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[54] **MICROSTRIP LATCHED FERRITE PHASE SHIFTER WHEREIN LATCHING PULSES PASS THROUGH GROUND PLANE**
9 Claims, 3 Drawing Figs.

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[51] Int. Cl. H01p 1/18, H01p 1/32
[50] Field of Search 333/24.1, 24.2, 1.1

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ABSTRACT: A latching ferrite phase shifter for microstrip transmission lines compatible with integrated circuits and incorporating two ferrite materials, one of which is sandwiched between the transmission line and a ground plane and the other of which is on the side of the ground plane opposite the transmission line. The ferrite material between the transmission line and the ground plane is designed to control the amount of phase shift produced by the phase shifter; while the other ferrite material on the side of the ground plane opposite the transmission line is isolated from microwave frequencies but forms a magnetic circuit with the first and has a coercive force and saturation magnetization much greater than that of the first to hold it in a magnetized state above its remanent point.

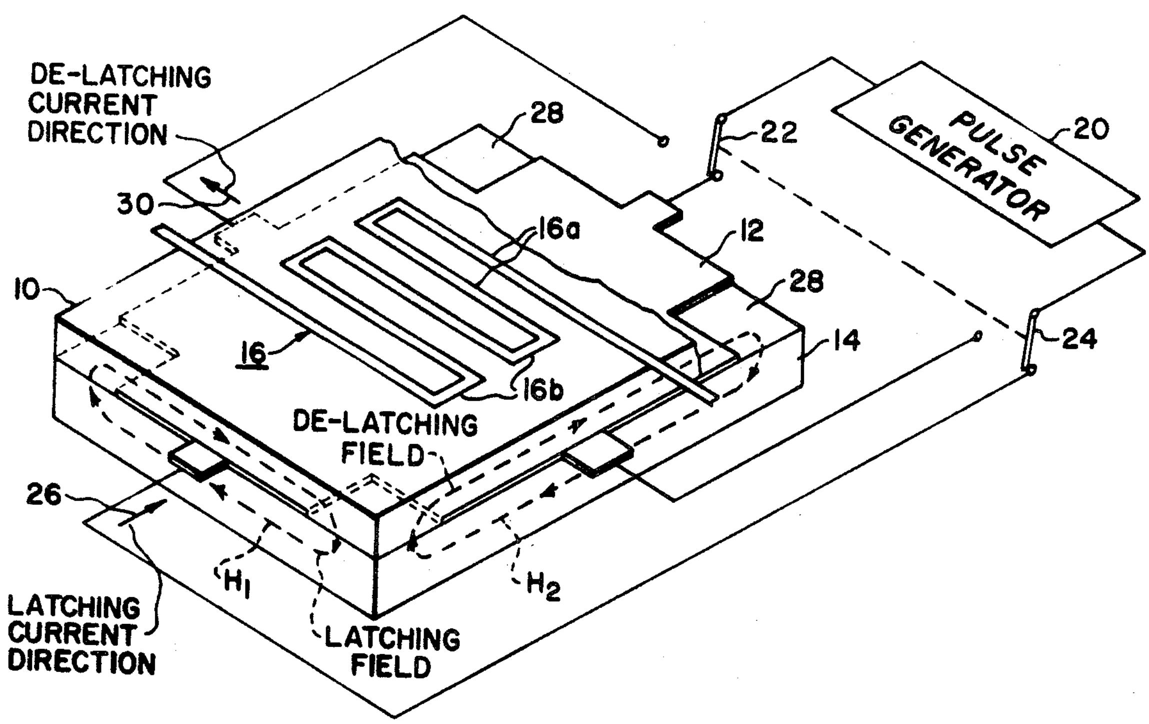
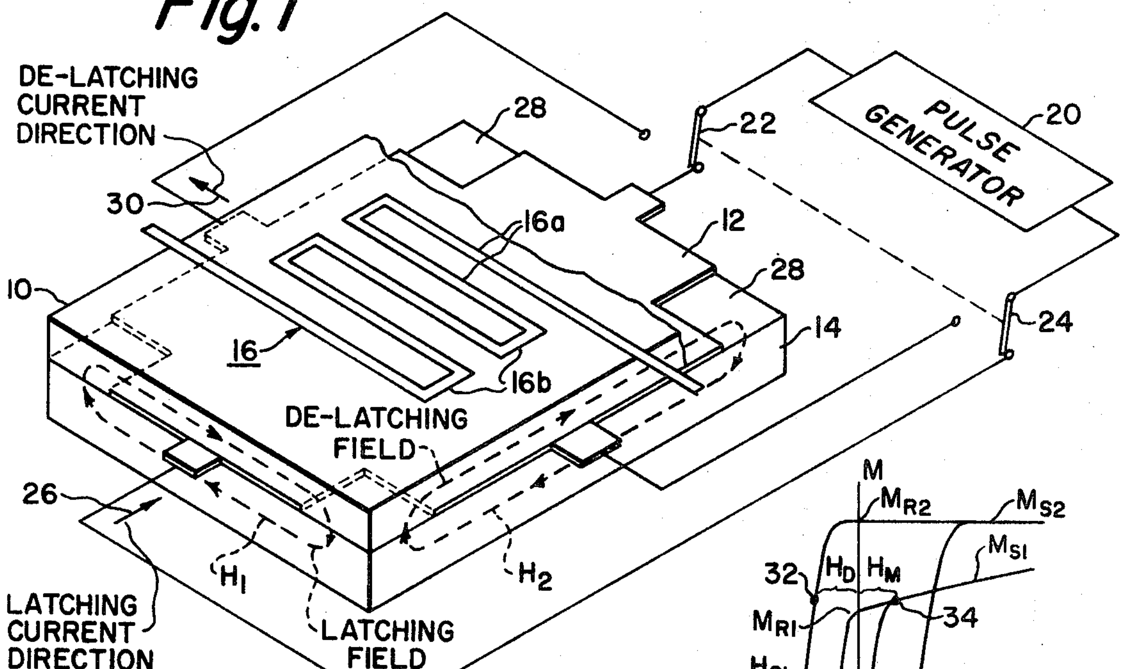


Fig. 1



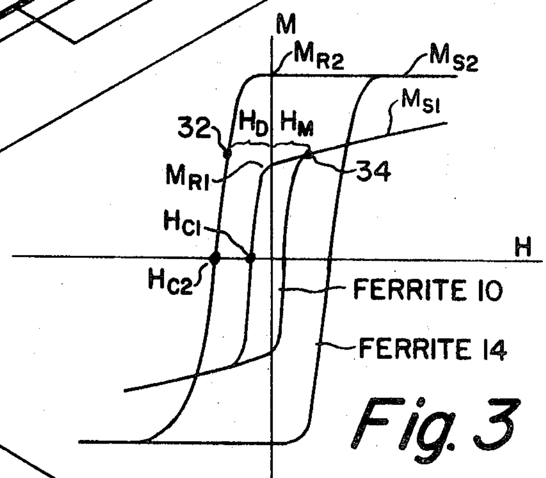
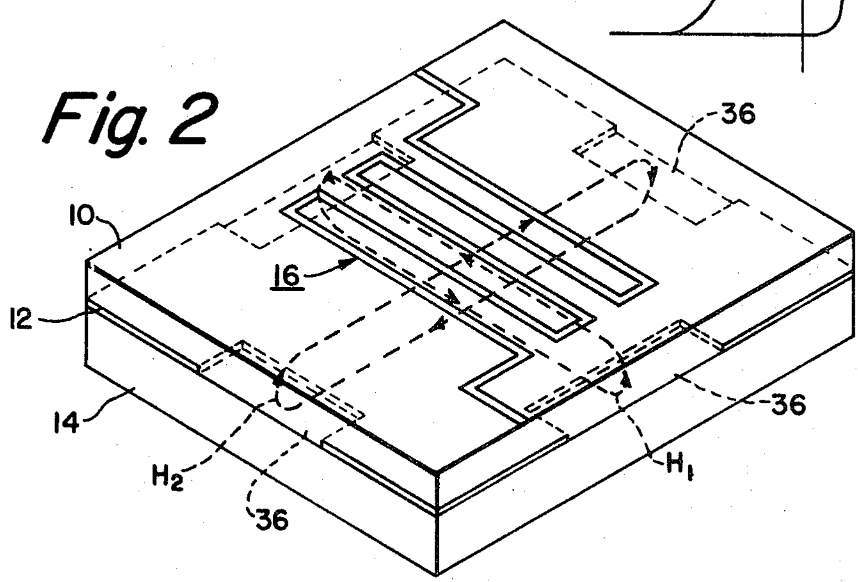


Fig. 3

Fig. 2



MICROSTRIP LATCHED FERRITE PHASE SHIFTER WHEREIN LATCHING PULSES PASS THROUGH GROUND PLANE

CROSS-REFERENCES TO RELATED APPLICATIONS

Application Ser. No. 821,344, filed May 2, 1969 and application Ser. No. 11,453, filed Feb. 16, 1970, both applications being assigned to the assignee of the present application.

BACKGROUND OF THE INVENTION

As is known, most prior art ferrite phase shifters have utilized flat slabs of ferrite material together with a biasing direct-current field. For switching, an electromagnet was sometimes used; but this resulted in relatively slower switching speeds. The development of digital latching phase shifters has eliminated the need for holding fields and has made possible submicrosecond switching speeds. In these designs, ferrite-magnetic toroids of various lengths are placed in a wave guide and latching wires passed through the centers of the toroids. By applying a current pulse of appropriate magnitude to the ends of the latching wire, the ferrite material can be driven close to saturation to effect a desired phase shift and will remain in a remanent magnetized state until a pulse of the opposite polarity is applied across the ends of the latching wire to drive the ferrite material out of its magnetized state. The toroid configuration is used since, among other reasons, it forms a complete magnetic circuit which facilitates retention of remanent magnetization once the pulse is removed.

With the availability of microwave transistors and other semiconductor devices usable at microwave frequencies, the microstrip transmission line has found wide application because of its compatibility with the fabrication and installation of passive components and active devices on the same substrate with the transmission line. Essentially, a microstrip transmission line is similar in operation to a coaxial TEM mode wave transmission line and consists of a strip of conductive material, corresponding to the center conductor of a coaxial transmission line, deposited on one side of a dielectric or semiconductive substrate, e.g., by photoresist techniques. The opposite side of the substrate is covered with a layer of conductive material comprising a ground plane and corresponding to the outer cylindrical conductor of a coaxial transmission line. With this configuration, and assuming that a source of signal wave energy is applied across the strip and ground plane on opposite sides of the substrate, an electromagnetic field pattern is established between the two.

In order to provide a latching phase shifter for such microstrip transmission lines, it is necessary to dispose the ferrite material in the space between the ground plane and the microstrip conductor itself, meaning that the thickness of the ferrite material has to be close to that of the integrated circuit substrate, a typical example being about 5 to 50 mils in the case of X-band and decreasing with increasing frequency. This poses a problem for microstrip latching ferrite phase shifters for two reasons. The first is that while the ferrite material can be driven into saturation by an appropriately applied pulse, difficulty is encountered in maintaining the flux density in the region of saturation. This is due to the fact that the ferrite film does not form a complete magnetic circuit as is the case, for example, with toroids used in conventional wave guides, and the film thickness to surface area ratio is high enough to create a demagnetizing field which reduces the effective remanent state much below the true material remanence. The second reason is that the film material must be optimized for microwave performance and to reduce insertion losses. When this requirement is satisfied, however, the material has an inadequate remanent magnetization value much below that of the saturated state.

In copending application Ser. No. 11,453, filed Feb. 16, 1970, a microstrip latching phase shifter is disclosed wherein many of the problems encountered in maintaining a ferrite film in a magnetized condition are obviated by providing a second magnetic material of higher coercive force in a magnetic circuit with the active ferrite film itself, this second material acting to insure that the active ferrite film will attain a desired degree of magnetization. This is accomplished in accordance with the teachings of that application by providing two ferrite films, one of which is in the path of the electromagnetic wave passing along the microstrip circuit and is designed to control the amount of phase shift produced by the phase shifter. The other of the ferrite materials is deposited over the microstrip conductor and exercises a magnetostatic interaction with the first, or forms a complete magnetic circuit with the first, and has a coercive force greater than that of the first to hold the first in the magnetized state. Since the coercive force of the second ferrite film above the microstrip conductor is greater than that of the active ferrite film itself, the active film can be held at a higher state of magnetization than would otherwise be the case, thereby increasing the phase shift attainable.

While the device shown in the aforesaid copending application is entirely satisfactory for its intended purpose, its performance can suffer from the fact that the electric field between the microstrip conductor in the ground plane on the other side of the active ferrite film will also intersect the upper ferrite film of higher coercive force. This means that the characteristics of the upper film, and in particular its saturation magnetization, must be optimized for microwave frequencies. For each operating frequency, there is a maximum value of saturation which can be used without encountering excessive insertion losses. This means, in effect, that the saturation magnetization of both films must be essentially the same.

SUMMARY OF THE INVENTION

In accordance with the invention, a microstrip latching ferrite phase shifter is provided incorporating two ferrite materials, one of which is in the path of an electromagnetic wave passing along the microstrip and the other of which acts as a "-keeper" to hold the first in a desired magnetized state, but wherein the second film is not in the path of the electromagnetic wave and need not be a microwave ferrite material. On the contrary, it can be optimized with respect to its magnetization characteristics only in particular, its saturation magnetization can be much greater than that of the active ferrite film.

The foregoing is accomplished by providing a second "-keeper" magnetic film beneath the ground plane of the latching circuit instead of on top of the microstrip. A separate latching wire for the phase shifter is now eliminated since the latching pulses can pass through the ground plane itself. After pulsing the ground plane, the microstrip circuit active ferrite is driven above the remanent state by the base ferrite of appropriately chosen magnetization characteristics. Preferably, the ferrites used are nickel ferrites and the ground plane is formed from gold to reduce insertion losses over those which would be encountered with other ferrite materials using platinum as the ground plane material.

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 a partially broken away perspective view of one embodiment of the invention;

FIG. **2** is a partially broken away perspective view of another embodiment of the invention; and

FIG. **3** illustrates the hysteresis curves of two typical superimposed ferrite films utilized in the invention shown in FIGS. **1** and **2**.

With reference now to the drawings, and particularly to FIG. **1**, the embodiment of the invention shown includes an active ferrite film **10** having a ground plane **12** deposited on its lower surface. Beneath the ground plane **12** is a second magnetic layer **14** which, as will be seen, acts as a "keeper" to maintain the upper active ferrite film **10** in a desired magnetized state.

Deposited on the upper surface of the active ferrite film **10** is a microwave transmission line or microstrip **16** formed as a meander line. It includes a number of convolutions having long, parallel legs **16***a* and short, parallel legs **16***b* at right angles to the legs **16***a*. The legs **16***a* define the primary direction of propagation of microwave energy through the microstrip transmission line **16**. Each of the ferrite films **10** and **14**, the ground plane **12** and the microstrip transmission line **16** may be formed by suitable deposition techniques.

As was mentioned above, the electromagnetic wave signal propagates between the ground plane **12** and the meander line **16** in the direction of the legs **16***a*. The magnetization of the ferrite film **10**, therefore, controls the phase shift in the microstrip. Since the lower "keeper" ferrite layer **14** is separated from the microstrip meander line **16** by the ground plane **12**, its characteristics, and particularly its saturation magnetization need not be optimized for microwave frequencies.

The magnetization of the films **10** and **14** is controlled by a current pulse generator **20** connected to the ground plane **12** as shown in FIG. **1** through switches **22** and **24**. When both switches **22** and **24** are in the positions shown in FIG. **1**, the current pulse will pass through the ground plane **12** in the direction of arrow **26**, thereby producing a latching field H_1 which is parallel to the direction of signal propagation along the meander line **16**. Note that the four corners of the ground plane are cut away as at **28** so that the upper ferrite film **10** contacts the lower film **14** in these areas to provide a complete magnetic circuit. The magnetic field H_1, being parallel to the direction of signal propagation, provides for maximum phase shift.

Alternatively, when the positions of the switches **22** and **24** are reversed with respect to those shown in FIG. **1**, a current pulse will flow through the ground plane **12** in the direction of arrow **30**, thereby producing a magnetic field H_2 which is at right angles to the direction of signal wave propagation. Under these circumstances, the phase shift is a minimum. Thus, by reversing the positions of switches **22** and **24**, the phase shift effected by the phase shifter can be switched from a maximum to a minimum.

The formula for differential phase shift per unit length, $\Delta\beta$, for a ferrite-loaded microstrip is:

$$\Delta\beta=\beta_d\left[1-\sqrt{\frac{1-\left(\frac{\omega m^2}{\omega}\right)}{1-1/2\left(\frac{\omega m^2}{\omega}\right)}}\right]$$

where $\beta_d=2\pi f/V_p$= phase constant for unmagnetized ferrite filled microstrip;

V_p= the microstrip phase velocity $c/\sqrt{\epsilon_r}$;

ϵ_r= relative dielectric constant of the ferrite;

ω_m=(2.8 MHz./gauss) $\times 4\pi$M; and

4πM= magnetization in gauss. Phase shift per unit length is a very steep function of the factor $\omega m/\omega$. In order to maximize the phase shift per unit length, it is necessary to operate at as high a $\omega m/\omega$ value as possible with the side condition that ω_{ms}, corresponding to $4\pi M_s$, the saturation magnetization, is not too close to the operating frequency ω. In a conventional latched phase shifter, ω_m will always be less than ω_{mr}, corresponding to the remanent magnetization. The remanent magnetization M_{mr} is always substantially less than M_{ms}, often by a factor of about 1.5, with a corresponding drastic increase in phase shift per unit length. When the phase shift per unit length is decreased, the length for 360° phase shift is increased, with a corresponding increase in insertion loss.

In the present invention, the factor $\omega m/\omega$ can be maximized by virtue of the fact that the "keeper" ferrite layer **14** is beneath the ground plane **12** and, therefore, is out of the path of the microwave energy passing along the meander line **16**. As a result, its saturation magnetization can be greatly increased. This is shown in FIG. **3** wherein hysteresis curves for the ferrite layers **10** and **14** are shown. The hysteresis curve for ferrite **14** has a much larger coercive force H_{C2} than that, H_{C1}, for ferrite **10**. At the same time, however, it has a much higher saturation magnetization M_{S2} than that of the ferrite **10**, M_{S1}. Likewise, the remanent magnetization M_{R2} of ferrite **14** is much higher than for that, M_{R1}, of ferrite **10**. The result is that by driving the ferrite **14** to point **32** on its hysteresis curve, the microwave ferrite **10** can be driven to point **34**, far above its remanent magnetization M_{R1}. As was explained above, this increases the value of $\omega m/\omega$ and reduces insertion losses.

For the case given in FIG. **3**, it is assumed that the cross-sectional areas of the layers **10** and **14**, perpendicular to the direction of flux propagation, is the same. Since the flux density in the two layers is the same, the magnetization, M, in both layers must be the same (i.e., points **32** and **34** must have the same ordinate. The demagnetizing field in layer **14**, H_D, is equal to the demagnetizing field, H_M, in layer **10**. Of course, if the thickness of layer **14** is greater than that of layer **10**, then point **34** can be higher than point **32** since the magnetization of layer **10** can be greater than that of layer **14**.

Calculations indicate that by using the system of the invention, it is possible to achieve a 37 percent improvement in figure of merit; where figure of merit is defined as phase shift divided by insertion loss. This 37 percent improvement in figure of merit assumes the use of nickel ferrites and a gold latching circuit. The importance of using nickel ferrite and a gold latching circuit arises from the fact that the latching circuit also plays the role of a microstrip ground plane and, therefore affects the insertion loss. When magnesium-manganese ferrites are employed, platinum has to be used as a ground plane because of the high reaction temperature which is above the melting point of gold. The resistivity of platinum, however, is about 6.1 times that of copper; whereas the resistivity of gold is only about 1.5 times that of copper. Consequently, the nickel ferrite-gold ground plane arrangement is highly desired over magnesium-manganese-platinum systems in order to achieve low insertion loss phase shifters; however the latter system can still be used (i.e., Mg-Mn-Pt) with improvement over prior art devices.

With reference now to FIG. **2**, another embodiment of the invention is shown wherein elements corresponding to those as shown in FIG. **1** are identified by like reference numerals. In this case, however, the corners of the ground plane **12** are not cut away. Rather, slots or notches **36** are provided at the four edges of the ground plane **12** to provide complete microwave circuits for latching field H_1 and the delatching field H_2. The connections to the pulse generator are not shown in FIG. **2**; however it will be appreciated that they are essentially the same as that shown in FIG. **1**. Note that the meander line **16** is bent so as not to lie over any of the notches **36**.

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.

We claim as our invention:

1. A latching ferrite phase shifter comprising a layer of ferrite material, a metallic microstrip conductor deposited on one side of said layer of ferrite material, a ground plane deposited on the other side of said layer of ferrite material, a second layer of ferrite material deposited on the side of said ground plane opposite said first-mentioned layer, means for connecting a source of latching pulses to two opposite sides of said ground plane, means for connecting a source of delatching pulses to the other two opposite sides of said ground plane, and connections between at least portions of said ferrite layers to provide complete magnetic circuits for the magnetic fields produced by said latching and delatching pulses respectively.

2. The latching ferrite phase shifter of claim **1** wherein said connections between portions of said ferrite layers are provided by cutaway portions at the four corners of said ground plane.

3. The latching ferrite phase shifter of claim 1 wherein the connections between said portions of the ferrite layers are provided by slots in the four edges of said ground plane.

4. The latching ferrite phase shifter of claim 1 wherein said ferrite layers comprise nickel ferrite and wherein said ground plane is formed from gold.

5. The latching ferrite phase shifter of claim 1 wherein said metallic microstrip conductor comprises a meander line.

6. The latching ferrite phase shifter of claim 1 including a pulse generator, and switch means for connecting said pulse generator alternatively to one pair of opposite sides of the ground plane and then the other pair of opposite sides.

7. The latching ferrite phase shifter of claim 1 wherein said second layer of ferrite material has a higher saturation magnetization than that of said first layer.

8. The latching ferrite phase shifter of claim 1 wherein said second layer of ferrite material has a higher coercive force and higher saturation magnetization than said first-mentioned layer of ferrite material.

9. The latching ferrite phase shifter of claim 1 wherein said second layer of ferrite material has a higher coercive force and higher saturation magnetization than said first-mentioned layer and wherein said first-mentioned layer is magnetized to a point above its remanent magnetization by a latching pulse.