

Jan. 8, 1963

H. SEIDEL

3,072,869

RECIPROCAL GYROMAGNETIC LOSS DEVICE

Filed April 29, 1959

2 Sheets-Sheet 1

FIG. 1

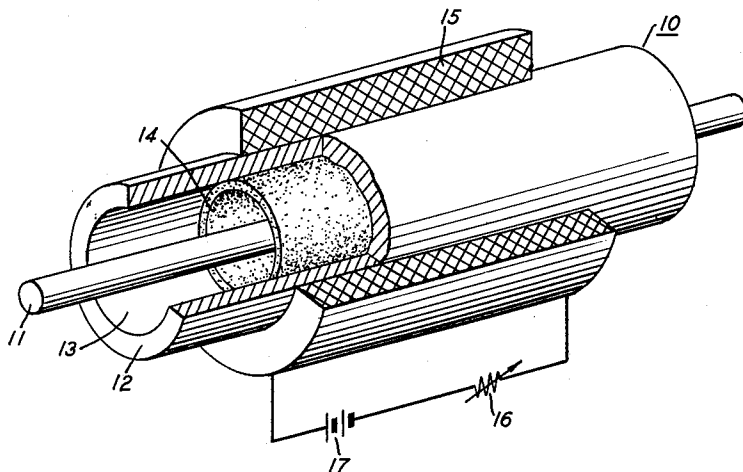


FIG. 3

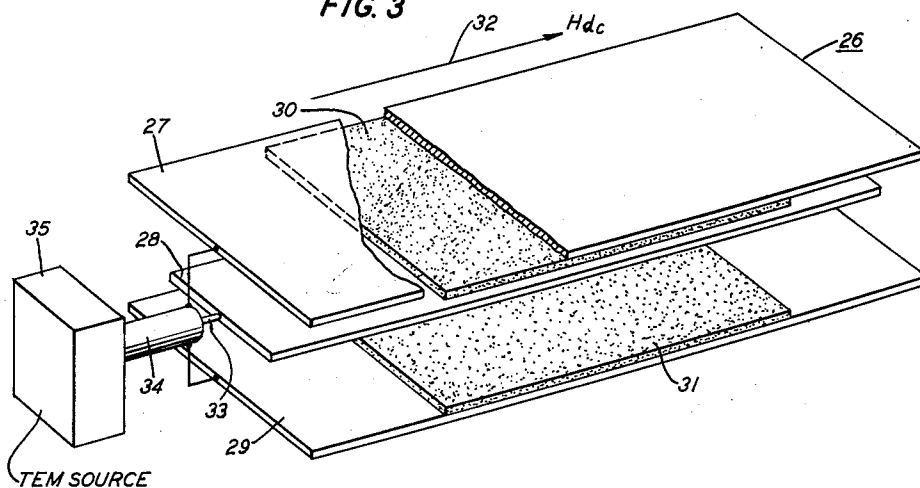
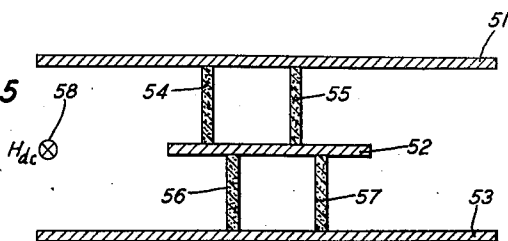


FIG. 5



INVENTOR
H. SEIDEL
BY *Ray M. Porter Jr.*

ATTORNEY

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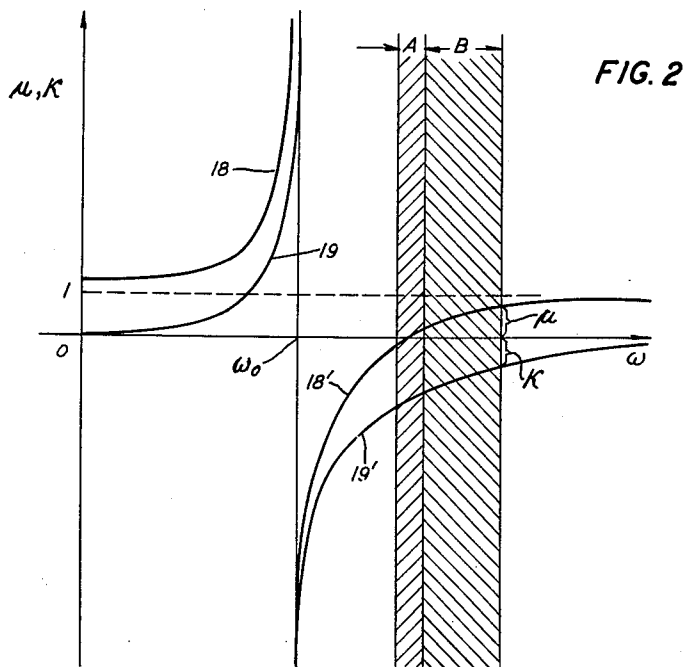
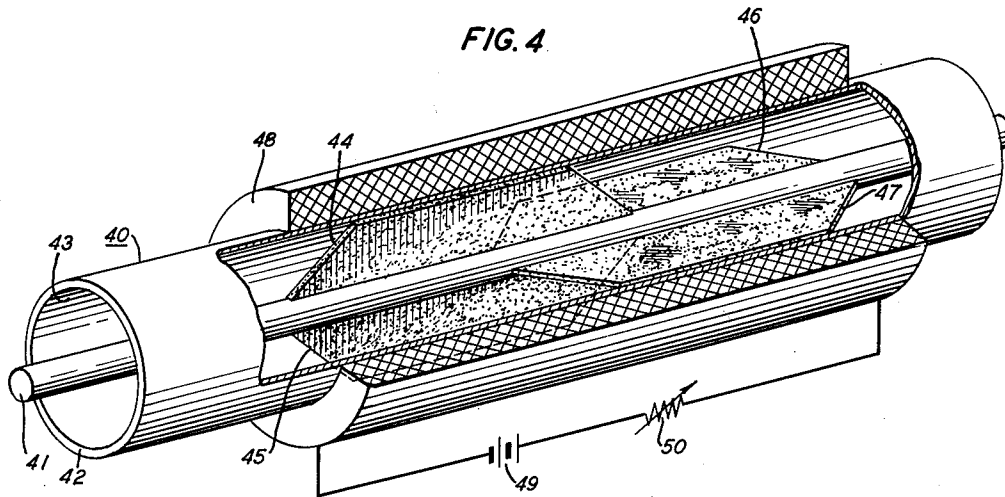
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2 Sheets-Sheet 2



INVENTOR
H. SEIDEL
BY *Ray M. Porter Jr.*

ATTORNEY

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RECIPROCAL GYROMAGNETIC LOSS DEVICE
Harold Seidel, Fanwood, N.J., assignor to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

Filed Apr. 29, 1959, Ser. No. 809,878

5 Claims. (Cl. 333-81)

This application is a continuation-in-part of my prior application, Serial No. 658,199, filed May 9, 1957, now abandoned. The invention relates to electromagnetic wave energy transmission and, more particularly, to reciprocal transmission loss structures employing gyromagnetic material.

The use of materials having gyromagnetic properties to obtain both reciprocal and nonreciprocal effects in microwave transmission circuits is widely known and has found numerous and varied applications in propagation structures of both waveguide and transmission line types. A résumé of early work done in this field is contained in an article entitled "The Behavior and Applications of Ferrites in the Microwave Region," by A. G. Fox, S. E. Miller, and M. T. Weiss, Bell System Technical Journal, January 1955, pp. 5-103. The Proceedings of the I.R.E., vol. 44, No. 10, October 1956, is devoted in major part to a more recent survey of uses and characteristics of ferrite.

The nonreciprocal effects of gyromagnetic material upon propagating electromagnetic wave energy have generally been explained in terms of an "electron spin coupling" concept whereby the spinning electrons couple with circularly polarized magnetic field components of wave energy propagated through the gyromagnetic medium. In accordance with this theory, a region of circular, or at least elliptical, polarization of the magnetic vector of the propagating wave must exist, thus necessitating both longitudinal and transverse magnetic field components. A large portion of the dominant modes of hollow pipe waveguides are characterized by such longitudinal components and therefore waveguides have been extensively used with gyromagnetic material to produce microwave circuit components. TEM wave mode structures, on the other hand, do not lend themselves to the spin coupling concept directly due to the absence of longitudinally extending magnetic components. The present inventor, in his copending applications, Serial Nos. 554,237 and 554,271, filed December 20, 1955, discloses several TEM wave mode structures which are loaded with gyromagnetic material and which exhibit nonreciprocal transmission characteristics.

Several disclosures of coaxial geometries utilizing gyromagnetic material and functioning as reciprocal resonance attenuators may be found in the prior art. The attenuation properties of the prior art devices are based upon a volumetric gyromagnetic resonance phenomenon and involve a complete filling of the cross sectional area of the guiding structure. However, the dielectric and magnetic losses introduced outside the desired attenuation band by the insertion of so large a quantity of relatively high dielectric constant material and the restriction of the bandwidth of the device to the resonance absorption line width of the gyromagnetic material are undesirably restrictive upon application of these coaxial devices widely in the art.

It is therefore an object of this invention to broaden the transmission loss bandwidths obtainable with gyromagnetic material in TEM wave mode structures.

It is a further object of the invention to utilize gyromagnetic material in a manner providing transmission losses which are inversely proportional to the volume of the material used.

It is a more specific object of this invention to utilize

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relatively small amounts of magnetized gyromagnetic material to obtain relatively large amounts of insertion loss of either a reflective or an absorptive character.

It has been observed that the insertion of magnetized gyromagnetic material into conductively bounded electromagnetic wave transmission structures adapted to propagate energy of solely transverse field character causes a significant perturbation of the normal TEM wave mode. In accordance with the present invention, it has been discovered that these perturbation effects may be most significantly utilized if the wave guiding structure is only partially filled with gyromagnetic material and the material is disposed in a region contiguous to at least one of the conductive boundaries of the guiding structure. According to the principles of the invention, the transmission loss effects realizable in structures partially filled with gyromagnetic material are significantly greater in magnitude than those realizable in completely filled structures.

In the embodiments of the present invention, the dominant mode wave energy applied to the guiding structure is described by a magnetic field pattern consisting of loops which encircle one conductor of the structure and which lie solely in planes transverse to the direction of energy propagation. One distinguishing characteristic of polarized gyromagnetic material is that a radio frequency, or R.F., magnetic field incident upon the polarized material and directed normal to the direction of polarization will generate a third magnetic component which is orthogonally directed to both the polarizing and R.F. magnetic fields. Thus, if a magnetic polarizing field is applied in the direction of a rate of change of phase, i.e., in the direction of propagation, of TEM wave energy in the guiding structures of the invention, orthogonal magnetic components will be generated which are directed radially between the conductor which is encircled by the R.F. loops and the conductive member or members which surrounds this conductor. The generated radial magnetic components have companion electric field components associated with them and the electric components, which are normal to the generated magnetic components, extend in directions parallel to the conductive boundaries. These generated components constitute the perturbation referred to above since their presence is not descriptive of the normal TEM wave mode. In accordance with the present invention, the tendency of the polarized gyromagnetic material to perturb the energy may be utilized to produce transmission loss effects by positioning the gyromagnetic material such that satisfaction of the boundary conditions at the conductive walls is extremely complex. When the boundary conditions, or constraints, are severe, the propagating wave energy becomes increasingly complex in distribution and is no longer describable in terms of a simple waveguide mode configuration. The condition obtaining may be described as one of turbulence. Depending upon the configuration of the gyromagnetic loading within the guide, one of the following phenomena predominates: (1) the propagation constants associated with the turbulent modes become imaginary with the result that wave energy in these modes is reflected from the gyromagnetically active region in a manner descriptive of cutoff, and (2) the wave energy in the turbulent state becomes highly concentrated in the gyromagnetic material and is attenuated by the inherent dielectric and permeability losses present. The degree of turbulence depends in part upon the relative complexity of the cross sectional geometry produced by the particular gyromagnetic loading.

Generally, there may be said to be two types of physical loading which produce turbulence. One type results in a predominantly reflective effect; the other results in a predominantly absorptive effect.

The first loading type may be described as rotationally

symmetric. In accordance with one principal embodiment of the invention a thin element of gyromagnetic material is disposed symmetrically about the center conductor of a dominant mode TEM wave guiding structure. When R.F. energy is applied and the element is polarized longitudinally, electric and magnetic components are generated as explained hereinabove. If the gyromagnetic material is spaced away from the conductive boundary walls, these generated field components form portions of simple modes supported by the loaded guiding structure. If, however, the gyromagnetic material is moved into a region contiguous to a conductive boundary, eddy currents set up in the wall by magnetic flux components which attempt to align themselves with the generated magnetic components normal to these walls act as a serious constraint upon the possible modal distributions. The eddy currents effectively short out the simple modes which includes the field components generated by the gyromagnetic material. In order to satisfy such a serious constraint, the propagating wave energy is forced to assume a highly complex or agitated state described by a multiplicity of higher order wave modes. In the rotationally symmetric embodiments of the invention, these higher order wave modes are of relatively low, but significant, turbulence. The lower order turbulence modes are characterized by imaginary propagation constants; i.e., they are in a state resembling the well-known cut-off condition in hollow pipe waveguides. Energy is, therefore, reflected from the gyromagnetically active region and the device acts as a reflective switch. In this manner, reflective transmission losses may be produced in a lightly loaded gyromagnetic device.

The second loading type may be described as a sectoral array. In accordance with a second principal embodiment of the invention longitudinally extending sectorally shaped thin elements or slabs of gyromagnetic material are disposed in a radial fashion between the conductors of a dominant mode TEM wave guiding structure. As in the rotationally symmetric embodiment described above, the incidence of TEM waves upon the longitudinally magnetized gyromagnetic elements results in the attempted generation of radial magnetic field components. If, however, the thin slabs or sectors contact conductive walls, the simple modes which would be set up in the absence of the constraint represented by the contact of the elements with the boundary wall are effectively shorted out by eddy currents set up in the walls. A turbulent wave state results. In the sectoral slab embodiments the constraint imposed by the contiguity between gyromagnetic material and conductive wall is nonuniform around the periphery of the conductive surfaces. This nonuniformity results since the gyromagnetic material takes the form of sectoral elements which are spaced apart and which therefore contact the conductive walls at spaced locations. In the presence of the nonuniform constraint, the propagating wave energy is forced to assume an agitated state even more complex in modal content than that which is present in the rotationally symmetric embodiments. These more complex modes are highly turbulent and tend to concentrate in the gyromagnetically active regions of the guiding structure. The energy may be thought of as being trapped within the gyromagnetic material much the same as energy is trapped in a resonant circuit. Thus, any inherent loss properties of the material will be effective to dissipate large quantities of the trapped wave energy. Since the gyromagnetic material does inherently have a certain amount of dielectric and permeability loss associated with it, the higher order turbulence modes produced by the sectoral array structures are dissipated within the loading material and the device acts as an attenuator. In this manner, high dissipative transmission losses may be produced in a lightly loaded gyromagnetic device.

The above and other objects and features of the invention, its nature and its various advantages will appear

more fully upon consideration of the accompanying drawing and the accompanying detailed description thereof.

In the drawing:

FIG. 1 is a perspective view, partially broken away, of a coaxial transmission line containing gyromagnetic material distributed in a rotationally symmetric manner in accordance with one principal embodiment of the invention;

FIG. 2, given for illustrative purposes, is a plot of the tensor permeability components μ and κ of gyromagnetic material as a function of frequency;

FIG. 3 is a partially broken away perspective view of the principal embodiment of FIG. 1 in a strip transmission line;

FIG. 4 is likewise a partially broken away perspective view of a coaxial transmission line containing gyromagnetic material distributed in a sectoral array in accordance with an additional embodiment of the invention; and

FIG. 5 is a cross sectional view of the sectoral array embodiment of the invention in a strip transmission line.

Referring more particularly to FIG. 1, a reciprocal reflective switch is shown as one illustrative embodiment of the present invention. The device of FIG. 1 includes a section of coaxial line 10 comprising an inner cylindrical conductor 11 and a concentric outer cylindrical conductor 12 separated by a region 13. Extending between inner conductor 11 and outer conductor 12 in region 13 is annulus 14. Annulus 14 should be contiguous to at least one boundary wall and, therefore, may contact conductor 11 or conductor 12. In FIG. 1, annulus 14 extends longitudinally within line 10 for a distance of at least several wavelengths of the energy transmitted in line 10.

The portion of region 13 not occupied by element 14 is filled with material whose physical constants differ from those of the gyromagnetic material of which element 14 is composed. This material may include air, polyethylene, or any of the many other dielectrics used for filling purposes. In the preferred embodiment of FIG. 1 the nongyromagnetic portion of region 13 is illustrated as air but the invention is by no means limited to this material.

Annulus 14 is composed of a material having electrical and magnetic properties of the type described by the mathematical analysis of D. Polder in *Philosophical Magazine*, January 1949, vol. 40, pp. 99-115. These materials are characterized by the fact that they exhibit gyromagnetic properties at microwave frequencies and may therefore be spoken of as gyromagnetic materials. The term gyromagnetic material is employed here in its accepted sense as designating the class of materials having portions of the atoms thereof that are capable of exhibiting a significant precessional motion at frequencies within the microwave frequency range, this precessional motion having an angular momentum, a gyroscopic moment, and a magnetic moment. Included in this class of materials are ionized gaseous media, paramagnetic materials, and ferromagnetic materials including the spinel ferrites and the garnet-like yttrium-iron compounds. One particular class of gyromagnetic materials suitable for use as element 14 in the present invention comprises an iron oxide combined with a quantity of bivalent metal such as nickel, magnesium, zinc, manganese or other similar material. As a specific example element 14 may comprise nickel-zinc ferrite prepared in the manner described in United States Patent 2,748,353 which issued to C. L. Hogan on May 29, 1956.

Element 14 is biased by a steady magnetic field which extends through the element in a direction in which the propagating wave energy is characterized by a rate of change of phase. As shown in FIG. 1, the polarizing field may be supplied by solenoid 15 which surrounds line 10 in the vicinity of element 14 and which is connected to voltage source 17. This field may also be generated by any other means which will produce the desired direction of magnetization in element 14. The field may be sup-

plied, for example, by a permanent magnet or by permanently magnetizing element 14 itself. The strength of the magnetizing field in element 14 can be varied by means of variable resistor 16 connected in series with source 17. The strength of the magnetizing field is adjusted to a value to be more fully discussed in a later portion of this specification.

FIG. 2 given by way of explanation, is a graphical plot of the tensor permeability components μ and κ associated with gyromagnetic material as a function of the radian frequency ω . The external biasing field H_{dc} is assumed to be held constant. The terms μ and κ , which are terms of the Polder tensor T, may be expressed ideally as

$$\mu = 1 + \frac{\omega_m \omega_0}{\omega_0^2 - \omega^2}$$

$$\kappa = \frac{\omega_m \omega}{\omega_0^2 - \omega^2}$$

where

$$\omega_0 = \gamma H$$

H = internal static magnetic field in oersteds,

$$\omega_m = 4\pi M_s \gamma$$

$\gamma = 2.8$ mc./oersted, the gyromagnetic ratio for electrons,

$4\pi M_s$ = saturation magnetization of the ferrite medium in oersteds, and

ω = angular frequency of the incident wave energy in megacycles.

Expressed in a cartesian representation, the Polder tensor becomes

$$T = \begin{vmatrix} \mu & i\kappa & 0 \\ -i\kappa & \mu & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

The determinantal value of the above matrix is seen to be $\mu^2 - \kappa^2$. One should expect, therefore, that operating conditions for which $\mu^2 = \kappa^2$ would be characterized by some physical singularity.

Considering for a moment the case of total gyromagnetic filling in a longitudinally magnetized coaxial structure, one finds that as the relative values of μ^2 and κ^2 converge, equate, and then diverge, the propagation constant changes from imaginary to real and that the physical wave energy characteristics of the structure exhibit a change from a cut-off state to a propagating state. Thus the point for which $\mu^2 = \kappa^2$ may be thought of as a singular point. A complete mathematical investigation of the propagation characteristics of this structure reveals that the infinite singularity of the expression

$$\frac{\mu^2 - \kappa^2}{\mu}$$

is likewise critical. This latter point may be regarded as a second singular point at which a change from low transmission loss to high transmission loss obtains, i.e., a change similar to the reverse of that occurring when $|\mu| = |\kappa|$.

In FIG. 2, curve 18, 18' represents the variation of μ with frequency and curve 19, 19' represents the concurrent behavior of κ . In accordance with the mathematical expressions given for μ and κ above, the curves begin at a value greater than unity, and zero, respectively, pass through an infinite singularity at $\omega = \omega_0$ and then asymptotically approach their limits for an infinite frequency. For frequencies above ω_0 it will be seen from FIG. 2 that μ decreases from a large negative value, passes through zero and approaches unity. Similarly, κ decreases from a large negative value but approaches zero through negative numbers without crossing the axis. The frequency for which μ passes through zero is

$$\omega_{\mu=0} = (\omega_0)^{1/2} (\omega_0 + \omega_m)^{1/2}$$

while the frequency for which $\mu^2 = \kappa^2$ is

$$\omega_{|\mu|=|\kappa|} = \omega_0 + \omega_m$$

Thus for ferrites with a saturation magnetization of the order of 10^3 , the condition $|\mu| = |\kappa|$ will obtain at a frequency substantially removed from that for which $\mu = 0$. In accordance with this separation of singular points for which transmission losses change significantly, the present invention provides transmission loss bandwidths much broader than were obtainable in prior art gyromagnetic devices. In FIG. 2, area A represents bandwidths obtainable with prior art resonance absorption devices. A typical bandwidth with such a device was of the order of 250 megacycles. Area B of FIG. 2 represents the added bandwidth obtainable with the present invention and will be noted to terminate at the condition of magnitude equality between μ and κ . Total transmission loss bandwidths obtainable with turbulence devices are of the order of 2500 megacycles.

It has been discovered that decreasing the volume of gyromagnetic filling in a longitudinally magnetized TEM mode propagation structure increases the realizable transmission loss. This effect is in direct contradistinction to resonance absorption devices in which the loss effect is volumetric in nature. In addition to the increase in the loss itself over the cut-off band, the losses outside the cut-off band due both to the magnetic and dielectric effects of the gyromagnetic volume itself are reduced, thereby producing a coaxial component capable of higher switching ratios.

In the case of the partially filled geometry, the increased magnitude of transmission loss is accompanied by a decrease in realizable bandwidth over which the loss may be sustained. The upper frequency of cutoff in the annulus geometry of FIG. 1; i.e., that frequency for which propagation is reinstated occurs when

$$\frac{\mu^2 - \kappa^2}{\mu} = -\frac{t}{w}$$

where

t = the thickness of the gyromagnetic annulus, and

w = the thickness of the dielectric annulus.

Though the cut-off bandwidth obtainable with the partially filled geometry is less than that realizable with the totally filled geometry, the magnitude of the loss is greater over the narrowed band and the band is still considerably greater than any previously obtainable with resonance absorption devices. For example, using a five inch annulus of .095 inch radial thickness composed of a ferrite of 2175 gauss saturation in a $\frac{3}{8}$ inch coaxial line subjected to the magnetizing field of 800 oersteds, a transmission loss of 70 decibels may be sustained over a 1800 megacycle band centered around 5500 megacycles.

In the operation of the device of FIG. 1 as a frequency band rejection filter, the appropriate strength of external magnetizing field may be determined from consideration of the conditions for which cutoff is initiated; i.e., the conditions for which $\mu = 0$. Recalling that

$$\omega_{\mu=0} = (\omega_0)^{1/2} (\omega_0 + \omega_m)^{1/2}$$

and that

$$\omega_0 = \gamma H$$

and defining the cut-off frequency $\omega_{co} = \omega_{\mu=0}$, it is easily seen that

$$H = \frac{1}{2\gamma} [\sqrt{\omega_m^2 + 4\omega_{co}^2} - \omega_m]$$

For a magnetic field strength in oersteds as defined above, the band of rejected frequencies will begin at the condition for which μ passes through zero. It may well be that in practice H_{dc} should be set at a somewhat lower value than that specified above in order that maximum transmission loss be realized at ω_{co} .

The embodiments of the present invention may be used

as modulators by varying the strength of the external magnetizing field applied to the gyromagnetic material in the presence of propagating rf wave energy of constant frequency. In this case, the condition of high transmission loss is initiated in the completely filled geometry at the field strength for which $|\mu| = |\kappa|$ and terminates for a field strength for which $\mu = 0$, the nature of the transmission change at the two singular points being reversed. The normal range of values of H_{dc} over which losses of the order of 70 decibels may be realized is 1000 oersteds, considerably more than in prior art gyromagnetic devices. It should be noted that in most practical applications of the components embodying the present invention, the strength of H_{dc} is at least great enough to saturate the gyromagnetic material. Anomalous effects may occur if the strength of the applied field is below this value.

FIG. 3 is a perspective view of an embodiment of the present invention in a strip transmission line. Specifically FIG. 3 is a strip line embodiment of the rotationally symmetric loading distribution of FIG. 1. In the figure, symmetrical strip line 26 comprises three parallel conductive plates 27, 28, and 29 separated by a dielectric medium. Plates 27, 28, and 29 are flat and parallel, outer plates 27, 29 being of equal width and center plate 28 being narrower in width and spaced midway between outer plates 27, 29. Between plates 27 and 28, and between plates 28 and 29 are elements 30, 31, respectively. Elements 30, 31 may be geometrically described as thin slabs with the broad faces thereof parallel to the conductive plates comprising the transmission line. The slabs extend along the length of line 26 for a distance which may be of the order of several wavelengths of the energy in line 26. In the preferred embodiment illustrated and in accordance with the discovery that partial filling produces higher transmission losses than complete filling, elements 30, 31 only partially fill the area between plates 27, 28, and 29. Elements 30, 31 are shown in contact with outer plates 27, 29 but they may contact opposite sides of plate 28 instead. If lateral radiation problems are neglected, slab 30 may contact outer plate 27 while slab 31 contacts inner plate 28.

Elements 30, 31 are composed of a material substantially identical to that of annulus 14 in FIG. 1. These elements exhibit gyromagnetic properties at microwave frequencies as previously mentioned.

As indicated by arrow 32, elements 30, 31 are subjected to a steady magnetic field in a direction parallel to plates 27, 28, and 29. The field thus extends longitudinally with respect to elements 30, 31 as well as with respect to the wave energy in line 26. Means for supplying the magnetic field are not illustrated for sake of clarity but the field may be supplied by a solenoid structure surrounding line 26, by a permanent magnet, or by permanently magnetizing elements 30, 31 themselves. The strength of this magnetizing field is determined in the manner hereinbefore mentioned. In general the magnetizing field should be of sufficient strength to saturate the gyromagnetic material. The strip line of FIG. 3 may be excited by a coaxial line comprising center conductor 33 connected to center plate 28 and outer conductor 34 connected to outer plates 27, 29. Source 35 supplies dominant TEM wave mode energy to coaxial line 33, 34. It will be recalled that this mode is characterized by radially extending electric field components and closed magnetic field loops, both lying entirely in planes transverse to the direction of wave energy propagation. The entire device of FIG. 3 may be inserted into a conductively bounded waveguide or shielding structure to eliminate radiation effects due to non-symmetrical excitation of the strip line geometry.

The operation of the device of FIG. 3 is much the same as that of FIG. 1 explained above in conjunction with FIG. 2. Essentially, the strip line counterpart of the rotationally symmetric gyromagnetically loaded coaxial line is a reflective switch providing high transmission

losses over a frequency band much broader than that realizable with prior art devices. In theory, TEM wave energy incident upon gyromagnetic material which is magnetized in the direction of a phasal rate of change of the energy undergoes a perturbation which, if the gyromagnetic loading is properly disposed within the line, results in the creation of turbulent or agitated wave mode patterns. Under these conditions a substantial band of frequencies is characterized by an imaginary propagation constant and thus wave energy of these frequencies does not propagate. The frequency band of rejection is initiated in the vicinity of the frequency which, for the external biasing field and ferrite magnetization involved, causes μ to become zero. This cut-off state continues as frequency increases until the vicinity for which the expression which defines the upper cut-off condition, namely,

$$\frac{\mu^2 - \kappa^2}{\mu} = -\frac{t}{w}$$

where:

t = thickness of gyromagnetic slab

w = thickness of dielectric between plate and slab

is satisfied. As stated before, this frequency band is greater than those realizable in prior art gyromagnetic devices.

FIG. 4 illustrates, in a partially broken away perspective view, a sectoral slab array in a circularly coaxial transmission line which functions as an essentially absorptive wave energy attenuator. Illustrated is a section of coaxial line 40 comprising cylindrical inner conductor 41 and cylindrical outer conductor 42. Conductor 42 is symmetrically disposed with respect to conductor 41 and is coaxial therewith. The conductors are separated by region 43, which comprises a filling dielectric which may be air, polyethylene, polyfoam, or any of the many other dielectrics used for filling purposes.

Extending in a longitudinal direction in line 40 between conductors 41, 42 are tapered radial elements 44, 45, 46, and 47. These elements are composed of a material having gyromagnetic properties at microwave frequencies. Geometrically, elements 44 through 47 are sectoral in cross section and have a longitudinal extent of at least several wavelengths of the energy in line 40. Elements 44 and 45 are substantially identical and extend longitudinally in diametrically opposite portions of line 40. Lying in a plane orthogonal to the plane containing elements 44, 45 and spaced at a distance of several wavelengths of the propagating energy further along the longitudinal extent of line 40 are elements 46 and 47. One observing the device of FIG. 4 from an end thereof would see a symmetrical array of four sectorally shaped elements spaced at 90-degree intervals between center conductor 41 and outer conductor 42.

Elements 44 through 47 are subjected to a static magnetizing field extending in the direction of energy propagation through line 40. As illustrated in FIG. 4 the polarizing field may be supplied by solenoid 48 which surrounds line 40 in the vicinity of the gyromagnetic elements and which is connected to source of potential 49. As stated before, this field may be supplied by any other appropriate means including a permanent magnet or by permanently magnetizing the elements themselves. The strength of the biasing field may be varied by means of variable resistor 50 connected in series with source 49.

As mentioned hereinabove, the sectoral geometry, when longitudinally magnetized in the presence of incident TEM wave energy, gives rise to a perturbation of the TEM waves which, if the gyromagnetic material is contiguous to a conductive boundary, results in a highly turbulent energy distribution. This complex wave energy concentrates in the gyromagnetic material and is dissipated by its inherent dielectric and permeability losses. The band of frequencies over which high attenua-

tion obtains in the sectoral geometry is initiated for the frequency at which the tensor permeability component μ of the gyromagnetic material passes through zero and is terminated at a frequency below that for which, in the totally filled case illustrated graphically in FIG. 2, $|\mu| = |\kappa|$. The magnitude of attenuation realizable with the sectoral geometry is substantially greater than that obtainable with the completely filled geometry and the bandwidths over which the attenuation obtains is broader than those realizable with prior art attenuators employing gyromagnetic material in coaxial transmission lines.

FIG. 5 is a cross sectional view of a strip line embodiment of the sectoral array of FIG. 4. The symmetrical strip line comprises parallel conductive plates 51, 52, and 53 separated by a dielectric medium which is illustrated as being composed of air in FIG. 5 but which may be of any other suitable filling material. Extending between plates 51, 52 and between plates 52, 53 are rectangularly shaped slabs 54, 55 and 56, 57, respectively. These elements are composed of gyromagnetic material hereinbefore described and are biased by an external magnetic field H_{dc} extending perpendicular to the plane of the paper as indicated by symbol 58. Elements 54 through 57 are illustrated as being asymmetrically disposed within the dielectric medium separating conductive plates 51, 52, 53. Since a symmetrical strip line will radiate wave energy laterally unless perfectly balanced, it will be necessary to enclose the strip line of FIG. 5 in a hollow conductive waveguide to prevent radiation. However, the asymmetry of the loading produces no significant increase in magnitude of attenuation or rejection bandwidth relative to the same quantities associated with symmetrical loading and thus the gyromagnetic members 54 through 57 may be arranged in a fashion producing a balanced transmission line without detracting from the attractiveness of the device.

The operation of the embodiment of FIG. 5 is equivalent to that of FIG. 4, producing wave energy absorption through the creation of turbulence effects caused by the complicated cross sectional geometry of the contiguous gyromagnetic loading.

In the sectoral array embodiments of FIGS. 4 and 5, the efficiency of the devices may be increased by further complication of the cross sectional geometry. Also, the sectors or slabs, as the case may be, may extend from one conductor only part of the way to the adjacent conductor, or some of the elements may extend completely between the conductors while others contact only one conductive surface. The particular number of elements used is not to be understood to be fixed at four as illustrated, by it should be remembered that as the number of elements is increased, the constant magnetic and dielectric losses in the propagating state associated with the completely filled geometry enter to a more significant degree and also that the maximum realizable attenuation will eventually decrease in accordance with the theory of total filling.

One of the principal advantages of the embodiments of the invention illustrated in FIGS. 3 and 5 are their simple mechanical form. These structures are easily adapted to standard printed circuit techniques in present use. Outer conductive plate 51 may be etched on one face of a dielectric slab which has been slotted to receive gyromagnetic elements 54, 55 and center plate 52 may be etched on the opposite face of the slab. In a similar fashion outer plate 53 may be etched on one surface of a second slotted dielectric slab which may contain elements 56, 57 and have an etched surface representing center plate 52 on its opposite surface. These two slabs are then combined such that the etched surfaces representing center plate 52 are aligned and adjacent. This type of construction is ideally suited to automatic fabrication processes.

In all cases, it is to be understood that the above-described arrangements are simply illustrative of a small

number of the many possible specific embodiments which can represent applications of the principles of the invention. Numerous and varied other arrangements can readily be devised in accordance with these principles by those skilled in the art without departing from the spirit and the scope of the invention.

What is claimed is:

1. A microwave component adapted to support dominant mode electromagnetic wave energy of solely transverse electric and solely transverse magnetic field distributions comprising,

a transmission path which is conductively bounded in at least two oppositely disposed regions,

a conductive member symmetrically positioned between said regions,

and means for operating said component in a cut-off condition in which said wave energy of frequencies between f_0 and f_2 propagating in either direction therethrough is highly attenuated,

said means comprising the combination of magnetically polarizable material positioned in the space between said regions and said member and contiguous to at least one conductive surface thereof, said material filling less than half of the area between said regions and said member and exhibiting ferromagnetic resonance in the presence of said wave energy at a frequency f_1 between f_0 and f_2 with a resonance line width which is less than

$$\frac{f_2 - f_0}{2}$$

nonmagnetic dielectric material extending coextensively along the entire length of said gyromagnetic material and filling the remainder of the area between said regions and said member,

and means for applying a magnetic field to said magnetically polarizable material in a direction parallel to the direction of propagation of said energy, said field having a strength relative to said frequency band of high attenuation which includes the region of ferromagnetic resonance.

2. The component according to claim 1 in which said conductive bounding regions comprise longitudinally parallel plates,

said conductive member comprises a metallic strip between and equally spaced from said plates,

and said gyromagnetic material comprises at least one rectangular slab extending longitudinally in the space between said plates and said strip.

3. An energy guiding component adapted to support dominant mode electromagnetic wave energy of solely transverse electric and solely transverse magnetic field distributions comprising,

a section of coaxial transmission line having two concentric cylindrical conductive boundaries which are conductively separate,

and means for operating said component in a cut-off condition in which said wave energy of frequencies between f_0 and f_2 propagating in either direction therethrough is highly attenuated,

said means comprising the combination of magnetically polarizable material positioned in the space between said conductive boundaries and contiguous to at least one of said conductive boundaries, said material filling less than half of the area between said boundaries and exhibiting ferromagnetic resonance in the presence of said wave energy at a frequency f_1 between f_0 and f_2 with a resonance line width which is less than

$$\frac{f_2 - f_0}{2}$$

nonmagnetic dielectric material extending coextensively along the entire length of said gyromagnetic material and filling the remainder of the area between said boundaries,

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and means for applying a magnetic field to said magnetically polarizable material in a direction parallel to the direction of propagation of said energy, said field having a strength relative to said frequency band of high attenuation which includes the region of ferromagnetic resonance.

4. An energy guiding component adapted to support dominant mode electromagnetic wave energy of solely transverse electric and solely transverse magnetic field distributions comprising,

a section of strip transmission line having three conductive members extending longitudinally parallel, the center one of said members being narrower in width than the outer members and equally spaced from each of said outer members,

and means for operating said component in a cut-off condition in which said wave energy of frequencies between f_0 and f_2 propagating in either direction therethrough is highly attenuated,

said means comprising the combination of magnetically polarizable material positioned in the space between said conductive members and contiguous to at least one of said conductive members, said material filling less than one half of the area between said members and exhibiting ferromagnetic resonance in the presence of said wave energy at a frequency f_1 between f_0 and f_2 with a resonance line width which is less than

$$\frac{f_2 - f_0}{2}$$

nonmagnetic dielectric material extending coextensively along the entire length of said gyromagnetic material and filling the remainder of the area between said members,

and means for applying a magnetic field to said magnetically polarizable material in a direction parallel to the direction of propagation of said energy, said field having a strength relative to said frequency band of high attenuation which includes the region of ferromagnetic resonance.

5. In combination, a conductively bounded transmission line section having first and second terminal ends and adapted to support dominant mode electromagnetic wave energy of solely transverse electric and solely transverse magnetic field distributions,

means for applying said wave energy at said first terminal end,

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means for receiving said energy at said second terminal end,

and means for operating said section in a cut-off condition in which said wave energy of frequencies between f_0 and f_2 propagating in either direction therethrough is highly attenuated,

said means comprising the combination of magnetically polarizable material positioned within the cross sectional area of said section between said terminal ends and contiguous to at least a portion of the conductive boundaries thereof, said material filling less than one half of said cross sectional area and exhibiting ferromagnetic resonance in the presence of said wave energy at a frequency f_1 between f_0 and f_2 with a resonance line width which is less than

$$\frac{f_2 - f_0}{2}$$

nonmagnetic dielectric material extending coextensively along the entire length of said gyromagnetic material and filling the remainder of said cross sectional area, and means for applying a magnetic field to said magnetically polarizable material in a direction parallel to the direction of propagation of said energy, said field having a strength relative to said frequency band of high attenuation which includes the region of ferromagnetic resonance.

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