March 25, 1969 J. P. AGRIOS ET AL 3,435,382

RECIPROCAL MICROWAVE FERRITE PHASE SHIFTER

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FIG. 1

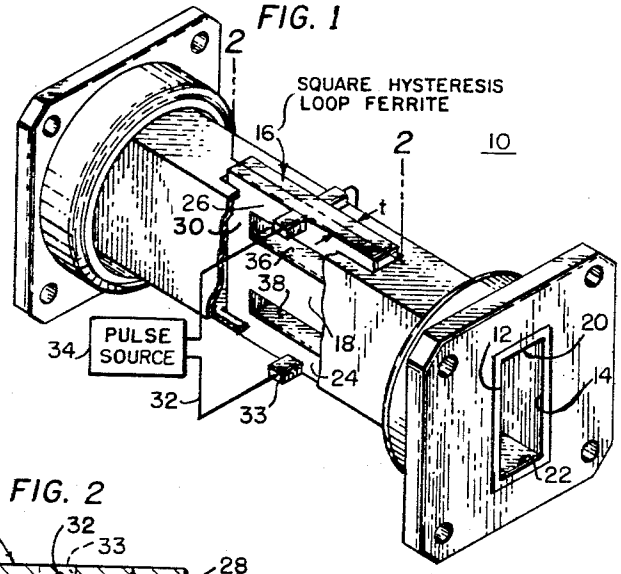


FIG. 2

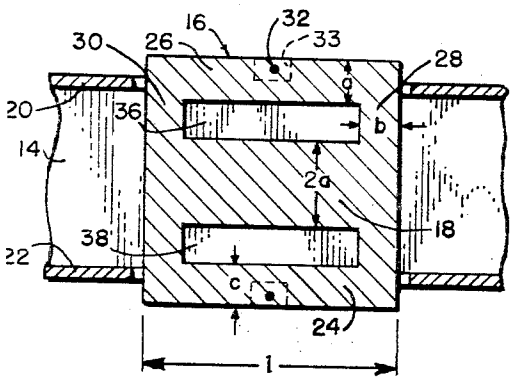
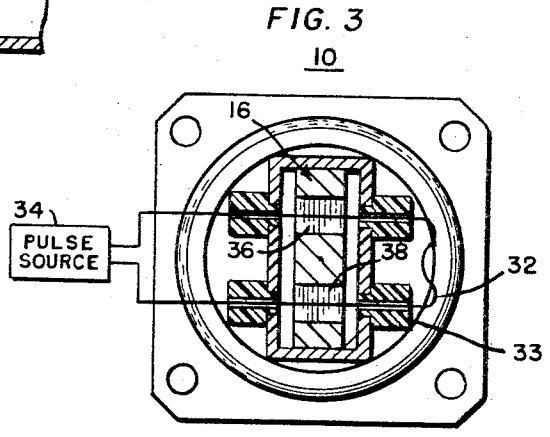


FIG. 3



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RECIPROCAL MICROWAVE FERRITE PHASE SHIFTER

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ABSTRACT OF THE DISCLOSURE

A microwave phase shifter includes a double window ferrite toroid centrally positioned within a rectangular waveguide section in a plane along the longitudinal axis of the waveguide. The ferrite material has a square hysteresis loop characteristic. A current pulse applied to the ferrite toroid determines the amount of phase shift. When the current pulse is removed the degree of phase shift is a function of the saturation magnetization at remanence.

This invention relates to reciprocal microwave phase shifters and more particularly to waveguide type microwave phase shifters utilizing ferrites.

The prior art has used ferrites with electrically controlled magnetic fields to produce various types of microwave phase shifters. One such phase shifter is shown in F. Reggia et al. Patent No. 3,212,031, issued Oct. 12, 1965. The Reggia phase shifter essentially comprises a ferrite rod located within a rectangular waveguide with a longitudinal magnetic field applied to the ferrite rod. In this type of phase shifter, the degree of phase shift is a function of the relative strength of the longitudinally applied D-C magnetic field and is also dependent on the length and physical characteristic of the gyromagnetic (ferrite) material. One of the major disadvantages of the above noted Reggia type phase shifter is the requirement of a continuous holding D-C current needed to maintain or latch the degree of microwave phase shift at a preselected value. Also, due to the continuous current requirement, a considerable amount of heat is generated which must be dissipated by some suitable means. This heat dissipation problem becomes more acute in electronically scanned antenna systems wherein the phase shifter must be mounted in close proximity to each other. Moreover, in such scanned antenna systems, the amount of D-C power required to electronically scan the antenna becomes so excessive that Reggia type phase shifters are impractical for use in light weight, low-power drain antenna systems.

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

It is another object of the present invention to provide a microwave reciprocal phase shifter which is operative by means of pulsed D-C currents.

It is still another object of the present invention to provide a microwave phase shifter wherein the degree of phase shift may be maintained or latched without the continuous application of D-C magnetizing currents.

It is still another object of the present invention to provide a microwave phase shifter wherein a ferrite toroid is longitudinally magnetized and reciprocal phase shift is affected as the ferrite toroid is magnetized between the two states corresponding to saturation magnetization at remanence and zero magnetization.

In brief, the present invention comprises a double window ferrite toroid centrally positioned within a rectangular waveguide section. The rectangular waveguide section is adapted to propagate microwave energy which is to be phase shifted, and the ferrite material has a square-loop hysteresis characteristic. Also included are means for

applying a current pulse to the ferrite toroid whereby a longitudinal magnetic field is produced in the center arm thereof and a closed magnetic loop is provided by the ferrite toroid. When the pulse is removed the remanent magnetic field is retained. The degree of phase shift is a function of the saturation magnetization at remanence and latching of the degree of phase shift is accomplished without the presence of a continuous D-C magnetizing current due to the saturation magnetization at remanence.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing in which:

FIGURE 1 is an isometric view, partially cut away, of a phase shifter embodying the invention;

FIGURE 2 is a section of FIGURE 1 taken along the lines 2—2 thereof; and

FIGURE 3 illustrates another embodiment of the invention wherein the ferrite toroid is completely within the waveguide.

Referring now to FIGS. 1 and 2 of the drawing, at **10** there is shown a rectangular waveguide adapted to propagate conventional TE_{10} mode microwave energy. Symmetrically and longitudinally positioned within waveguide **10** intermediate top and bottom waveguide walls **12** and **14** is a double window toroid section **16** made of a suitable ferrite material capable of operating in the microwave frequency ranges. The ferrite material chosen must possess rectangular loop magnetization characteristics. Double toroid section **16** is preferably square or rectangular in cross section, with the center portion **18** thereof being substantially centered between side waveguide walls **20** and **22**. As shown, the two side or branch arms **24** and **26** of double toroid **16** extend through the respective side walls of waveguide **10** and are in parallel alignment with center portion **18**. The interior surfaces of toroid side arms **24** and **26** may be plated with copper or silver to provide good continuity. If desired, the interior portions of ferrite side arms **24** and **26** may be coextensive with the interior of respective waveguide side walls **22** and **20**. The center portion **18** and side arms **24** and **26** of toroid **16** are interconnected by end arms **28** and **30** to provide a closed-lop magnetic path as hereinbelow described. By such an arrangement toroid section **16** is positioned in a plane along the longitudinal axis of waveguide **10** symmetrically spaced from the top and bottom waveguide walls **12** and **14**.

A conductor **32** extends through the exposed branch arms **24** and **26** substantially at the longitudinal centers thereof to form a loop, and has its terminals connected to a pulsed D-C current source **34**. The conductor **32** is orthogonally positioned with respect to the direction of electromagnetic waves propagated through waveguide **10**. It is to be understood of course that any suitable insulation means, as at **33**, may be used to insulate the conductor **32** from the waveguide walls. If desired, two or more conductors such as **32** may be utilized, the conductors and respective loops being equally spaced along the branch arms **24** and **26** and connected to a common pulsed D-C current source such as **34**. Although preferred, it is not necessary that all sections of the double window toroid **16** be fabricated from the same ferrite material. However, if fabricated from the same material, the dimensions *a*, *b*, and *c*, (FIG. 2) are made equal and the width of the center arm **18** (in FIG. 2) is made equal to 2*a*. Dimensions *t* and *l* will be dependent upon the desired characteristics of the microwave phase shifter.

Assuming a TE_{10} mode of electromagnetic wave enregy propagating through waveguide **10**, it can be seen that the strongest waveguide fields are concentrated within the center arm **18** of the toroid ferrite. The side

arms **24** and **26** of a toroid ferrite **16** will have a minor affect on the operation of the device inasmuch as they are located in areas where the propagated waveguide fields are weakest. To achieve a desired degree of phase shift, a D-C current pulse of predetermined amplitude is applied to conductor **32** from source **34**. Since the double toroid presents a closed-loop magnetic circuit, the application of the D-C current pulse will produce a longitudinal magnetic field in the center arm **18** of the double toroid **16** i.e., the magnetic field H produced within center arm **18** of toroid ferrite **16** is in the direction of the longitudinal dimension of waveguide **10**. For phase shifting purposes, center arm **18** may be considered as a longitudinally magnetized ferrite rod which, as is well known, is capable of achieving reciprocal phase shifts of the incident microwave propagating through the waveguide **10**. 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 hysteresis curve of the ferrite material and, as a result, the double window rectangular toroid **16** will remain magnetized at remanence. Differential phase shift is obtained by operating between the demagnetized state (zero flux) and the remanent state. By such an arrangement no current or power is used except when switching the states of magnetization, and only milliwatts of power are consumed during the switching operation. The degree of phase shift depends upon the saturation moment of the ferrite material and remanence, and also the physical dimension of the double window toroid hereinabove described.

Although FIG. 1 shows an H-plane waveguide configuration, it is to be understood that the phase shifter will operate in a similar manner for an E-plane waveguide configuration. Also, the center portion **18** of ferrite toroid **16** may be surrounded by a dielectric sleeve or the windows **36** and **38** of the ferrite toroid **16** may be completely filled with a low-loss dielectric material such as alumina. By this arrangement, the low-loss dielectric material would concentrate the propagating microwave energy near the center arm **18** of the ferrite toroid **16** and thus increase the degree of reciprocal phase shift or may sustain equivalent phase with less ferrite material, and thereby require less switching energy. It is to be understood of course that any suitable means well known in the art may be used to match the ferrite toroid **16** to the waveguide.

FIG. 3, in which like elements refer to like parts, shows another embodiment of the invention. The phase shifter of

FIG. 3 is similar to that shown in FIG. 1 except that the ferrite toroid **16** is mounted completely within the waveguide and the pulse carrying wire loop **32** is positioned within waveguide **10** and extends through the windows of the ferrite toroid.

In the embodiments shown in FIG. 1 and FIG. 3, a nonmicrowave ferrite may be used for the side arms or branches of the ferrite toroid.

While there has been described what is at present considered to be the preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is therefore aimed in the appended claim to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A reciprocal microwave phase shifter comprising,

a rectangular waveguide section having relatively wide top and bottom surfaces and relatively narrow side walls and adapted to propagate microwave energy,

a double window ferrite toroid, rectangular in cross section, centrally positioned within said waveguide section in a plane along the longitudinal axis of said waveguide section spaced from said top and bottom surfaces, the side arms of said ferrite toroid extending outside said side walls,

said ferrite having a square loop hysteresis characteristic,

and current pulsing means for producing a longitudinal magnetic field in the center arm of said ferrite toroid when energized and for retaining saturation magnetization at remanence when said current pulsing means is deenergized.

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U.S. Cl. X.R.

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