Feb. 23, 1971 D. C. BUCK 3,566,311

RECIPROCAL FERRITE FILM PHASE SHIFTER HAVING LATCHING CONDUCTOR FILM

Filed May 2, 1969 2 Sheets-Sheet 1

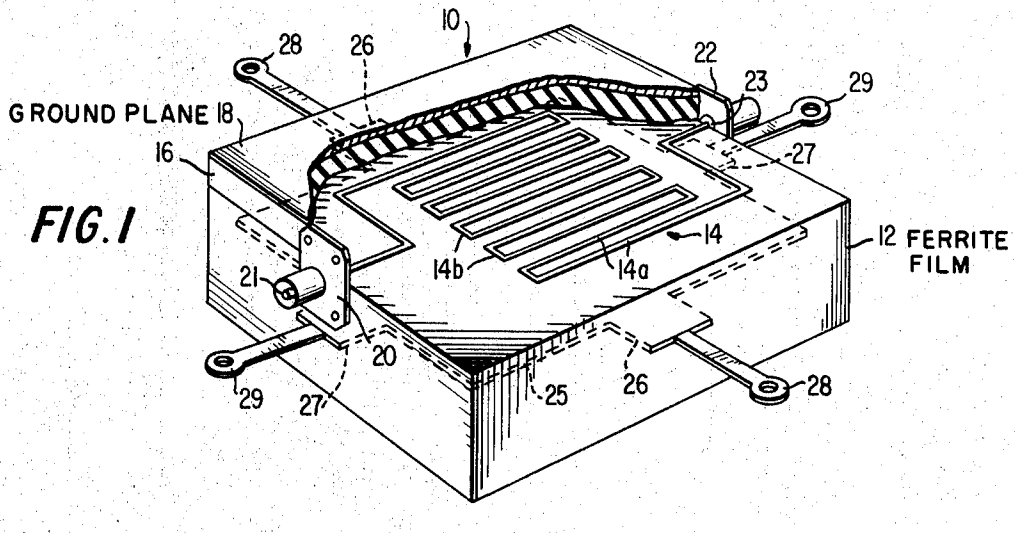


FIG. 1

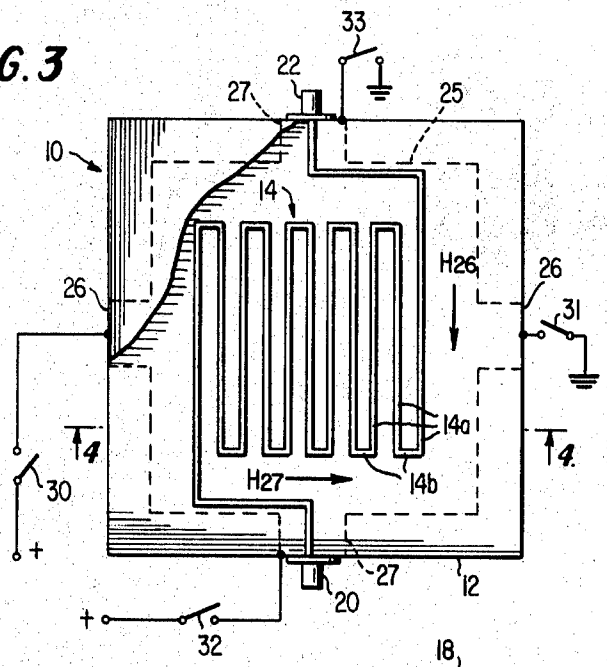


FIG. 3

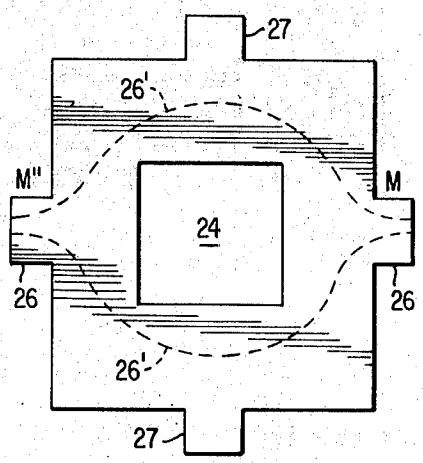


FIG. 2

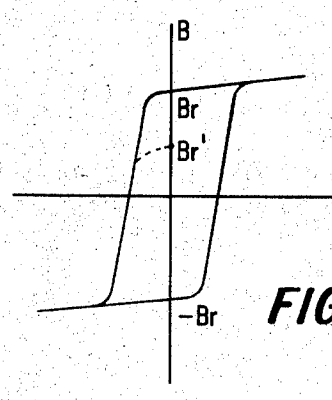


FIG. 5

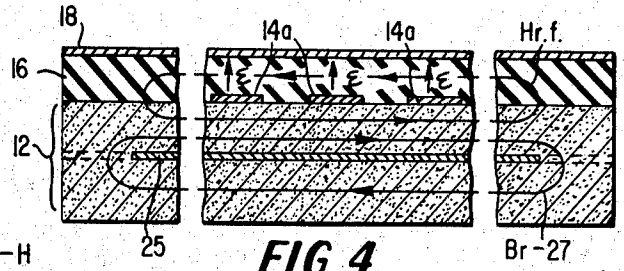


FIG. 4

INVENTOR
DANIEL C. BUCK

BY Ernest P. Klipfel

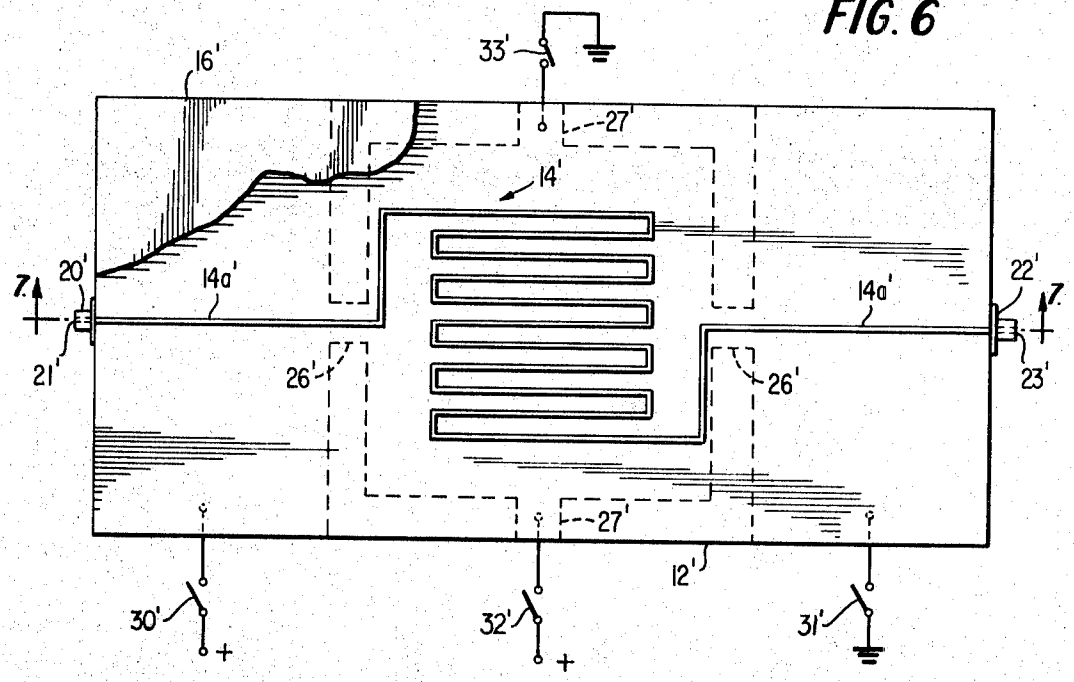
ATTORNEY

Feb. 23, 1971 D. C. BUCK 3,566,311

RECIPROCAL FERRITE FILM PHASE SHIFTER HAVING LATCHING CONDUCTOR FILM

Filed May 2, 1969 2 Sheets-Sheet 2

FIG. 6



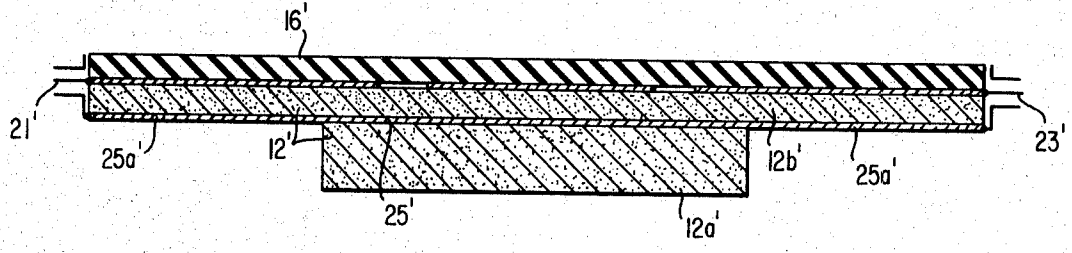


FIG. 7

INVENTOR
DANIEL C. BUCK

BY Ernest P. Klipfel
ATTORNEY

United States Patent Office 3,566,311
Patented Feb. 23, 1971

3,566,311

RECIPROCAL FERRITE FILM PHASE SHIFTER HAVING LATCHING CONDUCTOR FILM

Daniel C. Buck, Hanover, Md., assignor to Westinghouse Electric Corporation, Pittsburgh, Pa., a corporation of Pennsylvania

Filed May 2, 1969, Ser. No. 821,423
Int. Cl. H01p 1/18, 3/08
U.S. Cl. 333—31 9 Claims

ABSTRACT OF THE DISCLOSURE

The phase shifter comprises an integral structure of first and second separately deposited ferrite layers and an intermediate conducting film defining orthogonal latching current conducting paths and serving to structure the ferrite film in a double torroid configuration. A microwave transmission line includes a microstrip deposited on the second ferrite layer defining the direction of propagation of microwave energy. Energization of the conducting film for establishing a flow of latching current in a selected one of the conducting paths therein provides for flux driving the film to a remanent condition of magnetization in a corresponding, desired orientation, parallel or perpendicular to the direction of microwave propagation. Where β is the propagation constant of the microstrip, relative differential phase shift is expressed as $\Delta\beta/\beta$, and is a function of the remanent field strength in the direction of propagation. Alternate current pulsing of the conducting film to establish latching current in alternate ones of the current paths permits rapid switching between minimum and maximum relative phase shift conditions.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to a reciprocal ferrite film latching phase shifter for microwave transmission in the T.E.M. mode, and more particularly, to such a phase shifter of improved, integral construction employing a conducting film defining the latching current paths for flux driving of the ferrite film.

Description of the prior art

Heretofore in the prior art, substantial study and investigation has been made of the effects of propagation of microwave energy, particularly in ferrite-loaded microwave transmission circuits. Ferrite loading of such circuits provides for selective control of the amount of relative, or differential phase shift of the microwave energy propagated through the circuits. The amount of phase shift is a function of the frequency of the microwave energy, the circuit configuration, the characteristics of the ferrite, and the strength of the component of the D.C. magnetizing field in the direction of propagation of microwave energy through the microwave transmission circuit.

Generally, the component of magnetization in the direction of propagation of the microwave energy through a ferrite-loaded microwave transmission circuit controls the effective permeability of the ferrite to that microwave-energy propagation. This control of the effective permeability in turn controls the phase velocity of the microwave signal propagated through the circuit. By varying the effective permeability in the direction of propagation, varying amounts of differential phase shift of the microwave signal may be realized.

The applied magnetizing field for the ferrite loading element may be established either by continuous supply of a magnetizing current to suitable conductor means, such as a solenoid, associated with the ferrite element or

by a latching magnetizing current which controls the ferrite element to a remanent state of magnetization. Generally, the latching type operation is preferred since it requires less power, and the amplitude control of the magnetizing current is not as critical. Also, the latching operation is more readily adapted for digital control.

Reciprocal phase shift in a ferrite-loaded microwave transmission circuit requires that the applied D.C. magnetization be parallel to the direction of propagation of the microwave energy. By contrast, nonreciprocal phase shift results from the condition that the applied D.C. magnetization is perpendicular to the R.F. (radio frequency) magnetic field associated with the microwave propagation, and which field is elliptically polarized. This latter condition produces the nonreciprocal effect of different amounts of phase shifts for different directions of wave propagation.

As is well known, a wave guide transmission circuit cannot support a T.E.M. mode of transmission. Therefore, the condition for reciprocal phase shift cannot be realized in a ferrite-loaded wave guide. By contrast, a microstrip circuit may support a T.E.M. mode, and thus the condition for reciprocal phase shift may be realized in a ferrite-loaded microstrip circuit.

Heretofore, reciprocal latching, or remanent, ferrite phase shifters operable with T.E.M. microwave transmission systems have been very unsatisfactory in their design and effectiveness. As noted, reciprocal phase shift is achieved by applied D.C. magnetization in the direction of propagation. In general, however, a latching current cannot be developed in the direction of propagation in one of the conductors of a T.E.M. transmission system to achieve latching, because a current directed in the direction of propagation of the wave energy cannot produce a magnetic field having a component in that direction. As a result, the latching circuit configurations developed heretofore have been of complex design to assure avoidance of interference of the latching current and resultant applied D.C. magnetizing field with the microwave propagation.

One design of the prior art is the so-called coplanar type of reciprocal ferrite T.E.M. latching phase shifter. In this structure, the applied magnetization field is coplanar with the microwave transmission line. There results a poor distribution of the applied magnetizing field about the microwave transmission line or strip, and in neither state of latching for minimum or maximum relative phase shift are the fields of applied magnetization exactly parallel or perpendicular to the direction of propagation of microwave energy.

Other phase shifters of the subject type proposed heretofore have required stringent and impractical control of the dimensions and configurations of component portions of the phase shifter structures and particularly of the ferrite which sustains the remanent D.C. magnetizing field. Such devices are not only unfeasible for commercial production but also introduce undesirable and unacceptable operating parameters, such as prohibitively high insertion losses.

SUMMARY OF THE INVENTION

The foregoing and other defects of prior art reciprocal ferrite film latching phase shifters, for use with microwave transmission systems in the T.E.M. mode, are overcome by the phase shifter of the invention.

The present invention comprises an improvement of the invention disclosed and claimed in the copending application Ser. No. 821,344 entitled, "Reciprocal Ferrite Film Latching Phase Shifter," of Daniel C. Buck and Leonard Dubrowsky, filed concurrently herewith. In that invention, the latching current is supplied by pulsing of conductors received in channels provided therefor in the

ferrite film. The formation of such channels is a difficult task, where a single ferrite film is to be employed. Due to the small dimensions of the film, sophisticated techniques such as ultrasonic drilling must be used to form the channels through which the conductors must then be inserted. An alternative construction technique requires use of two separate ferrite layers at the common interface of which suitable channels are defined and which then are assembled, preferably with the latching conductors in place. Such an assembly requires accurate finishing of the juxtaposed surfaces of the two ferrite film portions to assure completion of a low reluctance magnetic path across the interface.

In accordance with the invention, the phase shifter comprises a controlled flux driven, ferrite film having a latching conductor structure formed integrally therewith, and an associated, microwave transmission line. More particularly, the ferrite film is formed in successive steps in lower and upper layers, or portions, and a conducting film defining latching current paths for flux driving of the film is found in an intermediate step between the lower and upper ferrite layers. The portions of the ferrite layers surrounding the conducting film comprise an integral structure, providing an excellent magnetic circuit or path. The successive layers of the ferrite film and the conducting film may be produced by chemical deposition techniques. The lower layer or portion, of ferrite material is deposited, preferably on a suitable supporting substrate, and next a conducting film of platinum or refractory material is deposited. The conducting film is then formed, as by conventional photoresist processes, to define the desired orthogonal latching current conducting paths, each of which is centrally located with respect to corresponding edges of the ferrite film. The second layer, or portion, of the ferrite film is then deposited. The conducting film structures the ferrite film to define effectively a double toroid which may be selectively driven to states of remanent magnetization by selectively supplying latching currents to appropriate ones of the conducting paths of the latching film. A microwave transmission line, or microstrip, is formed on the ferrite film, preferably by a deposition and conventional photoresist process, with the microstrip centrally located on the film. Preferably, the orthogonal latching conductor paths defined by the conducting film are oriented with respect to the microstrip to establish applied magnetizing fields oriented, respectively, parallel and perpendicular to the direction of propagation of microwave energy through the microstrip.

The microwave transmission line includes the microstrip deposited on the upper surface of the ferrite and a common ground plane parallel to the plane of the microstrip and spaced therefrom by a dielectric layer. In one embodiment, a dielectric layer and a ground plane are formed in successive steps on the microstrip and upper surface of the ferrite film. In another embodiment, the conducting film serves a dual function as the ground plane for the transmission line and the dielectric is provided by the upper layer, or portion, of the ferrite film.

In operation, microwave energy propagated through the microwave transmission line establishes an electrostatic field between the microstrip and its ground plane. By pulsing the conducting film to establish current flow in selected ones of the orthogonal latching current paths, there are produced corresponding and orthogonally related applied D.C. magnetizing fields for latching the film in corresponding remanent magnetized conditions of the same orientation as the applied fields. The latching currents thus provide a selectively controlled flux drive of the ferrite film to desired orientations of remanent magnetization.

The R.F. magnetic field resultant from the microwave propagation through the transmission line exists within the ferrite. The remanent D.C. field of the ferrite, produced by current pulsing through a selected latching current conductor path interacts with the R.F. magnetic field

of the microwave to produce a resultant differential phase shift.

Where β is the propagation constant of the microstrip, the relative phase shift can be expressed as $\Delta\beta/\beta$ and is a function of the component of the applied D.C. magnetization field in the direction of propagation. The phase shift β, as is well known, is a function of the frequency of the microwave transmission, and of the circuit configuration and characteristics of the ferrite, including its length in the direction of propagation. Thus, as the component of D.C. magnetization in the direction of propagation is alternated between maximum and minimum values by pulsing of the appropriate latching conductors, the relative phase shift is likewise varied between maximum and minimum amounts. The relative phase shift effect is reciprocal and does not depend on the direction of the D.C. magnetizing field but only its angle or orientation with respect to the direction of microwave propagation.

The reciprocal phase shift characteristic permits for compact design of the phase shifter by forming the microstrip into a spatially periodic circuit such as a meander line. The meander line is centrally positioned on the ferrite film, and provides maximum interaction of the R.F. and D.C. magnetization fields. However, at high frequencies such as X band, the guide wave length is so short that for applied magnetizing fields of reasonably high amplitude, the meandering is not required.

The phase shifter of the invention utilizes the desirable characteristics of latching, or remanent, magnetization and the reciprocal phase shifting effect to achieve a structure compact in size yet highly effective in producing rapidly and easily controlled phase shifting of microwave transmission in the T.E.M. mode. The structure as described provides for maximizing the orientation of the applied D.C. magnetization fields in either exactly parallel or exactly perpendicular orientations with respect to the direction of propagation of the microwave energy. In particular, the integral structure afforded by virtue of the deposited conducting film affords a more uniform distribution of the latching currents and the D.C. magnetizing fields produced thereby, and thus a more uniform region for interaction of the resultant fields of remanent magnetization of the ferrite and the R.F. magnetic fields generated by the propagated microwave. Thus, in addition to providing a simplified structure of compact size, the phase shifter of the invention is very efficient in operation and provides for highly accurate, and quickly and easily controlled phase shifting of microwave signals.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a phase shifter in accordance with the invention;

FIG. 2 is a planar view of the latching current conducting film employed in the phase shifter of the invention;

FIG. 3 is a planar, schematic view of the phase shifter of FIG. 1 with certain portions thereof broken away to facilitate an explanation of the theory of operation of the phase shifter;

FIG. 4 is a cross-sectional view of the phase shifter of FIG. 1, taken along the line 4—4 in FIG. 3;

FIG. 5 is a plot of a hysteresis curve defining the magnetization characteristics of the ferrite film employed in the phase shifter of the invention;

FIG. 6 is a planar, schematic view of a phase shifter in accordance with a second embodiment of the invention; and

FIG. 7 is a cross-sectional view of the phase shifter of FIG. 6.

DETAILED DESCRIPTION OF THE INVENTION

The phase shifter of the invention is of very compact size and relatively simple in design, yet provides for highly accurate and rapid control of relative, or differential,

phase shift of microwave energy propagated through a microwave transmission line, or microstrip, associated therewith. Further, the phase shifter provides for rapid switching between selected phase shift conditions, as described more fully hereinafter. To facilitate an understanding of the phase shifter of the invention, it has been shown in the drawings on a greatly enlarged scale, particularly in the thickness or height dimension.

In FIG. 1, the phase shifter **10** includes a ferrite film **12** of any ferrimagnetic material, and which may be formed on a support (not shown). A microwave transmission line, or microstrip **14** is deposited on the ferrite film **12**. As shown, the microstrip **14** is formed as a meander line, including a number of convolutions having long, parallel legs **14***a*, and short, parallel legs **14***b* at right angles to the legs **14***a*. The legs **14***a* define the primary direction of propagation of microwave energy through the microstrip line **14**. The spacing of the legs **14***a* preferably is approximately one-eighth the wave guide length.

A dielectric layer **16** is deposited on the surface of the film **12** and over the meander line **14**. A ground plane **18** is formed on the dielectric layer **16**. The microstrip circuit **14**, the dielectric **16**, and the ground plane **18** together provide the microwave transmission circuit of the phase shifter **10**. Suitable coaxial connectors **20** and **22** are mounted on the phase shifter **10** with a common ground connection to the ground plane **18** and having coaxial connector elements **21** and **23**, respectively, connected to opposite ends of the meander line **14**.

Each of the ferrite film **12**, the line **14**, the dielectric layer **16**, and the ground plane **18** may be formed by suitable chemical deposition techniques.

The thicknesses of the component portions of the structure are greatly enlarged in scale, and in practical circuit of the ferrite and dielectric layers **12** and **16** are of 25 to 50 mils in thickness, and the ground plane **18** may be of substantially less thickness. The meander line **14** may be less than 1 mil in thickness and 40 to 50 mils wide. For a lateral overall dimension of about two inches square for the phase shifter **10**, the meander line **14** occupies a central area of about 1½ inches square, including a total length of about five inches. The dimensions are not critical, however, and may be varied as required. The only critical limit is that the ferrite film be of sufficient thickness to avoid Faraday rotation effects.

As previously described, a conducting film is formed intermediate upper and lower portions of the ferrite film **12** to provide, or define, latching current conductor paths which are selectively energized for establishing desired orientations of the remanent magnetization of the ferrite film **12**. In FIG. 1, the conducting film is shown by hidden lines and identified by the numeral **25**. The film may be planar, and of substantially square or rectangular configuration as shown of somewhat similar dimensions than the external dimensions of the ferrite film **12**. Further, the film **25** is provided with pairs of tabs **26** and **27** which define the direction of current paths therethrough.

In FIG. 2 is shown the film **25** in a planar view with the other portions of the phase shifter **10** removed. If desired, an opening **24** may be provided in the interior of the film **25** to assure spreading of the current paths through the film and between corresponding pairs of the tabs. As illustrated, the opening **24** assures that the current paths indicated by dotted lines **26'** substantially spread throughout the dimension of the film **25**, between the associated tabs **27**. A similar spreading of the current path between the tabs **26** would occur.

Referring again to FIG. 1, the film **25** is formed as an intermediate step in the formation of the film **12**. Particularly, following deposition of a first portion or layer of the film **12**, the conducting film **25** is deposited and suitably formed, as by conventional etching processes, to the configuration as best seen in FIG. 2. The film preferably is of platinum or a refractory metal. The conducting film **25** need not be more than a few mils in thickness. If desired, prior to or simultaneously with the completion of the deposition of the film **12**, connectors as schematically illustrated at **28** and **29** may be affixed to the tabs **26** and **27** of the film **25** to provide for electrical connection to the film. Preferably, the second layer of the ferrite film **12** above the conducting film **25** is of less thickness than the portion below the conducting film **12**.

In FIG. 3 is shown a simplified and somewhat schematic, planar view of the phase shifter of FIG. 1 and in FIG. 4 is shown a cross section of the phase shifter, taken along the line **4—4** in FIG. 3. In FIG. 5 is shown a hysteresis curve of a ferrimagnetic material such as the film **12**. Reference will be had concurrently to FIGS. 3 through 5 in discussing the operation of the phase shifter of the invention.

In FIG. 3, the latching film **25** is shown by hidden lines to indicate its central location with respect to the major dimensions, or edges of the film **12** in the completed structure and also to illustrate the structuring of the ferrite film **12** resultant from the provision of the film **25** therein. Particularly, interconnected portions of the ferrite film **12** adjacent each edge thereof provide for a completed magnetic path past the boundary of the edges of the film **12** and between the adjacent edges of alternate tabs **26** and **27**. These regions effectively define a double toroid construction of the ferrite film **12**. The dual toroid construction of the ferrite film, as defined by the conductor film **25**, must be such that magnetic saturation of the ferrite film **12** does not occur in any region thereof, prior to that of the region of the film between the conductors and the plane of the meander line.

In FIG. 2 is shown the conducting film **25** including the tab pairs **26** and **27**. If desired, an opening **24** (not shown in FIG. 3 to simplify the illustration thereof) may be provided to assure spreading, or more uniform distribution of the current in an energized current path. More particularly, the film **25** is energized by supplying current thereto in a circuit including a pair of oppositely disposed tabs. Thus, there is shown by dotted lines a representative current path **26'** for the circuit including tabs **26**.

In FIG. 3, the current conducting path through the film **25** and defined by the tabs **26** is shown connected in an energizing circuit including a switch **30** at one end and a switch **31** at the other end, the latter being connected to a ground potential terminal. Similarly, the current path defined by the pair of tabs **27** is shown connected in an energizing circuit including a switch **32** at one end thereof and a switch **33** providing connection to a ground potential terminal. Each of the switches **30** and **32** is connected to a suitable energizing source, represented by a positive potential power supply terminal. Upon selective closure of each of the switch pairs **30**, **31** and **32**, **33**, a pulse of energizing current is caused to flow through the respectively associated conducting paths in the film **25** to create a coercive, or applied, D.C. magnetizing field of a related orientation for flux driving the ferrite film **12** to a state of remanent magnetization of that same orientation. The orientations of the applied magnetizing fields generated by the current pulses conducted through the paths defined by the tabs **26** and **27**, and thus of the remanent magnetization of the ferrite film **12**, are schematically represented by the flux paths labelled H_{26} and H_{27} associated with the corresponding pairs of tabs **26** and **27** which define the latching current paths.

The principal direction of propagation of microwave energy through the meander line **14** is that defined by the long legs **14***a* of the line **14**. As previously described, the ferrite film **12** exhibits reciprocal latching characteristics and thus the opposite directions of propagation of microwaves through alternate ones of the long legs **14***a* of the meander line **14** are immaterial as to the relative phase shift effected. The field H_{26} associated with the current path defined by tabs **26** thus is oriented at 0° with respect to, and thus parallel to, the primary direction of propagation of microwave energy through the meander line **14**, as

defined by the major legs **14***a*. By contrast, the magnetizing field H_{27} associated with the current path defined by tabs **27** is oriented at 90° with respect to, and thus perpendicular to, the direction of propagation and, particularly, is parallel to the short legs **14***b* of the meander line **14**. The alternate pulsing of these alternate current paths thus provides alternate directions of flux drive of the ferrite film to remanent states in these same orientations.

In FIG. 5 is shown a plot of the hysteresis curve of a magnetic medium, such as the ferrite film **12**, in accordance with an applied magnetization field, such as generated by a latching current pulse conducted by either of the latching current paths as above defined. As is well known, the strength of the applied magnetizing field H is a function of the amplitude of the magnetizing current. Further, the resultant magnetization B of the medium, such as the ferrite film **12**, is a function of the amplitude of the applied magnetizing field H, and increases with increasing values of H until magnetic saturation of the medium is reached. When the pulse terminates and thus upon reduction of the latching current to zero value, the value H of the magnetizing field similarly reduces to zero value. The magnetization of the medium then reduces to the remanent magnetization value identified as the remanent level B_r in FIG. 5. Similarly, a latching current of opposite polarity and of sufficient amplitude, creates a magnetizing field $-H$ which drives the ferrite medium to saturation in a negative direction; upon termination of the current, the medium returns to an opposite sense, or polarity, remanent level $-B_r$.

As discussed previously, the ferrite phase shifter of the invention is reciprocal, and thus regardless of the direction, or sense of the remanent magnetization, i.e., $+B_r$ or $-B_r$, which is established, the control of the relative phase shift will be in accordance with the corresponding component of magnetization oriented with the direction of propagation of the microwave through the meander line **14**. Thus, by supplying a sufficiently high current pulse to a selected one of the latching current conductor paths **26** and **27**, magnetizing fields H of sufficient intensity to drive the ferrite layer **12** to a latched condition in the corresponding orientations as previously described may produce either a maximum or a minimum amount of relative phase shift, respectively, in a microwave transmitted through the meander line **14**.

The field interaction which accomplishes the relative phase shift is illustrated in the cross-sectional view of FIG. 4. To facilitate illustrating the relationship of the interacting fields, the cross-sectional view includes selected, or broken, sections across the width of the phase shifter **10**, along the line **4—4** in FIG. 3. As above noted, the meander line **14** and the ground plane **18** define the microwave transmission line for the system. The T.E.M. mode of transmission is represented in FIG. 4 with respect to three of the major legs **14***a* of the meander line microstrip **14**. The R.F. electric field vector is thus shown established between the legs **14***a* and the ground plane **18**, traversing the dielectric layer **16**, and the R.F. magnetic field is represented by closed elliptical paths labelled $H_{R.F.}$. The cross section of the FIG. 4 further illustrates the remanent field in the ferrite **12** produced by pulsing of the current path **27**, the remanent field similarly being shown as a closed elliptical path labelled B_{r-27}. Although not shown, it is readily apparent that the remanent field B_{r-26} which is parallel to the major legs **14***a* of the meander line would be therefore perpendicular to the magnetic field $H_{R.F.}$ produced by the propagated microwave. Similarly, the field B_{r-27} will be perpendicular to the field $H_{R.F.}$ in the region of the short legs **14***b* of the meander line and the field B_{r-26} will be parallel to that field.

Selective pulsing of the conductor paths **26** and **27** therefore provides for establishing a remanent field exactly parallel to, or exactly perpendicular to the primary or principal direction of propagation of the microwave through the meander line **14**. The flux drive capability of the phase shifter of the invention thus provides for rotating the orientation of the saturated magnetization of the ferrite film in a plane of rotation parallel to the plane of the microstrip line **14**.

The phase shift of a phase shifter is measured as the total phase change between the input and the output as a function of the length of the conducting or transmission line therein. The differential phase shift, similarly, is a measure of the phase change per unit length of transmission line. The maximum net differential phase shift thus is a function of the difference between the total length of the major legs **14***a* and that of the minor legs **14***b*.

Where purely digital operation is desired, it will be apparent that the latching conductor paths should be energized with current pulses which exceed that required to establish the remanent magnetization condition. The amount of relative phase shift is also a function of the length of the ferrite in the direction of propagation, its physical configuration, and the length of the transmission line effected by the magnetization field produced in the ferrite. Thus, phase shifters of the type of the invention may be constructed to have desired amounts of relative phase shift for given microwave frequencies. A plurality of the phase shifters having appropriate characteristics therefore may be employed in a tandem arrangement and digitally controlled in various combinations to give a wide range of relative phase shifts.

Alternatively, for analog type applications, the amplitude of the latching currents may be controlled for providing intermediate steps, or amounts, or differential phase shift. As above noted, the amount of different phase shift is a function of the component of magnetization in the direction of propagation. The component may be adjusted in amplitude by controlling the amplitude of the magnetization of the ferrite layer aligned with the direction of propagation, through driving the latched ferrite layer through a minor loop of the hysteresis curve to a point or reduced amplitude remanent magnetization as indicated at B_r' in FIG. 5. Such control of magnetization through a minor loop requires energization of a selected current path of a controlled amplitude current pulse of opposite polarity to that which initially produced the remanent magnetization B_r, but of less amplitude than that which would cause saturation of the film in the opposite polarity.

In accordance with a further embodiment of the invention shown in planar and cross-sectional views in FIGS. 6 and 7, respectively, the conducting film also serves as a ground plane for the transmission line. In FIGS. 6 and 7, to which reference is made concurrently in the following description, portions of the phase shifter which are substantially identical to those of the preceding figures are identified by identical, but primed numerals. The phase shifter thus includes a meander line **14'** deposited on the upper surface of a ferrite film **12'**, the latter having formed therein at an intermediate position a conducting film **25'** which provides selectively energizable latching current conductor paths for latching the film **12'** in desired orientations with respect to the meander line **14'**. If desired, a protective layer **16'** of dielectric, or insulating type material may be formed over the meander line **14'**.

As best seen in FIG. 7, the ferrite film **12'** includes a lower layer, or portion, **12***a'* and an upper layer **12***b'* between which is formed the conducting film **25'**, the layers **12***a'* and **12***b'* being integral in regions surrounding the outer boundary or perimeter of the film **25'**. For a reason to be explained, however, the upper layer **12***b'* of the film **12'** is elongated relatively to the lower layer **12***a'* and thus includes laterally extending arms. The conducting film similarly includes lateral arms **25***a'* formed on the lower, exposed surface of the upper layer **12***b'* of the film **12'**. The lateral arms of the film **25'** are integral with the tabs **26'** and, as will be shown, provide electrical

connection thereto. The meander line 14' also includes lateral extensions 14a' extending over the arms of the ferrite layer 12b'.

Coaxial connectors 20' and 22' are provided for external connection to the microstrip transmission line and include central conductors 21' and 23', respectively, connected to the extensions 14a' of the transmission line 14' and outer connectors connected to the lateral extensions of the conducting film 25'. The film extensions are integral with and thus electrically connected to the tab pairs 26' of the film 25'.

The phase shifter of FIGS. 6 and 7 is most conveniently constructed by depositing the lower layer 12a' of the film 12' in the same dimensions as the upper layer 12b', as seen in FIG. 6, and in successive steps depositing the conducting film 25' including the lateral extensions 25a' and the second layer 12b' of the film 12'. Suitable photoresist techniques may then be employed for removing portions of the lower layer 12a' of the film 12' to expose the conducting film extensions 25a' in the final configuration as shown in FIG. 7. Following this construction, the meander line 14' including extensions 14a' may be deposited and a protective, insulating layer 16' then formed over the full extent of the upper layer 12b' of the film 12'.

The provision of the lateral extensions of the upper layer 12b' of the film 12' and of the associated conducting film extensions 25a', and meander line extensions 14a' provide both for convenience of making external connections and for isolation of external connection terminals from the region of the primary field interaction of the remanent D.C. magnetization of the film 12' and the R.F. field associated with a microwave propagated through the meander line 14'.

The operation of the structure of FIGS. 6 and 7 is substantially identical to that of the foregoing figures and thus there are provided switches 30' through 33' which function in a manner substantially as described with respect to the switches 30 through 33 to flux drive the ferrite film 12' to effect selected phase shift characteristics. A substantial distinction of the structure of FIGS. 6 and 7 from that of the foregoing figures, however, is that the upper layer 12b' of the ferrite film 12' now serves as a dielectric, spacing the meander line 14' from the conducting film 25' wherein the latter now serves as the ground plane. The meander line 14', the upper layer 12b' of the ferrite film 12', and the conducting plane 25' now define the microwave transmission line of the phase shifter. Thus, the use of a conducting film permits simplification of the structure of the phase shifter and reduction in cost by permitting elimination of a separate ground plane, while providing a more uniform remanent magnetization field distribution in the ferrite throughout the interaction region with the R.F. magnetic field of the propagated microwave.

In summary, the latching ferrite reciprocal phase shifter of the invention is of compact size and simplified construction, and provides latched or remanent magnetization fields having a distribution which maximizes the parallel, or alternatively, perpendicular relationship thereof to the microwave transmission circuit. The phase shifter is adaptable for either digital or analog operation, and a plurality thereof may be employed in a tandem arrangement and controlled to operate in various combinations for providing a wide range of selective amounts of phase shift.

I claim as my invention:

1. A reciprocal latching phase shifter for microwave transmission in the T.E.M. mode comprising:
- a ferrite film having lower and upper layers,
- a microwave transmission line associated with said film and defining the direction of microwave propagation with respect to said film,
- a conducting film formed integrally with said ferrite film between said lower and upper layers, and including means defining selectively energizable current paths therethrough for applying magnetizing fields to said ferrite film in predetermined orientations with respect to the direction of microwave propagation, and
- said lower and upper ferrite layers being integrally formed in the portions of said ferrite film surrounding said conducting film to define completed magnetic circuits respectively flux driven by said selectively applied magnetizing fields to establish corresponding remanent fields of magnetization of said ferrite film, the remanent fields being displaced in orientation through a plane of rotation parallel to the plane of the microwave transmission line, and interacting with a microwave propagated through said transmission line to effect corresponding, selective control of the relative phase shift of a microwave thus propagated.

2. A phase shifter as recited in claim 1 wherein:
- said conducting film and said integrally formed portions of said ferrite film layers structure said ferrite film to define double toroids, and
- said path defining means of said conducting film are respectively associated with said thus defined double toroids of said ferrite film for selectively flux driving said ferrite film to saturation to establish remanent fields of magnetization of predetermined orientations defined by the selectively energized current paths and respectively associated double toroids.

3. A phase shifter as recited in claim 1 wherein:
- said conducting film and said layers of said ferrite film are integrally formed in parallel relationship and of similar configuration, with said conducting film having boundaries of smaller dimensions than said ferrite film, and
- said path defining means of said conducting film comprises integral connector tabs formed in pairs at opposed boundaries of said conducting film and extending to the perimeter of said ferrite film to permit external connection to said conducting film for selective energization of the current paths defined thereby.

4. A phase shifter as recited in claim 3 wherein:
- said layers of said ferrite film are integrally formed in the portions thereof surrounding the boundaries of said conducting film and intermediate said connector tabs to define said completed magnethic circuits.

5. A phase shifter as recited in claim 3 wherein:
- said conducting film includes two pairs of said connector tabs related to each other to define substantially orthogonally related current paths through said conducting film, and
- one of said orthogonally related current paths is substantially parallel to the principal direction of propagation of said microwave through said microwave transmission line.

6. A phase shifter as recited in claim 1 wherein said microwave transmission line of said phase shifter includes:
- a microstrip formed on the upper surface of said supper ferrite layer, and
- means defining a ground plane in parallel, spaced, and insulated relationship to said microstrip.

7. A phase shifter as recited in claim 6 wherein:
- said means defining a ground plane comprises said conducting film, and
- said upper layer of said ferrite film provides the parallel, insulated, spacing of said microstrip from said conducting ground plane.

8. A phase shifter as recited in claim 1 wherein:
- said microwave transmission line comprises a meander line having a plurality of parallel main legs defining the principal direction of propagation of the microwave and a plurality of smaller legs perpendicular to

and joining said main legs in a series circuit connection, and

the relative phase shift of the microwave propagated through said meander line is a function of the net difference of the total length of the main and smaller legs of the meander line.

9. A phase shifter as recited in claim **8** wherein:

the boundaries of said conducting film are of larger dimensions than the boundaries of the meander line portion of the microwave transmission line.

References Cited

UNITED STATES PATENTS

3,447,143 5/1969 Hair et al. ---------- 333—31

ELI LIEBERMAN, Primary Examiner

P. L. GENSLER, Assistant Examiner

U.S. Cl. X.R.

333—24.1, 84