolant on the outside of cylindrical metal housing **76** whereby connections to the drive wires **18,19,20** may be made through the flanges **60** or **62** and the mating flange in the electronic system.

What is claimed is:

1. A ferrite phase shifter adapted to connect to rectangular waveguide of predetermined height and width, said ferrite phase shifter cmprising a ferrite bar of predetermined dielectric constant having a rectangular cross-section with a fired-in rectangular hole disposed longitudinally therethrough, the width of said ferrite bar being equal to said predetermined height; first and second low dielectric spacer bars of the same rectangular cross-section disposed coextensively adjacent both broad sides of said ferrite bar thereby to form a composite bar with said first and second sapcer bars having a combined thickness equal to said predetermined width less the height of said ferrite bar; a sheet of metallic foil disposed completely around the entire length of said composite bar in close proximity thereto thereby to provide a foil wrapped composite bar, said sheet of metallic foil having ears at the extremities of said composite bar on the sides thereof in contact with said ferrite bar; first and second flanges disposed about opposite extremities of said foil wrapped composite bar with said ears folded back and conductively attached thereto; a first rigid flat bar extending between aid first and second flanges adjacent to and co-extensive with said first spacer bar of said foil wrapped composite bar; second and third rigid flat bars extending between said first and second flanges adjacent to and co-extensive with said second spacer bar of said foil wrapped composite bar, said second and third rigid flat bars having an intervening space along the central portion of said second spacer bar of said foil wrapped composite bar; and no less than one driver wire penetrating into and extending along said rectangular hole through said foil wrapped composite bar at first and second places along said central portion of said second spacer bar; and a dielectric material within said rectangular hole of said ferrite bar, said dielectric material having a dielectric constant greater than said predetermined dielectric constant.

2. The ferrite phase shifter as defined in claim **1** additionally including spring means extending between said first and second and between said first and third rigid flat bars for supporting said foil wrapped composite bar along the entire length thereof.

3. The method of fabricating a ferrite phase shifter using a ferrite bar of rectangular cross-section having an "as-fired" longitudinal hole therethrough, said method including placing low dielectric spacer bars flush with both broad sides of said ferrite bar to form a composite bar, threading no less than one drive wire through one of said spacer bars along said longitudinal hole and out through one of said spacer bars, and wrapping a sheet of metallic foil around the entire length of said composite bar in close proximity thereto with said drive wires penetrating therethrough including providing a sheet of foil at least as long as said composite bar and of a width greater than the perimeter of the cross-section thereof, placing holes in said sheet of metallic foil in positions to accommodate said drive wires, supporting said sheet of foil and said composite bar with said drive wires disposed through corresponding holes therein, folding said sheet of foil up the sides of said composite bar, folding opposite sides of said sheet of foil over the top of said composite bar, and electrically connecting said opposite sides of said sheet of foil together while simultaneously holding said sheet of foil snug against said composite bar.

* * * * *

PO-1050
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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,761,845 Dated September 25, 1973

Inventor(s) James S. Ajioka and William R. Barten

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Cover page, directly beneath "United States Patent [19]"

Ajoika et al. should be:

--Ajioka et al.--

Signed and sealed this 14th day of May 1974.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents