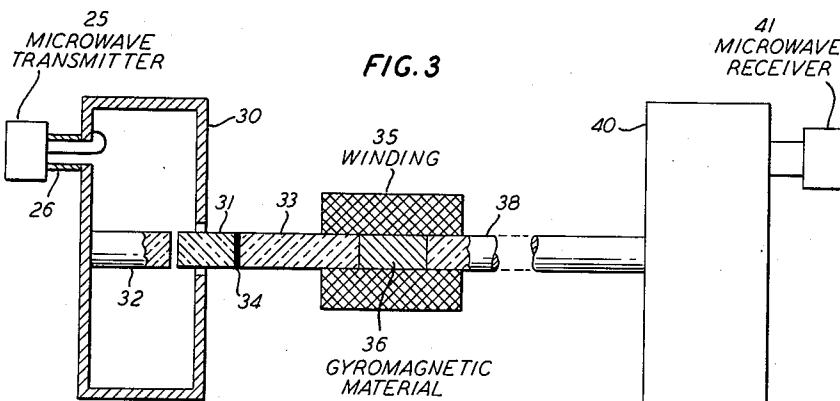
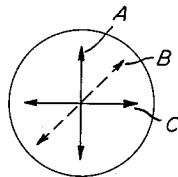
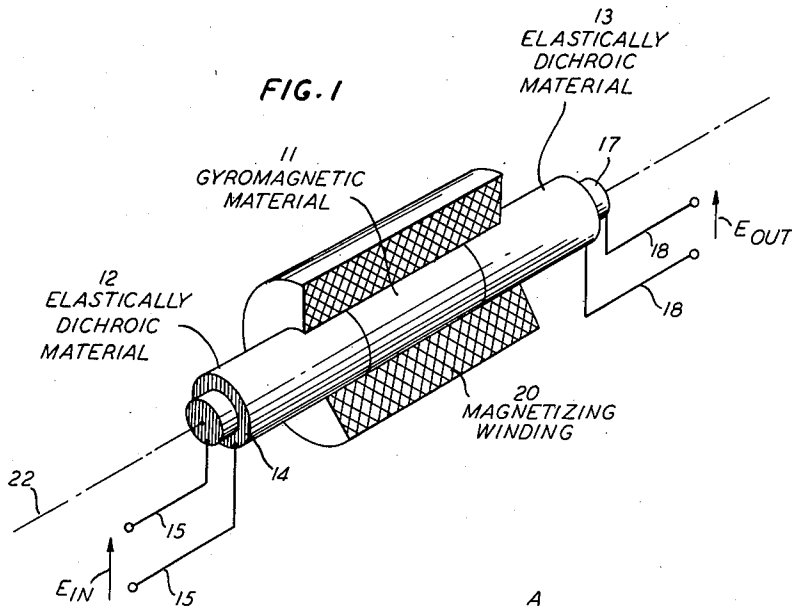


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ISOLATOR HAVING MAGNETICALLY CONTROLLED ACOUSTOGYRIC
MATERIAL COUPLING ELASTICALLY DICHROIC INPUT
AND OUTPUT POLARIZING ELEMENTS
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ISOLATOR HAVING MAGNETICALLY CONTROLLED ACOUSTOGYRIC MATERIAL COUPLING ELASTICALLY DICHROIC INPUT AND OUTPUT POLARIZING ELEMENTS

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The present invention relates to acoustical systems and more particularly to ultrasonic systems wherein operations are performed by utilizing the polarity of the transmitted acoustic wave.

It has been the time-honored practice in the communication sciences to convert sound into electrical energy so that the information in human speech might be more easily handled. Unlike electrical signals, acoustical waves could not be conveniently amplified, switched, or rapidly transmitted from place to place. Information handling systems used sound waves only in certain specialized applications, such as ultrasonic delay lines where the acoustic wave's slower velocity of propagation becomes an advantage.

Recent advances in ultrasonic device technology, however, suggest that complete acoustical systems operating at microwave frequencies might be constructed. Acoustical waveguides which, in many respects, are similar to their microwave counterparts have provided a method of transmitting acoustic waves over relatively long paths with little distortion. The application of these guided wave principles to delay lines is discussed in articles by Messrs. May, Meitzler and Meeker in volume UE-7, pages 35 to 58, IRE Transactions on Ultrasonics Engineering. High efficiency transducers capable of converting electrical oscillations into mechanical vibrations at microwave frequencies have also been developed. Notable among these new solid-state devices is the "depletion-layer" transducer described in U.S. application Serial No. 64,808, filed October 25, 1960, by Mr. D. L. White. A traveling wave amplifier of acoustic waves is described by Messrs. Hutson, McFee and White in the publication Physical Review Letters 7, page 237 (1961). Still other recent advances, such as magnetostrictive transducers, acoustical masers, and ultrasonic light modulators, still further indicate the great potential of acoustical systems.

Nearly any operation which may be performed by typical microwave devices may also be performed by an analogous acoustical device. It is possible, for instance, that a microwave system could be arranged to accept propagated electromagnetic energy, convert it into acoustical energy, modulate, detect, switch or amplify this acoustical energy as desired and then reconvert it into electromagnetic energy for retransmission. The obvious advantage to such an arrangement is its small size. Because of the much slower velocity of propagation of sonic energy, wavelengths are smaller. Devices which are necessarily large when electromagnetic signals are employed may be greatly reduced in size through the use of ultrasonics.

Normally, solids may sustain three types of elastic wave motion—(1) longitudinal (compressional), (2) surface (Rayleigh) and (3) transverse (shear). It is with the latter class of waves that the present invention is concerned. With transverse or shear waves the particles within the solid vibrate along paths perpendicular to the direction of propagation—and these vibrations may be "polarized."

One object of the present invention is to utilize the polarity of transverse elastic waves to provide a family of new and useful devices.

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A further object of the invention is to provide a non-reciprocal acoustic transmission channel.

A still further object of the present invention is to provide an acoustical isolator.

Still another object of the invention is the suppression of unwanted reflections within an acoustical delay line.

In a principal aspect, the invention takes the form of an acoustical isolator which allows the transmission of ultrasonic waves with less attenuation in one direction than in the opposite direction. According to the invention, polarized transverse waves are launched through a polarization dependent absorber into an elongated gyromagnetic, acoustical transmission channel.

One feature of the invention resides in the use of an elastically dichroic material as the polarization selective absorber.

According to another feature of the invention, the gyromagnetic material is subject to a magnetic field parallel to the longitudinal axis of the gyromagnetic crystal such that the polarity of the transverse wave is rotated by a predetermined angle, the direction of rotation being the same regardless of the direction in which the wave is traveling.

Still another feature of the present invention resides in its unique applicability in the suppression of unwanted "third-time-through" reflections commonly found in acoustical delay lines.

These and other features, objects and advantages of the present invention will become more apparent following a consideration of the following detailed description and drawings of specific embodiments of the invention. In the drawings:

FIG. 1 illustrates an acoustical isolator which employs features of the present invention;

FIG. 2 shows the nature of the polarity rotation achieved; and

FIG. 3 illustrates an acoustical delay line which utilizes the present invention to suppress unwanted reflections.

FIG. 1 of the drawings illustrates a first embodiment of the principles of the present invention. The arrangement shown in the figure is an "isolator"—so named because it can be used to isolate one transmission element from reflections arising from succeeding elements. The isolator comprises a cylinder of gyromagnetic material flanked on one side by a first polarization selective absorber 12 and on the other side by a second polarization selective absorber 13. A disc-shaped transducer 14 is affixed to the end of the absorber 12. The transducer 14 is provided with a pair of electrically conductive terminal platings to which are fastened the electrical input conductors 15. A similar output arrangement comprising a second disc-shaped transducer 17 and conductors 18 is affixed to the free end of the absorber 13. A magnetizing winding 20 is wound over the gyromagnetic cylinder such that an electromagnetic field is applied parallel to the longitudinal axis 22 of the isolator.

The transducer 14 is used to convert electrical oscillations which are applied across conductors 15 into mechanical vibrations. One of the circular faces of the transducer 14 is joined to the dichroic material 12 by a metallic bond and the other face is coated with a metallic plating. Whenever an electrical potential is applied across the conductors 15, an electric field parallel with the longitudinal axis of the isolator is set up across the transducer crystal 14. The transducer 14 may conveniently comprise an "AC cut" quartz crystal which, when subjected to an oscillatory electric field in the manner shown, will launch polarized transverse or "shear" waves into the absorber 12. With this form of transducer, the mechanical waves launched into the absorber

will have a polarity or direction of vibration which is parallel to the 1 0 0 axis or "pole direction" of the crystal 14. Other types of transducers might well be employed, of course, providing they generate the appropriate transverse waves rather than compressional waves. A detailed exposition of the characteristics of various forms of transducers and crystalline materials is contained in Mr. W. P. Mason's treatise, *Piezoelectric Crystals and Their Application to Ultrasonics*, D. Van Nostrand, Inc., 1950.

The absorber 12 is oriented such that it passes the polarized waves from the transducer 14 with minimum attenuation. Absorber 12 may be composed of any suitable material which exhibits elastically dichroic properties; that is, which supports and transmits transverse crystal lattice vibrations of one polarity more readily than vibrations of another polarity. A piezoelectric semiconductor, such as cadmium sulfide, is capable of providing the desired polarity dependent absorption. When used as the absorber 12 in the present invention, the CdS crystal is oriented such that the acoustical waves are propagated along a path perpendicular the hexagonal axis of the crystal. Under these conditions, those crystal lattice vibrations within the absorber 12 which are along the hexagonal axis are suppressed while those shear waves for which the displacement is perpendicular the hexagonal axis are unaffected. Thus the hexagonal axis of the CdS absorber 12, being the axis of maximum absorption, is placed perpendicular to the pole direction of the crystal transducer 14. A detailed exposition of the properties of piezoelectric semiconductors is given by Messrs. A. R. Hutson and D. L. White in an article entitled "Elastic Wave Propagation in Piezoelectric Semiconductors" which appeared in vol. 33 of the *Journal of Applied Physics*, pages 40-47, January 1962.

A similar configuration comprising the dichroic material 13 and output transducer 17 is attached to the other end of the gyromagnetic material 11. The absorber 13 and transducer 17 are oriented relative to one another so that the axis of minimum attenuation of the former is parallel with the pole direction axis of the latter. The pole direction axis of transducers 14 and 17 are at an angle to one another which is equal to the angle of polarity rotation experienced by waves as they pass through the gyromagnetic material 11.

The vertically polarized waves from transducer 14 enter the gyromagnetic cylinder 11 from the absorber 12. In this embodiment of the invention the gyromagnetic material comprises an yttrium-iron-garnet crystal whose crystal axis of circular symmetry is parallel to the longitudinal axis 22 of the cylinder. The forces of the magnetic field applied by magnetizing winding 20 and the forces of the acoustical vibrations interact causing the atoms within the crystal to vibrate at an angle to their original direction, though still in a plane perpendicular to the direction of wave travel. The amount of rotation depends upon several factors, among them the strength of the applied field. For yttrium-iron-garnet, a field strength on the order of 1,000 oersteds is appropriate. This "acoustrogyric" effect was predicted by Mr. C. Kittel in an article entitled "Interaction of Spin Waves and Ultrasonic Waves in Ferromagnetic Crystals," which appeared in volume 110, No. 4, *Physical Review*, May 1958. The effect was observed experimentally for the first time by applicant and Mr. R. C. LeCraw in an experiment described in the *Physical Review Letters*, vol. 8, pages 397-399, May 15, 1962.

The rotation of the polarity is nonreciprocal; that is, if the polarity of the acoustic waves were rotated in a clockwise sense (as viewed from the transmitting end) while traveling in a first direction through the crystal, the polarity would continue to be rotated in a clockwise direction (again as viewed from the transmitting end) upon being reflected back through the crystal. FIG. 2 of the drawings is included to illustrate this rotation. If

the wave had the vertical polarity A upon entering the gyromagnetic material, the polarity of the vibrations would be rotated to a new orientation B upon making a single pass through the material. If it were reflected back through the material it would be rotated still more to the new angle C. In FIG. 2 the amount of rotation for each pass through the crystal is shown to be 45°.

The isolator pictured in FIG. 1 allows signals to flow in one direction only. The input transducer 14 generates vertically polarized transverse waves. These waves pass through the elastically dichroic material 12 with little attenuation since the material is oriented with its axis of minimum absorption also vertical. In passing through the rotator 11 the polarity of the wave is rotated 45° to the new polarization B as shown in FIG. 2. Transducer 17 is oriented to be readily responsive to waves of polarization B and accordingly delivers an electrical output signal to conductors 18. If an input signal were applied instead to terminals 18, transducer 17 would launch acoustic waves of polarity B into the polarity dependent absorber 13. These waves would be rotated to polarity C while passing through the gyromagnetic material 11. Since the waves traveling in this direction are polarized along the axis of maximum attenuation of the acoustically dichroic material 12, the signal is almost completely absorbed. Still further suppression of the signal's amplitude results from the nature of the transducer 14 which does not readily respond to horizontally polarized waves.

FIG. 3 illustrates the manner in which the principles of the present invention may be used to suppress unwanted reflections in acoustical delay lines. The delay line shown in FIG. 3 operates at microwave frequencies. A microwave transmitter 25 passes the high frequency electrical signal through coaxial line 26 to energize coupling loop 27. The coupling loop protrudes into a re-entrant cavity 30. The cavity 30 possesses an aperture into which a polarized piezoelectric bar 31 is inserted.

The resonant cavity 30 is also provided with a tuning stub 32 to concentrate the electrical lines of force about the end of the piezoelectric bar 31. The cavity type transducer is described in more detail in U.S. Patent 3,037,174 which issued on May 29, 1962, to Messrs. H. E. Bommel and K. Dransfeld. Further design considerations of these microwave frequency transducers are disclosed in the article entitled "Excitation of Very-High-Frequency Sound in Quartz" by H. E. Bommel and K. Dransfeld which appeared in vol. 1, pages 234-236, *Physical Review Letters* (1958). The piezoelectric bar is joined by means of the bond 34 to a polarity dependent absorber 33 which comprises an elastically dichroic material. A silicon compound may be used to form such a bond. The rotator comprises magnetizing winding 35 and gyromagnetic material 36 bonded to the absorber 33. Sound waves passing through the rotator then enter the long delay channel 38. The delay channel 38 may conveniently be made of an oriented AC-cut quartz crystal rod whose piezoelectric properties may be utilized in the transducer 40. The receiving transducer 40, though not shown in detail, is like the transmitting transducer, the rod 38 projecting into a resonant cavity. A utilization circuit for microwave energy, receiver 41, is connected to transducer 40.

Both the electrical and acoustical input and output impedances must be perfectly matched within the delay line to prevent unwanted reflections. This is seldom possible in practice and undesirable reflections occur. Particularly objectionable are the so-called "third-time-through" reflections which arise when part of the acoustical signal reflects off the receiving end, travels back to the transmitting end, is again reflected, and then passes through the delay line for the third time to appear at the output as a spurious signal. The present invention provides means of suppressing such unwanted reflections. Electrical oscillations are converted into microwave frequency acoustic waves by the transmitting transducer. These acoustic waves are then transmitted through the

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quartz rod 31 and through the absorber 33 with polarity A (as shown in FIG. 2). As the waves pass through the rotator, the polarity of the lattice vibrations in the gyromagnetic crystal 36 are rotated by 45°. The acoustic waves are then delayed the desired amount by passing through the longer delay section 38 and, for the most part, are converted back into the original, though delayed, electrical signal by transducer 40. Some portion of the acoustical energy will be reflected from the receiving end transducer, however, and will pass back down the delay section the second time. The polarity of this unwanted reflection will be rotated to polarity C, and the absorber 33 will prevent its passage. Thus, the unwanted signal never reappears at the output as a false signal.

Numerous other arrangements and modifications of the device hereinbefore disclosed employing the principles of the invention can be readily devised by those skilled in the art without departing from the true spirit and scope of the invention.

What is claimed is:

1. In combination, a first elongated crystal having elastically dichroic properties, a source of electrical oscillations, means for converting said oscillations into mechanical vibratory energy in the form of transverse waves of a first polarity and for launching said energy into said first crystal, said first crystal being oriented such that said energy passes therethrough with substantially minimum attenuation, a nonreciprocal rotator for rotating the polarity of said energy from said first polarity to a second polarity, and utilization means responsive to waves of said second polarity positioned to receive energy from said rotator.

2. An acoustic wave transmission system comprising, in combination, an elongated, gyromagnetic, acoustical transmission channel, an elastically dichroic material coupled to one end of said channel, means for launching transverse polarized acoustic waves through said dichroic material into said channel, and means for applying a magnetic field parallel to the longitudinal axis of said channel such that the polarity of said waves is rotated by substantially 45° while said waves pass through said channel.

3. An acoustic system comprising a source of transverse polarized waves, an elastically dichroic material coupled to said source, and means coupled to said crystal for rotating the polarity of said transverse waves by sub-

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stantially 45° in a predetermined direction, said rotating means comprising a gyromagnetic crystal subjected to a magnetic field directed along the longitudinal axis of said crystal.

4. An acoustic system as set forth in claim 3 above wherein said gyromagnetic crystal is a crystal essentially composed of yttrium-iron-garnet whose crystal axis of circular symmetry is parallel to the direction of wave propagation.

5. In combination, a source of kilomegacycle microwave frequency electrical energy, a transducer for converting this energy into transverse polarized acoustical waves of the same frequency for launching said acoustical waves into an elastically dichroic material oriented such that said polarized waves are passed with minimum attenuation, an elongated gyromagnetic material coupled to said dichroic material, means for applying a magnetic field parallel to the longitudinal axis of said gyromagnetic material to cause the polarity of waves propagated through said material to be rotated by an angle of approximately 45°, and means coupled to said gyromagnetic material for reconverting said acoustical energy into electrical energy.

6. An arrangement as set forth in claim 5 wherein said gyromagnetic material comprises an elongated crystal substantially composed of yttrium-iron-garnet whose crystal axis of circular symmetry is parallel with the direction of propagation of said waves.

7. The combination in an acoustic delay line of a delay medium, signal input and output means, and means interposed between said input means and said delay medium for suppressing signals reflected from said output means which comprises, in combination, an elastically dichroic material coupled to said input means for passing acoustical signals with a given polarity while suppressing signals having a polarity perpendicular to said given polarity, and means coupled between said dichroic material and said delay medium for rotating the polarity of waves propagated therethrough by an angle substantially equal to 45°.

8. A combination as set forth in claim 7 wherein said means for rotating the polarity of propagated waves comprises an elongated gyromagnetic crystal subjected to a magnetic field parallel to the direction of wave propagation.

No references cited.