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E. M. GYORGY ETAL

3,051,917

METHOD OF SUPPRESSING SATURATION EFFECTS IN GYROMAGNETIC DEVICES

Filed June 22, 1960

2 Sheets-Sheet 1

FIG. 1

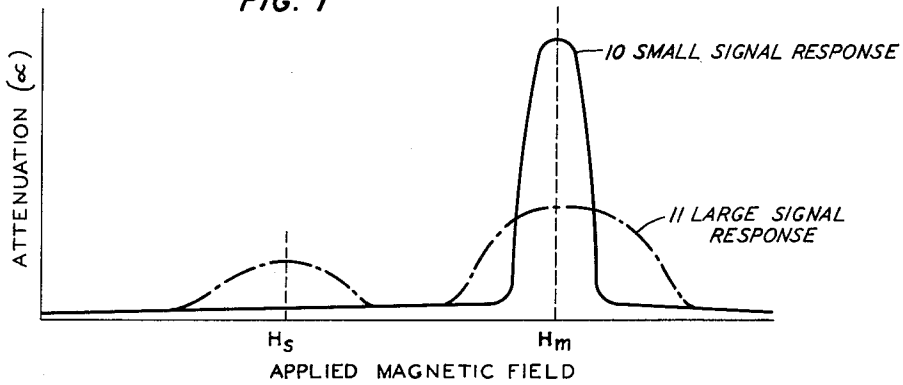


FIG. 2A

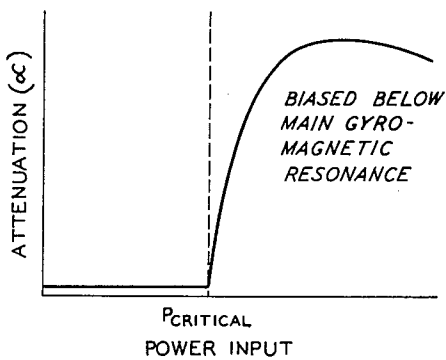


FIG. 2B

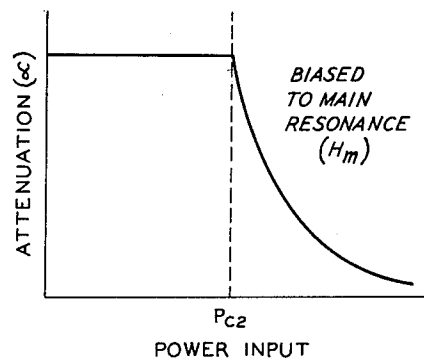
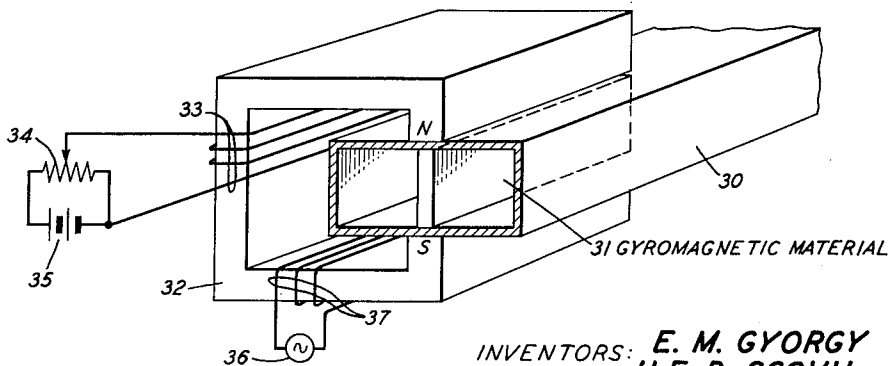


FIG. 3



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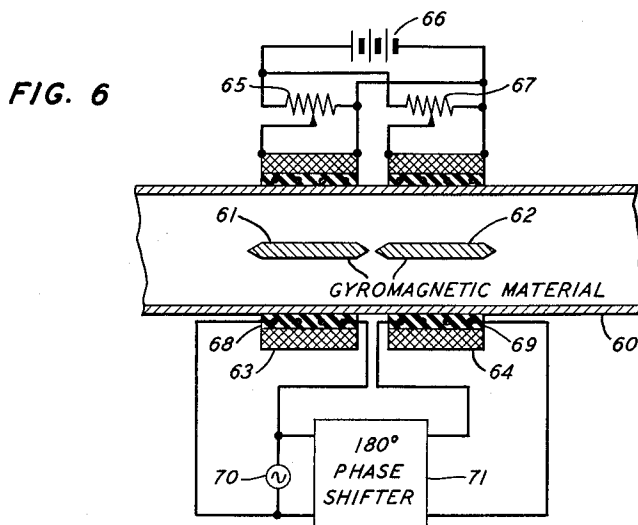
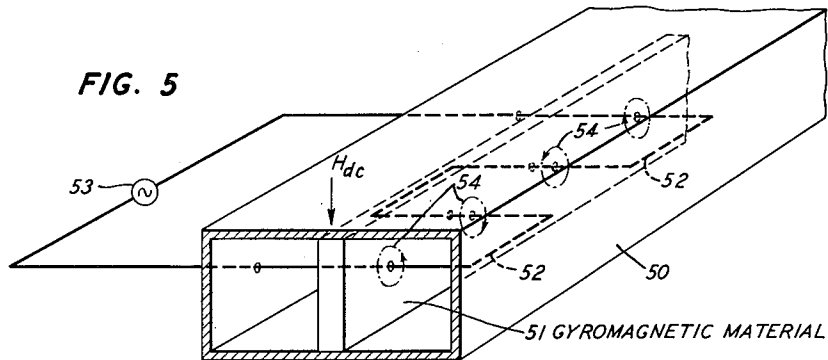
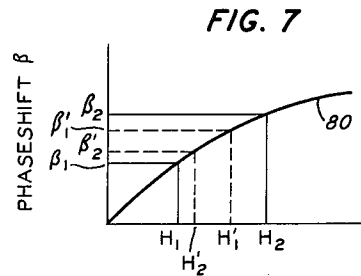
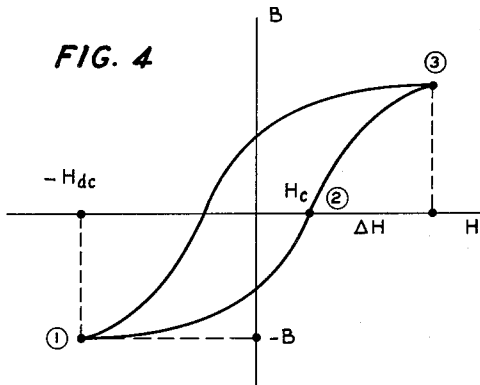
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2 Sheets-Sheet 2



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1

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METHOD OF SUPPRESSING SATURATION
EFFECTS IN GYROMAGNETIC DEVICES

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8 Claims. (Cl. 333—31)

This invention relates to electromagnetic wave devices using gyromagnetic materials and, in particular, to means for eliminating the anomalous attenuation effects produced by such gyromagnetic materials at high power levels.

It has been observed that materials of the type having the properties described by the mathematical analysis of D. Polder, Philosophical Magazine, volume 40, pages 99 through 115 (1949), have certain anomalous attenuation characteristics which were not predicted by Polder's theory. This class of materials, a chief one among them being ferrite, is characterized by certain unpaired electron spins which respond to a transmitted microwave signal by precessing gyroscopically about the line of an applied magnetic field. The interaction of these precession electrons with the applied microwave signal results in certain magnetic properties which have given these materials the name "gyromagnetic." Polder's so-called "small signal" theory predicts an attenuation characteristic as shown by the solid curve 10 in FIG. 1 of the drawings. Also shown in FIG. 1 is dashed curve 11 representing what may be called the large signal response of gyromagnetic materials. It will be observed that the large signal response exhibits certain anomalous characteristics in the regions of two particular applied field values which are not predicted by Polder's theory and are not present at smaller signal levels. Thus, at the field value H_s , the attenuation for large signals is much greater than for small signals, while at another field value H_m , the attenuation for large signals is much less than that for small signals. This large signal behavior of gyromagnetic materials has been observed by R. W. Damon, Review of Modern Physics, volume 25, pages 239 through 245, January 1953, and by N. Bloembergen and S. Wang, Physical Review, volume 93, pages 72 through 83, January 1954.

The effect of this large signal behavior has been to severely limit the operating range of electromagnetic wave devices employing gyromagnetic materials.

Gyromagnetic devices can be broadly divided into two classes: those biased below gyromagnetic resonance and which depend for their operation upon the effective permeability of the gyromagnetic element and its low attenuation, and those biased at resonance and which depend upon the effective high attenuation of the gyromagnetic element.

Because the so-called "large signal" effects can, in fact, occur at relatively low power levels, the performance of both classes of devices over a substantial range of operating signal levels is adversely effected by the anomalous characteristics of gyromagnetic materials.

It is, therefore, an object of this invention to avoid the so-called "large signal" behavior of gyromagnetic materials.

The anomalous behavior of gyromagnetic materials at high power levels has been explained as due to the excitation within the material of a class of short wavelength spin waves. (This is discussed by H. Suhl in an article entitled "The Theory of Ferromagnetic Resonance at High Signal Powers," The Journal of the Physics and Chemistry of Solids, volume 1, pages 209-227, April

2

1957. At high power levels the coupling of energy from the uniform precession to the spin waves is enhanced, substantially modifying the transmission properties of the gyromagnetic material.

It is, accordingly, a more specific object of this invention to inhibit the transfer of power between the uniform precession and the short wavelength spin waves.

Investigation has shown that the spin waves propagate within the gyromagnetic material in a preferred direction with respect to the uniform precession, and have a finite build-up time. In accordance with the invention, means are provided whereby the direction of the uniform precession is changed at intervals comparable to or less than the build-up time of the spin waves. By so modulating the sense of the uniform precession there is insufficient coupling between the uniform precession and the spin waves to enable their growth and propagation within the gyromagnetic material. The suppression of the above-mentioned short wavelength spin waves effectively avoids the so-called anomalous large-signal behavior of gyromagnetic materials.

The above-stated and other objects and advantages, the nature of the present invention, and its various features, will appear more fully upon consideration of the various illustrative embodiments now to be described in detail in connection with the accompanying drawings, in which:

FIG. 1, given for the purpose of explanation, is a graphical and qualitative representation of the attenuation versus applied magnetic field characteristic of gyromagnetic media showing the small signal and large signal responses;

FIGS. 2a and 2b, given for the purpose of explanation, are graphical and qualitative representations of the attenuation versus applied power characteristics of gyromagnetic media at the field values H_s and H_m , respectively, shown in FIG. 1;

FIG. 3 is a perspective view of an illustrative embodiment of the invention in which the modulating field is applied in the direction opposite to the magnetizing field;

FIG. 4, given by way of explanation, is a graph showing the hysteresis loop of a typical sample of gyromagnetic material;

FIG. 5 is a perspective view of a second embodiment of the invention in which the modulating field is applied oblique to the biasing field;

FIG. 6 shows a third embodiment of the invention illustrative of a method of reducing instantaneous variations in the transmission properties of microwave devices produced by the modulating field; and

FIG. 7, given by way of explanation, shows the manner in which the instantaneous phase shift of the device shown in FIG. 6 varies under the influence of the modulating field.

Referring more particularly to FIG. 1, there is shown, for the purpose of explanation, a graphical and qualitative representation of the attenuation (α) as a function of the applied magnetic biasing field characteristic of gyromagnetic materials. The term "gyromagnetic material" is employed here in its accepted sense as designating the class of magnetic polarizable materials having unpaired spin systems involving portions of the atoms thereof that are capable of being aligned by an external magnetic polarizing field and which exhibit a significant precessional motion at a frequency within the range contemplated by the invention under the combined influence of said polarizing field and a varying magnetic field component. This precessional motion is characterized as having an angular momentum and a magnetic moment. Typical of such materials are the ferromagnetic materials including the spinels such as magnesium aluminum fer-

rite, aluminum zinc ferrite and the garnet-like materials such as yttrium-iron garnet.

Solid curve 10 shows this characteristic for small signal levels below a critical value, to be discussed more fully below, and dashed curve 11 shows this characteristic for large signal levels above the critical value. The behavior of a gyromagnetic medium for small signals has been explained on the theory that in the presence of an applied magnetic field having an amplitude great enough to saturate the magnetic material, the unpaired electron spins in the medium line up parallel to one another and tend to behave gyroscopically as a single unit. Therefore, when the frequency of the applied signal is equal to the natural precession frequency of the electron spins, a resonant condition exists under which the electron spins are able to absorb large amounts of energy from the signal. This condition, which has been called the main gyromagnetic resonance, is shown at the applied field value H_m in FIG. 1. At all other field values the attenuation is very low and may be neglected.

The simple uniform precession theory used above, however, does not explain the shape of the attenuation characteristic at large signal levels, represented by dashed curve 11 in FIG. 1. At these large signal levels, the attenuation at main resonance becomes substantially lower and the resonance curve becomes substantially broader than at small signal levels. Furthermore, a second resonance, which may be termed the subsidiary resonance, appears at an applied field value of H_s , substantially less than H_m . An attempt will be made below to explain this anomalous behavior of polarized gyromagnetic media at high signal levels.

The small signal theory states that a microwave signal passing through a polarized gyromagnetic medium is coupled to the electron spins within the medium by means of the high frequency magnetic field components of the applied signal. The electron spins are thus driven en masse to precess gyroscopically at some angle about the line of the applied magnetic field. Not taken into account by this small signal theory is the coupling between this uniform precession of the electron spins and certain small perturbances in the electron spin system which may be called spin waves.

A gyromagnetic medium is continually in a state of thermal agitation, resulting in a minute and somewhat random misalignment of the electron spins. These perturbances can, by means of a Fourier analysis, be resolved into a series of waves, called "spin waves," which are all coupled to each other and to the uniform precession by means of interspin magnetic forces and electrostatic forces called exchange fields. A relatively narrow band of these spin waves, which may be called the preferred band, is much more strongly coupled to the uniform precession than the remainder of the spin waves due to a correspondence between their resonances in frequency and direction. The spin wave system, and especially the preferred band, can, by means of this coupling, absorb energy from the uniform precession. However, under conditions within the scope of the small signal theory, the energy loss to the spin wave system is sufficiently small to be negligible.

The condition of subsidiary resonance, represented by H_s in FIG. 1, will now be investigated. When biased below resonance, only very small amounts of energy can be coupled to the uniform precession due to the lack of correspondence between the applied frequency and the natural resonant frequency of the uniform precession. However, a small increase in the applied signal will nevertheless raise the excitation of the uniform precession slightly, allowing small amounts of energy to be transferred to the preferred spin wave band and thence to the remainder of the spin wave system. Eventually this energy is transmitted to the crystal lattice to be dissipated as heat. Since the excitation level of the spin wave system has not changed appreciably, the attenuation offered to

the microwave signal has not increased appreciably. So far the conditions have remained within the scope of the small signal theory.

As the power level of the applied signal continues to increase, however, a critical point is reached where the preferred band of spin waves can no longer transfer energy to the remainder of the spin wave system as fast as it is being received from the uniform precession. At this point, called the critical power level, the preferred band goes to a higher state of excitation to accommodate the increase in energy level. The excitation of the preferred band tends to build up rapidly since the coupling thereto is nonlinear, increasing with increasing signal level. This band, being resonant with the uniform precession, is now more strongly coupled to the uniform precession and therefore receives even more energy from the uniform precession. This further increases the excitation level of the preferred band, allowing even further amounts of energy to be coupled thereto. This build-up cycle continues until the power absorbed by the preferred band is just sufficient to balance the losses of the resonant system. It can be seen that an unstable condition exists at the critical power level which results in large amounts of energy being absorbed from the applied signal. This results in a large increase in the attenuation offered to the applied signal. Any further increase in the power level of the applied signal is substantially all diverted into the preferred spin wave band. This condition is shown as the subsidiary resonance hump in dashed curve 11 of FIG. 1 at applied field value H_s . The change in attenuation can more readily be seen in FIG. 2a.

In FIG. 2a there is shown, for the purpose of explanation, a graphical and qualitative representation of the attenuation versus power input characteristic of a gyromagnetic medium biased to a field value H_s as shown in FIG. 1. It can be seen that the attenuation is very low for power inputs below the critical power P_{c1} . At this point, however, the attenuation suddenly jumps to a very high value due to the resonance between the uniform precession and the preferred spin wave band. Beyond this point the attenuation decreases slightly but retains substantially its high value. The power level at which the run-away condition occurs is a function of the magnetic state of the gyromagnetic medium and the relaxation time of the preferred spin waves.

In the case of the main resonance at an applied magnetic field of H_m , the uniform precession is again coupled to a preferred band of spin waves having a frequency and direction of resonance closely resembling that of the uniform precession. Under this condition, however, the uniform precession is already absorbing large amounts of energy from the applied signal and is therefore near its maximum state of excitation. When the critical power level is reached and the preferred spin wave band can no longer get rid of energy as fast as it receives it, the preferred spin waves go to a higher state of excitation at the expense of the uniform precession. The removal of energy from the uniform precession decreases the coupling of this precession to the applied signal and hence the attenuation offered to the signal also decreases. Further increases in the power level of the applied signal result in further excitation of the preferred spin waves and a larger decoupling of the uniform precession from the applied signal. The attenuation therefore decreases and eventually goes to zero when the uniform precession is completely decoupled from the applied signal. This condition is shown as the decline and broadening of the main resonance peak in dashed curve 11 of FIG. 1 at applied field value H_m . The change in attenuation can more readily be seen by considering FIG. 2b.

In FIG. 2b there is shown, for the purpose of explanation, a graphical and qualitative representation of the attenuation versus power input characteristic of a gyromagnetic medium biased by a field H_m as shown in FIG. 1. It can be seen that the attenuation is very high for

5

power inputs below the critical power P_{c2} . At this point, however, the attenuation suddenly drops to a low value. Thereafter, the attenuation continues to decrease, approaching zero. The critical power level at which the decline in attenuation begins has been found to be governed by the same factors as govern the critical power level at subsidiary resonance.

In FIG. 3 a reciprocal phase shifter is shown, modified in accordance with the invention to eliminate subsidiary resonance effects and to thereby produce low-loss phase shift at radio frequency power levels substantially greater than the critical power level for the gyromagnetic material. Specifically, the phase shifter comprises a guide 30 of bounded electrical transmission line for guiding wave energy, which may be a rectangular waveguide of the metallic shield type having a wide internal cross-sectional dimension of at least one-half wavelength of the wave energy to be conducted thereby and a narrow dimension substantially one-half of the wide dimension.

Included within guide 30 are means for imparting a phase delay to the wave energy propagating therethrough. In particular, disposed within guide 30 is a thin vane 31 of gyromagnetic material. Vane 31 is symmetrically disposed within guide 30 along the longitudinal guide axis equally spaced from both narrow walls, with the long dimension of vane 31 extending longitudinally along the guide, parallel to the guide walls.

Vane 31 is biased by a steady magnetic field at right angles to the direction of propagation of the wave energy in guide 30. As illustrated in FIG. 3, this field may be supplied by an electrical solenoid having a magnetic core 32 and pole pieces N and S bearing upon the wide walls of guide 30 in a region substantially coextensive with the gyromagnetic vane 31. Turns of wire 33 are wound about core 32 and connected through a potentiometer 34 to a source of magnetizing current 35.

The operation of the phase shifter shown in FIG. 3 is based upon the effective permeability presented to the propagating wave. Since resonant absorption represents a loss for these applications, these devices operate in a range of applied magnetic fields between zero and that required to initiate the resonant phenomenon. In particular, the region of magnetic saturation is of primary importance since the effective permeability is greatest in this region. At power levels below the critical power level, low-loss phase shift is readily obtained. However, above the critical power level coupling between the uniform magnetic precession and the spin waves gives rise to the above-described subsidiary resonance effect which, for all practical purposes, substantially destroys the usefulness of the phase shifter.

In accordance with the invention the tendency to couple energy to the spin waves is inhibited by changing the direction of magnetization within the gyromagnetic vane 31. In the embodiment of the invention shown in FIG. 3 this is done by modulating the steady biasing field by means of a high frequency signal having an amplitude and frequency which will be explained in greater detail hereinafter. The modulating field is impressed upon the magnetic core 32 by turns of wire 37 which connect to a high frequency energy source 36.

For simplicity, source 36 is shown in FIG. 3 as a separate generator. It is understood, however, that source 36 would generally be associated with a power level detector that would monitor the power level in guide 30 and only gate source 36 on when the power level in guide 30 exceeded the critical power level of the gyromagnetic medium.

In operation, potentiometer 34 is adjusted to produce a steady biasing field having an amplitude sufficiently large to produce saturation in vane 31. So biased, the magnetization throughout the material is aligned parallel to the direction of the biasing field. Wave energy, having an amplitude less than the critical amplitude for the gyromagnetic material, will propagate along guide 30 and

6

past vane 31 with substantially little or no attenuation. Under this condition source 36 is gated off. As the power level of the propagating wave increases and approaches the critical power level, source 36 is gated on. The output of source 36 is a wave having an amplitude and frequency to reverse the direction of magnetization at a rate related to the spin wave build-up time in vane 31.

To determine the amplitude of the modulating field necessary to reverse the magnetization when the magnetic material is biased at or above saturation, reference is made to FIG. 4 which shows a typical hysteresis loop for the gyromagnetic material. Specifically, FIG. 4 shows the relationship between the magnetomotive force or magnetizing field H and the magnetic flux density B . Assuming the biasing magnetization to be $-H_{dc}$, the magnetic state of the material is that given by point (1) on FIG. 4. To reduce the magnetic flux, B , to zero from point (1) would require a reverse magnetomotive force of $H_c + H_{dc}$, where H_c is the coercive force for the material. This is indicated at point (2). To now reverse the magnetic flux in the magnetic material to some point (3), the application of an additional magnetomotive force ΔH is necessary.

It should be noted, however, that to go from state (1) to state (3) requires a finite time. The mere application of a reverse magnetomotive force will not, instantaneously, reverse the flux within the gyromagnetic material. Since it is necessary for the purposes of the invention to change the magnetization in a time that is short compared to the spin wave build-up time, the amplitude of the reversing force must be adjusted accordingly. Specifically, if the spin wave build-up time is τ_w , the switching time τ_s should be greater than τ_w . The magnetomotive force H_m required to switch at this rate is then

$$H_m = \frac{S_w}{\tau_s} + (H_{dc} + H_0) \quad (1)$$

where S_w , the switching coefficient, and H_0 , the threshold field, are constant of the material and are determined experimentally. A typical value of S_w is 0.2 oe. μ sec., while H_0 is approximately equal to $2H_c$. The spin wave build-up time, τ_w , being a function of the material, its geometry and the radio frequency power level, is also determined experimentally. This can be done by suddenly applying a radio frequency wave greater than the critical power level to the gyromagnetic element biased below resonance. Momentarily the output will rise to full transmission. As power is coupled to the spin waves and the spin waves build up, the output will exponentially fall off until a lower steady state output is reached. The time for the output to decline to approximately 37 percent of the peak output is one time constant, or τ_w . In a preferred embodiment τ_s is made equal to $\tau_w/10$.

In the embodiment of the invention shown in FIG. 3, given for the purpose of illustration, it is assumed that the gyromagnetic material is transversely biased to saturation and that the function of the microwave device is to introduce phase shift. It is to be understood, however, that for the purposes of this invention the function of the device could just as well be to introduce attenuation into the microwave system and for that purpose the gyromagnetic material is biased to gyromagnetic resonance. As was explained hereinbefore, when a resonantly biased attenuation is operated above the critical power level, the overall attenuation tends to decrease. By modulating the steady biasing field, as explained hereinbefore, coupling between the uniform precession and the spin waves is impeded and the tendency for the attenuation to decrease is avoided.

It will also be noted that in the illustrative embodiment of FIG. 3 the modulating field completely reverses the direction of the biasing field. However, as was pointed out, it is only necessary to change the direc-

tion of the magnetization within the gyromagnetic material. This would also include a change in direction less than 180 degrees. A modification of the embodiment of FIG. 3 wherein changes in the direction of magnetization less than 180 degrees are utilized as shown in FIG. 5.

The device shown in FIG. 5 comprises a section of waveguide 50, and a vane of gyromagnetic material 51 disposed therein. Vane 51 is biased by a steady magnetic field H_{dc} at right angles to the direction of propagation of the wave energy in guide 50. This field may be supplied by an electric solenoid, by a permanent magnetic structure, or vane 51 may be permanently magnetized if desired.

In the embodiment of FIG. 5 the steady biasing field H_{dc} is modulated by means of locally generated magnetic fields which tend to alter the direction of the biasing field. These local fields are produced by means of a conductive member 52 which is threaded through the gyromagnetic vane 51. As shown in FIG. 5, conductor 52 lies in a plane perpendicular to the electric field in guide 50 and passes through the broad surface of vane 51 over a region coextensive with the longitudinal dimension of the vane. Conductor 52 is energized by means of the high frequency energy source 53.

As before, when the amplitude of the wave energy is less than the critical level, source 53 is off. As the power level of the propagating wave increases and approaches the critical level, source 53 is gated on, energizing conductor 52 and producing local magnetic fields about conductor 52 in the region of the gyromagnetic element. Specifically, the magnetic field produced by the modulating source 53 comprises closed loops 54 surrounding conductor 52. The effect of these field components is to alter the direction of the net magnetic field over most of the volume of the gyromagnetic vane, thereby minimizing the tendency for energy to couple between the uniform precession and the spin waves. The amplitude of the modulating field will depend upon the application; that is, if the device shown in FIG. 5 is a phase shifter, the amplitude of the modulating field is adjusted so as to maintain the attenuation through the device below a specified maximum for the given operating level. If, on the other hand, the device in FIG. 5 is intended to be a resonant attenuator, then the amplitude of the biasing field is adjusted so as to maintain the attenuation above a specified minimum at the desired operating level. As before, however, the modulating rate is related to the spin wave build-up time for the given gyromagnetic element.

It is apparent from the above discussion that the net effective magnetization within the gyromagnetic element is varied as a function of time. While the desired effect of this variation is to disrupt the coupling between the magnetization and the spin waves, it also tends to modulate the instantaneous phase shift or attenuation produced by the microwave device. If the resulting overall phase shift or the resulting overall attenuation is still sufficient for the purpose intended, this modulation, or ripple, produced by the modulating wave may be tolerable. If, however, the variations produced by the modulating wave are not permissible, corrective measures can be taken. Perhaps the simplest corrective measure consists in cascading a number of gyromagnetic elements and suitably phasing the modulating field impressed upon them so as to reduce the net modulating ripple to a specified minimum level. A simple embodiment of such an arrangement is shown in the structure of FIG. 6, which is basically a phase shifter of the type described by F. Reggia and E.G. Spencer in an article entitled "A New Technique in Ferrite Phase Shifting for Beam Scanning of Microwave Antennas," November 1957, Proceedings of the I.R.E., pages 1514-1517, modified in accordance with the principles of the invention.

The co-called Reggia-Spencer phase shifter comprises

a pencil of gyromagnetic material disposed along the longitudinal axis of a rectangular section of waveguide. In this type of phase shifter the gyromagnetic element is longitudinally biased below saturation. While modulation of the longitudinal magnetic field in accordance with the principles of the invention will extend the power handling capabilities of this type of phase shifter, the instantaneous phase shift produced by the device will also vary, thus introducing what could be an objectionable phase shift ripple in the output wave.

This difficulty, however, may be readily obviated by modifying the phase shifter as shown in FIG. 6. Specifically, the overall phase shift is obtained in two parts by dividing the gyromagnetic element into two portions and separately controlling the magnetic fields applied to each of the two portions. The phase shifter shown in FIG. 6 comprises a section of rectangular waveguide 60 within which there are suitably supported two cylindrical rods 61 and 62 of gyromagnetic material. Rods 61 and 62 are longitudinally disposed within guide 60 along the guide axis and are longitudinally biased by means of solenoids 63 and 64, respectively, mounted outside of waveguide 60. Solenoid 63 is connected through potentiometer 65 to a source of magnetizing current 66. Similarly, solenoid 64 is connected through potentiometer 67 to said source of magnetizing current 66.

Since the rods are biased below saturation, the direction of magnetization is not parallel to the biasing field but instead varies throughout the volume of the rods. Thus, the instantaneous direction of magnetization can be varied by merely varying the intensity of the biasing field. Accordingly, the modulating field is applied parallel to the biasing field by means of the two additional solenoids 68 and 69, each of which extends over a region of guide 60 substantially coextensive with one of the rods. Solenoids 68 and 69 are energized from the same high frequency energy source 70. However, inserted in the circuit associated with solenoid 69 is the phase shifter 71 for introducing a 180 degree phase difference between the modulating current in solenoid 69 and the modulating current in solenoid 68, as will be explained in greater detail hereinafter.

Curve 80 of FIG. 7 shows the phase shift produced by each of the gyromagnetic rods, in the embodiment shown in FIG. 6, as a function of the instantaneous magnetizing field H . Assuming a total desired phase shift of β_3 degrees, the magnetizing field produced by solenoid 63 is adjusted to H_1 , producing a phase shift β_1 along rod 61, and the magnetizing field produced by solenoid 64 is adjusted to H_2 , producing a phase shift β_2 along rod 62, where $\beta_1 + \beta_2 = \beta_3$.

As the amplitude of the wave energy propagating along guide 60 approaches the critical level, source 70 is energized subjecting rods 61 and 62 to a varying magnetic field component which modulates the phase shift produced by each of said rods. Let us consider rod 61 first. Under the influence of solenoid 68, the total magnetizing field within rod 61 will start to increase, causing the total phase shift produced by rod 61 to increase in accordance with the variation defined by curve 80. Let us assume that the total magnetizing field for rod 61 increases to a point H_1' . The total phase shift produced by rod 61 is then increased to β_1' . Because of the 180 degree phase shift produced by phase shifter 71, the effect of the modulating field produced by solenoid 69 is to reduce the total magnetizing field in rod 62 from H_2 to H_2' , causing the total phase shift in this section of the device to decrease from β_2 to β_2' . Because curve 80 is substantially linear in the region under consideration, $\beta_1' + \beta_2'$ is substantially equal to $\beta_1 + \beta_2$. Thus, the total phase shift through the two sections of the phase shifter remains substantially constant even though the individual phase shift in each section may vary instantaneously due to the effect of the modulating field. It is obvious that by suitably arranging the phasing of the modulating fields, the num-

ber of gyromagnetic rods may be increased and the total phase shift divided among these additional rods, further reducing any ripple in the overall phase shift.

In all cases it is understood that the above-described arrangements are 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 scope of the invention.

What is claimed is:

1. An electromagnetic wave transmission device comprising a section of guided wave path having an element of ferromagnetic material disposed therein, said material characterized as having a first transmission constant for applied signals below a critical power level and a second transmission constant different than said first constant for applied signals above said critical power level, said material further characterized as having a given spin wave build-up time, means for establishing a given state of magnetization within said material, means for applying electromagnetic wave energy to said section of wave path having a power level greater than said critical power level, and means for preventing said material from assuming said second transmission constant including means for modulating said given state of magnetization at a rate not less than the reciprocal of the spin wave build-up time of said material.

2. The combination according to claim 1 wherein the direction of magnetization within said material is reversed by said modulating means.

3. The combination according to claim 1 wherein the direction of magnetization within said material is caused to change by said modulating means by an amount less than 180 degrees.

4. A high power, low-loss, microwave device including an electromagnetic wave transmission path having a power saturable ferromagnetic medium disposed therein, said medium characterized as having a low positive attenuation constant for applied signals below a critical power level, but capable of exhibiting a high positive attenuation constant to signals above said critical power level, said medium further characterized as having a given spin wave build-up time, means for applying a steady magnetic biasing field to said medium, means for applying electromagnetic wave energy to said path having a power level greater than said critical power level, and means for preventing said medium from exhibiting said high attenuation constant including means for modulating said magnetic field at a rate not less than the reciprocal of the spin wave build-up time of said medium.

5. A microwave phase shifter comprising a guided electromagnetic wave transmission path having an element of ferromagnetic material disposed therein, said medium characterized as having a low positive attenuation for applied signals below a critical power level but capable of exhibiting a high positive attenuation to signals above said critical power level, said medium further characterized as having a given spin wave build-up time τ_w , means for applying a steady magnetic biasing field H_{dc} to said medium in a given direction, means for applying electromagnetic wave energy to said wave path having a power level greater than said critical power level, and means

for reversing the direction of said biasing field at a rate $1/\tau_s$ greater than the reciprocal of the spin wave build-up time for said material, said reversing field having an amplitude

$$H_m = \frac{S_w}{\tau_s} + (H_{dc} + H_0)$$

where H_0 is the threshold field for said material, and S_w is the switching coefficient.

6. The combination according to claim 5 wherein the switching rate $1/\tau_s$ is approximately equal to $10/\tau_w$.

7. A phase shifter for electromagnetic wave energy comprising a section of conductively bounded waveguide supportive of said wave energy, first and second elongated elements of ferromagnetic material disposed in longitudinal succession within said waveguide, each of said elements presenting a first propagation constant to wave energy below a given power level and a second propagation constant to wave energy above said given power level, each of said elements also having a given spin wave build-up time, means for longitudinally magnetizing said first element at a first field intensity, means for longitudinally magnetizing said second element at a second field intensity greater than said first intensity, where said first and second intensities are less than that necessary to produce saturation in said elements, means for applying electromagnetic wave energy to said waveguide having a power level greater than said given power level, and means for increasing said first field intensity an incremental amount ΔH , and means for decreasing said second field intensity an incremental amount substantially equal to ΔH at a rate greater than the reciprocal of said given spin wave build-up time for said elements with the variation in said first element being 180 degrees out of time phase with respect to the variation in said second element.

8. A device for electromagnetic wave energy comprising a section of conductively bounded waveguide supportive of said wave energy, a plurality of n elements of ferromagnetic material disposed in longitudinal succession within said waveguide, each of said elements presenting a first propagation constant to wave energy below a given power level and a second propagation constant to wave energy above said given power level, each of said elements also having a given spin wave build-up time, means for magnetically biasing each of said elements at a different field intensity, means for applying electromagnetic wave energy to said waveguide having a power level greater than said given power level, and means for varying said different field intensities at a rate greater than the reciprocal of said given spin wave build-up time for said elements with the variation in each of said elements differing in phase by an amount equal to $360/n$ degree or whole multiples thereof.

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