

Jan. 9, 1962

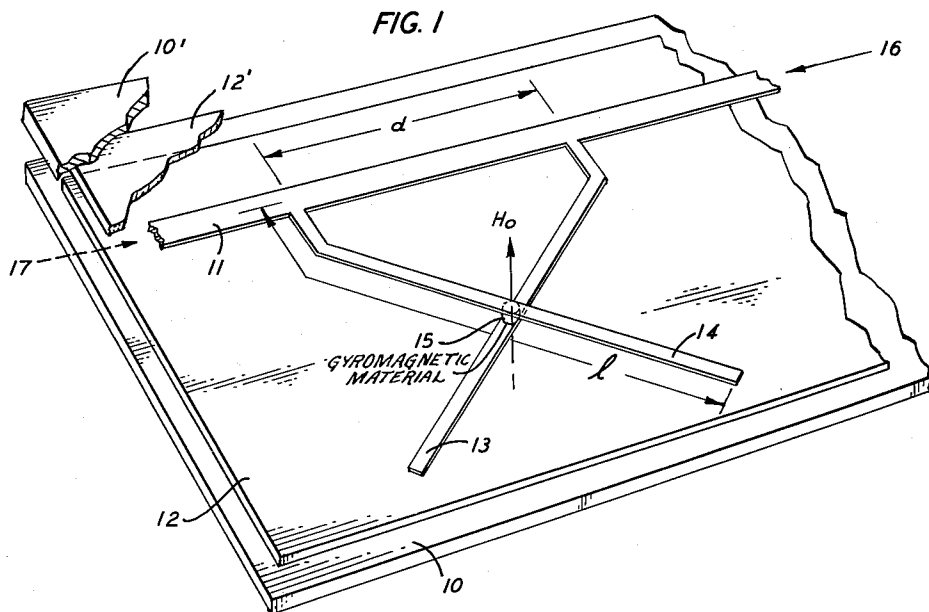
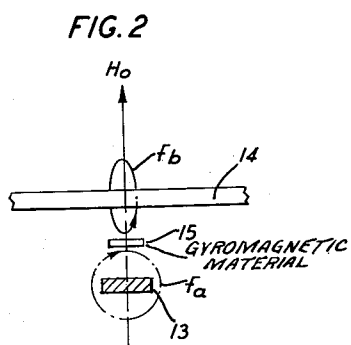
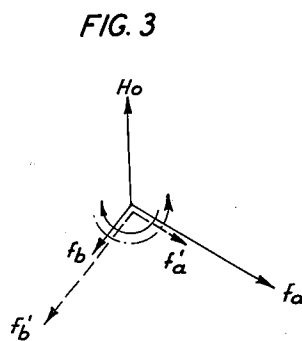
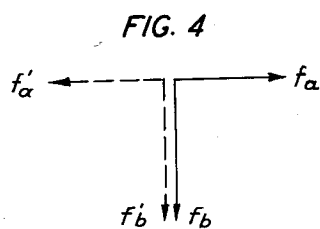
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3,016,497

NONRECIPROCAL ELECTROMAGNETIC DEVICE

Filed Dec. 8, 1959

4 Sheets-Sheet 1



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NONRECIPROCAL ELECTROMAGNETIC DEVICE

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FIG. 5

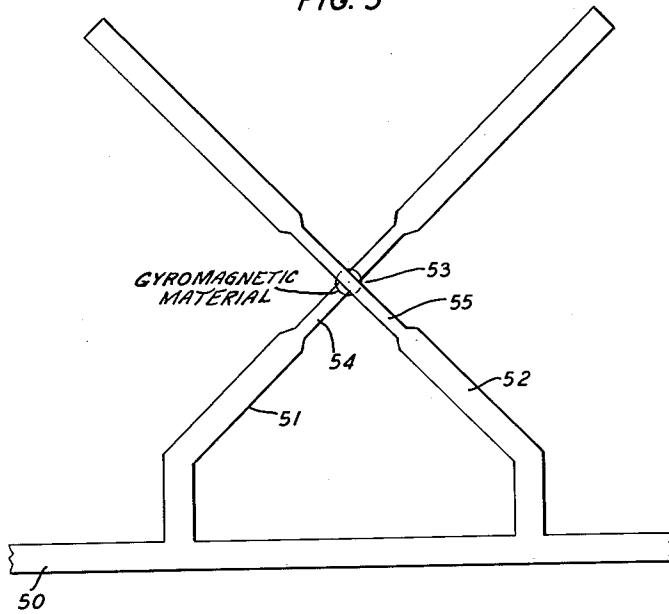
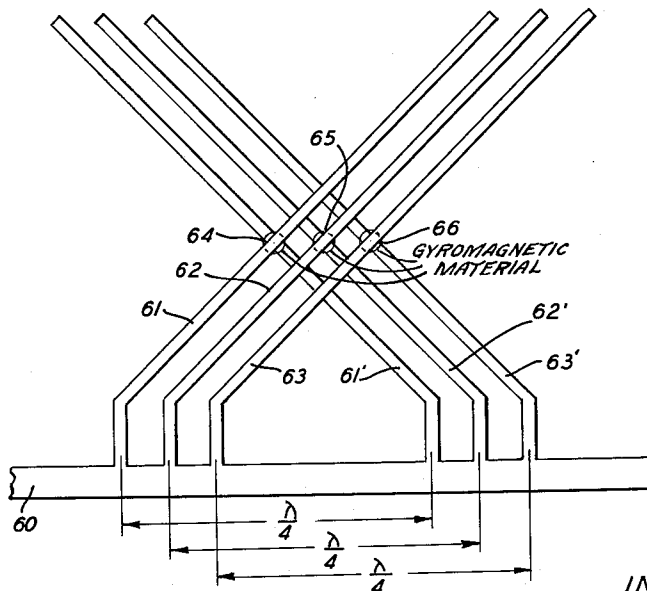


FIG. 6



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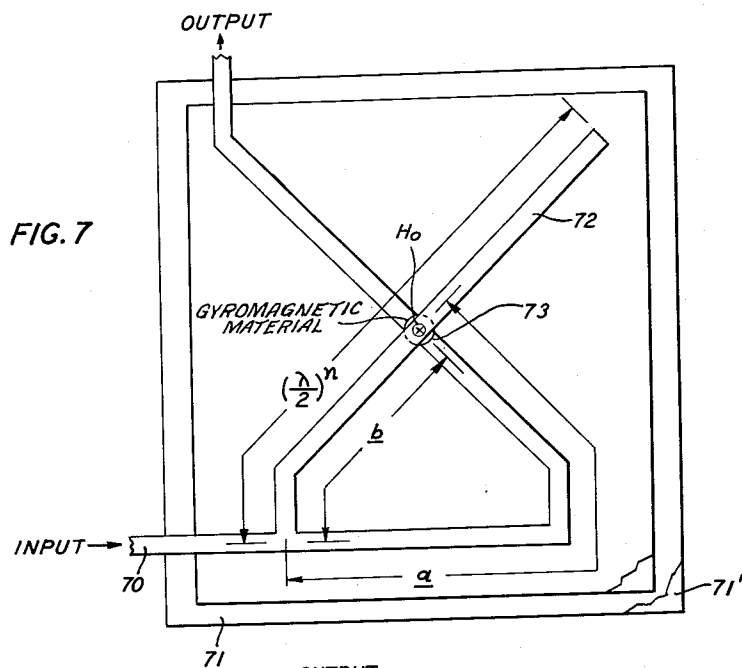
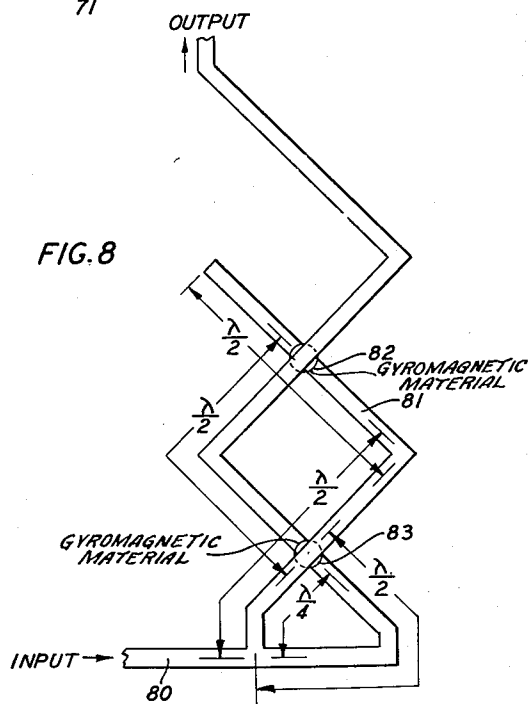
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NONRECIPROCAL ELECTROMAGNETIC DEVICE

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4 Sheets-Sheet 3



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3,016,497 NONRECIPROCAL ELECTROMAGNETIC DEVICE

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15 Claims. (Cl. 333—24)

This invention relates to nonreciprocal transmission circuits for electromagnetic wave energy, and more particularly to directional or nonreciprocal attenuators and phase shifters for use in two element transmission systems operating in the TEM mode.

The use of materials having gyromagnetic properties to obtain both reciprocal and nonreciprocal effects in microwave transmission circuits is widely known in the art. These materials have found numerous and varied applications in propagation structures employing waveguide components, and are therefore limited in their operation to the microwave frequency range and above. A résumé of the early work done using waveguide elements is contained in technical papers too numerous to mention. The need for nonreciprocal circuit elements, however, is at least as great in the lower frequency ranges in which two-line transmission components operating in the TEM mode are used. These lower frequency ranges include the ranges designated as very high frequency and ultra high frequency.

It is, therefore, the broad object of this invention to produce nonreciprocal transmission effects in transmission systems operating in the TEM mode.

In United States Patent 2,892,161, issued on June 23, 1959, to A. M. Clogston, there is disclosed structures and techniques for utilizing one or more of the several nonreciprocal effects produced by polarized elements of gyromagnetic material at frequencies of wave energy below a few thousand megacycles. These structures comprise two branch coaxial or balanced transmission line networks capable of introducing a nonreciprocal attenuation or nonreciprocal phase shift to wave energy in the frequency range in which coaxial and balanced transmission lines are used.

Like their microwave counterparts, the lower frequency isolators and nonreciprocal phase shifters operate by exciting in an element of polarized gyromagnetic material a circularly polarized component of radio frequency magnetic field that rotates in one sense relative to the steady polarizing field when the radio frequency wave is propagating in one direction, but in the opposite sense when the wave is propagating in the opposite direction. When the polarizing field is adjusted to the strength necessary to produce ferromagnetic resonance in the gyromagnetic material, a substantial part of the energy is absorbed for one direction of rotation and direction of propagation, but it is substantially unaffected for the other direction of rotation and direction of propagation. When the polarizing field is adjusted to a strength substantially below that necessary to produce ferromagnetic resonance, a nonreciprocal phase shift is produced. These prior art devices, however, tend to be large and relatively complicated in their structure, and require a fairly large piece of gyromagnetic material.

It is, therefore, a more specific object of this invention to simplify the means for generating circularly polarized radio frequency magnetic fields whose sense of rotation is a function of the direction of the wave propagation.

In the copending application of H. Seidel, Serial No. 777,924, filed December 3, 1958, now abandoned, there is described a simplified low frequency isolator using a small element, or disk, of gyromagnetic material, thus

affording some improvement over the Clogston structure. However, the Seidel isolator, for many applications, does not have as high an attenuation in the lossy direction as may be required.

It is, therefore, a further object of this invention to increase the loss ratio of nonreciprocal attenuators.

In accordance with the invention, an element of gyromagnetic material is simultaneously coupled to two resonant stubs spaced a quarter wave apart on the main transmission line. The delayed portion of the signal is fed back, and coupled to, a small element of gyromagnetic material so as to induce a magnetic field component at right angles to that induced by the other resonant stub. In this manner a discrete point of circular polarization, the sense of which is opposite for opposite directions of propagation, is established.

A steady biasing field is directed normal to the two radio frequency magnetic vectors and is adjusted to produce gyromagnetic resonance in the material at some given frequency. Depending upon the degree of coupling to the gyromagnetic material and the frequency of the applied signal relative to the resonant frequency to which the gyromagnetic material is biased, low-loss nonreciprocal phase shift or nonreciprocal attenuation effects are obtained.

A principal feature of the present invention is the use of resonant stubs to intensify the radio frequency magnetic field in the region of the gyromagnetic material. Since the power absorbed is proportional to the square of the magnitude of this field, there is a substantial increase in the attenuation produced with a given size gyromagnetic element.

It is an additional feature of the invention that the insertion loss in the forward direction produced by the resonant stubs is extremely small. Consequently, a number of stub sections may be cascaded along the line either for increasing the reverse loss without introducing an unduly large forward loss, or for band shaping purposes.

In a second embodiment of the invention, further intensification of the radio frequency field in the region of the gyromagnetic element is produced by tapering the resonant stubs at the crossover region.

These 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 is a perspective view of a strip transmission line isolator in accordance with the invention;

FIG. 2 is a close-up view of the crossover region, showing the magnetic fields in the region of the gyromagnetic material;

FIG. 3 shows, by way of illustration, the space orientation of the magnetic field vectors in the region of the gyromagnetic material;

FIG. 4 is a time vector diagram of the radio frequency magnetic fields in the region of the gyromagnetic material;

FIG. 5 shows a second embodiment of the invention using tapered stubs;

FIG. 6 is an iterated embodiment of the invention showing three pairs of crossed stubs;

FIG. 7 is a modification of the basic structure of FIG. 1 using a single tuned stub and a nonresonant line;

FIG. 8 is an iterated embodiment of the modified structure of FIG. 7 using a single resonant stub and a nonresonant line and having two crossover points;

FIG. 9 is a perspective view of a parallel wire isolator in accordance with the invention; and

FIG. 10 is a close-up view of the crossover region of the embodiment of FIG. 9 showing the magnetic fields in the vicinity of the gyromagnetic material.

Referring more particularly to FIG. 1, a perspective view of an illustrative embodiment of the present invention is shown connected and utilized to produce non-reciprocal transmission effects. The device comprises a section of balanced strip transmission line having first and second planar conductors 10 and 10', and a third or strip conductor 11. The planar conductors 10 and 10' constitute a pair of ground planes for the strip conductor 11. The three conductive members 10, 10' and 11 are separated, in parallel relationship, by layers of low-loss dielectric material 12 and 12'. The dielectric layer may comprise polystyrene, polyethylene, or any other suitable material.

Extending from, and conductively connected to, member 11 are the conductive members 13 and 14. The members, each of length l , are longitudinally displaced from each other along conductor 11 a distance d , and are bent so as to cross each other at right angles. Members 13 and 14 lie essentially in a plane parallel to the planar conductors 10 and 10' forming therewith a pair of open-ended stubs.

Located between conductive members 13 and 14 at the crossover point is an element of gyromagnetic material 15.

The term "gyromagnetic material" is employed here in its accepted sense as designating the class of magnetically 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 precessional motion under the combined influence of said polarizing field and an orthogonally directed varying magnetic field component. This precessional motion is characterized as having an angular momentum, a gyroscopic moment, and a magnetic moment. Typical of such materials are ionized gases, paramagnetic materials and ferromagnetic materials, the latter including the spinels such as magnesium aluminum ferrite, aluminum zinc ferrite and the rare earth iron oxides having a garnet-like structure of the formula $A_3B_5O_{12}$ where O is oxygen, A is at least one element selected from the group consisting of yttrium and the rare earths having an atomic number between 62 and 71, inclusive, and B is iron optionally containing at least one element selected from the group consisting of gallium, aluminum, scandium, indium and chromium. In the particular embodiment of the invention shown in FIG. 1, aluminum-substituted yttrium iron oxide is used.

The element of gyromagnetic material 15, in the illustrative embodiment of FIG. 1, is in the shape of a disk, disposed with its faces parallel to the plane of members 13 and 14 and parallel to the planar conductors 10 and 10'. The gyromagnetic element 15, however, may assume any other convenient shape since the particular shape is not essential to the operation of the invention.

A static magnetic field H_0 is applied normal to the face of disk 15 in the direction shown and is adjusted to produce gyromagnetic resonance at the operating frequency. The biasing field may be supplied by any suitable means (not shown) such as an electric solenoid, a permanent magnetic structure, or in some instances the disk 15 itself may be permanently magnetized.

To produce isolator action, conditions must be established whereby energy can be dissipated in one direction of transmission, designated the forward direction, to a substantially smaller degree than in the reverse direction of transmission. In the isolators constructed in accordance with the invention, the phenomenon of gyromagnetic resonance is utilized to provide the necessary loss mechanism. As is well known, magnetically polarized gyromagnetic materials exhibit distinctly different properties depending upon the nature of the applied magnetic fields. These unusual properties which are produced can be explained by recognizing that the gyromagnetic materials contain unpaired electron or nuclear spins which tend to align themselves with the polarizing field but which

can be made to precess about an axis parallel to the direction of this field by the application of a high frequency magnetic field. The magnetic moments associated with the spinning atomic particles, however, tend to precess in only one angular sense and resist rotation in the opposite sense. It is, therefore, evident that oppositely circularly polarized waves influence the gyromagnetic material differently, depending upon their sense of rotation. This is so since a circularly polarized wave rotating in one direction will be rotating in the easy angular direction of precession of the magnetic moments whereas an oppositely rotating circular polarized wave will be rotating in a sense inconsistent with the natural behavior of the magnetic moments of the gyromagnetic material. As a consequence, when the high frequency magnetic field is rotating in the same sense as the preferred direction for precession of the magnetic moments, it couples strongly to the gyromagnetic material. However, very little coupling takes place between the external magnetic field and the magnetic moments when the high frequency magnetic field is rotating in the opposite angular direction.

While this difference in coupling, and consequent difference in permeability provided by oppositely rotating circularly polarized magnetic fields is not limited to any particular frequency or polarizing field strength, particularly useful effects are observed at gyromagnetic resonance when the frequency of the circularly polarized magnetic field is the same as the natural precessional frequency of the magnetic moments as determined by the strength of the polarizing field. Under these particular conditions, a large amount of power can be extracted from a magnetic field circularly polarized in the preferred sense and absorbed in the gyromagnetic material. However, very little power is absorbed from an oppositely circularly polarized component.

It is apparent, therefore, that a circularly polarized magnetic field must be generated whose sense of rotation is dependent upon the direction of propagation of the signal through the system.

FIG. 2, given for the purposes of explanation, is a diagrammatical showing of the component magnetic field patterns in the region of the crossover point. In particular, the magnetic fields in the vicinity of the conductive members 13 and 14 are illustrated by the closed loops f_a and f_b encircling members 13 and 14, respectively, at the crossover point. The planes of the respective loops are normal to the longitudinal axes of the members 13 and 14. Since the members 13 and 14 cross at right angles to each other, the magnetic field components f_a and f_b are likewise normal to each other in the region of disk 15. The magnetizing field H_0 , also shown, is directed substantially normal to the plane of the conductive members and consequently normal to the field components f_a and f_b within disk 15. The spatial orientation of the various magnetic fields in the region of the gyromagnetic material is shown in the space vector diagram of FIG. 3.

Because of the time delay experienced by the wave energy in traveling from member 13 to member 14 along conductor 11, there is a corresponding time delay associated with the fields f_a and f_b . In particular, if at a particular operating frequency distance d in FIG. 1 is made to be a quarter of a wavelength in length, field f_b will lag field f_a by 90 degrees, as shown in the time vector diagram of FIG. 4. Because of this 90 degree time difference, as field f_a passes through its maximum amplitude and starts to decrease towards zero, field f_b is passing through zero and is starting to increase towards its maximum value. The effect of having the field components f_a and f_b varying in this manner is to produce the equivalent of a single resultant field vector which appears to rotate in space in the region of the gyromagnetic material 15. With the polarizing field H_0 directed normal to the plane of field components f_a and f_b , as shown in FIG. 3, a negative or counterclockwise rotation is produced when viewed along the direction of the biasing field. This

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sense of circularly polarizing magnetic field, however, is opposite to the natural precessional sense of the magnetic moments in the gyromagnetic material and little or no interaction takes place between the electrical energy and the gyromagnetic material and substantially all the wave energy introduced into the system in the forward direction, indicated by arrow 16, continues to propagate substantially unattenuated along conductor 11 past members 13 and 14.

However, for energy propagating in the reverse direction, indicated by the dotted arrow 17, there is a change in the sense of rotation of the resultant magnetic field vector. For transmission in the reverse direction, the resulting magnetic vectors f'_a and f'_b are, as before, 90 degrees out of space phase and are so shown as dotted vectors in FIG. 3. There is, however, a change in the relative time phase relationship between the magnetic field vectors such that the phase of f'_a lags f'_b by 90 degrees, as shown in FIG. 4. As a consequence, the resultant field produced by f'_a and f'_b appears to rotate in a positive or clockwise sense as viewed along the direction of the biasing field H_0 . This sense of rotation is the same as the preferred sense for precession of the magnetic moments in the gyromagnetic material and hence energy is absorbed from the circuit and dissipated in the gyromagnetic material.

In the preceding description of the operation of the nonreciprocal attenuator, it was explained how the radio frequency magnetic field interacts with the gyromagnetic material and how, under certain conditions, energy is transferred from the signal to the gyromagnetic element and dissipated therein. The amount of energy transferred can be shown to be a function of the susceptibility of the gyromagnetic material, μ'' , and the strength of radio frequency field H_{rf} . Specifically, the absorbed power P_{ab} is proportional to the product of μ'' and the square of the radio frequency magnetic field strength, that is,

$$P_{ab} = a\mu'' H_{rf}^2$$

where a is a constant.

It is apparent from this relationship that by increasing the value of H_{rf} the attenuation of the isolator in the reverse direction will be substantially increased. Hence, in accordance with the teachings of the invention, the radio frequency magnetic field components in the region of the gyromagnetic material are maximized by resonating the stubs formed by the ground planes 10 and 10' and conductive members 13 and 14 and crossing them in the region of their current maxima. Accordingly, the length l of members 13 and 14 are adjusted to have an electrical length of half a wavelength at the frequency to be attenuated. Since the current distribution along an open-ended half-wave stub is essentially sinusoidal, being a minimum at the ends, and a maximum at the center, the conductive members 13 and 14 are made to cross each other at their midpoints, or current maximum points, thus maximizing the radio frequency magnetic field to which the gyromagnetic material is subjected. It is, of course, understood that the length of either or both stubs may be increased by multiples of half a wavelength. The crossover point will, in the more general case, be at any odd multiple of a quarter wavelength from either end of the stub.

It should also be noted that since the stubs are tuned to half a wavelength of the frequency to be attenuated, they appear as a very high impedance across the main transmission line for wave energy propagating in the low-loss direction. The resulting low losses in the forward direction coupled with the high attenuation in the reverse direction produces an isolator having an exceedingly high reverse-to-forward loss ratio.

As was indicated above, the power absorbed by the gyromagnetic material is a function of the square of the magnetic field intensity. Because of this relationship, it

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is apparent that any measures which will tend to increase the amplitude of the radio frequency magnetic field in the gyromagnetic material will substantially increase the reverse loss. One simple expedient for increasing the field strength is shown in FIG. 5. It consists, essentially, in reducing the transverse dimensions of the conductive members comprising the resonant stubs at the crossover point so as to more effectively concentrate the radio frequency magnetic field in the region immediately surrounding the member. As shown in FIG. 5, each of the conductive members 51 and 52, extending from conductor 50, has a tapered longitudinal interval 54 and 55, respectively, along its length at the crossover point. The gyromagnetic element 53 is located between said members and about midway along the reduced sections 54 and 55.

In a particular embodiment of the invention constructed in accordance with the principles of the invention, a threefold increase in the reverse loss was effected by reducing the width of the stubs from 0.445 inch to .150 inch, a ratio of about 3 to 1.

In a third embodiment of the invention, shown in FIG. 6, a plurality of crossed stubs are used to increase the loss in the reverse direction. To illustrate such an arrangement, three pairs of conductive members 61—61', 62—62' and 63—63' are shown extending from the strip conductor 60. The planar conductors of the system, similar to conductors 10 and 10' of FIG. 1, are not shown.

The conductive members comprising each pair of conductive members as, for example, the pair 61—61', are longitudinally spaced along the transmission path a quarter wavelength from each other and tuned to a particular frequency to be attenuated. Accordingly, each pair may be tuned to the same frequency, thereby greatly increasing the reverse loss at a particular frequency, or each pair of members and the gyromagnetic material associated therewith may be tuned to a different frequency, to produce a band rejection filter having a given preselected bandwidth. Since the forward losses are very low, a large number of stub sections may be cascaded without unduly increasing the losses in the low-loss direction of transmission.

While the conductive members illustrated in FIG. 6 are shown as having uniform cross sections, they may, of course, be tapered, as explained above.

A second class of nonreciprocal devices, illustrated in FIGS. 7 and 8, utilizes a single resonant cavity in combination with a nonresonant section of transmission line.

In the embodiment of FIG. 7 there is shown a parallel two-conductor transmission line comprising the strip element 70 and the planar ground conductors 71 and 71'. Extending from, and conductively connected to, line 70 is the conductive member 72, which, with the planar ground conductors 71 and 71' comprise an open-ended stub. The conductive member, of electrical length

$$n\frac{\lambda}{2}$$

where n is any integer, crosses strip element 70 at right angles at a distance b along its length. Located between member 72 and strip element 70 at the crossover point is an element of magnetically biased gyromagnetic material 73.

With the stub length adjusted to be resonant at the operating frequency, $f = C/\lambda$, the crossover point is selected to occur at a current maximum point along the stub. The distance b from the junction point on strip element 70 to the crossover is accordingly an odd multiple of a quarter wavelength, that is,

$$b = (2m + 1)\frac{\lambda}{4}$$

where m is any integer.

To establish the proper field configuration in the gyro-

magnetic element, as explained hereinbefore with reference to FIGS. 2 to 4, the radio frequency field produced at the crossover point by signal current in element 70 must differ in time phase from the field generated by the resonant stub by 90 degrees. Accordingly, the distance a from the junction point on element 70 to the crossover point is made to differ from distance b by a quarter wavelength, that is, distance a is either a quarter wavelength greater or less than the distance b .

The high loss direction of the isolator shown in FIG. 7 will depend upon the relative lengths of a and b and the direction of the bias field H_0 . In the illustrative embodiment shown the terminal ends have been arbitrarily labeled "Input" and "Output."

A second embodiment of the single cavity isolator is the iterated structure of FIG. 8. In this embodiment the cavity and the nonresonant line are arranged to cross each other two or more times. With a resonant element of gyromagnetic material located at each of the crossover points the effect of a plurality of cascaded isolators is produced.

In FIG. 8 one conductor, 80, of a balanced strip transmission line is shown. The resonant stub comprising conductive member 81 and the planar conductor of the balance strip transmission line (not shown) of length λ , and line 80, are shown making two crossovers, one at a distance $\lambda/4$ along member 81 and one at a distance $3\lambda/4$ along member 81. These points correspond to the two current maximum regions of the cavity. The distance along line 80 from the junction point to each of the crossover points is a quarter wavelength longer than the corresponding distances along member 81. Thus, in FIG. 8, the distance along line 80 from the junction point to the first crossover is half a wavelength, and the distance from the first crossover to the second crossover is another half wavelength.

In the illustrative embodiments of the invention described above balanced strip transmission lines were used. These comprise a center, or strip conductor, and a pair of planar ground conductors. The balanced field configuration produced by such a structure lends itself nicely to the generation of circularly polarized fields. The invention, however, is not limited to this type of transmission line. Thus, for example, in the embodiment of the invention shown in FIG. 9, a parallel two-wire transmission line is used in conjunction with two resonant lines and a single piece of gyromagnetic material.

Specifically, the embodiment of FIG. 9 utilizes a two-wire transmission line comprising a pair of parallel conductive elements 90 and 91. Coupled to conductor 90 are the two crossed conductive members 92 and 93. Directly below the first pair of members, and extending from conductor 91, is the second pair of crossed conductive members 94 and 95. The members are oriented relative to each other such that members 92 and 93 are in a plane that is essentially parallel to the plane of conductive members 94 and 95, whereas conductive members 92 and 94 are in a plane that is essentially perpendicular to the plane of members 93 and 95. Essentially members 92 and 94 form a first resonant line and members 93 and 95 form a second resonant line.

Midway between the parallel planes defined by the crossed members 92 and 93 and members 94 and 95, and along the line of intersection of the two resonant lines 92-94 and 93-95 is an element of gyromagnetic material 96. Element 96 is supported between the planes of the crossed conductive members by a suitable low-loss dielectric material 97. A steady biasing field H_0 is applied in a direction along the line of intersection defined by the above-mentioned intersecting planes.

In FIG. 10, given for the purposes of explanation, the radio frequency magnetic field components in the vicinity of the gyromagnetic element 96 are shown. In particular, the magnetic fields in the vicinity of members 92 and 93 at the crossover point are illustrated by the closed

loops f_c and f_d encircling members 92 and 93, respectively. The planes of the respective loops are normal to the longitudinal axes of the members. Since the members intersect at right angles to each other, the magnetic field components f_c and f_d are likewise normal to each other in the region of gyromagnetic element 96.

Also shown are the magnetic fields in the vicinity of conductive members 94 and 95. These comprise the closed loops f'_c and f'_d encircling conductive members 94 and 95, respectively. Since these members also cross at right angles to each other, the magnetic field components f'_c and f'_d are likewise normal to each other in the region of element 96.

Because the instantaneous current in conductor 90 is opposite to the instantaneous current in conductor 91, the instantaneous currents in the respective stubs are likewise 180 degrees out of time phase. Thus, current i in member 92 flows in the opposite direction from current i' in member 94. As a result, the magnetic field components produced by corresponding members in the two lines encircle their respective members in the opposite sense so as to be in the same direction in the region of the gyromagnetic element. Thus, field components f_c and f'_c are in time and space phase, and field components f_d and f'_d are in time and space phase.

The action of the fields on the gyromagnetic material is the same as explained above with reference to FIGS. 3 and 4. By suitably spacing the crossed lines, the time phase of the magnetic fields at the gyromagnetic material can be adjusted so that the orthogonally intersecting fields are also in time quadrature, thus producing, in effect, a circularly polarized field in the vicinity of the gyromagnetic element whose sense of rotation is a function of the direction of propagation.

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. For example, the cavities need not be open-ended but may be shorted to the planar ground conductors 10 and 10' in FIG. 1. This, of course, will move the crossover point since the current maxima points will now be located at multiples of half a wavelength from the shorted cavity ends. Since shorting the cavities may introduce coupling problems where direct current potentials must be considered, the stubs may be capacitively coupled rather than conductively coupled.

What is claimed is:

1. A nonreciprocal electromagnetic wave device operating in the TEM mode of wave propagation comprising a section of transmission line having a plurality of conductive elements extending substantially parallel to each other, means for applying wave energy to said line at a given frequency, means for electromagnetically coupling said wave energy at two longitudinally spaced regions along said line which have a relative time phase difference of β degrees to a magnetically polarizable element of material capable of exhibiting gyromagnetic properties at said given frequency, said coupling means comprising a resonant shunt circuit coupled to said line at each of said regions tuned to said given frequency and supportive of magnetic field patterns having components thereof intersecting in said element at a given angle α , where α and β are proportioned to produce a resultant circularly polarized magnetic field in said element, and means for magnetically polarizing said element in a direction normal to the plane of said intersecting magnetic field components.

2. The combination according to claim 1 wherein said resonant circuit comprises an open-ended stub conductively coupled to said conductors.

3. The combination according to claim 1 wherein said

regions are a quarter wavelength apart at said given frequency.

4. The combination according to claim 1 wherein said coupled field components intersect at right angles to each other.

5. The combination according to claim 1 wherein said element is biased to gyromagnetic resonance at said operating frequency.

6. An electromagnetic wave transmission line supportive of wave energy in the TEM mode of wave propagation at a given frequency comprising two conductively continuous members extending coextensively over a given longitudinal interval of said line, a pair of open-ended stubs each having a length proportioned to resonate at said given frequency electromagnetically coupled to said line within said interval with the first of said pair of stubs being longitudinally displaced from the second of said pair of stubs a distance equal to a quarter wavelength at said given frequency, said stubs crossing each other at right angles in the region along their respective lengths wherein the current in each of said stubs is a maximum, an element of gyromagnetic material disposed between said stubs in said region, and means for magnetically biasing said element to gyromagnetic resonance at said given frequency.

7. The combination according to claim 6 wherein the cross-sectional dimensions of said stubs are reduced at said crossover region.

8. In a two-conductor transmission system supportive of electromagnetic wave energy at a given frequency in the TEM mode of wave propagation, a pair of lines resonantly tuned to said frequency electromagnetically coupled to said conductors, said pair of lines being spatially oriented relative to each other to produce a region of orthogonally intersecting magnetic field components, said pair of lines being longitudinally displaced along said conductors to produce a 90 degree time phase delay between said field components, an element of gyromagnetic material located in said region, and means for magnetically biasing said element in a direction perpendicular to said intersecting components.

9. A nonreciprocal electromagnetic wave device supportive of wave energy in the TEM mode of wave propagation at a given operating frequency comprising a section of strip transmission line having a first conductor disposed between and conductively insulated from two conductive ground planes, means for producing a region of circularly polarized magnetic field comprising a pair of longitudinally spaced conductive members extending from said first conductor and oriented to cross each other at a point along their respective lengths, an element of gyromagnetic material located between said members within said region, and means for magnetically biasing said element in a direction perpendicular to the plane of said members.

10. The combination according to claim 9 wherein said pair of conductive members are longitudinally spaced from each other an odd number of quarter wavelengths at said given frequency and wherein said members cross each other at right angles.

11. The combination according to claim 9 wherein said pair of members and said ground planes comprise a pair of resonant stubs tuned to said given frequency and wherein said members cross each other at a point along their respective length wherein the current is a maximum.

12. A nonreciprocal electromagnetic wave device operating in the TEM mode of wave propagation comprising

a section of transmission line supportive of wave energy at a given operating frequency having first and second elongated conductive members supported in spaced substantially parallel relation, said second conductor being wider than said first conductor, a third conductive member electromagnetically coupled to said first member and spatially oriented to cross over said first member at a plurality of longitudinally spaced points along said first conductor, an element of gyromagnetic material located between said first and third conductors at each of said points, and means for magnetically biasing each of said elements to gyromagnetic resonance at said given frequency.

13. A nonreciprocal electric wave component operating in the TEM mode of wave propagation comprising two substantially similar elongated conductive elements extending parallel to each other, first and second resonant lines coupled to said conductive elements, each of said lines comprising a pair of parallel conductive members with the pair of members of said first line defining a first plane and the pair of members of said second line defining a second plane, said first plane making a perpendicular intersection with said second plane, an element of gyromagnetic material disposed along said intersection, and means for electromagnetically exciting said lines to be 90 degrees out of time phase at the region of intersection.

14. A nonreciprocal electromagnetic wave device comprising means for guiding propagating electromagnetic wave energy at a given frequency, a pair of resonant stubs tuned to said frequency and electromagnetically coupled to said guiding means at two longitudinally spaced points therealong where the guided energies in said guiding means are ninety degrees out of time phase, said stubs being spatially oriented to cross each other at right angles, and a magnetically biased element of gyromagnetic material located between and electromagnetically coupled to said stubs.

15. A nonreciprocal electromagnetic wave device comprising means for guiding propagating electromagnetic wave energy, means for applying wave energy to said guiding means at a given frequency, means for electromagnetically coupling said wave energy at two longitudinally spaced regions along said guiding means which have a relative time phase difference of β degrees to a magnetically polarized material capable of exhibiting gyromagnetic properties at said given frequency, said coupling means comprising a pair of resonant shunt circuits tuned to said given frequency and supportive of magnetic field patterns having components thereof intersecting in said element at a given angle α where α and β are proportioned to produce a resultant circularly polarized magnetic field within said element, and means for magnetically polarizing said element in a direction normal to the plane of said intersecting magnetic field components.

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