Oct. 29, 1968

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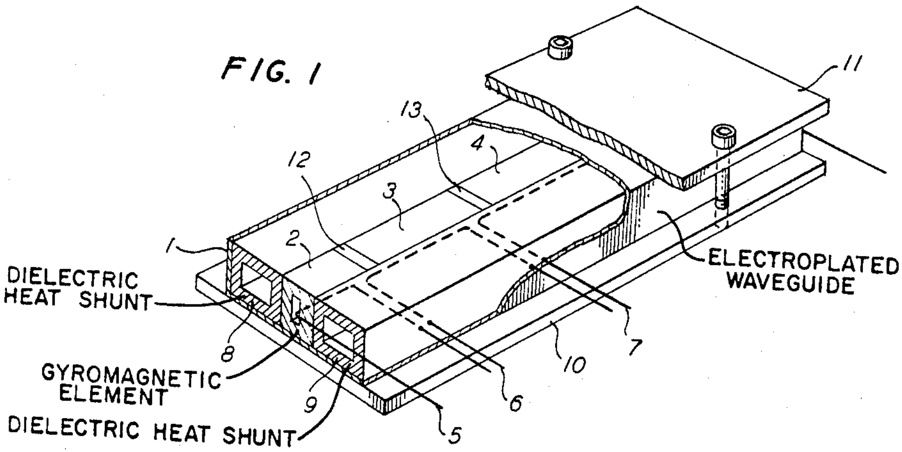
3,408,597

NONRECIPROCAL GYROMAGNETIC WAVEGUIDE DEVICE WITH HEAT TRANSFER MEANS FORMING A UNITARY STRUCTURE

Filed May 11, 1966

FIG. 1



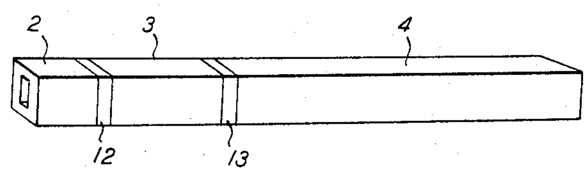


FIG. 2

FIG. 3

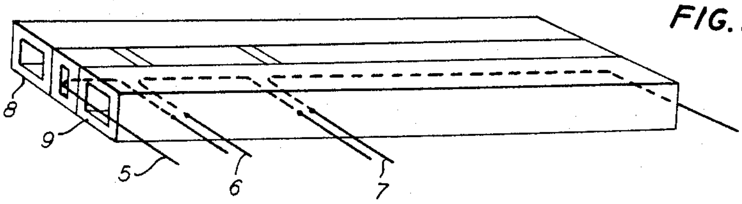


FIG. 4

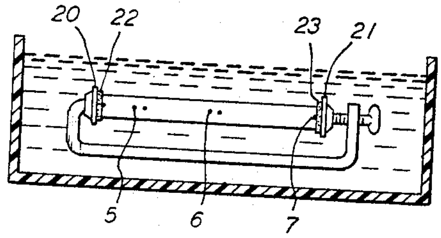
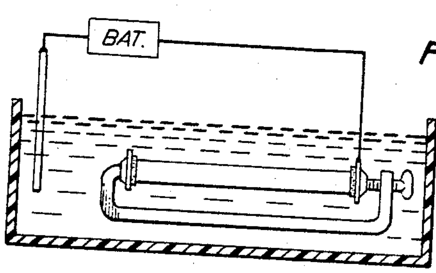


FIG. 5



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United States Patent Office

3,408,597

Patented Oct. 29, 1968

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NONRECIPROCAL GYROMAGNETIC WAVEGUIDE DEVICE WITH HEAT TRANSFER MEANS FORMING A UNITARY STRUCTURE

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Filed May 11, 1966, Ser. No. 549,325
4 Claims. (Cl. 333—24.1)

ABSTRACT OF THE DISCLOSURE

A waveguide device is constructed about a pair of dielectric heat transfer members which are bonded to a gyromagnetic element thus forming a mandrel having exact dimensions required for the waveguide. A conductive boundary, deposited upon the mandrel, forms a unitary structure which can be clamped to an external heat sink to provide an effective means for removing heat from the gyromagnetic element.

This invention relates to electromagnetic energy transmission devices and more particularly to waveguide devices constructed with provisions for cooling an internally situated element.

Waveguide devices frequently have internally disposed elements such as cores which interact with the electromagnetic energy propagating within. These elements are often composed of gyromagnetic materials to provide nonreciprocal operation. These nonreciprocal waveguide devices employing gyromagnetic materials are frequently limited in their power handling capabilities because the radio frequency energy dissipated in the gyromagnetic material causes the material to heat up. As the temperature of the material approaches the Curie temperature, the material begins to lose its gyromagnetic properties to in turn cause the characteristics of the overall device to be altered in an undesirable fashion.

Various attempts have been made to overcome this heat problem in high average power gyromagnetic waveguide devices. One such attempt has been directed towards obtaining gyromagnetic materials having higher Curie temperatures. Other attempts have been directed, where possible, towards modifying the structure of the various devices to provide efficient heat transfer paths between the gyromagnetic material and the outside surfaces of the waveguide. The heat transfer paths or heat shunts are usually used in conjunction with external heat sinks. However, when heat shunts are utilized in this fashion problems arise in the effort to form a secure bond between the heat transfer member and the gyromagnetic element. Because of the temperature gradients experienced, forces are created at the bonding surface which tend to rupture the bond and destroy the effectiveness of the heat transfer path.

In one particular waveguide structure of the prior art, an attempt has been made to provide a heat transfer member between the waveguide envelope and the internally situated gyromagnetic element without employing any bonding material. Patent 3,225,318, granted to W. C. Heithaus on Dec. 21, 1965, discloses a coaxial waveguide device fitted with a metallic heat transfer member inserted in the region between the coaxial conductors. This heat transfer member is designed to make thermal contact with the outer conductor and the ferrite elements within and is composed of a metallic material having spring-like properties which are utilized in positioning the member within the waveguide. However, the metallic composition of the heat transfer member results in some unwanted radio frequency magnetic field distortions. Furthermore, this method of positioning the heat transfer

member is less than permanent in that its location is subject to variations that may occur during the mechanical assembly or during the operation of the device, or both.

Accordingly, it is an object of this invention to provide an efficient heat transfer path from an element within a waveguide to the exterior thereof.

It is another object of this invention to provide a simple method of constructing a waveguide device with a heat transfer member securely positioned between the walls of the waveguide and an internally disposed member.

In accordance with the objects of the invention, a heat transfer member is positioned within a waveguide device between the walls of the waveguide and an internally disposed element wherein heat is generated during operation of the waveguide device. This internal element may be composed of a gyromagnetic material to produce nonreciprocal characteristics. The heat generated in this element by the radio frequency energy dissipated therein is transferred by the heat transfer member to and through the waveguide walls to a heat sink. The waveguide device is constructed by bonding a pair of dielectric heat transfer members to the gyromagnetic element to form a mandrel over which the waveguide is electroplated to produce a unitary structure which can then be further cooled by an attachment to a heat sink.

The present invention will be better understood upon consideration of the following detailed description when taken in conjunction with the accompanying drawing in which:

FIG. 1 shows a partially cut away perspective view of the construction of a device produced by the process described; and

FIGS. 2 through 5 illustrate a method of practicing the invention.

The invention is illustratively set forth in the context of a latching type digital ferrite phase shifter shown in FIG. 1 with portions of the structure cut away to facilitate the description thereof. This device comprises a rectangular waveguide **1** with a plurality of cores of gyromagnetic material internally disposed along the longitudinal axis of the waveguide. In the device shown, the longitudinal dimension of the three cores, **2**, **3** and **4**, are selected so that an incremental phase shift of 45° can be introduced to electromagnetic energy propagated within the guide by the judicious application of current pulses to coils individually wound through the apertures of each core. Illustratively, core **2** may be composed of some gyromagnetic material such as ferrite or garnet and coil **5** may be wound through the aperture of core **2** to produce a remanent field within the core in response to current pulses. This remanent magnetic field interacts with the circularly polarized components of the electromagnetic waves to introduce a phase shift having a magnitude dependent upon the direction of remanent field within the core. Each of the other cores may also have a winding which, when pulsed, controls the phase shift introduced by the device.

The temperature within each of the cores increases by virtue of the absorption of energy as the propagating electromagnetic energy level increases. Since the thermal contact each of the cores makes with the top and bottom faces of the waveguide and the thermal conductivity of the core material are insufficient to provide for the removal of the heat generated when the device is operated at high-power levels, the present invention provides additional heat removal paths in the form of dielectric heat shunts **8** and **9** placed on either side of the core. Each of these heat shunts extend longitudinally within the waveguide on either side of the longitudinal array of cores so that one wall makes thermal contact with a wall of the core array. The remaining three walls of each of these dielectric heat shunts are respectively in thermal contact with a side wall and the upper and lower walls of the waveguide to provide an efficient heat transfer path between the core and the waveguide. Heat sinks such as plates **10** and **11** can be fastened to the waveguide surfaces to provide for the removal of the heat transferred to the waveguide from the core. The particular heat sink employed can be selected to comply with the needs of the specific device and accordingly, for example, plates **10** and **11** may be provided with circulating coolants.

The method by which the illustrative device is produced is shown in FIGS. 2 through 5. One longitudinal wall of each of the dielectric heat shunts **8** and **9** is bonded to one wall of the longitudinal array of cores **2**, **3** and **4** (as shown in FIG. 2) to form a mandrel (as shown in FIG. 3) over which the waveguide is electroplated. The core array of FIG. 2 is obtained by stacking cores **2**, **3** and **4** end to end with separators in the form of dielectric slabs **12** and **13** bonded between the ends of abutting cores. The cross-sectional dimension of these dielectric slabs are selected to conform with those common to each core. As illustrated in FIG. 3, the dielectric heat shunt forms **8** and **9** are then bonded respectively to either side of this longitudinally stacked array. The cross-sectional dimensions of the core and the dielectric forms bonded on either side thereof are selected to form a mandrel having the overall internal cross-sectional dimension (within a permitted tolerance) of the waveguide that is desired. It is to be emphasized that though a mandrel having a rectangular cross section is shown, any desired cross section may be obtained by using suitable shaped dielectric forms.

The bonding material should be selected to provide the adhesive properties required with a minimum thickness between the bonded surface. Furthermore, the bonding material must be thermally conductive and not be such as to introduce excessive loss to the propagating microwave energy. In order to prevent the destruction of mechanical properties of the ferrite core when the material is heated, it is desirable that the bonding material also have the ability to cure at room temperature. It is also desirable for the bonding material to have a degree of pliability after curing in order to absorb the operational stresses created by temperature variation.

A bonding material that has been found to satisfy these requirements is an epoxy mixture containing 100 parts by weight of a base resin such as Epon 828 made by the Shell Chemical Corporation, 40 parts by weight of polysulphoride rubber such as LP_3 made by the Thiokol Chemical Corporation, and 20 parts by weight curing agent such as T1 hardener made by the Shell Chemical Corporation.

The dielectric forms **8** and **9** should be constructed from a material having sufficiently good thermal conductivity to be able to conduct away all the heat that reaches to the core surface. It must also have good microwave properties in that it should introduce little loss to propagating microwave energy and have a compatible dielectric constant. Additionally, the dielectric material used for the forms must have good mechanical properties in order to withstand the pressures created during the plating process and the pressures existing during the normal operation of the assembled device. Dielectric materials which satisfy these requirements include alumina, forsterite, berrylia and magnesium titanates.

The dielectric forms **8** and **9** are constructed with a longitudinally extending cavity in order to minimize the loss and dielectric loading otherwise introduced to propagating microwave energy. Also, the aperture of each of the cores may be filled with a dielectric material chosen for maximum differential phase shift per unit length of material and for minimum sensitivity to manufacturing dimensional tolerances in accordance with techniques understood by those versed in the art. Additionally, the dimensions of the core apertures are selected to obtain maximum differential phase shifts per unit length of core

material in accordance with considerations familiar to those versed in the art. The thickness of the walls of dielectric forms **8** and **9** is determined with knowledge of the fact that as the thickness increases the differential phase shift decreases while the efficiency of heat transfer increases.

After the core-heat shunt mandrel is formed in the manner described, holes parallel to the broad walls of the waveguide are drilled through dielectric form **9** and through each of the dielectric separators **12** and **13** along a path abutting the ferrite core. As can be seen from FIG. 3, a conductor (e.g., conductor **6**) is then inserted through the drilled holes and aperture of each core. Vinyl insulation is then placed over the conductor where it emerges from the mandrel. One end of the insulation is bonded and sealed at the mandrel exterior wall and the other end is extended beyond the conductor and heat sealed. If a dielectric separator is not placed at the exposed ends of cores **2** and **4** the insulation is retained within the core aperture for removal after the electroplating is completed.

The next step in the method for producing the device comprises sealing off all exposed mandrel surfaces over which deposition of waveguide material is unwanted. One technique includes selecting a pair of brass plates **20** and **21** with dimensions at least as large as the cross-sectional dimensions of the mandrel. One brass plate is then placed on each end of the mandrel with a rubber gasket (e.g., elements **22** and **23**) separation and this entire assembly is securely fastened by a C-clamp. With all of the openings in the mandrel thus hermetically sealed, an electroless deposition of a metal such as copper or nickel is plated over the mandrel surface (as shown in FIG. 4) to approximately a tenth of a mil thickness. This deposition provides a conducting interface between the insulating mandrel materials and the additional thickness of metal which is then electroplated (as shown in FIG. 5) over the electroless deposition to form the waveguide. The total thickness of the waveguide can be on the order of 10 to 50 mils.

After the waveguide is plated over the mandrel, the C-clamp, brass plates and rubber gaskets are removed. The copper conductors running through each core are extended and the assembly can be clamped to a suitable heat sink. As shown in FIG. 1, a unitary structure with each element securely and permanently positioned is thus formed. In particular, dielectric forms **8** and **9** make permanent and excellent thermal contact with both the cores and the waveguide surface to efficiently transfer heat generated in the core to the waveguide walls and heat sinks. Additionally, because of the unitary nature of the device, mechanical stresses created by virtue of temperature gradients can comfortably be withstood by the structure without any rupture of bonds existing amongst the elements.

While the invention is illustratively set forth in the form of a latching type digital ferrite phase shifter enclosed within a rectangular waveguide, other cross-section geometries for this type device and, indeed, other devices such as isolators and circulators may be constructed according to the teachings of the invention set forth herein. For each device a mandrel which includes an internally disposed gyromagnetic element is constructed to conform to the waveguide cross-sectional shape desired. A deposition of waveguide metal over the mandrel completes the assembly of the device desired. It is to be noted that the device illustrated may be constructed by a process other than that described such as, for example, forcing or sliding the heat shunt-core subassembly into a preformed waveguide.

It is therefore to be understood that the above-described arrangements are illustrative of the applications of the principles of this invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A waveguide device comprising: an internally positioned element composed of gyromagnetic material and positioned to produce non-reciprocal type operation in said waveguide; means for providing a heat transfer path from said element, said means including a mandrel having a pair of thermally conductive dielectric forms contiguously disposed with and bonded to said element to produce a geometrical configuration identical to said waveguide's internal cross-sectional dimensions; and a layer of electrically conductive material disposed about said mandrel to form a unitary structure, said layer deposited about said mandrel including an electroless deposition contiguous to said mandrel and an electroplated layer plated over said electrolessly deposited layer.

2. A waveguide device in accordance with claim 1 further comprising a coil wound about said internally positioned element, said coil having end terminals exterior to said device.

3. A waveguide device in accordance with claim 2 wherein the electroplated mandrel is clamped to a heat sink.

4. A waveguide device in accordance with claim 3 wherein each of said dielectric forms includes an internal cavity to prevent dielectric loading of said device.

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