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NON-RECIPROCAL WAVEGUIDE PHASE SHIFTER HAVING SIDE-BY-SIDE FERRITE TOROIDS

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FIG. 1

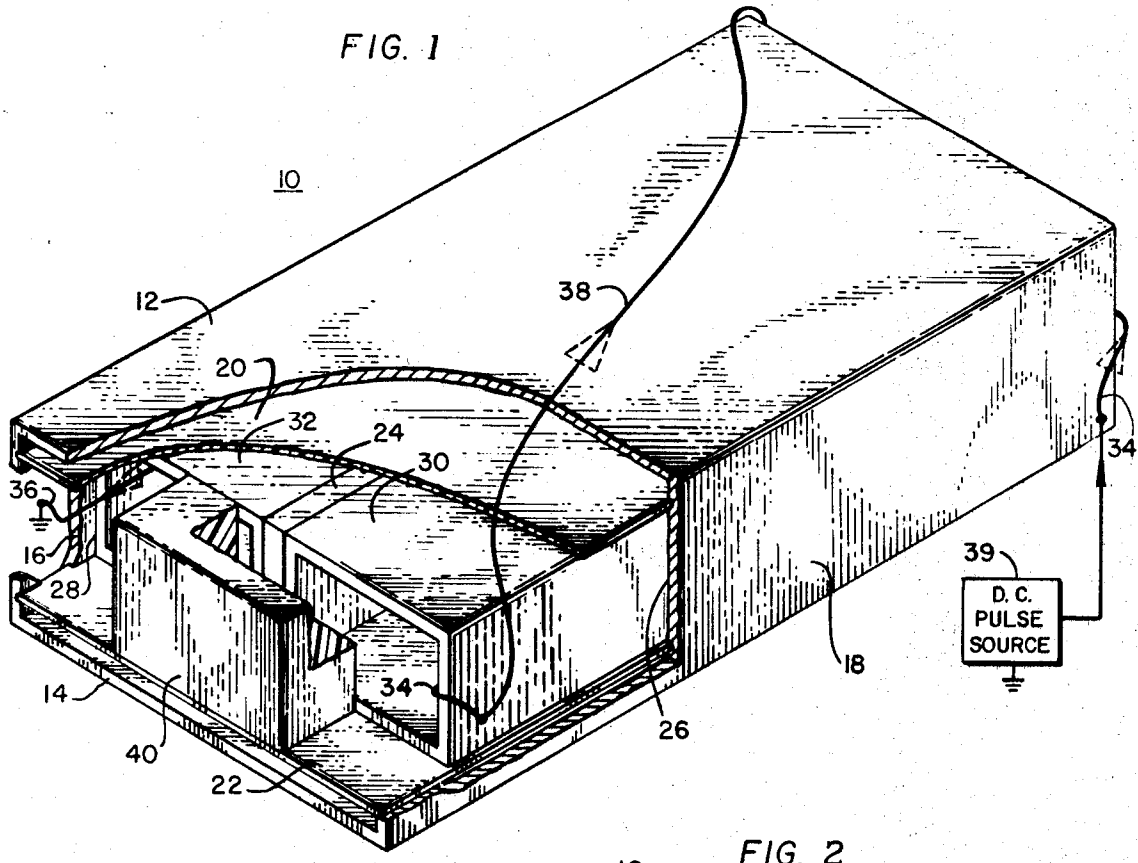


FIG. 2

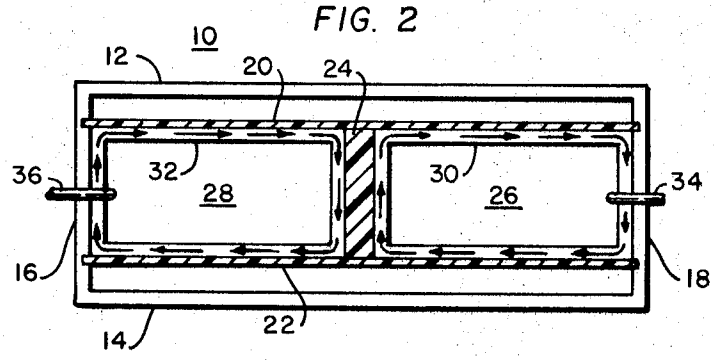
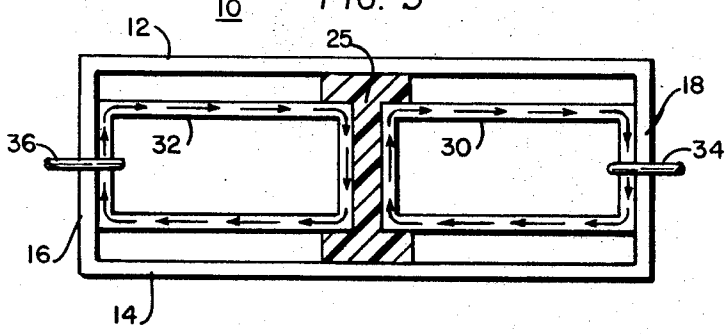


FIG. 3



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NON-RECIPROCAL WAVEGUIDE PHASE SHIFTER HAVING SIDE-BY-SIDE FERRITE TOROIDS

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U.S. Cl. 333—24.1 8 Claims

ABSTRACT OF THE DISCLOSURE

A non-reciprocal phase shifter utilizing two toroid ferrites positioned in spaced relationship longitudinally within a section of waveguide. The toroid ferrites are spaced from the top and bottom walls of the waveguide but the distal toroid ferrite surfaces are in intimate contact with the narrow waveguide side walls. A biasing magnetic means including a latching current produces magnetization in opposite directions in the respective spaced proximal toroid ferrite surfaces.

The invention described herein may be manufactured, used, and licensed by or for the Government for governmental purposes without the payment to use of any royalty thereon.

BACKGROUND OF THE INVENTION

This invention relates to microwave transmission circuits and more particularly to non-reciprocal ferrite phase shifting devices for use in microwave transmission circuits.

Magnetic materials in either metallic or insulator forms possess, to a larger or lesser degree, the tendency to remain magnitized, particularly if the material is in the form of a continuous loop. Such shapes as toroids and hollow cylinders are examples of such loops. In other words, a magnetic field magnetizes the material. After the field is removed a portion of the magnetization remains. Magnetic type ferrites have such remanent magnetized qualities and accordingly may be said to have a square loop hysteresis magnetic characteristic.

It is well known to use single full height ferrite toroids in the center of waveguides propagating microwave energy as non-reciprocal microwave energy phase shifters. Such units have proved to be efficient, multistable phase shifters which required relatively low drive power and completely eliminated the necessity of steady holding currents. However, the latching wire of such phase shifters is in the position of maximum electric field and hence is susceptible to breakdown in circumstances where phase shifters of high peak and average microwave power is required. Furthermore, intimate contact is required between the interfaces of the ferrite and the top and bottom broad walls of the waveguide to prevent possible moding and onset of corona and subsequent breakdown. It is imperative that no undue pressure be placed on a ferrite toroid which is quite magnetostrictive since the remanence magnetization of the toroid would be affected with pressure due to temperature changes.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved non-reciprocal ferrite phase shifter wherein the above noted limitations are overcome.

It is yet another object of the present invention to provide an improved non-reciprocal ferrite phase shifter which is capable of operating efficiently at relatively high peak power and high average power.

It is still another object of the present invention to provide a non-reciprocal ferrite phase shifter wherein the remanence magnetization of the ferrite is relatively stable with temperature.

In accordance with the present invention there is provided a non-reciprocal microwave energy phase shifter which includes a waveguide section having broad top and bottom surfaces and narrow side walls. Also included are a pair of spaced toroid ferrites positioned longitudinally within the waveguide section such that the distal toroid ferrite surfaces are in intimate contact with the narrow side walls. Further included are biasing waveguide means for producing magnetization in opposite directions in the respective spaced proximal toroid ferrite surfaces. The toroid ferrites are spaced from the top and bottom waveguide surfaces.

In one embodiment of the invention there is provided a unitary H-beam type structure for supporting the ferrites in position within the waveguide section, and with the cross arm of the H-beam structure being a septum separating the two toroid ferrites. The H-beam structure is made of a non-magnetic, non-conductive, low loss material having a high dielectric constant and a relatively high coefficient of thermal conductivity. The side arms of the H-beam structure are spaced from the top and bottom waveguide surfaces and coplanar therewith.

In another embodiment of the invention, the toroid ferrites are separated by an I-beam structure intermediate the top and bottom surfaces of the waveguide, with the toroid ferrites separated by and supported in the narrowed sections of the I-beam structure.

BRIEF DESCRIPTION OF THE DRAWING

For a better understanding of the invention, together with other and further objects thereof, reference is made to the accompanying drawing wherein:

FIG. 1 is an isometric drawing, partially cut away, illustrating an embodiment of the phase shifter;

FIG. 2 is a plan view partially in cross section, to illustrate the direction of magnetic fields in the ferrite toroids; and

FIG. 3 is a plan view, partially in cross section illustrating a second embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIGS. 1 and 2 of the drawing, at **10** there is shown a section of a rectangular waveguide havingrelatively wide top and bottom surfaces **12** and **14** and relatively narrow side walls **16** and **18**. Intermediate top and bottom surfaces **12** and **14** and coplanar therewith are a pair of longitudinally disposed spaced parallel dielectric plates **20** and **22** which are coextensive with the wide dimension of waveguide section **10**. The dielectric plates **20** and **22** equally spaced from the respective top and bottom surfaces **12** and **14** and are maintained in position within waveguide section **10** by means of suitable slots of channels provided therefor in the narrow side walls **16** and **18** of waveguide **10**. A relatively narrow rib or septum **24**, rectangular in cross section and made of a suitable dielectric material extends axially through waveguide section **10** and is integral with dielectric plates **20** and **22** to form a singular H-beam configuration structure. Septum **24** is coplanar with narrow walls **16** and **18**. By such an arrangement two side by side longitudinal compartments **26** and **28** are formed within waveguide **10** which are floating or spaced between the top and bottom surfaces **12** and **14** of waveguide **10**, with dielectric septum **24** common to both compartments **26** and **28**. The singular H-beam structure comprising septum **24** and dielectric plates **20** and **22** is preferably made of non-

magnetic, non-conductive, low loss material having a high dielectric constant and a relatively high coefficient of thermal conductivity. One such material is a doped beryllium oxide known by the trade name "Thermalox K." Other materials that may be used are magnesium titanate and boron nitride.

Positioned within compartment 26 and coextensive therewith is a toroid 30 of ferrite material, preferably rectangular, and dimensioned such that its respective outer peripheral surfaces are in contact with the four respective walls of compartment 26. Similarly, a toroid 32 of ferrite material is positioned in like manner within compartment 28 and coextensive therewith. Both ferrites are made of identical ferrite materials responsive to microwave RF energy and characterized by a square loop hystersis magnetic characteristic. One such ferrite is known in the art as the Al-Dy yig type ferrite. Discrete latching wires 34 and 36 extend through compartments 26 and 28, respectively. As shown, wire 34 extends longitudinally through compartment 26 close to the inner surface of the wall of toroid 30 which abuts narrow waveguide wall 18 of waveguide 10 and emerges at opposite ends of toroid 30 through holes provided therefor in narrow waveguide wall 18. Similarly, wire 36 extends longitudinally through compartment 28 close to the inner surface of the wall of toroid 32 which abuts narrow wall 16 of waveguide 10 and emerges at opposite ends of toroid 32 through holes provided therefor in narrow waveguide wall 16. The terminals of latching wires 34 and 36 are connected so that the current pulse in both latching wires is in the same direction when pulsed by a D-C source. This can be readily accomplished by connecting the wires 34 and 36 by conductor 38 as shown, and applying a D-C pulse source across the respective free ends of latching wires 34 and 36. The direction of the current flow is indicated by the dashed arrow heads. Matching boron nitride transformers as at 40 are conventionally provided at both ends of waveguide 10.

For optimum performance at X-band, septum 24 and plates 20 and 22 should have relatively narrow widths, preferably and respectively, about .042" and .025" thick; the air gaps between dielectric plates 20 and 22 and respective top and bottom waveguide surfaces 12 and 14 are about .050"; and the septum 24 and dielectric plates 20 and 22 are made in a monolithic form from material characterized by a high dielectric constant and a relatively high coefficient of thermal conductivity. Also, a suitable silicone compound may be applied to the interfaces of the dielectric septum 24 and the toroids 30 and 32, and the longitudinal slots supporting the dielectric plates 20 and 22 within waveguide 10 may be coated with a copper loaded silicone grease.

The operation of the phase shifter is best described in connection with FIG. 2. With the latching current in both ferrites in the same direction, the direction of the biasing magnetic fields or flux within each of the ferrite toroids 30 and 32 is shown to be clockwise so that the magnetization is in opposite directions on both sides of septum 24. With such an arrangement, the phase shifter will be non-reciprocal, that is, the differential phase shift with respect to the dominant propagating TE_{10} mode will be different in one direction than in the other. The degree of phase shift will, of course, depend upon the magnitude and polarity of the D-C pulsing current and the length of waveguide 10. For example, with the shown clockwise direction of the respective magnetic fields, the relative state of phase shift may be said to be 0° for a given magnitude of D-C current pulse. If the D-C current pulse is reversed, but not necessariliy at the same given magnitude, then the respective magnetic fields will be in the counterclockwise direction and, for example, a 90° differential phase shift could be achieved. The interaction between the RF magnetic field of the TE_{10} dominant waveguide mode and the magnetization in the ferrite toroids to produce the differential phase shift of the propagating electromagnetic wave is well known in the art and no further explanation thereof is believed necessary. Latching is obtained by using the square loop hysteresis characteristic of the ferrite material. Thus, after the D-C pulse is removed, the magnetization will follow the square loop hystersis curve of the ferrite material so that both ferrite toroids 30 and 32 will remain magnetized at remanence.

FIG. 3 illustrates another embodiment of the invention. Referring now to FIG. 3, where like numbers refer to like elements, the longitudinal septum 25 within waveguide 10 has an I-beam configuration and is positioned intermediate the top and bottom waveguide surfaces 12 and 14. As shown, the ferrite toroids 30 and 32 are positioned and supported on either side of the septum 25 within the narrowed portions of the I-beam configuration. As in FIG. 1, septum 25 is made of a dielectric material having a relatively high coefficient of thermal conductivity and a relatively high dielectric constant. For optimum performance silicon grease is applied to the interfaces of the ferrite toroids 30 and 32 and the narrowed I-beam walls wherein the ferrites are supported; the ferrite toroids 30 and 32 and narrow waveguide walls 16 and 18; and the I-beam septum 25 and top and bottom waveguide surfaces 12 and 14.

We wish it to be understood that we do not desire to be limited to the exact details of construction shown and described, for obvious modifications will occur to a person skilled in the art.

What is claimed is:

1. A non-reciprocal microwave energy phase shifter comprising

a waveguide section having broad top and bottom surfaces and narrow side walls, a pair of spaced toroid ferrites positioned side by side longitudinally within said waveguide section such that the distal toroid surfaces are in intimate contact with said narrow walls,

a dielectric septum separating said ferrite toroids along the longitudinal axis of said waveguide,

and biasing magnetic means for producing magnetization in opposite directions in the respective spaced proximal toroid ferrite surfaces,

said toroid ferrites being spaced from said top and bottom waveguide surfaces.

2. The phase shifter in accordance with claim 1 wherein said biasing magnetic means comprises a D-C pulse source and a current carrying first and second wires positioned along respective distal toroid ferrite surfaces, said wires being arranged such that when connected to said pulse source the latching current in each wire will be in the same direction.

3. The phase shifter in accordance with claim 1 wherein said dielectric septum is intermediate said top and bottom surfaces and comprises an I-beam configuration, with said toroid ferrites supported in the narrowed portion of said I-beam structure.

4. The phase shifter in accordance with claim 2 and wherein said dielectric septum is intermediate said top and bottom surfaces and comprises an I-beam configuration, with said toroid ferrites supported in the narrowed portion of said I-beam structure.

5. The phase shifter in accordance with claim 2 and further a unitary H-beam structure made of dielectric material, the cross bar of said H-beam structure being said septum separating said toroid ferrites, and the respective side arms of said H-beam structure being positioned and parallel with said top and bottom waveguide surfaces, respectively, and spaced therefrom.

6. The phase shifter in accordance with claim 5 and further including channels in said narrow waveguide walls for maintaining said H-beam structure in position within said waveguide.

7. The phase shifter in accordance with claim 5 wherein the unitary H-beam structure is made of non-magnetic non-conductive, low-loss material having a high dielectric constant and a relatively high coefficient of thermal conductivity.

8. The phase shifter in accordance with claim 3 wherein the I-beam structure is made of non-magnetic, non-conductive, low-loss material having a high dielectric constant and a relatively high coefficient of thermal conductivity.

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PAUL L. GENSLER, Primary Examiner

U.S. Cl. X.R.

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