

[54] **MICROSTRIP-SLOT LINE PHASE SHIFTER**

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[73] Assignee: **The United States of America as represented by the Secretary of the Army**

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[52] U.S. Cl.**333/24.1, 333/31 R, 333/84 M**

[51] Int. Cl.**H01p 1/32**

[58] Field of Search**333/1.1, 24.1, 24.2, 31 R**

[56] **References Cited**

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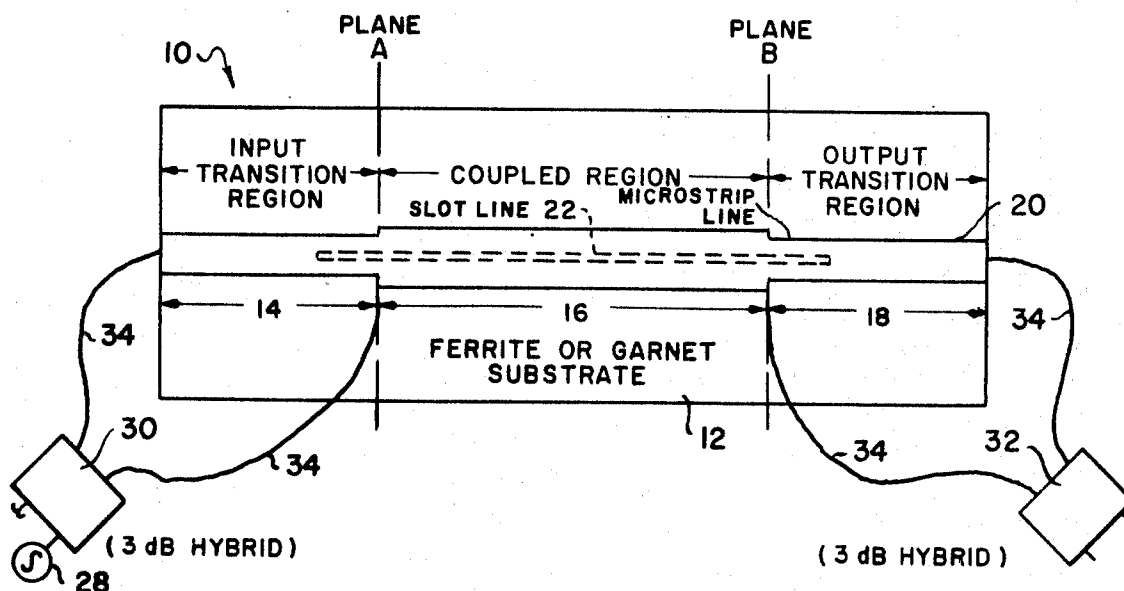
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[57] **ABSTRACT**

A microwave-integrated-circuit phase shifter comprising a dielectric substrate such as ferrite, one side being metallized to form a slot line and the other being metallized to form a parallelling microstrip transmission line, the two lines being coupled together through the dielectric substrate. A region of circular polarization of the input signal is set up between the lines and a magnetic field which is adjustable in amplitude is applied in the direction of the two lines. Variation of the amplitude of the magnetic field varies the amount of phase shift between the input and output of the device.

8 Claims, 5 Drawing Figures



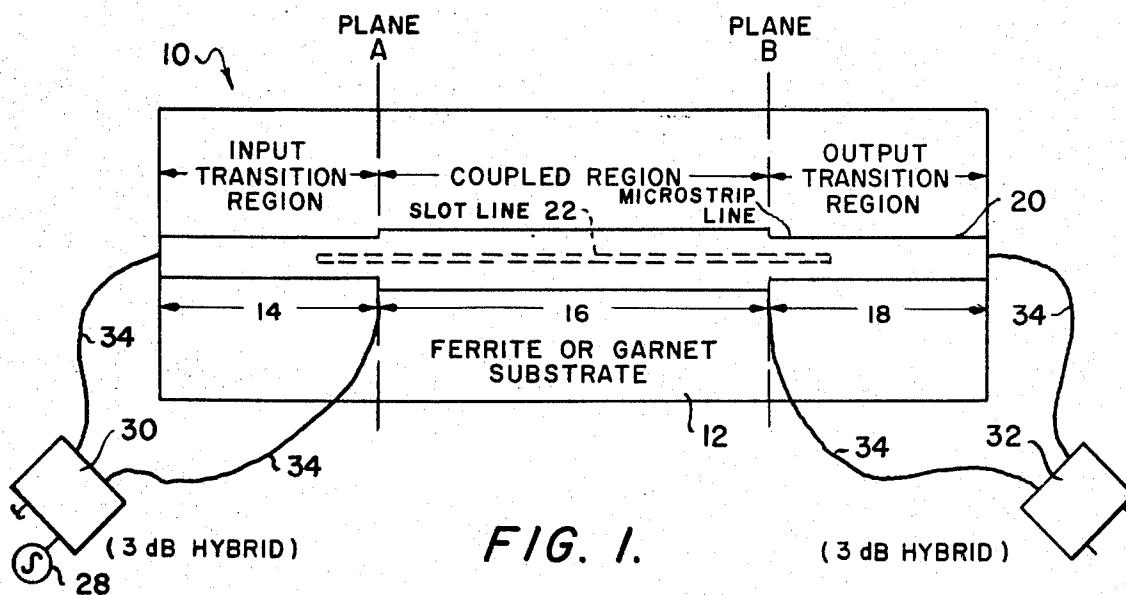


FIG. 1.

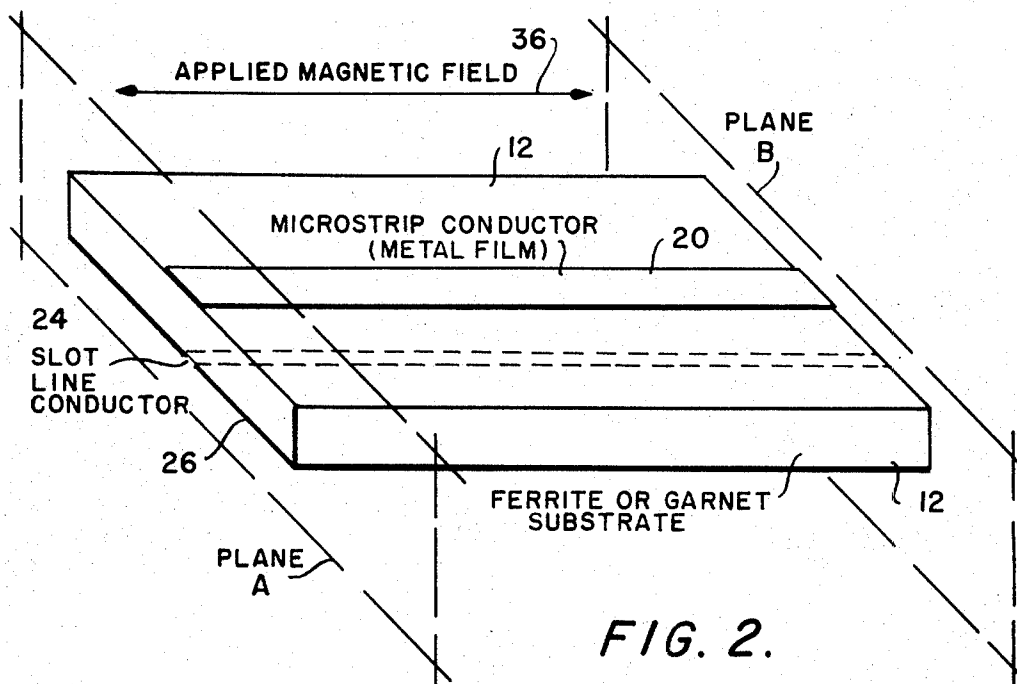


FIG. 2.

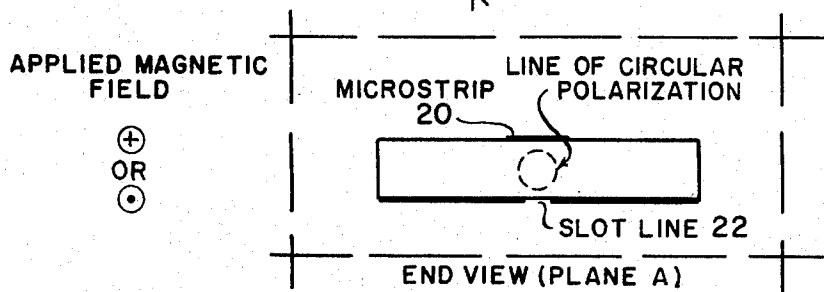


FIG. 3.

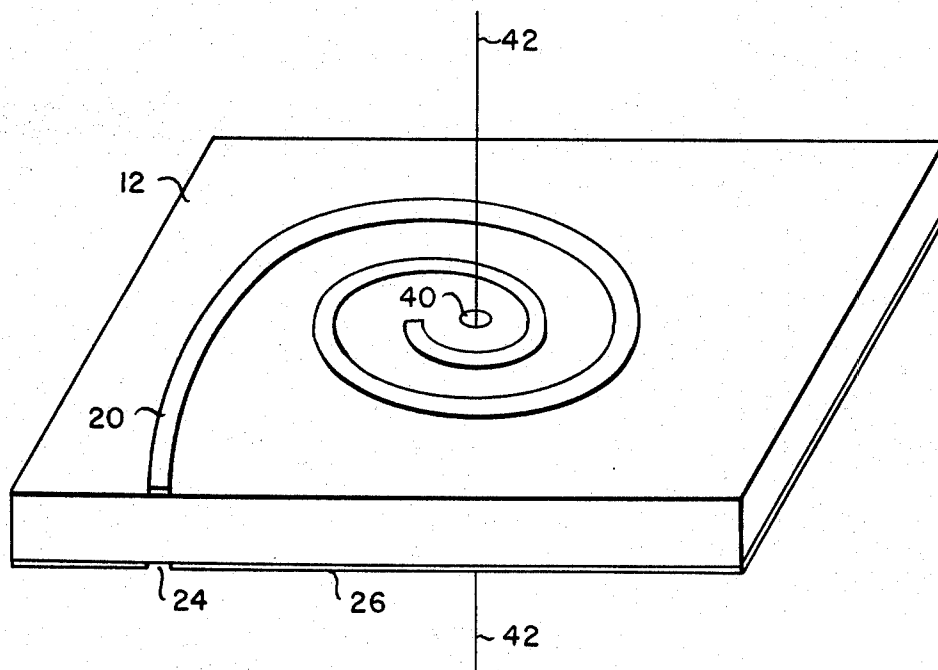


FIG. 4.

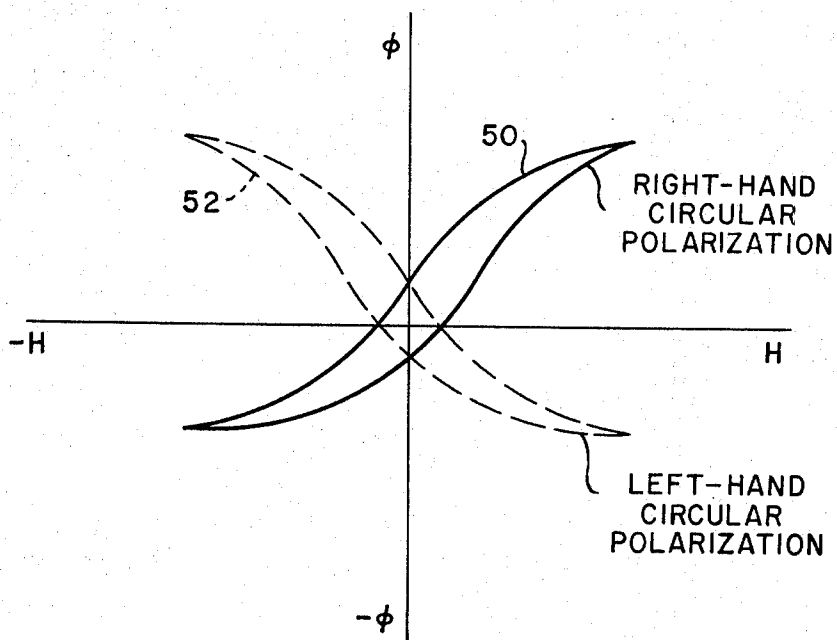


FIG. 5.

MICROSTRIP-SLOT LINE PHASE SHIFTER

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates to phase shifters and especially to a microwave-integrated-circuit (MIC) phase shifter utilizing a combination of a microstrip and a slot transmission line in conjunction with a variable-strength magnetic field.

Modern electronics has been exploring the potentialities of extremely small and thin circuits for application to such fields as radar and electronic counter measures. The conventional planar phase shifters which have been devised so far have low figures of merit (low degree of phase shift per db of loss) and rather limited bandwidths. A MIC phase shifter with a wide bandwidth and higher figure of merit capable of both reciprocal and non-reciprocal phase shifting is a constant goal of workers in this area of electronics.

It is therefore an object of this invention to provide a MIC phase shifter with a larger bandwidth.

Another object is to provide a MIC phase shifter with a better figure-of-merit than has hitherto been available.

A further object is to provide a MIC phase shifter adaptable to both reciprocal and non-reciprocal phase shifting.

SUMMARY OF THE INVENTION

The objects and advantages of this invention are provided by a MIC consisting of a ferrite-type substrate slab having thin films on opposite sides, the film on one side forming a slot line and on the other side a microstrip transmission line paralleling the slot line. The input r.f. signal is split into two signals differing by 90° in phase and these are applied to the transmission lines so that a circularly polarized r.f. magnetic field is formed in the coupled region of the lines. An adjustable magnetic field is applied to the device in the direction of the paralleled transmission lines. The output of the lines is then recombined into a single r.f. signal the phase of which differs from that of the input signal by an amount depending on the magnitude of the applied magnetic field.

Other objects, advantages and novel features of the invention will become apparent from the following description of the invention when considered in conjunction with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of an embodiment of the invention;

FIG. 2 is an isometric view of the coupled region of the substrate;

FIG. 3 is an end view of the coupled region schematically indicating the circular polarization of the r.f. field;

FIG. 4 is a schematic illustration of the coupled region of another embodiment of the invention; and

FIG. 5 is a curve of the phase versus magnetization curve for the dielectric substrate.

DETAILED DESCRIPTION OF THE INVENTION

The invention comprises a slot transmission line and a microstrip transmission line formed on a slab of dielectric substrate. The device 10 is shown in top view in FIG. 1, the coupled region portion of FIG. 1 (the region between planes A and B) being shown in isometric view in FIG. 2. The substrate 12 is a slab or wafer of dielectric material, preferably ferrite or garnet; the important property of the substrate is that it has tensor permeability. It is believed that the tensor permeability produces a phenomenon analogous to Faraday rotation which provides the phase shift in the device. Three regions are formed on the substrate 12: first, an input transition region 14 from the left end (as seen in FIG. 1) to plane A; second, a coupled region 16 from plane A to plane B; and third, an output transition region 18 from plane B to the right end. (Planes A and B are planes passed vertically through the substrate.)

The microstrip line 20 is a thin conductive film laid on the top side of the substrate 12 and the slot line 22 comprises a slot 24 formed in the conductive film 26 covering the bottom of the substrate. (This can be seen clearly in FIGS. 2 and 3.) The slot 24 continues into the input and output transition regions 14 and 18. The microstrip-line width in this embodiment is smaller in the transition regions than in the coupled region 16, although this is not necessarily so (this depends on impedance relations). The coupled region 16 is the region in which the two lines parallel each other and are coupled together, i.e., the fields of the two lines couple in this region to form a circularly polarized electromagnetic field (or, more generally, an elliptically polarized field). (See FIG. 3).

The remainder of the apparatus comprises an r.f. generator 28, an input hybrid junction 30 and an output hybrid junction 32, as well as coaxial cables 34 for coupling signals from the junctions to the lines and vice versa. An r.f. signal is fed from the generator 28 to the input hybrid junction 30. Here it is divided into signals of equal amplitude, preferably, which are 90° out of phase. One signal is coupled to the slot line 22 and the other to the microstrip line 20. The coupling is shown only schematically in FIG. 1. The transition regions 14 and 18 are used to couple from coaxial cable to slot line and to microstrip line and to couple between slot line and microstrip line. (These techniques are known in the art and are therefore not shown herein except schematically.) The ground plane is the film 26 along the bottom of the substrate 12. The portions of transmission line in the transition region do not have to be parallel as they do in the coupled region.

The two signals are coupled from the transmission lines to coaxial lines which feed into the output hybrid junction 32, where the signals are recombined to form a single output signal.

An external, d.c., variable-amplitude (i.e., adjustable in amplitude) magnetic field 36 is applied to the device so that a magnetic field exists in the substrate in the coupled region between the transmission lines; the field is parallel to the coupled section of the transmission lines. It has been found that this magnetic field 36 acts to introduce a phase shift between the recombined r.f. signal output hybrid junction 32 and the original r.f. input signal from the generator 28. The phase shift is a

function of the amplitude of the d.c. magnetic field 36 and the amount of phase shift can be varied by adjustment of the amplitude of the field 36. It is obvious that a time-varying phase shift can be obtained by applying a time-varying magnetic field 36.

FIG. 4 shows in schematic form the coupled region of another embodiment of the invention. In this embodiment, the microstrip line 20 and the slot 24 of the slot line are formed in parallel spirals around a central hole 40 through which a wire 42 extends. The wire 42 is connected to a current source (not shown), preferably to a source which provides a pulse of current. The input and output means and transition regions are not shown in this figure.

The microstrip line is open-circuited and the slot line is short-circuited at the inner end of each line. The reason for this is as follows: Assume that the wave travelling in the forward direction along the microstrip line is 90° ahead of that travelling along the slot line. The reflected wave on the microstrip line will not be changed in phase but the reflected wave on the slot line will be changed in phase by 180°. Thus, there is a +90° difference in phase between the forward waves and a -90° difference in phase between the reflected waves. Effectively what this means is that if the circular polarization for the forward waves is assumed to be right-hand circular polarization, this has been converted to left-hand circular polarization for the reflected waves (since the direction of the external field is not altered). This permits operation in the high-phase-shift region of the phase-shift v . magnetization curve, ϕ v . H, (see FIG. 5) of the dielectric thus providing a greater amount of phase shift for the device. (For the reflected wave, the dotted ϕ v . H curve 52 would be operative since the reversal of direction of travel would, in effect, amount to making the magnetization, H, negative if the direction of the field were considered to be positive for the forward direction of travel. It should be noted that for the right-hand circular polarization curve 50, operation in the negative magnetization region provides a smaller phase shift per unit of H than does operation in the positive magnetization region.)

This device can be operated by cutting a pulse of current of predetermined strength through the wire in either direction. The strength of the current provides a certain amount of magnetization on the ϕ -H curve while the current is maintained. When the current is removed, the magnetization falls to zero but the phase shift falls to some remanent value. In magnetic theory, this would result from the molecules remaining in a partially aligned state, thereby providing a magnetic field within the coupled region between the transmission lines.

To obtain a maximum difference in phase shift, the following procedure would be employed:

1. A positive current pulse is applied to wire 42. The current pulse is of finite duration and sufficient magnitude to drive the dielectric to saturation.

2. After the current pulse is terminated, the dielectric drops to its remanent state (which is a function of the pulse magnitude). The lines have a corresponding electrical length (which provides some degree of phase shift).

3. A negative current pulse is now applied and, upon its duration, the lines will have a corresponding electrical length.

4. The difference between the two electrical lengths is the differential phase shift.

For intermediate values of differential phase shift, remanent states corresponding to minor loops on the θ -H curve are used.

Obviously many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed and desired to be secured by Letters Patent of the United States is:

1. A microstrip/slot line phase shifter comprising, in combination:

a substrate formed from dielectric material having tensor permeability;

microstrip transmission line means comprising a thin metallic film deposited on one side of said substrate;

slot transmission line means comprising a thin metallic film deposited on the side of said substrate opposite said microstrip line, said slot line film having a slot therein containing no metal;

said slot line running parallel to said microstrip line over at least a portion of its length to form a coupled region through said substrate,

input signal coupling means for coupling an r.f. signal to said transmission lines including means to split said r.f. signal into two parts which are 90° out of phase with each other and means to couple one part of the split signal to said slot line and the other part to said microstrip line;

output signal coupling means including means for combining two out-of-phase r.f. signals into a single r.f. signal and means for coupling the outputs of said slot and microstrip lines into said combining means; and

means for producing a magnetic field through the coupled region of said substrate codirectional with the direction of said transmission lines in said coupled region.

2. A phase shifter as in claim 1, wherein said substrate is formed from ferrite.

3. A phase shifter as in claim 1, wherein said substrate is formed from garnet.

4. A phase shifter as in claim 1, wherein said input r.f. signal is split into two parts of equal amplitude.

5. A phase shifter as in claim 1, wherein said magnetic field is a d.c. magnetic field.

6. A phase shifter as in claim 1, wherein said magnetic field is adjustable in strength.

7. A phase shifter as in claim 1, wherein said slot line and said microstrip line are in inwardly spiraling form along the length of the coupled region, one of said lines being short-circuited at its inner end and the other being open-circuited at its inner end;

said substrate being formed with a hole through it located at the center of the spiral, and

said means for producing a magnetic field comprises means for producing a circular magnetic field substantially codirectional with said transmission line spirals.

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8. A phase shifter as in claim 7, wherein said means for producing a magnetic field comprises a conductor running through said hole in a direction perpendicular to the plane of said transmission lines for connection to a current source.

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