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2,887,665

HIGH FREQUENCY ISOLATOR

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FIG. 1

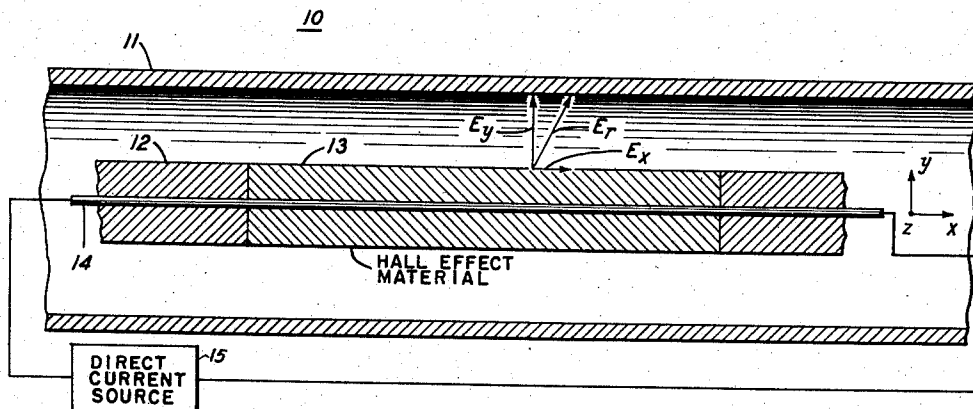


FIG. 2

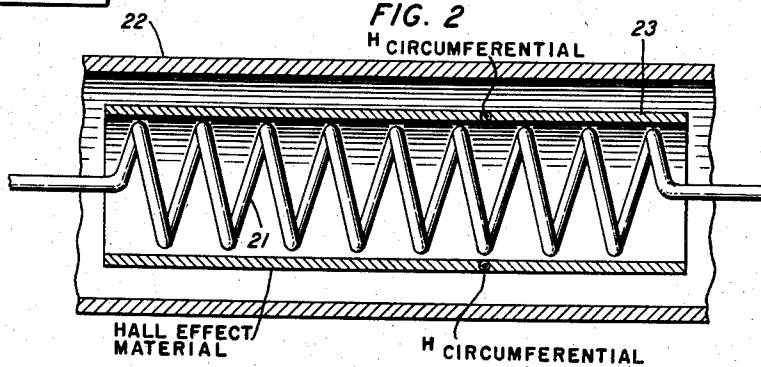
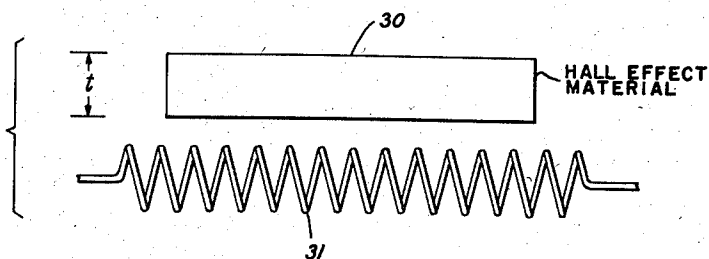


FIG. 3



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HIGH FREQUENCY ISOLATOR

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6 Claims. (Cl. 333—24)

This invention relates to electromagnetic wave transmission devices and more particularly to such devices having nonreciprocal transmission properties.

An object of this invention is to supply a wave energy isolator which is useful at frequencies much below microwave frequencies.

Another object is to provide a coaxial cable type isolator.

A nonreciprocal wave transmission device is one which causes the attenuation or phase shift of a wave propagating through it in a given direction to be different from the attenuation or phase shift of a similar wave propagating in the reverse direction through the device. While numerous examples of such devices are known, one type which can be cited as an example is the microwave polarization rotating device and coupling network shown in United States Patent 2,644,930 to Luhrs et al. The arrangement shown in this patent utilizes the rotation of a polarized electromagnetic wave propagating through a Faraday effect material, such as a ferrite, to obtain nonreciprocal transmission characteristics. However, because of the nature of the Faraday effect materials at present available and the structural requirements of the presently known ways of utilizing them, the range of application of the above mentioned type of isolator is not easily extended to frequencies much below microwave frequencies of the order of 1000 megacycles, nor to structures which can be connected directly in coaxial cable transmission lines. The present invention seeks to supply a device which can be used at frequencies much lower than microwave frequencies and which provides nonreciprocal transmission directly of a coaxial cable mode electromagnetic wave.

The operation or mode of action of the present invention depends upon the Hall effect rotation of an electromagnetic wave as distinguished from the Faraday effect rotation. As a result certain important structural differences exist between the above prior art device and the following illustrative embodiments of this invention. One of these differences is that the steady magnetic biasing field in the former is applied parallel to the axis of wave transmission whereas in the latter it is applied circumferentially thereof. Other important differences will become apparent hereinafter.

The Faraday effect produced by certain magnetic materials is believed to be caused by the gyroscopic precession of spinning electrons in the materials whereas the species of Hall effect utilized in the present invention is caused by the nonreciprocal motion of electrons within a material subject to crossed electric and magnetic fields. For a comprehensive explanation of Faraday effect the reader is referred to an article appearing in the November 1953 issue of the Bell System Technical Journal beginning on page 1333, entitled "Ferrites in Microwave Applications" by J. H. Rowen. However, because of its close connection with the present invention a short explanation of Hall effect will be given here. Briefly, Hall effect is the nonreciprocal change in current flow through

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a material which occurs when a magnetic field not parallel to the current flow is applied to the material. If i represents the current vector, E the electric field vector, and H the magnetic field vector, then the current flowing through a Hall effect material is

$$i = \sigma E + \alpha (E \times H) \quad (1)$$

where σ is the conductivity of the material and α is the Hall constant related to the Hall coefficient R_H as follows: $\alpha = -R_H \sigma^2$. Assuming that the magnetic field is unvarying and aligned along the Z axis, that there is no Z component of electric field E and that E varies sinusoidally, the x and y components of current are

$$i_x = j(\omega \epsilon \pm \alpha H) E_x \quad (2)$$

$$i_y = j(\omega \epsilon \pm \alpha H) E_y \quad (3)$$

where ϵ is the dielectric constant of the material. From these last two equations it can be shown that the difference, Δ loss, between the attenuation of a circularly polarized electric wave rotating in one direction in the xy plane and the attenuation of a similar wave rotating in the opposite direction is proportional to

$$\frac{2\alpha H}{\sigma}$$

Explained in other terms, Equations 2 and 3 show that the effective dielectric constant for one direction of transmission through the Hall effect material is different from the effective dielectric constant for the opposite direction of transmission. Accordingly, the losses in the two directions are different. The fact that there is a difference in loss is used to advantage in the following illustrative embodiments.

In accordance with the present invention in one specific embodiment thereof, indium-antimony, a Hall effect material, is substituted for a portion of a length of the center conductor of a coaxial cable and is magnetized in such a way that the transmission loss of energy propagating in one direction through the cable is substantially different from the loss in the opposite direction. Further details of this and other embodiments of the invention will best be learned, however, from a consideration of the following description given in connection with the drawings of these embodiments.

In the drawings:

Fig. 1 shows a longitudinal cross section of an illustrative embodiment of the invention in which a portion of a coaxial cable has a length of its center conductor made of Hall effect material;

Fig. 2 shows a longitudinal cross section of a second illustrative embodiment in which a length of the center conductor of a coaxial cable is wound as a helix and is surrounded by Hall effect material; and

Fig. 3 shows a side view of another embodiment in which Hall effect material is placed in field coupling relation to a slow wave propagating circuit.

Referring now in detail to the drawings, the illustrative embodiment of the invention shown in Fig. 1 is a coaxial cable type isolator 10. This isolator consists of a coaxial cable 11 in which a length of its inner conductor 12 partially comprises Hall effect material 13. This material may be selected from any of the materials showing Hall effect, but is preferably a eutectic alloy of indium-antimony, a material showing the effect to a high degree, which has a relatively large Hall coefficient R_H and relatively small conductivity σ . The coefficient R_H is defined in chapter 8 of "Electrons and Holes in Semiconductors," by W. Shockley, D. Van Nostrand, 1953. In conjunction with material 13, in order to produce the desired nonreciprocal transmission effect in isolator 10 a magnetic field must be applied at right angles to the plane of rotation of the polarized electric field,

A convenient way of doing so in the instant embodiment is by passing a direct current from schematically shown source 15 through conductor 14 which is aligned with the axis of cable 11. The resulting magnetic field will lie circumferentially around this axis and will permeate material 13. If the plane of the paper upon which the drawings appear is taken as the xy plane with the x coordinate parallel to the axis of cable 11 and the z coordinate into the paper as indicated in Fig. 1, then the resulting electric vectors E_r at the upper and lower longitudinal tangents of the surface of material 13 will be polarized in the xy plane and the magnetic field generated by the current in wire 14 will be perpendicular to the xy plane taken through these tangents. A diagram of the upper resulting electric vector lying in the xy plane is shown in Fig. 1. The components of this vector are E_y which depend upon the voltage difference between the inner and outer conductors of cable 11 and E_x which depend upon the conduction current flowing in material 13. From symmetry it is readily seen that the resulting electric vectors at other points around the circumference of material 13 are also perpendicular to the circular magnetic field. For a wave propagating from left to right through isolator 10, circularly polarized electric vectors E_r will rotate in one direction while for a wave propagating from right to left, they will rotate in the opposite direction. Accordingly, the difference between the transmission losses in the two directions will be proportional to

$$\frac{2\alpha H}{\sigma}$$

It should be understood in this regard that the total difference in loss depends upon factors including the kind of Hall effect material used, the length and amount of this material and the strength of the current flowing through wire 14. Any or all of these factors may be chosen to produce the loss desired.

Fig. 2 shows a modification of the isolator of Fig. 1. Here a length 21 of the inner conductor of coaxial cable 22 is wound as a helix and has surrounding it Hall effect material 23 which should preferably be a eutectic alloy of indium-antimony. Winding the inner conductor for part of its length into a helix increases the axial component of the electric field and thereby enhances the non-reciprocal transmission property of the isolator but at the same time this causes an undesirable impedance mismatch not present in the structure of Fig. 1. A circumferential magnetic field permeating material 23 may be applied by any convenient means such as a current carrying wire similar to wire 14 in Fig. 1. The principle of operation of the embodiment of Fig. 2 is substantially the same as that of isolator 10.

Fig. 3 is another illustrative embodiment of the invention wherein Hall effect material 30, which may be the same kind as material 13 disclosed above with respect to Fig. 1, is positioned in close proximity to a wave propagating helix 31. A magnetic field aligned so that the vector product $E \times H$ in Equation 1 is non-zero should be applied throughout the active volume of material 30. The thickness t and the length and width of this material are not critical and may be chosen according to the amount of directivity in transmission that is desired. Thickness t , however, should usually be at least as thick as the skin depth of penetration of electromagnetic waves into material 30 at the frequency of operation. Material 30 should be placed as close as convenient to the surface of helix 31 but this spacing is likewise not critical. The principle of operation of this arrangement is substantially the same as that of isolator 10. In general, in the embodiment of Fig. 3, any slow wave circuit, such as those disclosed in United States Patent 2,659,817 to C. C. Cutler, which generates a strong axial component

of electric field may be used in place of helix 31. The configuration of material 30 may be modified accordingly.

The above embodiments are presented in illustration and not in limitation of the invention. Various changes and modifications in these embodiments will occur to those skilled in the art and these changes and modifications may be made without departing from the spirit or scope of the invention as set forth. It should be noted in this connection that nonreciprocal transmission can be obtained with Hall effect material by the electric field displacement method in a way similar to that outlined in the copending application of S. E. Miller, Serial No. 362,193, filed June 17, 1953.

What is claimed is:

1. In combination, a coaxial cable having an inner and an outer conductor which are conductively separate, Hall effect material positioned within the path of wave energy guided by said cable symmetrically with respect to each of two normal planes passing through the center of both of said conductors, and means for establishing a circular magnetic biasing field coaxial with the conductors of said cable and permeating said Hall effect material.

2. The combination of elements as in claim 1 in which a length of said inner conductor partially comprises said Hall effect material.

3. The combination of elements as in claim 1 in which a length of said inner conductor is wound as a helix and said Hall effect material is positioned symmetrically with respect to said helix.

4. The combination of elements as in claim 1 in which said Hall effect material is a eutectic alloy of indium-antimony.

5. Nonreciprocal electromagnetic wave energy transmission means including in combination, a source of electromagnetic wave energy characterized by solely transverse electric field components, dual conductor coaxial wave guiding means adapted to support said wave energy connected thereto, and a polarized element of Hall effect material longitudinally extending within said means and having a transverse extent sufficient to coact with a substantial number of said transverse components whereby said components are modified and appear to rotate in longitudinal planes within said material, said rotation being opposite in sense for opposite directions of propagation of wave energy through said means, said polarization being effected by magnetic biasing means producing a constant field normal at all points to said longitudinal planes containing said rotating electric field vectors.

6. A nonreciprocal electromagnetic wave energy component comprising a conductive member having an axis, at least one conductive boundary coaxial with and electrically insulated from said conductive member, a cylinder of Hall effect material surrounding the conductive member of said component and extending in the direction of propagation of wave energy therethrough, and means for establishing lines of constant magnetic intensity which permeate said element and extend in an encircling fashion about said conducting member.

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