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NON-RECIPROCAL WAVE TRANSMISSION

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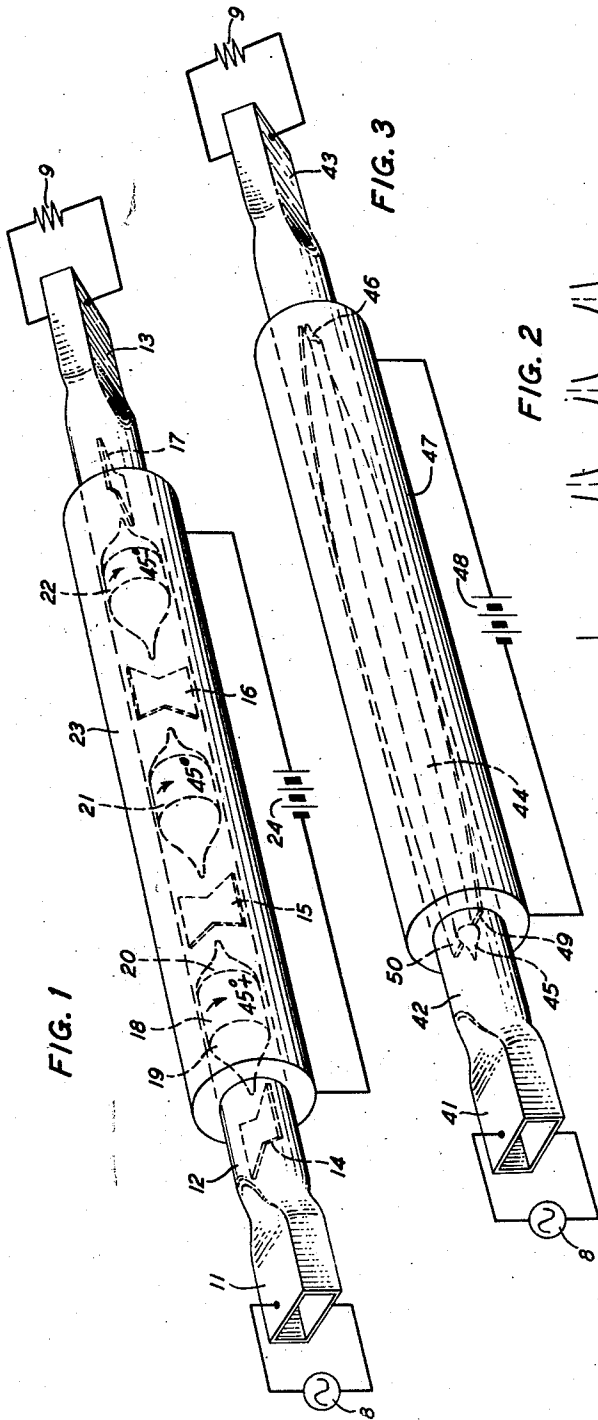


FIG. 2

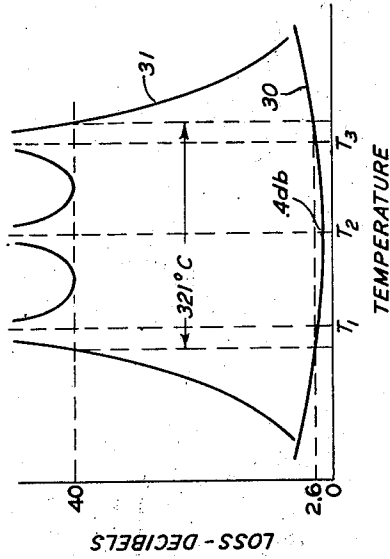
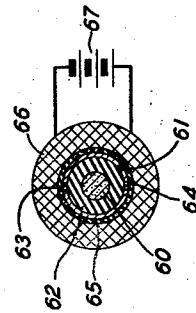


FIG. 4



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**NON-RECIPROCAL WAVE TRANSMISSION**

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4 Claims. (Cl. 333-24)

This invention relates to non-reciprocal electrical wave transmission devices, and, more particularly, to improved one-way transmission devices employing an anti-reciprocal rotation of the polarization of electromagnetic wave energy which may directionally isolate one electrical circuit from another.

The desirability of directional isolation in electromagnetic wave systems has been apparent for some time. For example, a very simple but particularly useful application of an isolator is found in a system in which wave generation equipment, for example, a frequency modulated oscillator, is to be worked directly into a transmitting antenna. As is well known, serious matching problems are encountered in such a system since any reflection or other return of energy from the antenna has an undesirable effect upon the oscillator. An isolator, therefore, having low loss or attenuation for waves passing from the oscillator to the antenna and high return loss or attenuation for waves passing from the antenna to the oscillator, would greatly simplify the problem. Until recently, such a non-reciprocal transmission medium was unknown.

Lately, the antireciprocal Faraday-effect rotation of a magnetized element of ferromagnetic material has been exploited to provide such an isolator. The Faraday-effect element is combined with a polarization-selective attenuator so that in the forward direction of transmission the polarization of the wave is rotated by the Faraday-effect element into the plane of minimum loss in the attenuator, while in the return direction the polarization of the wave is rotated into the plane of maximum attenuation. Such a system is disclosed in the copending application of C. L. Hogan, Serial No. 252,432, filed October 22, 1951, which has matured into United States Patent No. 2,748,353, May 29, 1956, and in his publication, "The Microwave Gyrotor," in the Bell System Technical Journal, January 1952.

It has been shown experimentally that Faraday rotation obtained in known ferromagnetic materials varies as a function of ambient temperature and to some extent also as a function of frequency. Consequently, an isolator employing a ferromagnetic element adjusted for the proper rotation at one temperature will be capable of a maximum return loss only at that temperature for which the adjustment was made. At temperatures either above or below this, the Faraday rotation will no longer rotate the return waves into the plane of maximum loss of the attenuator, and some undesired power will return to the sending end of the isolator. One solution to this would be to operate the ferromagnetic element in a temperature controlled medium, but the necessary complications thereby involved would seriously limit the extent of feasible application of the device. Similar difficulties are presented by the frequency variations of the amount of rotation in the ferromagnetic element.

It is an object of the present invention to attenuate, by new and improved apparatus, wave energy propagated in one direction along a transmission path to a substantially

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greater degree than wave energy propagated in the other direction along said path.

Further objects of the invention are to reduce the effects of ambient temperature and to reduce the operating frequency variations in connection with ferromagnetic isolators.

In accordance with a first specific embodiment of the present invention a plurality of Faraday-effect rotators and a plurality of polarization-selective attenuators are arranged along a wave energy transmission path. Each rotator is adjusted for maximum return loss with respect to one or more of the attenuators at slightly different operating temperature and/or operating frequencies. The combined effect gives a relatively high attenuation for return wave energy and a relatively low forward loss at all temperatures and frequencies within the range of the temperatures and frequencies for which the overall device is adjusted.

In a second specific embodiment each of the separate rotators are in effect combined into a single elongated rotator and the several attenuators are replaced by a single attenuator that spirals along the length of the rotator. The combination results, as will be explained in detail below, in an isolator having negligible loss in the forward direction and a substantial return loss, both being substantially independent of temperature and frequency.

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 in the following detailed description of these drawings.

In the drawings:

Fig. 1 is a perspective view of a first specific isolator in accordance with the invention, showing the physical relationship of three Faraday-effect rotators and four polarization-selective attenuators;

Fig. 2 represents the loss or attenuation versus temperature characteristic of the isolator of Fig. 1; and

Fig. 3 is a perspective view and Fig. 4 is a cross-sectional view of an alternative of Fig. 3, each showing a single rotator and a related spiral attenuator in accordance with the second embodiment of the invention.

Referring more specifically to Fig. 1, a one-way transmission device in accordance with the first embodiment of the invention is illustrated which connects an oscillator 8 to a load 9 with relatively low loss, and which isolates oscillator 8 by a relatively high loss from energy which might be reflected from load 9. As illustrated, this isolator comprises a rectangular wave guide 11 which will accept and support only plane polarized dominant mode waves from oscillator 8 for which the electric vector, which determines the plane of polarization of the wave, is parallel to the short side of rectangular wave guide 11. Guide 11 tapers into a round wave guide 12 to the opposite end of which is joined another rectangular wave guide 13. Guide 13 will accept and support only plane waves polarized at an angle, illustrated as 135 degrees clockwise as viewed from and with respect to the polarization of waves in guide 11. By means of the smooth transition from the rectangular cross-section of either guide 11 or guide 13 to the circular cross-section of guide 12, the dominant mode in either guide 11 or guide 13 is coupled to and from the dominant mode in circular guide 12 having a parallel polarization. The diameter of guide 12 is preferably chosen so that only the several polarizations of this dominant mode can be propagated.

Spaced along the length of guide 12 are a plurality of polarization-selective attenuators comprising resistive vanes 14 through 17, respectively. Vane 14 is positioned

in the end of guide 12 adjacent guide 11 and is diametrically disposed in guide 12 in a plane perpendicular to the electric polarization in guide 11 so as to absorb and dissipate waves having their plane of polarization perpendicular to the plane of polarization of waves in guide 11. The other resistive vanes 15, 16 and 17, respectively, are each disposed in guide 12 in a plane inclined 45 degrees (clockwise as viewed from guide 11) to the plane of the immediately preceding vane. The sense of this progressive inclination is the same as that of the angle between guides 11 and 13.

Except for their respective angles of disposition, vanes 14, 15, 16 and 17 may be identical and may each be a thin sheet of low dielectric constant material, for example, polystyrene, coated with a film of resistive material, for example, carbon black, or may consist solely of carbon or other resistive material. In order to prevent reflections from the edges of vanes 14 through 17, these edges may be tapered over a distance of several wavelengths, thus making the plane of each half of vanes 14 through 17 a trapezoidal shape. Thus, a wave polarized perpendicular to the plane of any vane will suffer only negligible attenuation, while a wave polarized parallel to the plane of the vane will induce currents in the resistive material and will be dissipated thereby. It is obvious to one skilled in the art that other means of absorbing wave energy of selected polarization may be employed.

Interposed between vanes 14 and 15 in the path of the electromagnetic wave passing therebetween in guide 12 is suitable means of the type which produces an antireciprocal Faraday-effect rotation of the plane of polarization of these waves such that an incident wave impressed upon a first side of the rotator 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. As illustrated by way of example in Fig. 1, this means comprises a ferromagnetic element 18, with conical transition members 19 and 20 in accordance with usual practice, mounted inside guide 12 approximately mid-way between vanes 14 and 15. Similar ferromagnetic elements 21 and 22 are located in guide 12 between vanes 15 and 16 and 16 and 17, respectively.

Elements 18, 21 and 22 may be made of any of the several ferromagnetic materials which each comprise an iron oxide with a small quantity of bivalent metal such as nickel, magnesium, zinc, manganese, or other similar material in which the other metals combine 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, elements 18, 21 and 22 may be made of nickel-zinc ferrite prepared in the manner described in the above-mentioned publication and copending application of C. L. Hogan. As there disclosed, this material has been found to operate satisfactorily as a directionally selective Faraday-effect rotator of polarized electromagnetic waves when placed in the presence of a longitudinal magnetizing field of strength below that required to produce ferromagnetic resonance in the material.

Suitable means for producing the necessary longitudinal magnetic field surrounds elements 18, 21 and 22, which means may be, for the purposes of illustration, a single solenoid 23 mounted upon the outside of guide 12 and supplied by a source 24 of energizing current. The polarity of the field is chosen so that the direction of rotation for a wave propagated from left to right through elements 18, 21 and 22 (as indicated by the arrows on the elements) is clockwise when viewed from the left and thus in the same sense as the angles between vanes 14 and 15, 15 and 16, 16 and 17, and between guides 11 and 13. It should be noted that elements 18, 21 and 22 may be magnetized to the proper strength alternatively

by separate solenoids, by permanent magnet structures, or they may be permanently magnetized if desired.

As an alternative, the required Faraday-effect rotation may be obtained by employing three antireciprocal rotators of the type disclosed in the copending application of E. H. Turner Serial No. 339,289, filed February 27, 1953, and in my copending application Serial No. 360,795, filed June 10, 1953.

Whatever form of Faraday-effect element is employed, the magnitudes of rotation of the three elements are adjusted for a given mid-band frequency and at the center of a range of ambient temperature variation so that one of said elements produces substantially a 45 degree rotation of the plane of polarization for a single passage of electromagnetic wave energy, and the other two of said elements produce an angle somewhat larger, and somewhat smaller, respectively, than 45 degrees. Considerations involved in selecting the amount of this difference will be considered hereinafter. For the particular type of rotator illustrated in Fig. 1, the magnitude of rotation produced by elements 18, 21 and 22 is approximately directly proportional to the thickness of the material traversed by the waves and to the intensity of the magnetization of the material. If elements 18, 21 and 22 are each subject to the same intensity of magnetization by solenoid 23, the above-described difference in rotation is obtained by varying or properly choosing the thickness of the material comprising each element. However, by suitably winding solenoid 23 so that a different magnetic field intensity is provided for each element, the intensity of the individual fields may be adjusted either with or without differences in the physical dimensions of the elements.

For convenience in the explanation that follows, assume that for a given temperature  $T_2$  and a given frequency, element 18 produces a rotation greater than 45 degrees; element 21 produces a rotation of 45 degrees; and element 22 produces a rotation less than 45 degrees. Thus, element 21 may be somewhat shorter than element 18, and element 22 somewhat shorter than element 21. This means that at some temperature  $T_1$  lower than  $T_2$  element 22 will produce precisely a 45 degree rotation while both elements 21 and 18 will produce a rotation, respectively, larger than 45 degrees. Similarly, at a temperature  $T_3$  higher than both  $T_1$  and  $T_2$ , element 18 will have a rotation of 45 degrees, while elements 21 and 22 will rotate the polarization less than 45 degrees. A similar analysis applies to frequencies above and below the given mid-band frequency.

The operation of the isolator of Fig. 1 may easily be seen by tracing the path of energy from oscillator 8 to load 9 and the return path of a wave reflected by load 9 for the mid-band frequency and at the mid-range temperature  $T_2$ . Thus, a vertically polarized wave introduced from oscillator 8 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 19 to element 18. Element 18 rotates the wave slightly more than 45 degrees in the same sense as the angle existing between guide 11 and guide 13 (in a clockwise direction as indicated by the arrow on element 18 in the drawing).

The rotated wave may be resolved into two components with respect to vane 15, i. e., a major component of the wave at right angles to the plane of vane 15 and a very small component of the wave parallel to the plane of vane 15, representing the amount the rotation exceeded 45 degrees. The small component will be dissipated by vane 15. The major component of the wave will pass vane 15 unaffected and will be rotated 45 degrees by element 21 in the direction of the arrow thereon. This brings the wave into a polarization perpendicular to the plane of vane 16 past which the wave travels unaffected to element 22. Element 22 rotates the polarization of the wave somewhat less than 45

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degrees in the direction of the arrow thereon, bringing the polarization of the major component of the wave into a plane perpendicular to vane 17 past which the wave travels unaffected through guide 13 to load 9. A small component of the wave rotated by element 22 will lie in the plane of vane 17 (representing the amount that the rotation falls short of 45 degrees), and will be dissipated by vane 17.

Curve 30 of Fig. 2 represents the loss versus temperature for the forward traveling wave just described. At the temperature  $T_2$  the loss represented by curve 30 accounts for the two small components lost in vanes 15 and 17 and the incidental loss in the ferromagnetic material of elements 18, 21 and 22. In a typical embodiment, this loss will not exceed about 1 decibel. As the temperature is increased or decreased from this value, the loss will increase as shown by curve 30 only slightly due to the additional power lost in vane 16. Within the range between  $T_1$  and  $T_3$  the increase in power lost by one of vanes 15 or 17 is compensated by the decrease in power lost in the other.

Assume now that a substantial return component of the wave energy is reflected by load 9. This reflected wave travels past vane 17 unaffected thereby, inasmuch as the plane of the vane is perpendicular to the polarization of the wave, to element 22. Element 22 rotates the return wave slightly less than 45 degrees in the direction indicated by the arrow on element 22. The rotated wave may be resolved into two components with respect to vane 16, i. e., a major component in the plane of vane 16 and a small component perpendicular to the plane of vane 16. The major component will be dissipated by vane 16. The small component will pass vane 16 and will be rotated 45 degrees by element 21 in the direction of the arrow thereon. This brings the small component into the plane of vane 15 by which it is dissipated. Thus, at the temperature  $T_2$  all energy in the reflected wave is dissipated either in vane 16 or vane 15. This results in substantially infinite discrimination between the forward wave and the return wave through the isolator of Fig. 1 as represented by the infinite loss portion of curve 31 of Fig. 2 at the temperature  $T_2$ .

At the temperature  $T_3$ , for which the rotation of both elements 21 and 22 is greater than 45 degrees, a small component perpendicular to the plane of vane 15 will pass on to element 18 to be rotated 45 degrees into the plane of vane 14 and dissipated thereby. Thus, at the temperature  $T_3$  as indicated by curve 31 on Fig. 2, infinite discrimination will be found for the isolator. At the temperature  $T_1$  for which the rotation of element 22 is precisely 45 degrees, all wave energy will be dissipated in vane 16. Again, infinite discrimination, as represented by curve 31 of Fig. 2, is found for the isolator. At intermediate temperatures, the discrimination is substantially less than infinite but is well within acceptable limits for practical applications of the isolator.

Specific design data of an isolator for any given application depends upon the maximum return loss required, the range of ambient temperature variation over which this loss must be maintained and the number of 45 degree sections of the isolator. Obviously, for a given number of sections, a much higher discrimination may be obtained over a limited range than may be obtained over a wider range. In a typical embodiment, it has been determined that each 45 degree section will produce 40 decibels of return attenuation over a temperature range of substantially 9.35 degrees centigrade. However, for a given specific embodiment employing three such sections as in Fig. 1, with the temperatures  $T_1$ ,  $T_2$  and  $T_3$  at which each section produces a 45 degree rotation, respectively, spaced substantially 138 degrees centigrade apart, a return loss of at least 40 decibels will be maintained over a temperature range of 321 degrees as shown in Fig. 2. The forward attenuation or loss at the extreme

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temperature values under this condition would only be 2.6 decibels greater than the loss due to the ferrite elements alone. This is represented on an exaggerated scale by curve 30 of Fig. 2. It has been found that in a typical sample of ferromagnetic material, the rotation changed 0.28 percent per degree centigrade. Thus, on the basis of the above specific values, element 18 should be adjusted to produce a rotation of approximately 62.4 degrees, element 21 of approximately 45 degrees and element 22 of approximately 27.6 degrees, all at the center range temperature  $T_2$ . Obviously, these adjustments need not be accurately made.

Three 45 degree sections have been illustrated in Fig. 1 as a typical embodiment. Two sections, however, will give substantial improvement over a single section and the number of sections may be further increased to increase the operating band and/or the minimum discrimination within the band, if desired. It should be noted in this connection that a multiple of four sections will place the output polarization in the same plane as the input polarization.

In order to simplify the description above, operation of the isolator of Fig. 1 has been explained with reference to variations of temperature alone. However, since as noted above, the effect of frequency upon the rotation of ferromagnetic materials is similar to the effect of temperature, i. e., it has been observed that substantially a 3 percent change in rotation occurs for a 1 percent change in frequency; therefore, the same compensating effects of the isolator are found for variations in frequency or for simultaneous variations in frequency and temperature. Thus, on the basis of specific values given above, the isolator would maintain a return loss of at least 40 decibels over a change in frequency of substantially 30 percent. From the standpoint of actual use this extremely broad stability with respect to frequency is of far more practical significance than the broad temperature range since such a frequency band would not be unusual in a broad band transmission system, whereas so great a temperature variation would be exceptional.

Referring now to Fig. 3, a second embodiment of an isolator in accordance with the invention is shown, which in basic design principles is similar to the isolator of Fig. 1 but which has several advantages thereover, including compactness of construction and substantially infinite discrimination between the forward wave and the return wave at any frequency and/or temperature.

The isolator of Fig. 3 comprises a section of rectangular wave guide 41 which tapers into a section 42 of circular guide. Guide 42 tapers in turn into a second section 43 of rectangular wave guide displaced by an angle to be defined from guide 41. These guides are identical to the corresponding components of Fig. 1. Axially located within guide 42 is an elongated cylinder 44 of ferromagnetic material similar to the materials of the Faraday elements of Fig. 1. Conical transition members 45 and 46 are provided at each end of cylinder 44 in accordance with usual practice. Cylinder 44 is several wavelengths in length and has a diameter which may be in the order of one-third that of guide 42. Cylinder 44 is supported in its axial position by two thin spiral vanes 49 and 50 of resistive material. Vanes 49 and 50 are provided with equal smooth helical twists of constant pitch so that they remain on opposite sides of element 44 and lie along a common diameter in any cross-section along the wave guide. They commence in the end of guide 42 adjacent to guide 41 in a plane normal to the electric polarization supported by guide 41 and end in the end of guide 42 adjacent to guide 43 in a plane normal to the electric polarization supported by guide 43. Vanes 49 and 50, like the vanes of Fig. 1, may be constructed of thin sheets of low dielectric constant material coated with a film of resistive material or they may be made entirely of resistive material. In either event, the resistance of vanes 49 and 50 should be sufficiently high that their

tendency to distort the wave fields and to shift the wave polarization by acting as guiding structures is small. A single vane extending through element 44 may replace vanes 49 and 50, if desired.

Element 44 is supplied with a longitudinal magnetic field by solenoid 47 energized by source 48 of such strength and polarity that element 44 produces a Faraday-effect rotation of wave energy passing from left to right along guide 42 having the same rotation per unit length at the mid-band temperature and frequency as the rotation per unit length of vanes 49 and 50.

Thus, the polarization of a vertically polarized wave introduced from the left into guide 41 will be normal to the plane of vanes 49 and 50 upon their first encounter with the vanes and will be rotated by element 44 during passage down guide 42 so that the polarity of the wave remains normal to the plane of the vanes at every point along their length. The rotated waves emerge at the right in the proper polarization for acceptance by guide 43. For this passage, therefore, a minimum of wave energy will be dissipated in vanes 49 and 50. As the temperature and/or frequency shifts from the center value and the Faraday rotation of element 44 changes, the polarization of the wave will depart slightly from this optimum value and small attenuation will be introduced to the forward traveling wave.

A return wave introduced to the isolator of Fig. 3 by way of guide 43 will be initially polarized normal to vanes 49 and 50 at their right-hand ends. As this wave is propagated to the left along guide 42, element 44 progressively rotates the polarization of the wave so that an increasingly larger component of the electric field vector is brought into the plane of vanes 49 and 50 to be dissipated thereby. When the wave has propagated such a distance that its total rotation is 45 degrees, the entire electric vector will have been brought into the plane of vanes 49 and 50 and an opportunity presented for the wave to be completely dissipated in vanes 49 and 50. Since this condition is independent of the exact rotation per unit length produced by the ferromagnetic material of element 44, the attenuation to the return wave is independent of temperature and frequency changes which might vary the rotation.

Successive opportunities for dissipation are presented as any remaining wave energy continues to propagate to the left. Certain design considerations may, therefore, be explained which depend for the most part upon the attenuation required for the return wave in a certain application. Each time the return wave is rotated through a full 90 degrees, the electric vector thereof will pass through the plane of the resistive material. Thus, the total rotation for one direction of travel through the isolator should be at least 45 degrees and may be much larger. In the particular embodiment of Fig. 3, the total rotation is illustrated as 135 degrees which provides two regions of maximum attenuation where the electric vector lies in the plane of the resistive material. It is, of course, not necessary that the total rotation be a multiple of 45 degrees if a more convenient angular relationship of the wave-guide terminals to the connected wave-guide system is provided by some other angle. The longitudinal length of vanes 49 and 50 should be in the order of several wavelengths. However, the longer this length per unit of rotation, the more dissipative material is presented to the wave energy. Thus, the larger the expected return wave, the longer the total isolator length should be.

Fig. 4 represents a cross-sectional view of an isolator which is quite similar in construction and mode of operation to the isolator of Fig. 3. In the device of Fig. 4, a central pencil of ferrite 60 is supported within the circular conducting wave guide 61 by a cylinder of dielectric material 62 which may, for example, be polyfoam, a form of aerated polystyrene having a dielectric constant only slightly greater than 1. The wave guide 61 is provided with a pair of elongated, opposed, spiral slots 63

and 64 which, together with the hollow cylinder of lossy material 65, take the place of the resistive vanes 49 and 50 of Fig. 3. The isolator of Fig. 4 is, therefore, substantially the same in construction as the device of Fig. 3 with the exception that the polyfoam cylinder 62, the slots and the lossy material 65 are substituted for the resistive vanes 49 and 50 of Fig. 3. In addition, the spiral slots 63, 64 of Fig. 4 have the same pitch as the vanes 49 and 50 of Fig. 3 but are 90 degrees displaced relative to the points where the resistive vanes of Fig. 3 touch the wave guide.

The slots 63 and 64 are cut completely through the conducting sheath 61; and surrounding the sheath 61 is the jacket 65 of lossy material, which may, for example, be a lamp black loaded thermosetting plastic, and which serves to dissipate wave energy passing through the slots 63 and 64. The wave entering the structure in the direction of low loss transmission has its polarization rotated by the ferrite so that in every cross-section its electric vector will point directly across from one to the other of the two slots. For a wave traveling in the high loss direction of transmission, the polarization is rotated so that at times the electric vector is perpendicular to the line joining the slots in opposite walls. At such points, the attenuation for this wave is a maximum, corresponding to the high loss points along the spiral vane structure of Fig. 3. In order to prevent resonance effects for particular lengths of the slot, it may be desirable in some cases to divide the slot aperture by a plurality of fine conducting wires connecting opposite sides of the slot and spaced less than half a wavelength apart. For completeness, it may be noted that a longitudinal field is applied to the ferrite element 60 by a suitable induction means such as the electromagnet 66 energized by the battery 67.

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 one-way transmission device to be interposed along the path of linearly polarized electromagnetic wave energy, said device comprising means for progressively rotating the polarization of said energy as said energy is propagated along said path, said rotation being anti-reciprocal of the Faraday-effect type, resistive material interposed along said path in a radially extending plane, said plane being normal to the electric polarization of said progressively rotated wave energy for one direction of propagation along said path.

2. In an electromagnetic wave transmission system, a section of electromagnetic wave guide of circular cross-section, an antireciprocal Faraday-effect element for rotating the polarization of wave energy propagated along said guide interposed in said section, said element producing a given rotation per unit length thereof at a given temperature and frequency, and a spiral vane of resistive material disposed in said section, said vane being radial in said guide at every transverse cross-section along its length, said vane having a spiral rotation per unit length equal to said rotation per unit length of said element.

3. In combination, a wave-guide section adapted to support linearly polarized electromagnetic wave energy in a plurality of polarizations, means at each end of said section for coupling a linearly polarized wave to and from said section in a predetermined polarization at each end, means for rotating wave energy propagated from one end of said section to the other from the predetermined polarization in said one end through intermediate polarizations into the predetermined polarization in said other end, and a vane of resistive material commencing in said one end in a plane perpendicular to said polarization in said one end and spiraling into a plane perpendicular

to said polarization in said other end, said vane being substantially perpendicular to intermediate polarizations of said rotated wave for propagation from said one end to said other end, said rotation being antireciprocal whereby said vane is substantially parallel to at least one of said intermediate polarizations of said rotated wave for propagation from said other end to said one end.

4. In combination, a wave guide section adapted to support electromagnetic wave energy in a plurality of polarizations, means at each end of said section for coupling a linearly polarized wave to and from said section in a predetermined polarization at each end, means for rotating wave energy propagated from one end of said section to the other from the predetermined polarization in said one end through intermediate polarizations into the predetermined polarization in said other end, said rotation being antireciprocal, and means for attenuating wave energy components of a selected polarization to a substantially smaller degree than wave energy components perpendicular to said selected polarization, wherein

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said means for attenuating and said means for rotating extend along a common region of said section and wherein said selected polarization is substantially parallel to the polarization of said rotated wave at every point along said region for propagation from said one and to said other end under a given temperature and frequency condition.

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