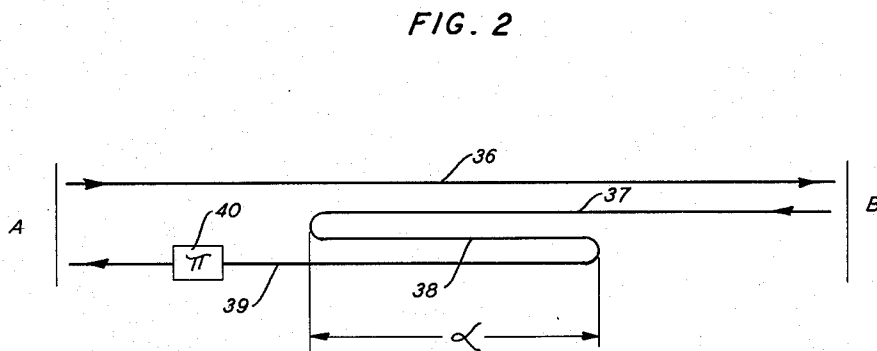
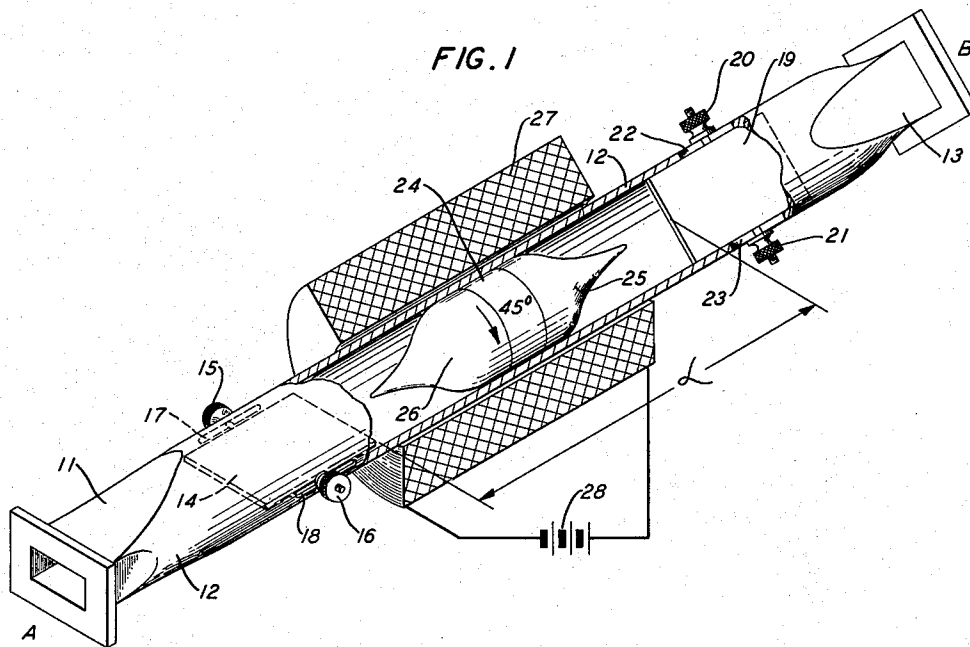


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DIRECTIONAL PHASE SHIFTER

2 Sheets-Sheet 1



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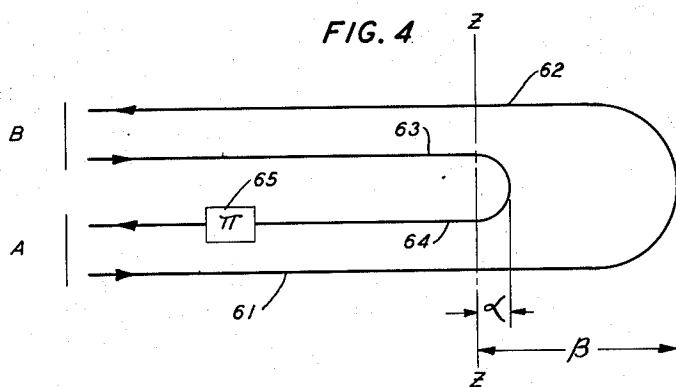
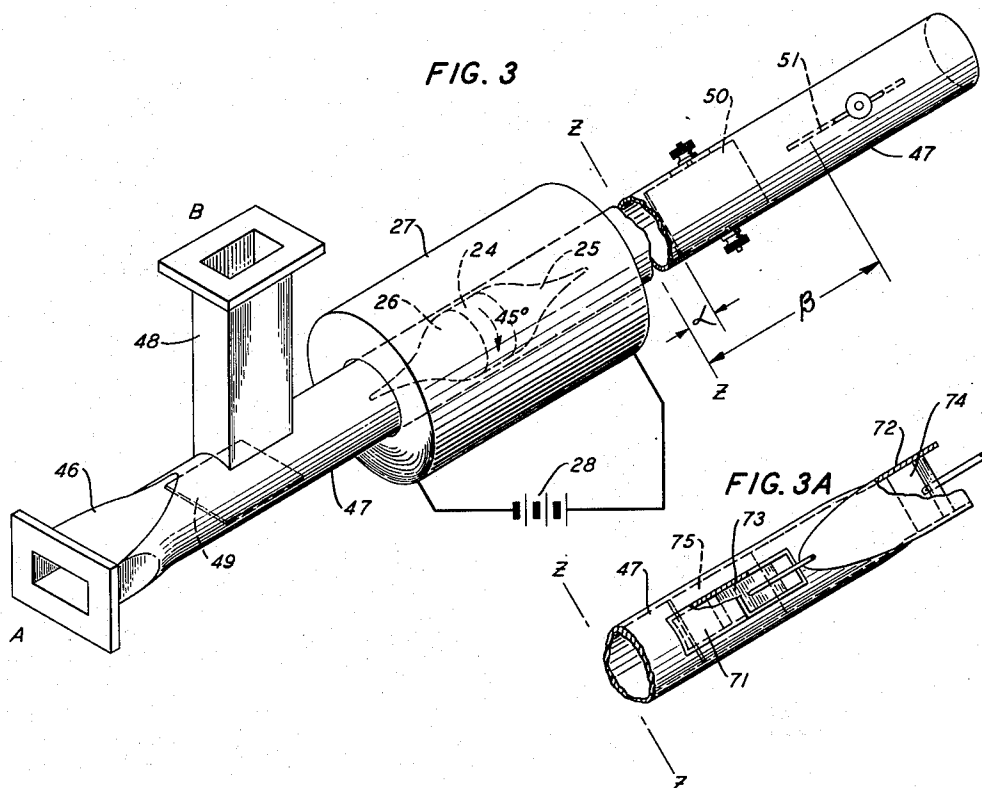
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DIRECTIONAL PHASE SHIFTER

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2 Sheets-Sheet 2



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2,760,166

DIRECTIONAL PHASE SHIFTER

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8 Claims. (Cl. 333—31)

This invention relates to electromagnetic wave transmission systems and, more particularly, to directional phase shifting devices having non-reciprocal phase properties.

In electromagnetic wave transmission systems, it would be desirable in numerous applications to introduce a first value of phase shift to energy traveling in one direction through the system and a second and different value of phase shift to energy traveling in the opposite direction of transmission therethrough. For example, in a repeater system in which one set of components serves jointly for communication in two directions, say in one direction for transmission and in the other for reception or for communication in one direction at a first frequency and in the opposite direction at a different frequency, it would be desirable to separately equalize the phase characteristics of the system for each direction of transmission. Heretofore, however, it has been extremely difficult, if not impossible, to obtain such a non-reciprocal value of phase shift.

It is an object of the invention to introduce a non-reciprocal phase shift to energy conveyed along a microwave transmission path.

It is a further object of the invention to introduce a phase shift or phase delay to energy traveling in one direction along a microwave transmission path without introducing a corresponding phase shift or phase delay to energy traveling in the opposite direction along said path.

It is a more specific object of the invention to introduce a first predetermined value of phase shift to wave energy traveling in one direction along a microwave transmission path and to introduce a second and different predetermined value of phase shift to energy traveling in the opposite direction therealong.

In the specific embodiments in accordance with the invention to be hereinafter described in detail, the non-reciprocal property of the phase shifting device is supplied by a Faraday-effect element. As will be shown, this element rotates the polarization of the electric vector of electrical energy passing through it with respect to reflecting elements interposed along the path, whereby electrical energy traversing the device in one direction will be reflected along a different path length, experiencing a different phase delay, from the path length and phase delay of energy traversing the device in the opposite direction.

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

In the drawings:

Fig. 1 is a perspective view of a phase shifter, in accordance with the invention, introducing a predetermined unidirectional phase shift to electrical energy traversing therethrough;

Fig. 2 is a diagrammatic representation of the path

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lengths followed by electrical energy traversing the device of Fig. 1, given for the purpose of explanation;

Fig. 3 is a perspective view of a phase shifter, in accordance with the invention, introducing separately adjustable phase shifts to electrical energy traversing the device in two directions;

Fig. 3A represents an alternative modification of Fig. 3 in accordance with the invention; and

Fig. 4 is a diagrammatic representation of the path lengths followed by electrical energy traversing the device of Figs. 3 and 3A, given for the purpose of explanation.

In more detail, Fig. 1 shows a rectangular wave guide 11, which supports a vertically polarized plane wave, tapering into a round wave guide 12 to which is joined another rectangular wave guide 13 which will accept only plane waves polarized at an angle, preferably 45 degrees, with respect to the polarization of waves in guide 11. The rectangular wave guides 11 and 13 will accept and support only TE₁₀ waves in which the electric vector, which determines the plane of polarization of the wave, is parallel to the short side of the rectangular wave guide. By means of the smooth transition from the rectangular cross-section of either guides 11 or 13 to circular cross-section of guide 12, the TE₁₀ mode goes over from either guide 11 or 13 into TE₁₁ mode in circular guide 12. The dimensions of these guides are preferably chosen so that only the dominant mode in each can be propagated. Positioned in the end of guide 12 adjacent guide 11 is a highly conductive reflecting vane 14 which may be several wavelengths in length and is diametrically disposed in guide 12 in a plane perpendicular to the electric polarization in guide 11 so as to reflect waves having their plane of polarization perpendicular to the polarization in guide 11. Vane 14 is held in this position and adapted for longitudinal position adjustment along the length of guide 12 by means of thumb-screw studs 15 and 16 extending, respectively, through opposite slots 17 and 18 in the wall of guide 12. Located a distance α along guide 12 from vane 14 is a second reflecting vane 19, disposed in guide 12 in a plane 45 degrees inclined to the plane of vane 14. Except for the angle of disposition, vane 19 is similar in all respects to vane 14, being held in position by thumb-screw studs 20 and 21, extending through oppositely disposed slots 22 and 23.

Thus, rectangular wave guide 11 and vane 14 constitute a pair of polarization-selective termini for one end of guide 12. Guide 11 is a connecting terminal by which TE₁₀ mode wave energy having a plane of polarization parallel to the narrow dimension of the rectangular cross-section thereof may be coupled to and from the TE₁₁ mode in guide 12 which has the same polarization. Any other polarization of wave energy in guide 12 will not pass through the polarization-selective terminal comprising guide 11. Vane 14 is a polarization-selective reflecting termination by which only the TE₁₁ mode of wave energy in guide 12 having a polarization orthogonal to the TE₁₁ mode therein to which guide 11 is coupled, is reflected by the vane 14. Wave energy polarized perpendicular to this reflecting polarization, i. e., perpendicular to the plane of vane 14, may pass along the guides in either direction unaffected by vane 14. Thus, vane 14 and wave guide 11 constitute conjugate termini of guide 12 in that wave energy for which vane 14 is effective will not be affected by guide 11 and, conversely, wave energy coupled to guide 12 by guide 11 will not be affected by vane 14. The vane 19 and guide 13 at the other end of guide 12 constitute a like reflecting termination and connecting terminal, respectively, having, however, their respective planes of reflection and coupling displaced by a 45 degree angle from the corresponding planes of vane 14 and

guide 11. It is obvious to one skilled in the art that other coupling means may be employed to couple to the proper polarizations of waves in guide 12. It is also obvious that other means of reflecting wave energy of the proper polarization may be provided, one such means being illustrated hereinafter with respect to Fig. 3A, for example.

Interposed between vanes 14 and 19 in the path of electromagnetic waves passing therebetween in guide 12 is suitable means of the type which produces an anti-reciprocal rotation of the plane of polarization of these electromagnetic waves, in other words, a Faraday-effect element having such properties that an incident wave impressed upon a first side of the element emerges on the second side polarized at a different angle from the original wave and an incident wave impressed upon the second side emerges upon the first side with an additional rotation of the same angle. Thus, the polarization of a wave passing through the element first in one direction and then in the other undergoes two successive space rotations or space phase shifts in the same sense, thereby doubling the rotation or phase shift undergone in a single passage. As illustrated by way of example in the drawing, this means comprises a Faraday-effect element 24 with accompanying conical transition members 25 and 26, which may be of polystyrene and are provided to cut down reflections from the face of element 24, mounted inside guide 12 approximately mid-way between vanes 14 and 19. As a specific embodiment, element 24 may be a block of magnetic material, for example, nickel-zinc ferrite prepared in the manner disclosed in the copending application of C. L. Hogan, Serial No. 252,432, filed October 22, 1951, having a thickness of the order of magnitude of an inch. This material has been found to operate satisfactorily as a directionally selective Faraday-effect rotator for polarized electromagnetic waves to an extent up to 90 degrees or more when placed in the presence of a longitudinal magnetizing field of strength which is readily produced in practice and in such thickness is capable of transmitting electromagnetic waves, for example in the centimeter range, with very small attenuation. Suitable means for producing the necessary longitudinal magnetic field surrounds element 24 which means may be, for the purpose of illustration, a solenoid 27 mounted upon the outside of guide 12 and supplied by a source 28 of energizing current. It should be noted, however, that element 24 may be permanently magnetized. The angle of rotation of polarized electromagnetic waves in such magnetic material is approximately directly proportional to the thickness of the material traversed by the waves and to the intensity of the magnetization to which the material is subjected, whereby it is possible to adjust the amount of rotation by varying or properly choosing the thickness of the material comprising element 24 and the intensity of magnetization supplied by solenoid 27.

In the simplified view of the phenomenon involved as offered in said Hogan application, a plane polarized wave incident upon the magnetic material in the presence of the magnetic field produces two sets of secondary waves in the material, each set of secondary waves being circularly polarized. The two sets of secondary waves are circularly polarized in opposite senses and they travel through the medium at unequal speeds. Upon emergence from the material the secondary waves in combination set up a plane polarized wave, which is in general polarized at a different angle from the original wave. It should be noted that the Faraday rotation depends for its direction upon the direction of the magnetic field. Thus, if the direction of the magnetic field is reversed, the direction of the Faraday rotation is also reversed in space while retaining its original relationship to the direction of the field.

The operation of the directional phase shifter of Fig. 1 may be conveniently explained with reference to the diagram of Fig. 2. Thus, a vertically polarized wave introduced at terminal A into guide 11 travels past vane 14

unaffected thereby inasmuch as the plane of the vane is perpendicular to the polarization of the wave, and past transition member 26, to element 24. The thickness of element 24 and the potential from source 28 are adjusted as pointed out hereinbefore to give a 45 degree rotation of the plane of polarization in the same direction as the angle existing between guide 11 and guide 13. Thus, as shown in Fig. 1, the polarization of the wave is rotated 45 degrees in a clockwise direction, as indicated by the arrow on element 24 in the drawing, thereby bringing the plane of polarization at right angles to the plane of vane 19, the preferred direction for unaffected transmission past vane 19 and into the preferred polarization for passage through guide 13 to terminal B. This straight through passage of wave power from terminal A to terminal B is illustrated on Fig. 2 by line 36. On the other hand, a vertically polarized wave applied at terminal B to guide 13 passes vane 19, is rotated 45 degrees by element 24 in the direction of the arrow thereon, bringing the wave into a polarization parallel to the plane of vane 14. This passage is indicated by line 37 on Fig. 2. In view of this polarization, vane 14 reflects the wave back to element 24 which again rotates its polarization 45 degrees in the direction of the arrow bringing the wave into a polarization parallel with the plane of vane 19. This passage is indicated by line 38 on Fig. 2. Vane 19, therefore, reflects the wave again through element 24 where it receives a further 45 degree rotation in the direction of the arrow, bringing its plane of polarization perpendicular to the plane of vane 14 and into the preferred direction for transmission past vane 14 and through wave guide 11 to terminal A. This passage is indicated by line 39 on Fig. 2.

Assuming an initial polarization of the wave as that in guides 11 and 13 for its passage from terminal A to terminal B, it will be seen that on passage from terminal B to terminal A the wave leaving guide 11 has been inverted or has experienced a phase delay of π degrees with respect to the assumed initial polarization. This phase inversion is indicated on Fig. 2 by an element 40 introducing a phase delay of π . It is thus readily seen from Fig. 2 that the wave on passing from terminal B to terminal A has traveled along a path longer by the addition of 2α than the path from terminal A to terminal B and has in addition experienced a phase inversion of π . Thus, by regulating the longitudinal positions of vanes 14 and 19 in guide 12, the distance α and the corresponding unidirectional phase shift $2\alpha + \pi$ may be arbitrarily chosen.

Fig. 3 shows an embodiment in accordance with the invention, whereby a first arbitrary value of phase shift is introduced to microwave energy traveling from terminal A to terminal B, and a second and different predetermined value of phase shift is introduced in traveling from terminal B to terminal A. The directional phase shifter of Fig. 3 comprises a rectangular wave guide 46 which supports a vertically polarized wave, tapering into a round wave guide 47 to which is joined by a shunt plane junction a second rectangular wave guide 48 perpendicular to both guides 46 and 47 which guide 48 will accept only horizontally polarized waves. Thus, guides 46 and 48 comprise a pair of conjugately related terminals or branches in that a wave launched in either one will not appear at the other. A highly conductive reflecting vane 49 is preferably placed in circular guide 47 opposite the junction aperture of guide 48 to reflect into guide 48 those waves having their plane of polarization coincident with the plane of vane 49. The spacing between vane 49 and the aperture of guide 48 may be adjusted to give maximum power transfer in this circuit. At a point to the right of guide 48 along guide 47 is a Faraday-effect rotator comprising element 24, its associated conical members 25 and 26, and means for supplying a magnetic field 27, the last-named components being substantially identical to those bearing corresponding reference numerals in Fig. 1, described hereinbefore. At distances

to the right of element 24 along guide 47, which distances will be considered in detail hereinafter, are respectively located two highly conductive reflecting vanes 50 and 51 disposed within guide 47 in planes at right angles to each other and at 45 degrees to the plane of polarization of a wave in guide 46. Vanes 50 and 51 are each adapted for longitudinal position adjustment along the length of guide 47 in the same manner as were vanes 14 and 19 of Fig. 1.

Thus, guides 46 and 48 comprise a pair of polarization-selective connecting terminals by which wave energy in two orthogonal TE₁₁ mode polarizations may be coupled to and from one end of guide 47. Vanes 50 and 51 constitute a second pair of polarization-selective reflecting terminations at the other end of guide 47 by which each of the two orthogonally related TE₁₁ modes in guide 47 which have their planes of polarization respectively related by 45 degrees to the planes of polarization to which guides 48 and 46 are coupled, are reflected back along the length of guide 47. As will be shown hereinafter with respect to Fig. 3A, the wave energy in those planes of polarization may be reflected by members coupled in different ways to the proper planes in guide 47.

The operation of the directional phase shifter of Fig. 3 can be conveniently explained with reference to the diagram of Fig. 4. Thus, a vertically polarized wave introduced at terminal A into guide 46 travels past vane 49 unaffected thereby inasmuch as the plane of the vane is perpendicular to the polarization of the wave, and travels past the aperture of guide 48 to element 24. The thickness of element 24 and the magnetic field applied thereto are adjusted to give a 45 degree rotation in a clockwise direction, as indicated by the arrow on element 24 in the drawing. Thus, the wave emerging from element 24 is brought into a plane of polarization at right angles to vane 50, the preferred direction for transmission past vane 50, and into the plane of vane 51. This passage of wave power is indicated by line 61 on Fig. 4. In view of the polarization of the wave at vane 51, the wave is reflected back toward element 24, again passing vane 50. Element 24 rotates its polarization 45 degrees in the direction of the arrow bringing the wave into a polarization parallel with vane 49 which reflects it into guide 48 with the proper polarization for passage to terminal B. This passage is indicated by line 62 on Fig. 4.

On the other hand, a horizontally polarized wave applied at terminal B to guide 48 is reflected by vane 49 toward element 24 which rotates the polarization 45 degrees in the direction of the arrow bringing the polarization of the wave into the plane of vane 50. This passage is indicated by line 63 on Fig. 4. Vane 50, therefore, reflects the wave again through element 24 where it receives a further 45 degree rotation in the direction of the arrow bringing its plane of polarization perpendicular to the plane of vane 49 and into the preferred direction for transmission past vane 49 and through wave guide 11 to terminal A. This passage is indicated by line 64 on Fig. 4.

As in the phase shifter of Fig. 1, if an initial polarization of the wave is assumed as that in guides 46 and 48 for its passage from terminal A to terminal B, it will be seen that on passage from terminal B to terminal A, the wave leaving guide 46 has been inverted or has experienced a phase delay of π degrees with respect to the assumed initial polarization. This phase inversion is indicated on Fig. 4 by an element 65 introducing a phase delay of π . If the relative path lengths from terminal A to terminal B, and from terminal B to terminal A, are compared by measuring the distances to the reflecting vanes 51 and 50, respectively, from an arbitrary point common to each path, such as a point at section Z—Z, it will be seen that the path from terminal A to terminal B depends upon a distance 2β , β being the distance from section Z—Z to reflecting vane 51, and that the path from terminal B to terminal A depends upon a distance $2\alpha + \pi$, α being the distance from section Z—Z to reflect-

ing vane 50. Thus, by separately regulating the longitudinal positions of vanes 50 and 51 in guide 47, a first arbitrary value of phase shift 2β may be introduced to microwave energy traveling from terminal A to terminal B, and a second and different arbitrary value of phase shift $2\alpha + \pi$ may be introduced to microwave energy traveling from terminal B to terminal A. It should be noted that while, as shown in the drawings, the distance α is smaller than the distance β , this relationship may be reversed without affecting the operation of the phase shifting device so long as the respective planes of orientation of vanes 50 and 51 are not changed.

Fig. 3A shows an alternative modification of Fig. 3 having phase shifting properties identical to those of the device of Fig. 3, which properties have been shown in Fig. 4. According to the modification of Fig. 3A, round wave guide 47 tapers into a rectangular wave guide 72 which supports a wave polarized in a plane inclined 45 degrees with respect to the polarization of a wave guide 46. Guide 47 is joined in a shunt plane junction by a second rectangular guide 71 which is perpendicular to both guides 47 and 72 and which will accept waves from guide 47 having a plane of polarization inclined at 45 degrees to the polarization of those waves accepted by guide 48. A highly conductive reflecting vane 75 is positioned with respect to the aperture of guide 71 and bears the same relation thereto as vane 49 to the aperture of guide 48. Thus, guide 71 accepts those waves formerly reflected by vane 50 of Fig. 3, and guide 72 accepts those waves formerly reflected by vane 51 of Fig. 3. Shorting pistons 73 and 74 terminate guides 71 and 72, respectively, in a reflecting manner and the position of these reflecting pistons along the guides 71 and 72 determines the values of the relative delays α and β , respectively, as shown on Fig. 4.

While the two directional properties of the phase shifting devices in accordance with the present invention have been primarily stressed herein, it should not be overlooked that the disclosed structures may also serve to introduce a desired value of phase shift into a system conveying energy in only one direction. In such a system two pre-adjusted values of phase shift may be alternately inserted in the system merely by reversing, either by hand or by suitable switching means, the direction in which the energy traverses the disclosed phase shifting devices.

In the particular case in which the phase shift in one direction is 180 degrees different from the phase shift in the other direction, the present phase shifting devices then exhibit the properties of the circuit element known as a "gyrator," for which numerous applications are disclosed in said copending Hogan application and in the publications referred to therein.

A further embodiment of a unidirectional phase shifting device having properties identical to those of Fig. 1 herein may be obtained by terminating in a reflecting manner the branches *c* and *d* of the four branch switching system disclosed in Fig. 9 of said copending Hogan application. A further embodiment having phase shifting properties identical to those of the phase shifter of Fig. 3 may be obtained by terminating in a reflecting manner terminals *b* and *d* of the four branch switching system disclosed in said Fig. 9.

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 by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A non-reciprocal phase shifting device for electromagnetic wave energy comprising a section of circular wave guide, a pair of conjugate microwave connections coupled to one end of said guide for wave energy polarized in orthogonal planes therein, a pair of highly conductive diametrical vanes disposed in the other end of said guide,

7. A device for producing a Faraday-effect rotation of linearly polarized wave energy in a reflecting termination having high reflection properties and low absorption properties by which said energy is reflected back to said guide.

2. A non-reciprocal phase shifting device for electromagnetic wave energy comprising a wave-guide section having a characteristic impedance and adapted to support said energy in orthogonal polarizations, a pair of polarization-selective wave-guide connections at one end of said guide each adapted to couple to and from one orthogonal polarization of wave energy in said one end, a pair of wave-guide reflecting terminations at the other end of said guide, each of said terminations presenting a characteristic impedance substantially different from said guide characteristic impedance to wave energy having an orthogonal polarization respectively related by a given angle to a polarization in said one end, and means for producing a polarization rotation interposed in said guide between said ends, said means producing an angle of rotation in the same sense as viewed in the direction of propagation of wave energy through said guide for opposite directions of propagation therethrough which is equal to said given angle.

3. A device in accordance with claim 2, wherein said given angle is equal to 45 degrees.

4. A phase shifting device for electromagnetic wave energy comprising a section of circular wave guide, a pair of wave-guide connections located at one end of said guide to couple wave energy to and from single planes of polarization in said guide, a pair of reflecting members located at the other end of said guide to present a substantially short circuit to wave energy incident upon said members in planes of polarization, the planes of said members being different from each other and from the planes to which said connections are coupled, and means including a polarization rotator interposed in the path of wave energy between said connections and said members for producing a polarization rotation of wave energy propagated from said one end to said other end equal to the angle between the particular plane of one of said members and the plane to which one of said connections is coupled and of wave energy propagated from said other end to said one end equal to the angle between said particular plane and the plane to which the other of said connections is coupled whereby wave energy applied to said one connection is rotated into the plane of reflection of said one member and hence into the plane of said other connection.

5. A non-reciprocal phase shifting device for electromagnetic wave energy comprising a section of circular wave guide adapted to support said energy in orthogonal polarizations, a first pair of orthogonal polarization-selective wave-guide connections at one end of said guide each adapted to couple to and from one orthogonal polarization of wave energy in said one end, a second pair of orthogonal polarization-selective wave-guide connections at the other end of said guide each adapted to couple to and from orthogonal polarizations respectively related by a given angle to a polarization in said one end, means for producing a polarization rotation interposed in said guide between said ends, said means having an angle of rotation in the same sense as viewed in the direction of propagation of wave energy through said guide for opposite directions of propagation therethrough which is equal to said given angle, two of said termini being terminated in a reflecting termination having high reflection properties and low absorption properties by which said energy is reflected back to said guide.

8. A non-reciprocal phase shifting device for producing a given differential phase shift for opposite directions of propagation of electromagnetic wave energy therethrough comprising a section of circular wave guide, a first pair of orthogonal wave polarization-selective termini coupled to one portion of said guide, a second pair of orthogonal wave polarization-selective termini coupled to another portion of said guide, and an antireciprocal rotator for producing a Faraday-effect rotation of linearly polarized wave energy interposed between said portions, two of said termini being each a connecting terminal by which said energy may be coupled to and from said guide, the remaining two of said termini being each a reflecting termination having high reflection properties and low absorption properties by which said energy is reflected along said guide, at least one of said reflecting termini being movable with respect to the other of said reflecting termini for providing an adjustable electrical distance therebetween which is equal to a function of said given differential phase shift.

6. A non-reciprocal phase shifting device for producing a given differential phase shift for opposite directions of propagation of electromagnetic wave energy therethrough comprising a section of circular wave guide, a first pair of orthogonal wave polarization-selective termini coupled to one portion of said guide, a second pair of orthogonal wave polarization-selective termini coupled to another portion of said guide, and an antireciprocal rotator for producing a Faraday-effect rotation of linearly polarized wave energy interposed between said portions, two of said termini being each a connecting terminal by which said energy may be coupled to and from said guide, the remaining two of said termini being each a reflecting termination having high reflection properties and low absorption properties by which said energy is reflected along said guide, at least one of said reflecting termini being movable with respect to the other of said reflecting termini for providing an adjustable electrical distance therebetween which is equal to a function of said given differential phase shift.

7. A device for producing a predetermined differential phase shift in electromagnetic wave energy for opposite directions of propagation therethrough comprising a section of wave guide capable of supporting said wave energy in four polarizations each of which is angularly displaced from the adjacent ones by 45 degrees, an antireciprocal rotator interposed in said guide for antireciprocal rotation of the energy in any one of said polarizations on one side of said rotator into an adjacent one of said polarizations on the opposite side of said rotator, a pair of polarization-selective wave guide connections to said guide coupled to said wave energy in two of said polarizations, and means for presenting a movable point of substantial short circuit to each of the remaining two of said polarizations, said points being at an adjustable electrical distance from each other which is equal to a function of said predetermined differential phase shift.

8. A non-reciprocal phase shifting device for producing a given differential phase shift for opposite directions of propagation of electromagnetic wave energy therethrough comprising a section of circular wave guide, an antireciprocal rotator for producing a Faraday-effect rotation of linearly polarized wave energy interposed in said guide, a pair of wave polarization-selective wave guide connections coupled to said guide one on each side of said rotator, and a pair of wave polarization-selective reflecting termini coupled to said guide one on each side of said rotator, each of said reflecting termini having high reflection properties and low absorption properties for the wave polarization orthogonal to the polarization coupled to the wave guide connection on the same side of said rotator, and at least one of said reflecting termini being movable with respect to the other of said reflecting termini for providing an adjustable electrical distance therebetween which is equal to a function of said given differential phase shift.

References Cited in the file of this patent

UNITED STATES PATENTS

1,742,115	Whittaker	Dec. 31, 1929
2,441,598	Robertson	May 18, 1948
2,607,849	Purcell	Aug. 19, 1952
2,644,930	Luhrs	July 7, 1953