

Aug. 26, 1958

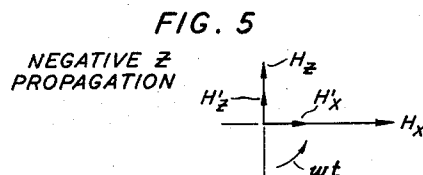
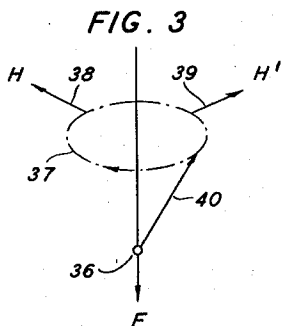
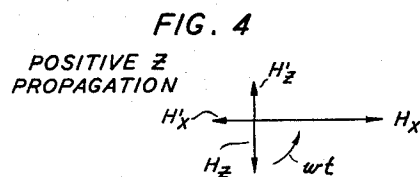
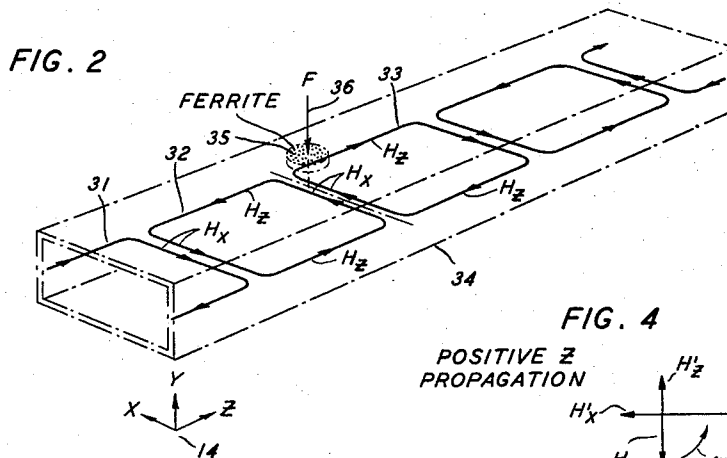
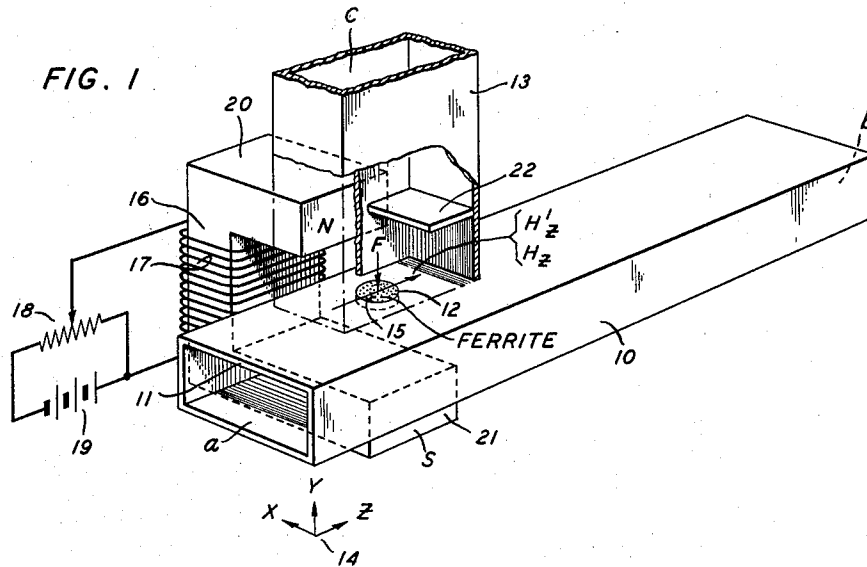
S. E. MILLER

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NON-RECIPROCAL WAVE TRANSMISSION

Filed Aug. 17, 1953

2 Sheets-Sheet 1



INVENTOR
S. E. MILLER
BY *Ray M. Porter Jr.*
ATTORNEY

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2 Sheets-Sheet 2

FIG. 7

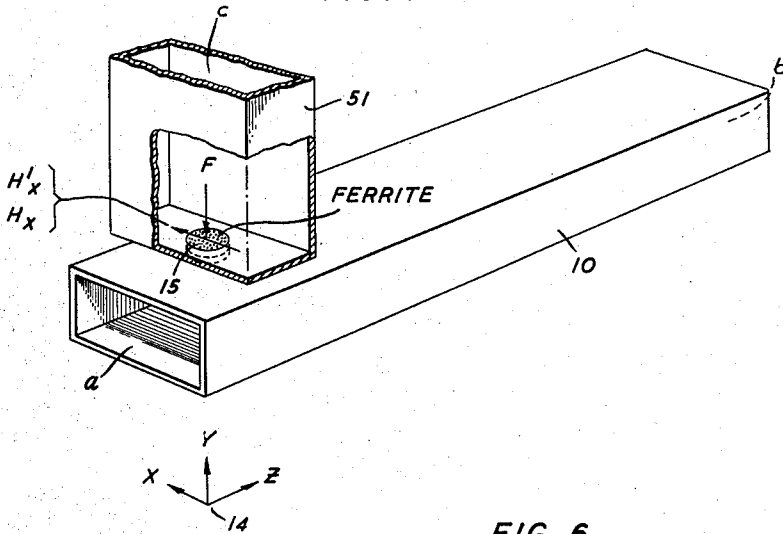


FIG. 6

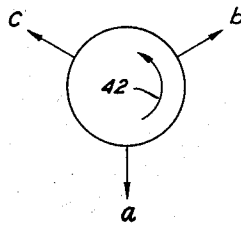
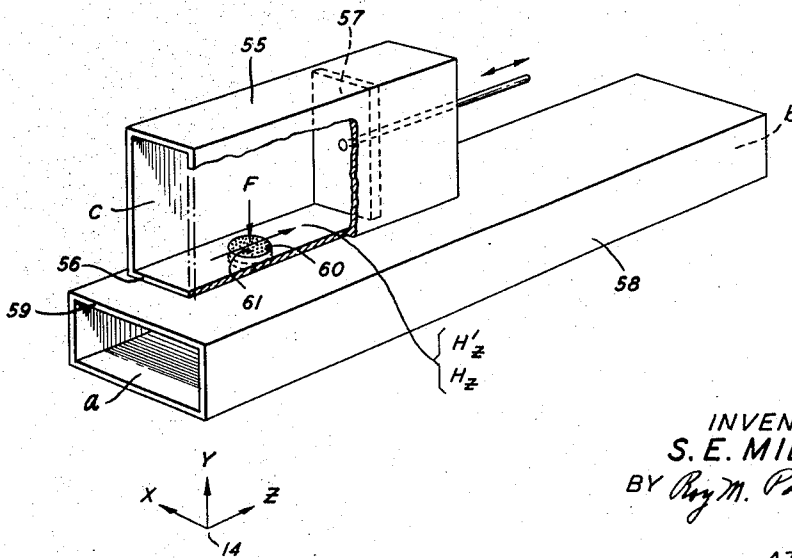


FIG. 8



INVENTOR
S. E. MILLER
BY Roy M. Porter, Jr.

ATTORNEY

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NON-RECIPROCAL WAVE TRANSMISSION

Stewart E. Miller, Middletown, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application August 17, 1953, Serial No. 374,772

14 Claims. (Cl. 333-10)

This invention relates to electrical transmission systems and, more particularly, to multibranch circuits having non-reciprocal transmission properties for use in said systems.

It is an object of the invention to establish non-reciprocal electrical connections between a plurality of branches of a multibranch network by new and simplified apparatus.

Recently, the electromagnetic wave transmission art has been substantially advanced by the development of a whole new group of non-reciprocal transmission components. A large number of these have utilized one of the non-reciprocal properties of gyromagnetic materials, most often designated ferromagnetic materials or ferrites. One of the more important of these components is a multibranch network known as a "circulator" circuit. While the several circulators heretofore invented have had different physical appearances and structural arrangements, each having its own specific advantage and usefulness, each has had the electrical property that energy is transmitted in circular fashion around the branches of the network so that energy appearing in one branch thereof is coupled to only one other branch for a given direction of transmission, but to another branch for the opposite direction of transmission. This affords a circuit component with an entirely new electrical property.

Numerous applications of the circulator as a circuit element have been devised. It has been included in modulator circuits and in compressing and expanding circuits. It has been used as a TR-box type coupling between an antenna, transmitter and receiver circuits, as a channel dropping or branching circuit in multichannel microwave systems, and in many other applications. Intuitively, those familiar with the art feel that the surface of the many applications of the circulator has only been scratched, and numerous other applications are being continually conceived.

It is another object of the present invention to provide new and improved types of circulators.

In accordance with the present invention, it has been found that when an element of polarized ferromagnetic material is employed as the coupling means between first and second electrical transmission structures, such as hollow conductive wave guides, it exhibits coupling properties quite different from the conventional coupling probe or aperture. The ferromagnetic coupling element not only couples each component of the magnetic field of an initial wave from the first structure into the second, but in effect generates a new component corresponding to each initial component, at right angles to the initial component, and displaced from it by 90 degrees in time. The relative phases of these coupled components depend upon the direction of wave propagation through the first structure.

A principal feature of the present invention resides in the physical orientation of the second structure so that it is excited only by two coupled components that are in the same phase for one direction of propagation in

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the first structure, and equal in amplitude and opposite in phase for the opposite direction therein. Thus, only wave energy traveling in said one direction in the first structure is coupled into the second structure. By means of a particularly located reactive element in the second structure, energy in the second structure is coupled into the first structure by the ferromagnetic coupling element and launched therein only for said opposite direction of propagation. This results in a three terminal circulator circuit.

Certain primary advantages of the circulator in accordance with the present invention stem from the very small amount of ferromagnetic material required in the apparatus. In other types of circulators, the ferromagnetic material is in the form of an element that fills or partially fills to a substantial extent the cross-section of the wave-guide structure. In other types, the material is in the form of a member that extends longitudinally in the structure for an appreciable distance or consists of a plurality of smaller elements distributed along this distance. In the present embodiments, however, the ferromagnetic material is limited to a single thin disc or wafer located in a compact wave-guide structure within or near a single coupling aperture. Obviously, this reduces the bulk and weight of the circulator apparatus. Furthermore, it allows more carefully manufactured, and, therefore, more expensive, ferromagnetic material to be employed without unduly increasing the cost of the total apparatus. Finally, all presently known ferromagnetic materials inherently introduce a certain amount of loss to wave energy passing therethrough. Therefore, a reduction in the amount of material employed is accompanied by a substantial increase in the efficiency of the apparatus.

In certain aspects the structures of the present invention may be considered as improvements upon the structures disclosed in the copending application of E. H. Turner Serial No. 374,529, filed August 17, 1953.

These and other objects and features, the nature of the present invention, and its various advantages, will appear more fully upon consideration of the various specific illustrative embodiments shown in the accompanying drawings and described in the following detailed description of these drawings.

In the drawings:

Fig. 1 is a perspective view of an embodiment of the present invention showing a junction of wave-guide structures coupled by a ferromagnetic coupling element;

Fig. 2, given by way of illustration, shows the magnetic field configuration of the dominant mode wave in a rectangular wave guide in the vicinity of a ferromagnetic coupling element;

Fig. 3 diagrammatically represents the precessing moment of a free electron and the magnetic fields associated therewith in a ferromagnetic coupling element;

Figs. 4 and 5 are vector diagrams representing the phase relationships of the magnetic components in the vicinity of a ferromagnetic coupling element for waves propagating in opposite directions, respectively, in the guide of Fig. 2;

Fig. 6 is a schematic representation of the circulator coupling characteristic for the embodiment of Fig. 1;

Fig. 7 is a perspective view of a modification of Fig. 1 showing a junction of wave-guide structures in an alternative physical orientation; and

Fig. 8 is a perspective view of a third embodiment of the invention in which the guides are located and coupled longitudinally.

Referring more specifically to Fig. 1, a nonreciprocal three branch microwave network or three branch circulator circuit is shown as an illustrative embodiment of the present invention. This network comprises a first

section 10 of bounded electrical transmission line for guiding wave energy which may be a rectangular wave guide of the metallic shielded type having a wide internal cross-sectional dimension of at least one-half wavelength of the energy to be conducted thereby and a narrow dimension substantially one-half of the wide dimension. A second rectangular wave guide 13, substantially identical to guide 10, abuts guide 10 with its transverse end connected to wall 11. Thus, guide 13 makes a T-type junction with guide 10 in which the wide dimension of guide 13 is parallel to the axis of guide 10. The narrow dimension of guide 13, according to the preferred embodiment of the invention, is slightly off centered on wall 11 for the reasons to be noted hereinafter.

For reference purposes hereinafter, guides 10 and 13 are located in a coordinate system represented by the divergent vectors 14 labeled x , y and z . The vector x indicates a positive sense along the transverse wide dimension of guide 10 and narrow dimension of guide 13; y indicates a positive sense along the transverse narrow dimension of guide 10 and the longitudinal direction of propagation in guide 13; and z indicates a positive sense along the longitudinal direction of propagation in guide 10 and the transverse wide dimension of guide 13. The left and right ends of guide 10 are labeled terminals a and b , respectively, and the upper end of guide 13 is labeled terminal c .

Lines 10 and 13 are electromagnetically coupled by a polarized gyromagnetic coupling element which may be, as illustrated, a slightly elongated aperture 12 in wall 11 which is filled by a plug-like disc of gyromagnetic material 15. Aperture 12 is displaced to one side of the longitudinal center line of wall 11 of guide 10 by a distance to be defined more precisely hereinafter, but which will in a practical embodiment be in the order of one-fifth of the wide dimension of guide 10. As noted above, guide 13 is also displaced on wall 11, so that in a preferred embodiment of the invention, the abutting end of guide 13 may be centered about aperture 12. In this position maximum coupling to the wave field pattern within guide 13 is obtained. However, as will appear more clearly hereinafter, it is this displaced location of aperture 12 that affects the operation of the invention and only secondarily the location of guide 13. Therefore, if a particular mechanical assembly is facilitated thereby, guide 13 may be located symmetrically upon wall 11. Similar comments apply to all embodiments shown hereinafter.

Disc 15 has a thickness substantially equal to the thickness of wall 11 and a diameter which is small compared to one wavelength. For example, the diameter of disc 15 may be in the order of three-quarters of the narrow guide wall dimension. The thickness of disc 15 may be substantially increased, however, and may advantageously take the form of a probe or post extending a substantial distance into guide 10. Alternately, the gyromagnetic material may be a wafer-like member placed next to the inside of wall 11 and covering aperture 12.

As a specific example of a gyromagnetic medium, disc 15 may be made of any of the several ferromagnetic materials combined in a spinel structure. For example, disc 15 may comprise an iron oxide with a small quantity of one or more bivalent metals such as nickel, magnesium, zinc, manganese or other similar material, in which the other materials combined with the iron oxide in a spinel structure. This material is known as a ferromagnetic spinel or a ferrite. Frequently, these materials are first powdered and then molded with a small percentage of plastic material, such as Teflon or polystyrene. As a specific example, disc 15 may be made of nickel-zinc ferrite prepared in the manner described in the publication of C. L. Hogen, "The microwave gyrator," in the Bell System Technical Journal, January 1952, and in his copending application Serial No. 252,432, filed October

22, 1951, now United States Patent 2,748,353, granted May 29, 1956.

Disc 15 is biased by a steady polarizing magnetic field, of a strength to be described. As illustrated in Fig. 1, this field is applied transversely, i. e., at right angles to the direction of propagation of wave energy in guide 10 and may be supplied by a solenoid structure comprising a C-shaped magnetic core 16 having pole pieces 20 and 21, respectively. Turns of wire 17 on core 16 are so wound and connected through a rheostat 18 to a source of potential 19 that they produce an N pole in pole piece 20 and an S pole in pole piece 21. Pole piece 20 bears against the center portion of the wide wall of guide 13 at a point somewhat above wall 11 and pole piece 21 extends underneath guide 10 so that the lines of magnetic field are substantially normal to the plane of disc 15 as they pass through it, as represented schematically by the vector labeled F . This field may, however, be supplied by an electrical solenoid with metallic core of other suitable physical design, by a solenoid without a core, by a permanent magnet structure, or the ferromagnetic material of disc 15 may be permanently magnetized if desired.

A reactive impedance is located in guide 13, which may be, as illustrated, a conductive septum 22 positioned transversely in guide 13 at a position above wall 11. The function and adjustment of septum 22 will be discussed hereinafter in connection with the operation of the circulator of Fig. 1.

Before proceeding further with a detailed examination of the preferred mode of operation of the circulator of Fig. 1 and the several adjustments necessary to obtain this operation, the unusual properties of a ferromagnetic coupling element, including within the term "coupling element" both the ferromagnetic disc 15 and its associated aperture 12, as it serves to couple magnetic field components from within guide 10 into guide 13, must be thoroughly understood. For this purpose, reference is made to the explanatory Fig. 2.

In Fig. 2 are shown representative loops 31, 32 and 33 of the high frequency magnetic field of a dominant mode wave in rectangular wave guide 34 at a particular instant of time. These loops lie in planes which are parallel to the wide dimension of guide 34. Guide 34 is located, for the purpose of explanation, in the x - y - z coordinate system defined with reference to Fig. 1. Therefore, the predominantly transverse magnetic field components of the wave are labeled H_x , while the predominantly longitudinal components are labeled H_z . The arrows on the individual loops 31, 32 and 33 indicate their polarity at a given instant of time and their sense is arbitrarily defined by the coordinates 14. Located in the top wall of guide 34 at a point off the center line thereof and, therefore, at a point having both H_x and H_z components is a ferromagnetic coupling element 35 such as element 15 of Fig. 1 described above. Element 35 is biased by a magnetic field as represented schematically by vector 36 labeled F .

The performance of element 35 under these conditions can be explained by the recognition that the ferromagnetic material of element 35 contains unpaired electrons spins which tend to line up with the applied magnetic field. These spins have an associated magnetic moment which can be made to precess about the line of the biasing magnetic field keeping an essentially constant moment component in the direction of the applied biasing field but providing a moment component which may rotate in a plane normal to the field direction. Such a moment is shown schematically in Fig. 3 by vector 40 for an electron 36. Thus, when a reciprocating high frequency magnetic field of electromagnetic wave energy as represented by the vector 38 labeled H on Fig. 3 is impressed upon the moment, the moment will commence to precess in one angular sense as represented by the arrow on orbit 37 and

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to resist rotation in the opposite sense. The combined effect of many such electrons and their associated moments produces in the ferromagnetic material not only a flux representing the impressed magnetic field H , but also a flux representing a reciprocating field at right angles in space and delayed by 90 degrees in time from the applied field H . The effective field produced by the induced flux may be thought of as an induced field and represented on Fig. 3 by a vector 39 labeled H' at right angles to and 90 degrees around orbit 37 from the inducing magnetic component H . The intensity of the induced magnetic field H' depends upon the strength of the applied magnetizing field F .

Such is the coupling effect of element 35 of Fig. 2 when it is excited by the H_z and H_x components within guide 34. An examination of the magnetic field components presented at the outside of guide 34 by element 35 will reveal the following components: a portion of the original transverse components H_x , a component in the z -direction induced by H_x which will be designated H_z' , a portion of the original longitudinal components H_z , and a component in the x -direction induced by H_z which will be designated H_x' .

The relative phases of these components depend upon the direction of propagation of the wave energy in guide 34 and may most readily be determined separately with the aid of the vector diagrams of Figs. 4 and 5, representing respectively, the positive direction of propagation in guide 34 and the negative direction of propagation therein.

In Figs. 4 and 5 the following convention is adopted. The passage of time ωt is represented by rotation in a counter-clockwise direction with the initial instant of time pictured in Fig. 2 represented by the right-hand extension of the abscissa. Therefore, the component H_x which in Fig. 2 has its maximum positive amplitude at the position of element 35 is represented by the vector H_x extending horizontally to the right on both Figs. 4 and 5. The component H_z' induced by H_x is also shown on Figs. 4 and 5 by the vector H_z' extending upward indicating that this induced component reaches its maximum positive amplitude in the z -direction 90 degrees later in time than the component H_x which produced it. This relationship may be assumed as fixed, therefore, regardless of the direction of propagation.

Note, however, on Fig. 2, that when the wave in guide 34 is propagating in the positive direction, the component H_z of loop 32 is increasing to its maximum negative value while the component H_x is decreasing from its maximum positive value. In other words, the component H_z is in a phase 90 degrees ahead in time from the component H_x and may be represented by the downward vector H_z on Fig. 4. The component H_x' induced by H_z , therefore, reaches its maximum negative value 90 degrees later in time from the component H_z which induced it. The positive maximum of H_x' is then 90 degrees ahead in time from H_z and may be represented by a vector H_x' extending to the left in Fig. 4. Thus, the components H_z' and H_z and also the components H_x' and H_x are out of phase for the positive direction of propagation.

Now, when the wave in guide 34 is propagating in the negative direction, the component H_z of loop 33 is increasing to its maximum positive value, while the component H_x is decreasing from its maximum positive value. H_z is, therefore, 90 degrees behind in time from the component H_x and would for this direction of propagation be represented by an upward vector H_z on Fig. 5. Since the positive amplitude of the component H_z' induced by H_z is still 90 degrees ahead in time from H_z , it is represented by a vector extending to the right. Thus, for the negative direction of propagation, the H_z and H_z' components, and also the H_x and H_x' components are in phase.

It is realized, of course, that the specific reference to

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"positive" and "negative" values, and to "ahead" and "behind" in time are completely arbitrary and apply only to the illustrative senses shown on Fig. 2. Also, a phase delay of 90 degrees which is inherent in any coupling through an aperture has been disregarded inasmuch as it would affect all components alike. This explanation does, however, serve to demonstrate that for one direction of propagation past the coupling element 35, the initial and induced x -direction components and the initial and induced z -direction components are out of phase, while for the opposite direction of propagation, they are in phase, respectively. It also serves to indicate that for said one direction the H_z component of the inducing wave is ahead of the H_x component thereof while in said opposite direction H_z is behind H_x . It has been demonstrated experimentally that these four components exist with these relative phases regardless of whether the polarizing magnetic field is perpendicular or parallel to the direction of propagation, although it is much more difficult to obtain a physical picture by way of explanation of the latter condition. In certain of the following illustrative figures and in the explanation directed thereto, the biasing field will be shown as perpendicular to the direction of propagation in one specific guide and parallel thereto in another, but it should be understood that this condition may be reversed in each case.

Returning now to Fig. 1, it will be noted that of the four above-described components presented at element 15 only the H_z and H_z' components can excite a mode which can be supported in guide 13 and are so represented by the vector extending in the z -direction across element 15. Now the amplitude of the component H_z in guide 13 depends upon the position of aperture 12 on wall 11, this component being zero when aperture 12 is on the center line of wall 11 and maximum at the edges thereof. On the other hand, the amplitude of the component H_z' is substantially independent of the location of aperture 12 and depends primarily on the strength of the magnetizing field F . In accordance with the present invention, the strength of the magnetizing field F is selected with respect to the location of aperture 12 so that the components H_z and H_z' are equal. In a typical embodiment in which aperture 12 is displaced away from the center line by one-fifth of the wide dimension of the guides, the strength of the magnetizing field required is substantially that required to saturate the ferromagnetic material of element 15. This field is substantially below that required to produce ferromagnetic resonance in the material.

Thus, microwave energy applied to guide 10 by way of terminal a would produce H_z and H_z' components in guide 13 which are equal in amplitude, but as demonstrated with reference to Figs. 2 through 5, opposite in phase. Therefore, no energy will be coupled into guide 13 and all energy applied at terminal a will appear at terminal b of guide 10. This condition is indicated schematically on Fig. 6 by the radial arrows labeled a and b , respectively, associated with ring 41 and arrow 42 diagrammatically indicating progression in the sense from a to b .

A wave applied to terminal b of guide 10 will produce H_z and H_z' components at element 15 which are in phase and a portion of the energy in guide 10 will be coupled into guide 13 depending upon the size and impedance of aperture 12. The remaining energy, if any, will pass on to terminal a and it will be demonstrated hereinafter how this remaining portion may be made very small.

A wave applied to terminal c of guide 13 will have substantially only z -direction components at element 15. This will produce in guide 10 a z -direction component and also an induced component in the x -direction which is 90 degrees later in time than the z component which produced it. As noted above with reference to Figs. 2 and 5,

it is the wave traveling in the negative direction in guide 10 that has this phase relationship, i. e., an x-direction component 90 degrees behind the z-direction component. Conversely, this phase relationship between the exciting components will produce a wave propagating only in the negative direction in guide 10. The necessary amplitude relationship between the exciting x and z-direction components for excitation of such a negative traveling wave at the position of element 15 is inherently obtained by the location of aperture 12 and the setting of the magnetic field strength F defined above. Thus, the portion of the wave in guide 13 coupled into guide 10 will appear at terminal a only. The magnitude of this coupled energy is determined by the size and impedance of aperture 12 and energy, if any, that is not coupled into guide 10 will be reflected back to terminal c.

However, the function of septum 22 is to reflect a component of the wave coupled from terminal b into guide 13 back into guide 10 in such phase and amplitude as to cancel the wave mentioned above from terminal b which passes on to terminal a. Because of the thermal equilibrium requirements in the structure, septum 22 when performing the above-mentioned function simultaneously serves the function of matching the impedance of terminal c for a wave applied thereto to that of terminal a through the coupling of element 15. Therefore, the size and position of septum 22 are selected most readily by applying a signal at terminal c and adjusting septum 22 until no wave energy is reflected back at terminal c. This adjustment may be made with the aid of a conventional standing wave detector. The resulting terminal connections are indicated schematically on Fig. 6 which shows that all energy applied to terminal b will be coupled to terminal c and all energy applied to terminal c will be coupled to terminal a. The coupling characteristic thus represented is the characteristic of a group of networks heretofore designated circulator circuits because they have electrical properties such that electrical energy appearing in one branch thereof is coupled to only one other branch for a given direction of transmission but to another branch for the opposite direction of transmission.

An alternative embodiment of the circulator of Fig. 1 is represented in Fig. 7 in which guide 13 of Fig. 1 is replaced by guide 51 oriented with the narrow dimension thereof parallel to the axis of guide 10. The wide dimension of guide 51 is slightly off-centered on wall 11 of guide 10. While in Fig. 1 guide 13 was excited by the z-direction components coupled to it by element 15, the present embodiment depends for its operation upon the x-direction components at element 15. Thus, the H_x and H_x' components presented to guide 51 by element 15 are transverse therein and can excite a mode of propagation which can be supported in guide 51. These x-direction components are, therefore, represented by the vector extending in the x-direction across element 15. Since these two components are in phase for the negative direction of propagation in guide 10, as shown in Fig. 4, and out of phase for the positive direction of propagation therein, as shown in Fig. 5, the operation of the circulator of Fig. 7 is substantially identical to that described above for Fig. 1. To indicate this, the left and right ends of guide 10 are labeled a and b, respectively, and the upper end of guide 51 is labeled c. Circulator action takes place between the terminals in the order a, b and c.

Another embodiment of the three terminal circulator is represented by Fig. 8, in which a guide 55 is located with a narrow wall 56 contiguous to wide wall 59 of guide 58. An aperture 60 containing a ferromagnetic coupling element 61 is positioned in the contiguous walls 56 and 59. Element 61 is displaced from the center line of wall 59, but may be on the center line of wall 56, and has coupling properties identical to element 15 of Fig. 1. As in the embodiment of Fig. 1, z-direction

components are presented to guide 55 by coupling element 61. Since these components coincide with the longitudinal components of the dominant mode in guide 55, wave energy in this mode will be excited. One end of guide 55 is terminated in an adjustable piston 57 of electrically conducting material.

Thus, wave energy applied to terminal a of guide 53 is transferred to terminal b thereof since for this direction of propagation components H_z and H_z' in guide 55 are out of phase as shown in Fig. 4. Wave energy applied at terminal b is partially coupled into guide 55 by element 61 since H_z and H_z' are in phase as indicated in Fig. 5, the remainder passing on in the direction of terminal a of guide 58. The portion of the wave energy in guide 55 which travels toward piston 57 is reflected by piston 57 back to element 61. By adjusting the position of piston 57, a component of the reflected energy that returns through element 61 into guide 58 may be made to cancel the component of the wave energy which passed on toward terminal a. Thus, all energy applied at terminal b is coupled into guide 55 and appears at terminal c thereof.

Wave energy applied to terminal c of guide 55 will be coupled by element 61 into guide 58 as a z-direction component followed 90 degrees later in time by an induced x-direction component. As shown heretofore with reference to Figs. 2 and 5, this phase relationship will produce a wave propagating only in the negative z-direction in guide 58 toward terminal a thereof. The preceding adjustment of piston 57 inherently matches the impedance of terminal c to terminal a for wave energy propagating along this path.

An embodiment depending upon the x-direction components presented at element 61 and, therefore, bearing the same relation to the embodiment of Fig. 8 as did the embodiment of Fig. 7 to Fig. 1, may be obtained by turning guide 55 90 degrees so that it crosses guide 58. Otherwise, the operation of such an embodiment would be the same as the operation of the preceding embodiments disclosed in detail.

In all cases, it is 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 scope of the invention.

What is claimed is:

1. In an electromagnetic wave energy transmission system, first and second sections of shielded transmission line for supporting said wave energy, said energy as supported in said lines having longitudinally and transversely extending magnetic field components, a single magnetically polarized gyromagnetic element coupling between said lines, said element being polarized outside the region of gyromagnetic resonance and being positioned in one of said lines in a location for which said energy has both said field components and positioned in the other of said lines in a location for which said energy has only one of said components, and means for matching the impedance of said other line to said one line through said coupling element.

2. The combination according to claim 1, wherein said lines are rectangular wave guides having respectively perpendicular longitudinal axes, the wider wall of one of said guides being perpendicular to the wider wall of the other, said wider wall of said one guide being parallel to the plane of the narrower wall of the other.

3. The combination according to claim 1, wherein said lines are rectangular wave guides having respectively perpendicular longitudinal axes, the wider wall of one of said guides being perpendicular both to the wider wall and to the plane of the narrower wall of the other.

4. The combination according to claim 1, wherein said

lines are rectangular wave guides with the wider wall of one of said guides contiguous and parallel to the narrower wall of the other.

5. The combination according to claim 4, wherein said impedance matching means comprises a reflecting member terminating one end of said other guide.

6. In combination, a pair of conductive wave guides for electromagnetic wave energy, said guides making a T-type junction one with the other, an element of ferromagnetic material located at said junction in a region of polarized magnetic field components of said energy, said element being in a region of both longitudinal and transverse polarization of said field components in one of said guides, said element being in a region of a single polarization of said field components in the other of said guides, and said element being polarized outside the region of gyromagnetic resonance by a steady polarizing magnetic field applied to said element in a direction perpendicular to said single polarization in the other of said guides.

7. In combination, a first section of wave guide for electromagnetic wave energy of rectangular cross-section, said guide having a pair of wide and a pair of narrow conductive walls, a second section of wave guide for electromagnetic energy having a transverse end, said end abutting one of said wide walls of said first guide, said energy as supported in said guides having longitudinally and transversely polarized magnetic field components, coupling means including an element of magnetically biased gyromagnetic material coupling through an aperture in said wide wall within the area abutted by said end, said element being in a region of both said longitudinally and transversely polarized magnetic field components in said first guide, said element being in a region of a single polarization of said field components in said second guide, such that energy coupled through said aperture from said first guide to said second guide in the direction of said single polarization is equal in amplitude to energy induced in said second guide by said element in the direction of said single polarization.

8. The combination according to claim 7, wherein said element is located at a position on said wide wall displaced from the longitudinal center line thereof.

9. The combination according to claim 7, wherein said wide wall has an aperture therein and wherein said gyromagnetic material is disposed within said aperture.

10. The combination according to claim 7, wherein said element is a member of ferromagnetic material.

11. The combination according to claim 7, including a reactive means located in said second guide, whereby the impedance of said second guide is matched to the impedance of one end of said first guide for energy applied to said second guide and to the impedance of the other end of said first guide for energy leaving said second guide.

12. In combination, first and second conductive wave guides adapted for propagating electromagnetic wave energy in respectively opposite longitudinal directions, said energy as supported in said guides having longitudinally and transversely polarized magnetic field components, means for coupling energy from said first to said second guide including a single aperture and a magnetically biased element of gyromagnetic material, said element being in a region of both longitudinally and transversely polarized field components in said first guide, said element being in a region of a single polarization of said field components in said second guide such that the component of energy coupled through said aperture from said first guide to said second guide in the direction of said single

polarization is equal in amplitude to and in time phase with the component of energy induced in said second guide by said element in the direction of said single polarization for one direction of propagation of electromagnetic energy in said first guide and the component of energy coupled through said aperture from said first guide in the direction of said single polarization is equal in amplitude to but 180° out of time phase with the component of energy induced in said second guide by said element in the direction of said single polarization for the opposite direction of propagation of electromagnetic energy in said first guide.

13. In combination, first and second conductive wave guides adapted for propagating electromagnetic wave energy in respectively opposite longitudinal directions, means for coupling energy from said first to said second guide including a single aperture and an element of gyromagnetic material physically associated with said aperture, said aperture being positioned relative to the field patterns in said guides for exciting from wave energy in said first guide a first component of energy in said second guide to form a first wave of energy in said second guide capable of propagating in said opposite directions, said gyromagnetic material exciting from wave energy in said first guide a second component of energy in said second guide at right angles to said first component, said second component being capable of forming a second wave of energy in said second guide capable of propagating in said opposite directions, and means for applying a magnetizing field to said material of strength and direction making said second wave equal in amplitude and opposite in phase to said first wave for one of said directions of propagation.

14. In an electromagnetic wave energy transmission system, first and second sections of shielded transmission line for supporting said wave energy, said energy as supported in said lines having longitudinally and transversely extending magnetic field components, a single gyromagnetic element coupling between said lines, said element being magnetically polarized outside the region of gyromagnetic resonance in a first direction and being positioned in said first line in a location for which said energy has both said field components and positioned in said second line in a location for which said energy has only one of said components, said element coupling to one of said field components in said first line having a second direction different from said first direction to induce a component in said second line having a third direction parallel to said one component different from said first and second directions, and means for matching the impedance of said second line to said first line through said coupling element.

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