FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

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SLOT LINE NONRECIPROCAL PHASE SHIFTER

16 Claims, 5 Drawing Figs.

ABSTRACT: A nonreciprocal microwave energy phase shifter utilizing a slot line for propagating microwave energy and a ferrite member which is magnetically biased to produce a magnetic field therein which is orthogonal to and interacts with the RF magnetic field cyclically generated along the slot line. The ferrite may be in the form of a toroid to provide a closed-loop magnetic field and which is produced by a latching current.
SLOT LINE NONRECIPROCAL PHASE SHIFTER

BACKGROUND OF THE INVENTION

This invention relates to nonreciprocal microwave devices and more particularly to nonreciprocal phase-shifting devices employing a slot line for propagating microwave energy. A nonreciprocal phase-shifting device is one which will shift by a given amount the phase of microwave energy passing in one direction through the device and will shift by a different amount the phase of the microwave energy passing in the opposite direction through such device. In the microwave region, miniaturization of components becomes an absolute necessity, and since presently available phase-shifting devices are rather complicated and bulky, such devices have proved to be impractical for use in microwave circuitry.

SUMMARY OF THE INVENTION

It is accordingly an object of the present invention to provide an improved nonreciprocal phase-shifting device for microwave systems which are extremely small and light in weight.

It is another object of the present invention to provide an improved nonreciprocal phase-shifting device adapted for use with slot lines.

In accordance with one embodiment of the invention, the nonreciprocal phase shifter includes a ferrite substrate, a slot line on one surface of the substrate for propagating RF microwave energy, and means for producing in the substrate a magnetic bias field orthogonally oriented to the RF magnetic field of the propagated microwave energy. The ferrite substrate may be in the form of a toroid having a substantial longitudinal dimension and have a square hysteresis loop magnetization characteristic.

In another embodiment of the invention, the nonreciprocal phase shifter includes a dielectric substrate with the slot line on one surface of the substrate. Also included is a ferrite toroid positioned over the slot line and means for producing a closed magnetic field loop in the toroid which is characterized by a square hysteresis loop.

BRIEF DESCRIPTION OF THE DRAWING

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

FIG. 1 illustrates one embodiment of the invention;
FIG. 2 illustrates another embodiment of the invention wherein a ferrite toroid is utilized to provide a latching-type phase shifter;
FIG. 3 illustrates a modified version of the phase shifter shown in FIG. 2; and
FIGS. 4 and 5 illustrate a phase shifter in accordance with the invention wherein a dielectric substrate is utilized as the support for the slot line.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, there is shown at 10 a ferrite substrate on which is deposited, by any suitable means well known in the art, a slot line 12. Slot line 12 comprises a parallel pair of longitudinally spaced metal strips 14 separated by a very narrow slot 16. A variable DC magnetic bias field is applied transversely to ferrite substrate 10 in the direction H by any suitable means well known in the art. Microwave energy propagated along the slot line 12 sets up an RF electric field across the slot 16 and an RF magnetic field at 17 whose field lines are orthogonal to the RF electric field. Since the RF magnetic field lines curve and return to the slot 16 at one-half wave intervals they may be considered to be elliptically polarized along the longitudinal dimension thereof. With the RF magnetic field and DC magnetic bias field orthogonally oriented as shown, an interaction will occur between the RF propagating wave and the electron spins of the ferrite to cause the permeability of the ferrite to be different for the two directions of microwave propagation. While the physical length of the slot line 12 will introduce a delay or phase shift in the propagated microwave energy, the change in permeability in the ferrite superimposes on this phase shift a further phase shift hereinafter referred to as a differential phase shift. By changing the magnitude of the applied DC magnetic bias field across ferrite substrate 10, the magnitude of the differential phase shift is changed and hence a variable microwave phase shifter results. The nonreciprocal characteristic of the phase shifter is due to the orthogonal orientation of the RF magnetic field and the DC magnetic bias field which may be varied by any suitable means as, for example, by an electromagnetic actuator.

FIGS. 2-5 illustrate digital-latching-type phase shifters employing the same principles of operation as that shown in FIG. 1. In these figures like reference numerals refer to like elements. Referring now to FIG. 2, at 20 there is shown a ferrite toroid having a substantial longitudinal dimension and a square hysteresis loop magnetization characteristic. The slot line 12 is longitudinally and axially positioned on an outer surface of ferrite 20 such that the slot 16 of slot line 12 is substantially along a line parallel to the longitudinal axis of ferrite toroid 20. A single or multiple wound conductor 22 extends longitudinally through the opening 24 of ferrite toroid 20 and is looped around an inner and outer surface of the toroid as shown. The terminals of conductor 22 are connected at 28. As in FIG. 1, the DC pulsed DC current source 26. While the conductor 22 is shown looped around the toroid surface distal the slot line 12, the conductor loop 22 may also be wound around any other portions of ferrite toroid 20 which does not include slot line 12. With the pulsed DC current in the direction shown by arrow 27, the closed magnetic field path produced in ferrite toroid 20 will be that indicated at 28. As in FIG. 1, the DC magnetic bias field and the RF magnetic field of a wave propagated along slot line 12 are orthogonally oriented to provide the interaction for achieving a nonreciprocal phase shift of the RF propagated wave. Latching is obtained by using the square loop hysteresis characteristic of the ferrite toroid 20. Thus, after the DC energizing pulse is removed, the magnetization will follow the square loop hysteresis curve of the ferrite material so that ferrite toroid 20 will remain magnetized at remanence. By changing the amplitude or the pulse width of the current pulse from source 26, the remanent magnetization of ferrite toroid 20 can be changed to yield a change in the differential phase shift of the device.

In FIG. 3, slot line 12 is shown positioned longitudinally within the ferrite toroid 20 along one inner surface thereof. As in FIG. 2, the slot 16 of slot line 12 is along a line parallel to the longitudinal axis of the toroid 20 and the ferrite is energized by passing a latching DC current pulse through a suitable wire conductor 22. The latching and phase-shifting operation of the device shown in FIG. 3 is similar to that shown in FIG. 2.

In FIG. 4, the slot line 12 is positioned on a dielectric substrate 30 and the ferrite toroid 20 is positioned above the slot line 12 such that the slot 16 is parallel to the longitudinal axis of the toroid. The ferrite toroid 20 is energized by passing a DC current pulse through a suitable wire conductor 22 to provide the orthogonal magnetic bias means. RF energy propagated along slot line 12 will produce an RF magnetic field which is elliptically polarized along the longitudinal dimension of slot 12 so that it interacts with the orthogonally oriented latching magnetic bias. If desired, substrate 30 may be replaced by a second ferrite toroid magnetized in a direction opposite to that shown for ferrite toroid 20.

FIG. 5 illustrates another embodiment which employs the same principle of operation as that shown in FIGS. 1-4. Referring now to FIG. 5, the substrate 30 on which slot line 12 is longitudinally positioned is included by ferrite toroid 32. A latching current is provided by passing a DC pulse through wire conductor 22 which extends longitudinally through a central aperture 34 provided therefor in substrate 30.
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 nonreciprocal microwave energy phase shifter comprising
   a ferrite substrate,
   a slot line on one surface of said substrate for propagating
   RF microwave energy,
   and means for producing in said ferrite substrate a magnetic
   bias field orthogonally oriented to the RF magnetic field
   of said propagated microwave energy.

2. The phase shifter in accordance with claim 1 wherein said slot line comprises a pair of longitudinally spaced metal strips separated by a very narrow slot, and wherein said RF magnetic field is elliptically polarized along said narrow slot.

3. The phase shifter in accordance with claim 2 wherein said ferrite substrate is in the form of a toroid having a substantial longitudinal dimension.

4. The phase shifter in accordance with claim 3 wherein said slot is along a line parallel to the longitudinal axis of said ferrite toroid.

5. The phase shifter in accordance with claim 3 wherein the magnetization of said ferrite toroid is characterized by a square hysteresis loop.

6. The phase shifter in accordance with claim 4 wherein the magnetization of said ferrite toroid is characterized by a square hysteresis loop.

7. The phase shifter in accordance with claim 3 wherein said slot line is on one outer surface of said ferrite toroid and said magnetic-field bias-producing means is in circuit with a portion of said ferrite toroid not including said slot line.

8. The phase shifter in accordance with claim 4 wherein said slot line is on one inner surface of said ferrite toroid and said magnetic-field bias-producing means is in circuit with a portion of said ferrite toroid not including said slot line.

9. A nonreciprocal microwave energy phase shifter comprising
   a substrate,
   a slot line on one surface of said substrate for propagating
   RF microwave energy,
   a ferrite toroid positioned over said slot line,
   and means for producing a closed magnetic-field loop in said toroid, said magnetic field being characterized by a square hysteresis loop.

10. The phase shifter in accordance with claim 9 wherein said substrate is a dielectric.

11. The phase shifter in accordance with claim 10 and further including a latching current-carrying conductor extending through the aperture of said ferrite toroid.

12. The phase shifter in accordance with claim 11 wherein said ferrite toroid is above said slot line.

13. The phase shifter in accordance with claim 10 wherein said ferrite toroid surrounds said slot line and said dielectric substrate.

14. The phase shifter in accordance with claim 13 and further including a central aperture in said dielectric substrate and a latching current conductor extending through said aperture.

15. The phase shifter in accordance with claim 12 wherein the slot of said slot line is along a line parallel to the axis of said ferrite toroid.

16. The phase shifter in accordance with claim 9 wherein said substrate is a second ferrite toroid.