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FERRITE DEVICE FOR EFFECTING RECIPROCAL PHASE SHIFT OR ATTENUATION

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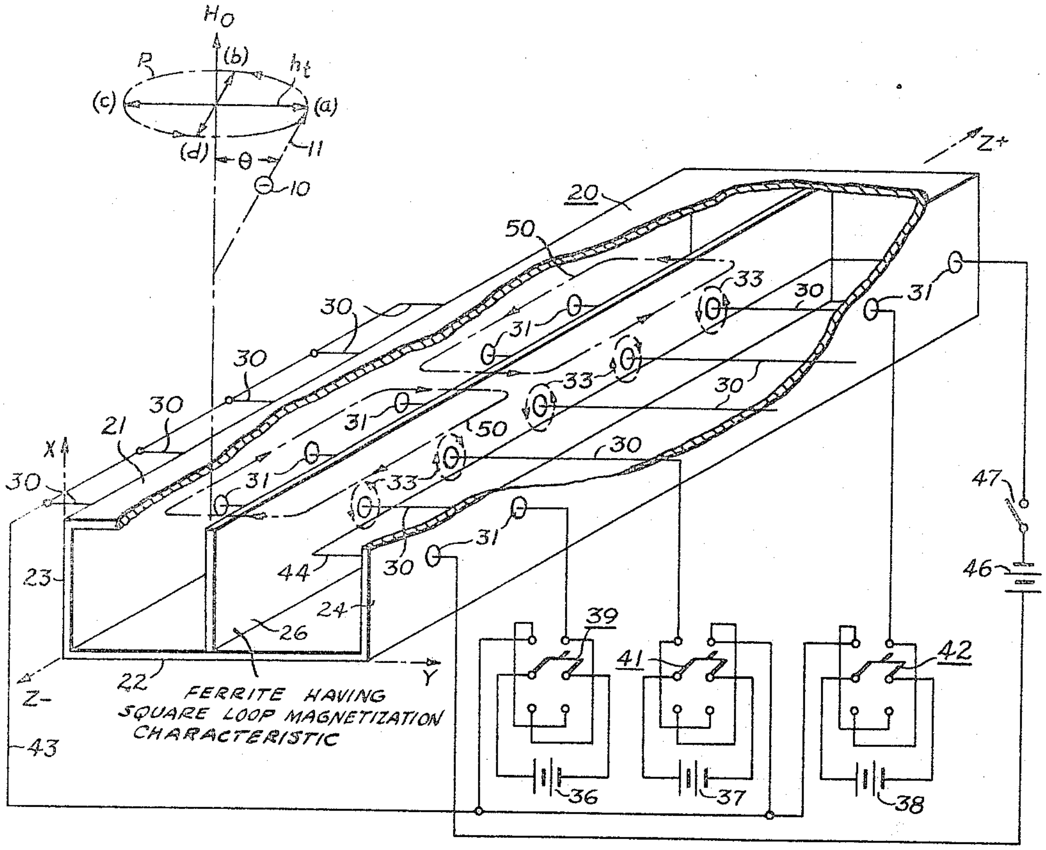

FIG. 1.

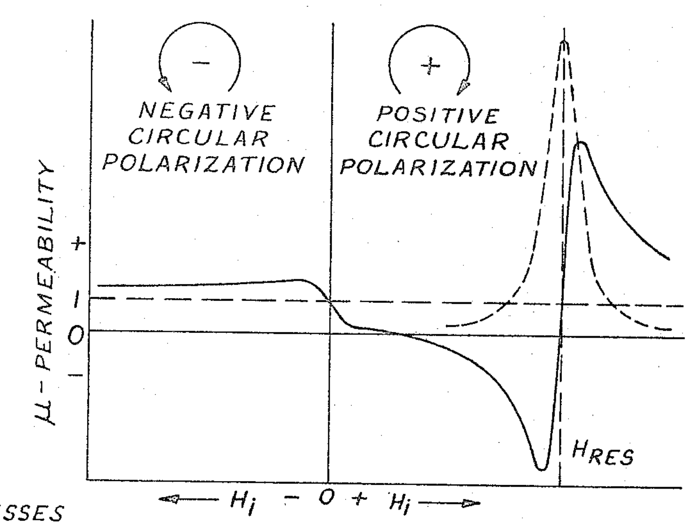

FIG. 2.

WITNESSES

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FERRITE DEVICE FOR EFFECTING RECIPROCAL PHASE SHIFT OR ATTENUATION

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This invention relates to reciprocal electromagnetic wave transmission apparatus and particularly to improved microwave apparatus for effecting reciprocal phase shift or attenuation of microwave energy propagated through it.

More particularly the invention relates to such microwave apparatus utilizing gyromagnetic ferrite materials by means of which the phase or attenuation of the wave energy may be varied. The invention contemplates the use of square loop ferrites whereby the control can be varied by latched steps, thus providing digital control.

The use of materials, such as ferrites, having gyromagnetic properties to obtain both reciprocal and non-reciprocal effects in microwave transmission circuits is widely known and is widely used in various applications, both in waveguides and transmission lines. Since it is the gyromagnetic properties of ferrites that are essential to the operation of this invention, hereafter ferrites will be used synonymously with gyromagnetic materials.

Ferrites belong to a class of materials having properties which make them particularly adaptable to use in microwave devices. They have essentially the same magnetic properties of iron and other ferromagnetic materials and at the same time have characteristics which give rise to unique microwave behavior, namely, extremely high resistivity, moderately high dielectric constants and controllable permeability. Microwave energy can enter and pass through substantial amounts of the material without excessive attenuation. In the process the wave has an opportunity for strong interaction with the spinning electrons which are responsible for the magnetic properties of the material. Faraday rotation and other non-reciprocal properties of microwave systems are manifest as a result of this interaction.

Modern physical analysis shows that the ferromagnetic property of matter arises from the spin property of the electron. Ferrites, in particular are characterized by certain unpaired electron spins. Most of the electrons in ferrites are paired with the spins pointed in opposite directions. Their effects cancel each other and do not contribute to any first order magnetic effects. By virtue of certain forces between the electrons, known as "exchange forces" some electrons prefer to line up with the spins in parallel and may be easily oriented en mass, by the application of a relatively small magnetic field. This makes the materials appear "magnetic."

The presence of thermal energy has an opposite effect in that it tends to create disorder in the alignment of electron spins. As a result the spins never all line up perfectly with an applied field. The condition when the maximum number are so aligned with an applied field is called saturation. However, it can be assumed that out of the total number of unpaired electron spins a certain fraction do line up with an applied field and their en mass action can be considered as a single spinning electron for purposes of analysis. Since the spinning electrons have mass and an electric charge they may be considered as magnetic dipoles, or tiny gyroscopes, spinning on their axes of rotation. These spinning electrons respond to a transverse magnetic force that deflects their axes by precessing gyroscopically about their original position parallel to the applied field at a frequency depending upon the magnitude of the applied static field. This is called the "gyromagnetic" property.

Because ferrite materials have numerous spinning electrons distributed therein, when these materials are immersed in a direct current magnetic field the magnetic dipoles (or gyroscopes) are aligned parallel to the magnetic field, that is, the axes of rotation of the rotating electrons are parallel to the magnetic field. A linearly or circularly polarized electromagnetic field that is transverse to the direct current magnetic field has the effect of producing the gyromagnetic precession. When the precessional (angular) velocity of the dipoles about the magnetic lines of force of the applied magnetic field is substantially equal to and in the same direction as the rotating magnetic field of the electromagnetic wave, a phenomenon known as "gyroresonance" occurs. When gyroresonance exists the magnetic dipoles tend to precess about the applied magnetic lines of forces at progressively increasing angles as their energy states increase.

This precessional motion is highly damped in gyromagnetic materials so that there is a tendency for the magnetic moment vector to gradually "spiral in" until it comes into alignment with the magnetic field. It is the interaction of the electromagnetic wave tending to deflect the spin axis from parallelism with the biasing magnetic field which causes the ferrite material to absorb microwave energy at the gyroresonant frequency. Both phase shifting and attenuation accompanies the interaction between the electromagnetic wave and the spinning electrons of the ferrite. As shown in the drawings, and as further explained later, sharp changes in the permeability take place in the vicinity of gyroresonance. The behavior of ferrites is profoundly dependent upon whether the frequency of the interacting electromagnetic waves is greater or less than, or equal to, the gyroresonant frequency.

Gyromagnetic devices can be broadly divided into two classes, namely, (a) those biased above and below gyromagnetic resonance and dependent for their operation upon the effective permeability of the gyromagnetic element and its low attenuation and (b) those biased at resonance and which depend upon the high effective attenuation of the gyromagnetic material. The devices in category (b) become reciprocal or non-reciprocal isolators or attenuators for reasons heretofore mentioned. On the other hand, devices of category (a) produce reciprocal or non-reciprocal phase shift or reciprocal reflections.

Furthermore, because of the profound effect of gyroresonance, the classification of gyromagnetic microwave devices as to their being reciprocal or non-reciprocal, that is, as to whether they have the same or different characteristics for both directions of transmission, is dependent upon their internal static flux distribution and whether the material is placed in such a position in the waveguide so that it couples to a linearly polarized mode on the one hand, or to an elliptical or circularly polarized mode on the other hand.

When the ferrites are positioned in a rectangular waveguide symmetrically with respect to the center line of the guide and the magnetization is so arranged that the amplitude and direction patterns of the biasing flux is the same direction on both sides of the center line the device will be reciprocal, that is, will have the same transmission characteristics, in either direction with respect to the dominant TE_{10} mode. As will be explained in connection with the drawings, for values of angular precessional velocity other than at gyroresonance, attenuation is small although the permeability factor remains to cause phase shift.

An understanding of the above somewhat over-simplified summary description of gyromagnetic microwave devices is necessary for an appreciation of the significance of the present invention. A more complete explanation of the operation of gyromagnetic materials in microwave apparatus will be found in an article entitled, "The Behavior and Application of Ferrites in the Microwave Region," by A. G. Fox et al., Bell System Technical Journal, volume 34, January 1955, pages 5–103. Also the Proc. I.R.E., volume 44, No. 10, October 1956, is devoted in major part to the uses and characteristics of ferrites as applied to microwave apparatus.

The present invention provides reciprocal microwave apparatus utilizing gyromagnetic materials in the form of ferrites having a square loop magnetization characteristic and provides means for establishing closed path magnetization in the materials in planes parallel to the direction of propagation, the means being selectively controllable for establishing "latched" regional magnetization near saturation in the material to provide digitized or stepped phase shift or attenuation control.

A primary object of the present invention is to provide a novel and improved reciprocal microwave phase shifter or attenuation device.

Another object is to provide a reciprocal phase shifter or attenuating device for microwaves which can be readily electrically controlled to provide selected amounts of phase shifting.

Another object is to provide a novel and improved reciprocal microwave phase shifter or attenuation device using a ferrite material which can be magnetically latched in a selected position to give a selected phase shift and which does not require power to hold it in the latched position.

Still a further object is to provide a novel and improved reciprocal microwave phase shifter or attenuation device using ferrites in which the gyromagnetic properties of the ferrites can be readily latched into a selected magnetic condition to give a selected phase shift or attenuation and can be unlatched and relatched to a different condition at a very fast rate.

A still further object is to provide a novel and improved reciprocal microwave phase shifter and attenuation device using a slab of gyromagnetic material in which closed path magnetization is established within the slab in planes parallel to the direction of propagation.

The invention itself, however, both as to its organization and method of operation, as well as additional objects and advantages will best be understood from the following description when considered in connection with the accompanying drawing, in which:

FIGURE 1 is an isometric view of a section of a waveguide with an associated functional diagram for facilitating an understanding of the present invention;

FIG. 2 is a graph for facilitating an understanding of the invention.

Basically, the present invention contemplates a reciprocal microwave component including a section of microwave guide structure and utilizing gyromagnetic material having a square loop magnetization characteristic, wherein the gyromagnetic material is so positioned in the waveguide structure that when regionalized closed path magnetization is established in the gyromagnetic material in planes parallel to the direction of propagation of the electromagnetic wave selected values of phase shift or attenuation are "latched" in.

Latchable, non-reciprocal devices using ferrites, are already known. A description of such device appears in the Proceedings of the IRE, vol. 44, October 1956 pages 1421 to 1430. That publication describes a resonant type attenuator or isolator using the gyromagnetic resonance of the material to absorb microwave energy transmitted in one direction. In that device when the microwave energy in the guide is propagated in a given direction with the gyromagnetic material biased to the gyroresonant frequency, the microwave loss component of the magnetic permeability of the material reaches a sharp maximum and the microwave energy at that frequency is absorbed. Devices of this type derive their non-reciprocity from the fact that in a rectangular waveguide there is a region on either side of the center line, intermediate the center line and the narrow walls, in which the magnetic field

of the electromagnetic wave energy supported in the guide has a transverse field component and a longitudinal field component. The two components are out of phase by 90° so that the net field is circularly or elliptically polarized and appears to rotate in one sense for one direction of propagation along the guide and it appears to rotate in the opposite sense for propagation in the opposite direction. Gyromagnetic material located in these regions and having internal flux directed in opposite directions transverse to the magnetic field of the electromagnetic wave on opposite sides of the center line reacts in different manner to electromagnetic wave energy propagated in opposite directions. This is what makes that device have non-reciprocal characteristics. On the other hand, if the amplitude and direction patterns of flux in the gyromagnetic material is symmetrical on opposite sides of the center line, the device is reciprocal.

An example of a reciprocal electromagnetic wave transmission system utilizing gyromagnetic materials is disclosed in a patent to Gyorgy et al. 3,051,917. Although this patent utilizes ferrites in a waveguide in which magnetic flux is introduced in a pattern symmetrical about the axis of propagation, the device is not capable of selected latchable control of phase shift or attenuation because the ferrite is maintained in a saturated condition at all times for a purpose foreign to the objectives of the present invention. Such ferrite cannot be "latched" into selected regions, or areas, of magnetization because the main static magnetic bias is dominant and the auxiliary modulating source cannot form closed path localized magnetization. Furthermore, since the main static field is generated outside of the waveguide structure and is introduced through the walls of the waveguide the required highly inductive magnetic winding and the eddy current effect in the waveguide walls make it impossible to accomplish rapid switching.

From what has been said previously it should be obvious that the unique characteristics of gyromagnetic materials which make them so useful in microwave devices is their extremely high resistivity, moderately high dielectric constant and their responsiveness to magnetic flux to change their permeability to electromagnetic wave energy. It is believed that a mere statement that their DC permeability is represented by a square loop B–H characteristic curve gives a sufficiently complete mental picture to compare with the graph of FIG. 2 which qualitatively illustrates the permeability of the ferrites to electromagnetic waves as a function of internal magnetic flux. This comparison when fully comprehended greatly facilitates the understanding of all these devices.

It is the change in permeability of the ferrites to electromagnetic wave energy that makes it possible to change their phase shifting or attenuating characteristics, including their reciprocity. The pattern and the density of the magnetic flux in the materials as disposed with respect to the mode of propagation in the waveguide determines their microwave behavior. The flux pattern and density can be readily controlled to give different results. The prior art shows many ways for controlling this flux for providing various and different results. The present invention provides a further and novel method and means for controlling the DC flux for accomplishing an improved result.

Although those skilled and working in the art are familiar with the fundamental mechanism by which the action of gyromagnetic materials change the propagation characteristics of microwave devices it may be helpful for some readers to present a brief review of this operation at this point. For a more detailed explanation the reader is referred to the aforementioned article in the Bell System Technical Journal. Although the present invention is reciprocal it is desirable to understand the gyromagnetic mechanism that distinguishes between reciprocal and non-reciprocal devices.

The permeability of ferrites to electromagnetic waves is due to the effects of certain unpaired electrons of the ferrites which behave, en masse, gyroscopically as illustrated in the schematic diagram portion of FIG. 1. Since electrons have an electron charge and mass and since they are always spinning in their axis they can be considered as gyroscopes. Accordingly, the en masse effect of these spinning electrons may be represented symbolically by a single electron represented at **10**. When these spinning electrons are immersed in a DC biasing magnetic field, represented by H_0, there is a tendency for all the axes of the electron spins to align themselves with the biasing field. Incidentally, it should be mentioned that H_0 represents internal magnetic flux and may be provided by a magnetomotive force applied externally or by flux induced directly in the material. If the spin axis is momentarily deflected from parallelism with the biasing field H_0 by a transverse magnetic field vector h_t the electron will not return to its original position immediately but will precess in the manner of a gyroscope about the DC biasing field vector H_0 with the upper end of the magnetic moment vector **11** describing a circular path P at angular velocity or frequency ω_0, which is proportional to the magnitude of the biasing field. The direction of rotation is determined by the direction of the static flux vector. A momentary transverse field h_t will start the precessing but unless successive transverse components are applied synchronously the circle **10** would gradually diminish in size to zero when the vector **11** would be again parallel to H_0.

The angular (or precessional) frequency ω_0 is called the gyromagnetic resonance frequency and the behavior of the ferrites in microwave devices is profoundly dependent upon whether the frequency of the alternating transverse magnetic field component of the electromagnetic wave is greater or less than or equal to the gyromagnetic resonance frequency. This frequency also called "Larmor" frequency, is:

$$\omega_0=\gamma H_0 \quad (1)$$

where γ is equal to the ratio of the magnetic moment to the angular momentum. When this precessional frequency ω_0 is substantially equal to and is in the same direction as the rotating transverse magnetic field component h_t, gyroresonance in the ferrite is obtained. When this gyroresonance exists certain of the magnetic dipoles, depending upon the degree of magnetization, tend to precess about the lines of the biasing field H_0 at a progressively increasing angle θ. This precessional motion is highly damped and therefore, when the precessional frequency ω_0 is the same as the frequency of the wave energy in the microwave guide, energy will be absorbed from the electromagnetic wave, the angue θ being determined by the point at which the absorption just balances the losses in the ferrite.

In the illustrated embodiment of the present invention in FIG. 1 the model for illustrating the gyromagnetic mechanism is shown as associated with a ferrite element on the center line of a rectangular microwave guide propagating in the dominant TE_{10} mode.

Since a linearly polarized alternating vector can be resolved into two oppositely rotating circularly polarized components it will be seen that the rotating vector h_t can be resolved into two oppositely rotating circularly polarized components. Since the direction of precession is dependent upon the direction of the internal static flux, it will be seen that with an internal flux pattern in planes parallel to the direction of propagation in the central ferrite element there is a circularly polarized electromagnetic vector rotating in the correct direction for electromagnetic waves travelling in either direction and accordingly the device is reciprocal. Also, for closed path magnetization in planes removed from the center line but parallel to the direction of propagation there will be components of bias field corresponding to that required to give reciprocal characteristics.

The graph of FIG. 2 shows the relation between the internal DC magnetic field and the permeability and attenuation of the ferrites to the magnetic fields of electromagnetic waves. The dotted curve indicates the imaginary or loss component of permeability that is, attenuation, and the solid line curve indicates the real component of permeability. It is noted that there is an abrupt change in both parameters in the vicinity of values of internal flux, H_{RES} which biases the ferrite to gyroresonance.

In accordance with the present invention a latchable reciprocal phase shifter or attenuator is provided in which the gyromagnetic element is preferably located symmetrically about the center line, primarily because the amplitude and direction patterns of flux in any given transverse plane must be symmetrical about the center line to provide maximum reciprocity. The magnetization means provided is such that localized closed paths of magnetic force are created in the ferrite slab in planes parallel to the propagation axis so that the magnetization can be "latched in" in localized region, whereby selected phase shift or attenuation can be "latched in" and no no holding power is necessary to maintain the latching. Furthermore, the magnetization, or magnetomotive, force is generated wholly within the wave guide structure. Also, in any transverse plane the regionalized flux is poled in the same direction on both sides of the center line.

The illustrative embodiment of the invention in FIG. 1 comprises a bounded electrical transmission line in the form of a section of rectangular microwave guide **20** having such dimensions as to propagate an electromagnetic wave in the dominant TE_{10} mode. Such a waveguide has a wide internal dimension of at least one-half wavelength of the propagated wave. However, as understood in the art, due to high dielectric loading by the ferrite this dimension may appropriately be reduced. The waveguide is provided with horizontal parallel broad sides **21** and **22** and vertically disposed short side walls **23** and **24**. The internal dimension of the broad sides is at least one-half wavelength of the propagated wave and the short dimension is substantially one-half of the wide dimension. Disposed centrally of the waveguide section **20** is means for imparting a variable phase delay and/or attenuation in the form of a ferrite slab **26** centered on the axis of the waveguide and disposed parallel to the side walls **23** and **24**. The ferrite slab **26** may be secured to the broad side walls **21** and **22** in any conventional manner as by cementing. If desired, the ferrite slab **26** may not extend the full distance between the top wall **21** and the bottom wall **22** but instead its height may be reduced by interposing strips (not shown) of conducting material or insulating material having a dielectric constant substantially the same as that of the ferrite slab **26** between the ends of the slab **26** and the top and bottom walls. Instead of the rectangular guide shown it will be apparent that the invention is also applicable to H-type guide having two spaced conductive strip members corresponding to the board faces of the guide illustrated.

One of the salient features of the present invention is the novel arrangement for changing the apparent permeability of the ferrite loaded waveguide section **20** by providing means for variably magnetizing selected regions of the slab **26** between zero and near saturated magnetization state. To this end, a plurality of suitable conductors **30** extend transversely of the waveguide section **20** and the ferrite slab **26** and are suitably insulated by insulating bushings **31** from the opposite short sides **23** and **14** of the waveguide. The conductors **30** are preferably, but not necessarily, spaced half way between the top and bottom broad sides **21** and **22** and also extend through apertures in the ferrite slab **26**. In the illustrative embodiment in FIG. 1 five transverse conductors **30** are illustrated, evenly spaced, but this is only illustrative of the basic arrangement.

There are several factors which can be changed in accordance with the desired amount of phase shift desired and the type of control that is desired. First of all, the spacing between the conductors 30 may be changed in appropriate relation to other factors to provide the desired control. The spacing between these conductors would, to a certain degree be dependent upon the amplitude of the current which is supplied to the conductors 30 to produce closed circuit magnetic paths 33 indicated by the dotted circle which represent localized magnetized regions around each of the wires. Means, such as a suitable source of current, illustrated in the drawing as batteries 36, 37 and 38, are provided for energizing each one of the respective conductors 30. Since wires 30 pass through the ferrite slab 26 at right angles to its sides, the axis of the guide section 20 and the direction of propagation, current through the wires will induce flux in the slab 26 in planes parallel to the axis of the guide.

As will be seen from FIG. 2, the degree of magnetization of the ferrite will determine whether the device operates as a phase shifter or an attenuator. By appropriately selecting ferrites they may be latchable at or below resonance to provide phase shift or attenuation, as desired.

Suitable switches 39, 41 and 42 of the double pole, double-throw type, are connected in the respective battery circuits with the respective conductors. Conductor 43 is common to all of the circuits for supplying the current through the conductors 30. It will be readily apparent to those skilled in the art that in most practical applications the battery sources and the switches would be replaced by suitable pulse generators or a pulse generator associated with a suitable matrix for selectively energizing the conductors 30 with appropriate current of the proper polarity in order to vary the effective permeability of the slab 26.

As an illustration, if all of the conductors 30 were energized simultaneously with current in the same direction and of the same amplitude there would be a minimum of net transverse magnetic flux in the ferrite 26 since the flux in the adjacent areas around individual conductors would be flowing in opposite directions in the portion of the ferrite strip 26 between the conductors. On the other hand, the maximum net transverse flux will be obtained when the current in adjacent conductors is flowing in opposite directions so that the flux between individual conductors would be in additive relation.

It will be readily apparent that many permutations and combinations of net flux in step adjustment may be provided by energizing each of the conductors 30 singularly, or in any proper combination, such as by successively energizing all of the conductors in the same direction or alternately in opposite direction or alternately in opposite directions. The spacing between the conductors could also be related to the maximum amplitude of the current pulses supplied to the conductors in order to get the desired steps of change of permeability or attenuation.

When it is desired to reset the ferrite slab 26 to its zero state a suitable demagnetizing conductor 44 is suitably secured, as by cementing, to the center of the ferrite slab 26 and extends longitudinally of the latter. This conductor, of course, is appropriately insulated from the other conductors 30. A suitable source of voltage, indicated at 46, could be applied through switch 47, and poled so that the current through the connector 44 would return the ferrite slab strip 26 to its zero, or reset, state.

It will be readily apparent from the above description that a net internal magnetic biasing field, corresponding to the biasing field H_0 mentioned in connection with the gyromagnetic model dipole 10, will determine the action that takes place as the microwave energy is propagated by the ferrite loaded section 20 of the microwave transmission circuit. In accordance with this invention the internal magnetic flux is generated directly in closed paths in the ferrite and the shape, area and intensity of the closed path magnetization regions are dependent upon the permutations combinations, such as spacing of the conductors 30, magnitude and direction of current, etc. No dominating external field is present or desired. The net internal magnetic flux or field, corresponding to H_0 for the model dipole 10 is that portion of the closed path flux at the exact point under consideration.

The magnetic flux can be latched in the desired magnetization state by a short current pulse and it is not necessary to maintain the current through the conductors 30 once they have been energized to place the area immediately surrounding the conductor in the desired state of magnetiztaion. It should be pointed out that the reciprocal phase shift is dependent upon the net magnetization of the ferrite slab and also upon the length of the portion of the ferrite which is so magnetized.

Since the conductors 30 are parallel to the magnetic field of the electromagnetic wave as indicated by the dotted rectangles 50 in FIG. 1 no voltage is induced therein by the propagated wave and they do not interfere with the propagation of the wave through the guide. Since the body of the ferrite slab 26 around the individual wires provide closed magnetic paths the residual magnetization is large and the ferrite remains magnetized when the current flow ceases. Instead of the wires 30 being energized from separate respective sources they may all be connected in series and energized from a single source. It will be apparent that numerous permutations or combinations of the arrangement in FIG. 1 can be made.

When the current flow in adjacent wires is directed opposite to each other the transverse component of magnetic flux is at a maximum and when currents in adjacent wires are in the same direction the field is minimized except, of course, under conditions where the wire 44 is energized to erase all the residual magnetism in the ferrite strip 26. The number of wires desired will be determined by the size of the minimum steps of the control desired. By appropriate programming the currents in the individual wires a number of phase shift increments that is a significant multiple of a number of wires can be obtained as previously indicated.

Although the invention has been illustrated only in one embodiment it will be readily apparent to those skilled in the art that very many changes can be made without departing from the spirit of the invention.

What is claimed is:

1. Electromagnetic wave apparatus comprising a waveguide structure having at least first and second parallel elongated conductive members of such transverse dimension as to support propagation of electromagnetic wave energy of selected frequency with said electromagnetic wave having a magnetic field pattern forming closed loops parallel with said elongated conductive members, an element of gyromagnetic material having a square loop magnetization curve extending longitudinally of said waveguide structure and effectively constituting a plurality of elements spaced longitudinally of said structure, a plurality of electrical conductors extending parallel to said conductive members and transverse to the direction of propagation and extending through said gyromagnetic element for producing localized magnetized regions of closed path flux in said gyromagnetic element in planes parallel to the longitudinal axis of said waveguide structure and means for selectively energizing said conductors with electric current pulses for producing simultaneously spatial variations of the net magnetic field intensity, said magnetic flux remaining at the residual magnetization value when said electric currents are removed.

2. Reciprocal phase shifter apparatus for electromagnetic wave energy comprising a section of conductively bounded waveguide of rectangular configuration and adapted to support electromagnetic wave energy in the TE_{10} mode, an element of gyromagnetic material having a square loop magnetization curve arranged symmetrically about the axis of said waveguide section, a plurality of electrical conductors extending transversely through said

gyromagnetic material, said conductors being parallel to the magnetic field of the electromagnetic wave, and means for selectively energizing said conductors for establishing closed path magnetization in said material in planes parallel to the longitudinal axis of said waveguide.

3. Means for controlling the propagation of electromagnetic wave energy comprising a section of conductively bounded waveguide of rectangular cross section for supporting wave propagation in the dominant TE_{10} mode, an element of ferromagnetic gyromagnetic material having a squar loop magnetization curve within said guide, a plurality of conductors extending through said gyromagnetic material and parallel to the plane of the magnetic field of the elecrtomagnetic wave and transverse to the direction of propagation, and means for selectively energizing said conductors for selectively establishing in said element closed path magnetic flux having a component in planes transverse to the magnetic field of the propagated electromagnetic wave and parallel to the axis of said waveguide, said magnetic flux being symmetrically disposed with respect to the center line of said waveguide and having spatial variations in the direction of the longitudinal axis of said waveguide.

4. Reciprocal electromagnetic wave apparatus comprising a section of waveguide structure having at least spaced first and second parallel elongated conductive members of such transverse dimension as to support propagation of electromagnetic wave energy of selected frequency in a dominant mode having a magnetic field pattern forming closed loops in planes parallel with said elongated conductive members and with an electric field perpendicular to said conductive members, a thin rectangular element of gyromagnetic ferrite material having an essentially square loop magnetization curve positioned centrally of and extending longitudinally of said waveguide structure with its major cross-sectional dimension as viewed along the direction of propagation being parallel to the electric field of said dominant mode, magnetic biasing means comprising a plurality of spaced current conductors extending through said ferrite element and parallel to said conductive members of said waveguide structure and perpendicular to the longitudinal axis of said structure for producing in said ferrite material localized magnetized regions of closed path magnetic flux when electric current flows through said conductors, means for supplying direct current pulses selectively to individual conductors, the selective energization of said conductors being effective to vary the number and intensity of said localized magnetized regions of closed loop magnetic flux, said magnetic flux remaining at the residual magnetism value when said electric current in said conductor is removed.

5. The combination as set forth in claim **4** in which said ferrite material is of such type that the magnitude of said residual magnetization is such as to produce gyromagnetic resonance at the frequency of operation and produce attenuation of the electromagnetic wave energy.

6. The combination as set forth in claim **4** wherein the ferrite material is of such type that the magnitude of residual magnetism is that which will not produce gyromagnetic resonance at the frequency of operation, thereby substantially eliminating attenuation while producing phase shift.

7. The combination as set forth in claim **4** and means for demagnetizing said element in the form of a conductor extending longitudinally of, and adjacent to said gyromagnetic element and including means for establishing a pulse of direct current in said conductor.

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