United States Patent

Buck

[15] **3,680,010**

[45] **July 25, 1972**

[54] FERRITE WAVEGUIDE PHASE SHIFTER EXHIBITING NEGATIVE PHASE SHIFT

[72] Inventor: **Daniel C. Buck**, Hanover, Md.

[73] Assignee: **Westinghouse Electric Corporation**, Pittsburgh, Pa.

[22] Filed: **April 3, 1969**

[21] Appl. No.: **813,073**

[52] **U.S. Cl.** .....**333/31 A**, 333/24.1

[51] **Int. Cl.** **H01p 1/18**

[58] **Field of Search**.....333/24, 24.1, 24.2, 24.3, 31, 333/31 A

[56] **References Cited**

UNITED STATES PATENTS

3,030,593	4/1962	Aulock	333/24.1 X
3,076,946	2/1963	Hewitt	333/24.1 X
3,080,536	3/1963	Dewhirst	333/24.1
3,187,274	6/1965	Owen et al.	333/24.1 X
3,401,361	9/1968	Schloemann	333/24.1 X
3,434,077	3/1969	Heath et al.	333/24.1
3,435,382	3/1969	Agrios et al.	333/24.1 X

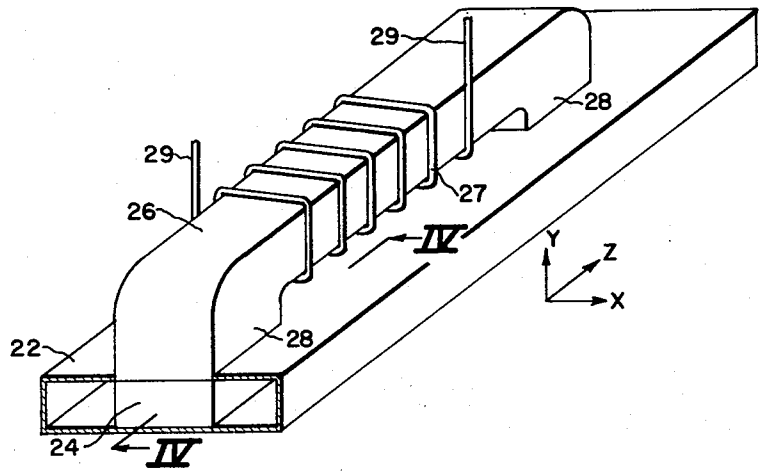
Primary Examiner—Paul L. Gensler

Attorney—F. H. Henson and E. P. Klipfel

[57] **ABSTRACT**

Described is a longitudinally magnetized, latching ferrite reciprocal phase shifter for use in wave guides having a thickness which causes the wave energy to experience a negative phase shift in passing through the ferrite, and wherein the ferrite material itself fills only the center portion of the wave guide and is longitudinally magnetized by means of coil means surrounding one or more U-shaped magnetically permeable members external to the wave guide but forming with the ferrite within the wave guide a toroid-type magnetic circuit.

9 Claims, 6 Drawing Figures



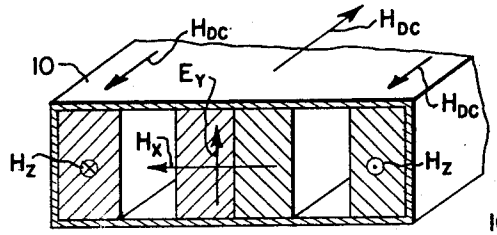


Fig. 2 PRIOR ART

Fig. 1
PRIOR ART

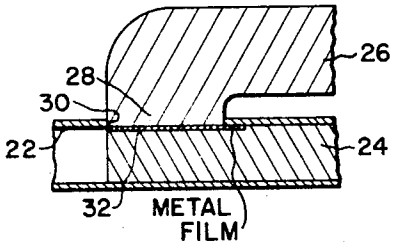


Fig. 4

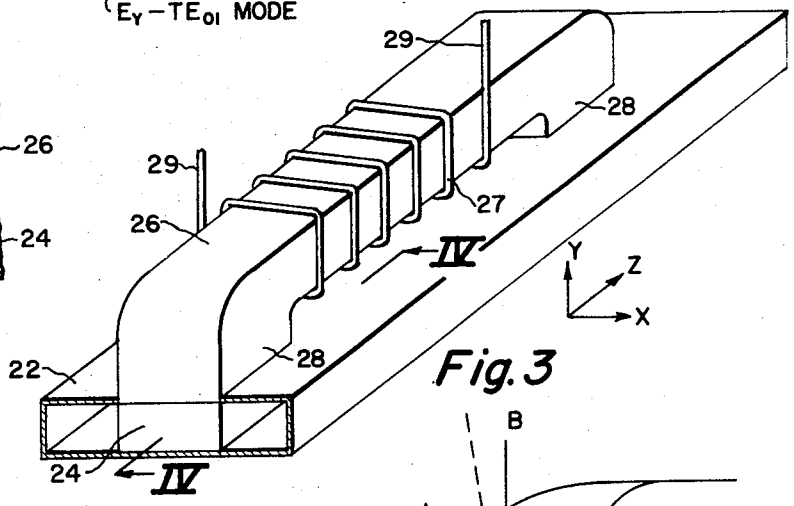


Fig. 3

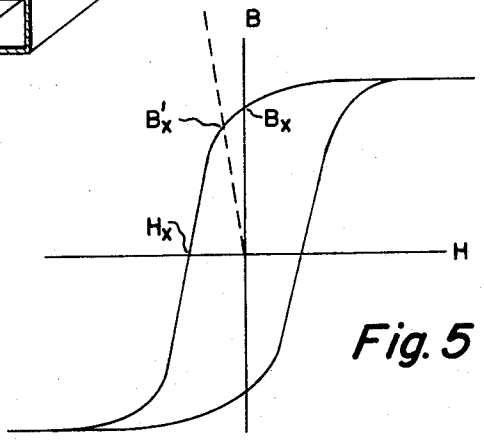


Fig. 5

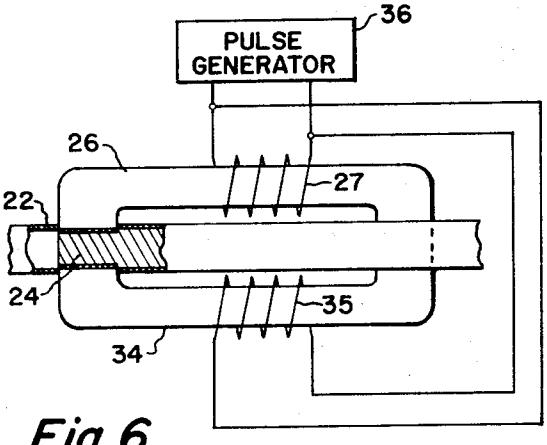


Fig. 6

INVENTOR.
DANIEL C. BUCK
BY
Ernest P. Klipfel
ATTORNEY

FERRITE WAVEGUIDE PHASE SHIFTER EXHIBITING NEGATIVE PHASE SHIFT

BACKGROUND OF THE INVENTION

Longitudinally magnetized reciprocal ferrite phase shifters are now well known and comprise ferrite bodies of various shapes disposed within a wave guide and provided with a latching coil, usually a single turn of wire, which produces a saturating magnetic field within the ferrite. Recently, it has been shown that such phase shifters show anomalous behavior in that some devices show increasing phase shift with increasing applied field, while others show decreasing phase shift with increasing applied field. When the thickness of the wave guide (i.e., its dimension perpendicular to the broad walls) is below a certain critical value, the phase shift experienced is negative in that the phase decreases with applied magnetic field. On the other hand, when the thickness of the wave guide is above the aforesaid critical thickness, the phase shift is positive and the phase increases with applied magnetic field.

It can be shown that there are two competing mechanisms which govern the type of phase shift. These can be termed "μ-effective" and "Faraday rotation." The former mechanism is effective when the thickness of the wave guide is below the aforesaid critical value; while the latter sets in when the guide is thick enough to support a cross-polarized electric field of the same order of magnitude as the incident electric field.

To date, most latching reciprocal wave guide phase shifters have been incorporated into "thick" wave guides in which the ferrite produces a positive differential phase shift. In such devices, the entire ferrite toroid is placed within the wave guide since, among other reasons, optimum positive phase shift is acheived when the ferrite does not touch any of the guide walls. However, since the return path of such devices is in regions of the guide in which the alternating current magnetic field is parallel to the direct current applied field, this part of the ferrite acts as a dielectric filling in the guide and degrades the phase shift by dielectric loading. Thus, such prior art phase shifters as applied to electrically "thick" wave guides are inherently inefficient in operation.

SUMMARY OF THE INVENTION

As an overall object, the present invention seeks to provide a new and improved latching reciprocal ferrite phase shifter for electrically thin wave guides in which wave energy experiences a negative phase shift in passing through a longitudinally magnetized ferrite body.

More specifically, an object of the invention is to provide a latching ferrite phase shifter of the type described wherein the ferrite body occupies only the central portion of the wave guide and is longitudinally magnetized by means of one or more U-shaped members external to the wave guide and provided with encircling latching coils means.

In accordance with the invention, a latching ferrite phase shifter is provided comprising a wave guide section having a ferrite body centrally disposed therein and having a thickness in the direction parallel to the electric vectors of incident wave energy which is small enough to cause wave energy to experience a negative phase shift in passing through the ferrite. Openings are provided in the long transverse dimensional walls of the wave guide section at opposite ends of the ferrite body. These openings receive the legs of a U-shaped member of magnetically permeable material provided with an encircling latching coil.

In order to continue the wave guide wall in the area of the openings, the ferrite body, which is in engagement with the top and bottom walls of the wave guide section, is provided with a metallic coating, preferably formed by vacuum deposition or plating techniques. This coating, being interposed between the ends of the legs of the U-shaped member and the ferrite body, introduces points of magnetic reluctance into the closed magnetic circuit comprising the ferrite body itself and the external U-shaped member. However, by having highly polished ferrite surfaces and by keeping the thickness of the metal coatings small as possible, but greater than a microwave skin depth, the magnetic reluctance introduced by the coatings results in only a very small degradation in remanent magnetization.

The ferrite body, for maximum negative phase shift, extends all the way from the top to the bottom wall of the wave guide section and must be thin compared to the plane wavelength in an extended, non-tensor, ferrite dielectric medium. In this respect, the ferrite thickness should be no greater than about 0.13 times the aforesaid plane wavelength.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIG. 1 is an illustration of a prior art phase shifter for electrically thick wave guide sections and incorporating a pair of ferrite bodies in the form of toroids;

FIG. 2 is a cross-sectional view taken along line II—II of FIG. 1;

FIG. 3 is an illustration of one embodiment of the latching ferrite phase shifter of the present invention;

FIG. 4 is a cross-sectional view taken along line IV—IV of FIG. 3 showing the evaporated or plated film in the magnetic flux path for the ferrite body of the present invention;

FIG. 5 is a hysteresis curve illustrating the operation of the ferrite phase shifters of the invention; and

FIG. 6 is an illustration of another embodiment of the invention employing two U-shaped magnetically permeable members external to the wave guide.

With reference now to the drawings, and particularly to FIGS. 1 and 2, a prior art latching ferrite phase shifter is shown comprising a wave guide section **10** containing a pair of ferrite toroids **12** and **14** in side-by-side relationship. Passing through the openings in each toroid is a latching wire **16** or **18**. When direct current pulses are applied to the latching wires **16** and **18**, direct current magnetic fields H_{DC} are generated in the two toroids **12** and **14**. Note that the direct current magnetic field H_{DC} in toroid **12** flows in a counterclockwise direction; while that in toroid **14** flows in a clockwise direction, the two direct current magnetic fields moving in the same direction along the abutting center legs of the toroids identified in FIG. 1 as the "active region."

The electric field, E_Y, of the incident wave energy is perpendicular to the long transverse dimension of the wave guide; while the magnetic field associated with the wave energy rotates in a path at right angles to the electric vectors E_Y. The traveling magnetic field defines a closed loop and is divided into two portions, H_X being that portion which moves transverse to the direction of wave propagation and H_Z being that portion which travels parallel to the direction of wave propagation.

It can be seen that the return magnetic path in such devices is in regions of the wave guide section in which the alternating current magnetic field, H_Z, is parallel to the direct current applied field H_{DC}. As a result, this part of the ferrite (i.e., the outer legs of the toroids) acts as a dielectric filling in the guide, and degrades guide, phase shift by dielectric loading. The coupling coefficient is proportional to the relative cross-sectional guide area occupied by the active part of the ferrite, this being identified in FIG. 1 as the "active region" and comprising the abutting legs of the toroids **12** and **14**. In general, phase shift in a device such as that shown in FIG. 1 is due to coupling from the incident TE_{01} mode to a cross-polarized TE_{10} mode, which is beyond cutoff, and therefore evanescent.

It is well known that optimum positive phase shift in an electrically thick wave guide such as that shown in FIGS. 1 and 2 is achieved when the ferrite does not touch any of the guide walls. It should not touch the side walls because of the dielectric loading effects discussed above in the region where the applied direct current magnetic field is parallel to the alternating current magnetic field. The ferrite should not touch the top and bottom broad guide walls because the fields in the region of the walls are not free to rotate due to the condition $\bar{n} \times \bar{E} =$

0 and $\bar{n} \times \bar{H} = 0$ of the conducting walls, where $\bar{n}$ is a unit vector normal to the wall.

One embodiment of the present invention is shown in FIGS. 3 and 4 and comprises a wave guide section 22 in which the dimension along the Y-axis is less than that in the prior art device shown in FIG. 1 such that wave energy passing through the guide will experience a negative, rather than positive, phase shift in passing through a ferrite body 24 centrally disposed within the wave guide section 22. Typical dimensions of the guide are 0.040 inch in the Y-direction and 0.5 inch in the X-direction. Ordinarily, the Y-dimension of the wave guide section 22 will be less than one-quarter wavelength; however this is not necessarily controlling, the only requirement being that the thickness of the guide be such that the aforesaid negative phase shift will occur. In contrast to the prior art device shown in FIG. 1, the ferrite slab 24 in the embodiment of the invention shown in FIG. 3 can touch the upper and lower broad side walls with no degradation in performance. This is true because here the phase shift is due only to changes in effective permeability of the ferrite medium. As a result, the toroid of the latching magnetic circuit can be completed outside the wave guide, thereby eliminating many of the disadvantages of the embodiment of FIG. 1, making use of the fact that no degradation in performance is obtained when the ferrite is brought up to the guide wall as is the case in other reciprocal latching designs.

Thus, a U-shaped magnetic member 26 formed from ferrite or other suitable soft magnetic material is provided outside the wave guide section 22 and has downwardly depending legs 28 which extend through openings 30 (FIG. 4) formed in the upper wall of the wave guide. Plated or evaporated onto the upper surface of the ferrite block 24 in the area of the openings 30 are metal coatings 32. Such coatings will, in effect, form a continuation of the wave guide wall; but, at the same time, will present very little magnetic reluctance in the magnetic circuit comprising the ferrite block 24 and the U-shaped member 26. In order to reduce the effective magnetic reluctance in the magnetic circuit, the ferrite surfaces are preferably highly polished; and the metal film thickness is maintained as small as possible. At X-band, for example, the metal thickness can be about 0.1 mil thick. The magnetic reluctance is then of the order of about 4×10^{-4} oersteds per gauss. For typical ferrites, this results in only a small degradation in remanant magnetization. Surrounding the U-shaped member 26 is a latching coil 27 having terminals 29 adapted for connection to a pulse generator 1 not shown. The magnetic reluctance of the metal film can be further reduced by making it of a soft ferromagnetic metal whose remanant flux density B_r is greater than that of the ferrite. The metal film thickness should be greater than a skin depth to avoid microwave energy from leaking through to the U-shaped member. This will also reduce microwave insertion loss.

Assume, for example, that the hysteresis loop for the ferrite material 24 is as shown in FIG. 5 wherein the coercive force, H_X, may be in the order of about 2 to 5 oersteds and the remanent flux density, B_X, without considering the metal films 32 in the magnetic circuit, is 2,000 gauss. Assuming that the reluctance of the gap is 4×10^{-4} oersted per gauss, the remanant flux density is then reduced to a lower value B'_X, but this is only about 0.8 oersted which is much less than the coercive force of the material.

The ferrite block 24, for maximum negative phase shift, in which case it can extend all the way to the top and bottom walls of the wave guide, should be no thicker than about 0.13. λ_D where λ_D is the plane wavelength in an extended, non-tensor, ferrite dielectric medium.

In FIG. 6 another embodiment of the invention is shown in which elements corresponding to those of FIG. 3 are identified by like reference numerals and wherein a second U-shaped magnetically permeable member 34 is provided on the underside of the wave guide section 22 and extends through openings in the bottom guide wall to engage thin metal films provided on the underside of the ferrite, similar to that shown in FIG. 4. A second latching coil 35 surrounds the member 34 and is connected, along with coil 27, to a common pulse generator 36. Thus, two return paths are provided for the magnetic flux passing through the ferrite body 24.

Although the invention has been shown in connection with certain specific embodiments, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention.

I claim as my invention:

1. In a latching ferrite phase shifter, the combination of a rectangular wave guide section having broad side walls and narrow side walls and having disposed therein a rectangular ferrite dielectric body whose cross section has a major dimension and a minor dimension with its major dimension being parallel to and centered along said broad side walls and having its minor dimension orthogonal to said broad side walls, said minor dimension of said body and the dimension of said narrow side walls of said wave guide section being no greater than substantially 0.13 times the wavelength in said dielectric body, said minor dimension causing incident wave energy to experience a negative phase shift in passing through said ferrite dielectric body, said ferrite body extending between, and in contact with said broad walls, openings in at least one of said broad walls opposite the ends of said ferrite body, a generally U-shaped member of magnetically permeable material having legs extending through said openings and forming with said ferrite body a closed magnetic circuit, a latching coil encircling said U-shaped member to induce latched magnetic flux in said magnetic circuit.

2. The phase shifter of claim 1 wherein the electric vectors of incident wave energy are perpendicular to said broad side walls.

3. The phase shifter of claim 1 wherein said U-shaped members are formed from ferrite material also.

4. The phase shifter of claim 1 wherein said U-shaped members are formed from a soft magnetic material other than ferrite.

5. The phase shifter of claim 1 including a second U-shaped member of magnetically permeable material having legs extending through openings in a broad side wall opposite said first-mentioned openings and also forming with said ferrite body a second closed magnetic circuit.

6. The phase shifter of claim 1 wherein opposite ends of the ferrite body beneath said openings are coated with metal films which form a continuation of the wave guide wall in the areas of the openings.

7. The phase shifter of claim 6 wherein the thickness of said metal films is about 0.0001 inch.

8. The phase shifter of claim 6 wherein the metal film is greater than a skin depth in thickness.

9. The phase shifter of claim 6 wherein the film is of a soft ferromagnetic metal.

* * * * *