May 10, 1966 J. E. MAY, JR., ETAL 3,251,026

ACOUSTICAL SYSTEM

Filed April 12, 1963 2 Sheets-Sheet 1

FIG. 1

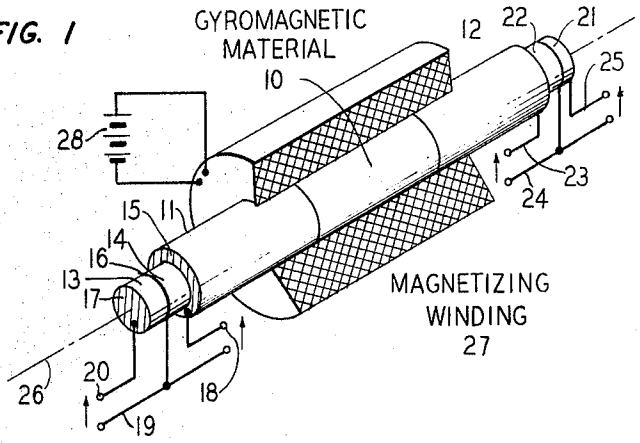


FIG. 2

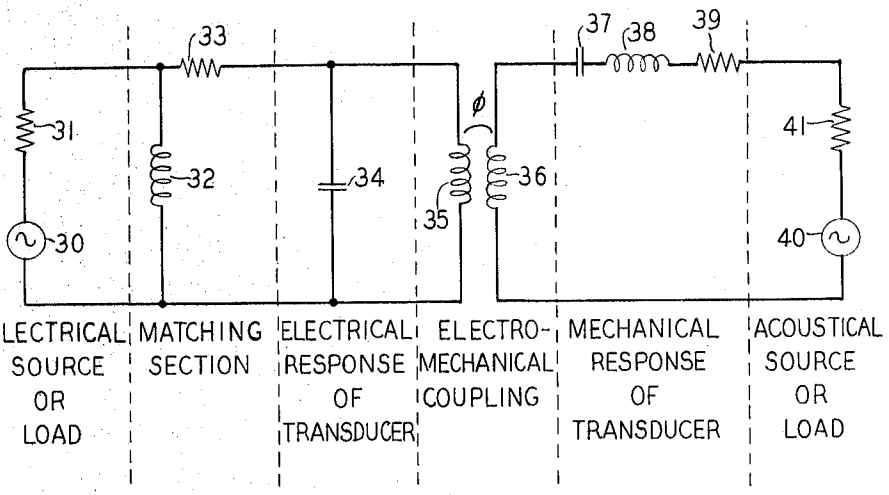


FIG. 3

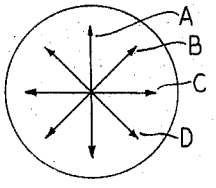
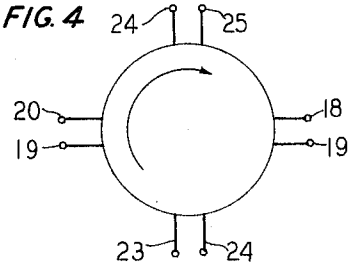


FIG. 4



INVENTORS J. E. MAY, JR.
J. H. ROWEN

BY Reg M. Porter Jr.

ATTORNEY

ACOUSTICAL SYSTEM

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FIG. 5

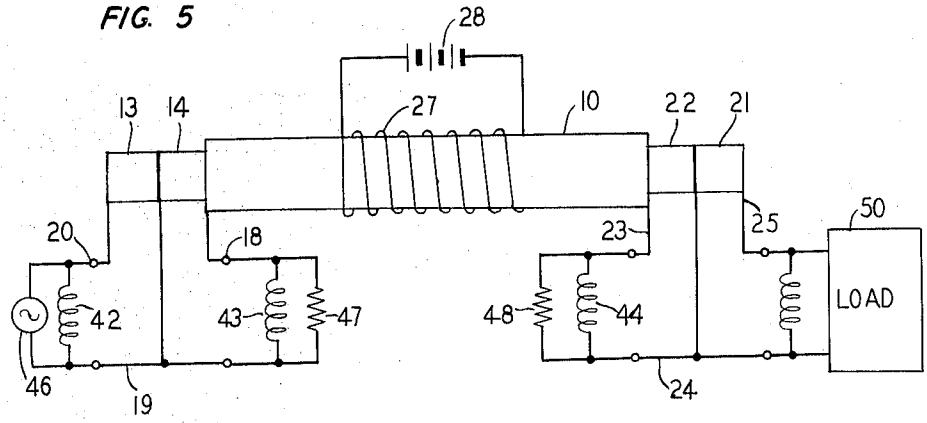


FIG. 6

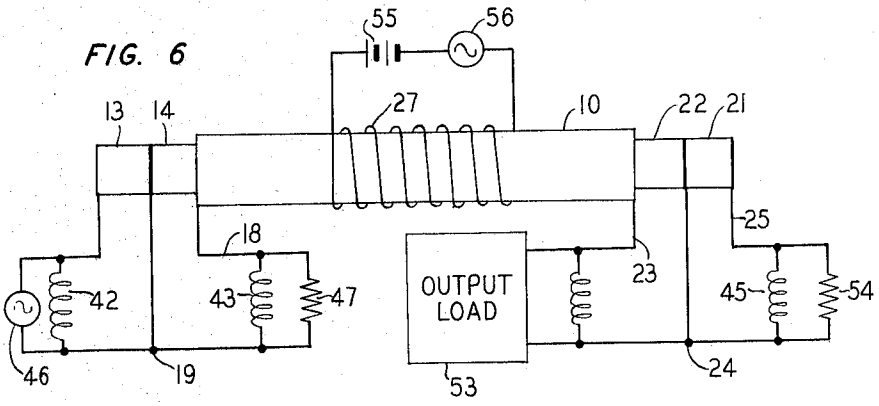
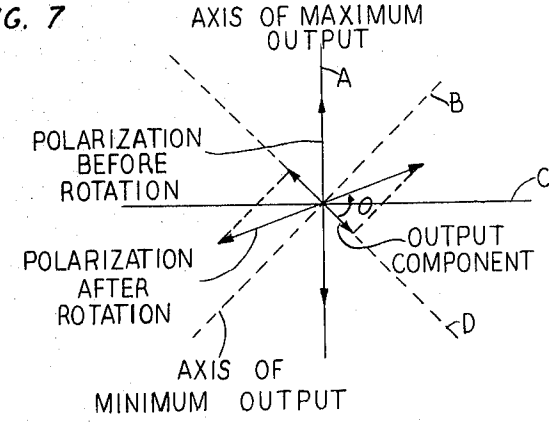


FIG. 7



United States Patent Office 3,251,026 Patented May 10, 1966

3,251,026

ACOUSTICAL SYSTEM

John E. May, Jr., Whippany, and John H. Rowen, Florham Park, N.J., assignors to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

Filed Apr. 12, 1963, Ser. No. 272,798
10 Claims. (Cl. 340—15)

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

In the past, electronic systems have employed acoustical wave propagation through solids and liquids only in certain specialized applications, such as in ultrasonic delay lines where the slower velocity of propagation of sound waves is a useful characteristic. Recent advances in ultrasonic device technology, however, have yielded a wide variety of new and useful acoustic arrangements. Acoustcal 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 frequencies extending up into the microwave frequency ranges have also been developed. The intensity of acoustic signals may be increased by means of a novel, solid state, acoustical traveling wave amplifier which is described by Messrs, Hutson, McFee and White in the publication Physical Review Letters 7, pp. 237 (1961). An ultrasonic wave detector is described in U.S. application Serial No. 199,178, filed May 31, 1962 by D. L. White. Other recent developments, such as magneto-restrictive transducers, acoustcal masers, and ultrasonic light modulators, still further indicate the great potential of acoustical systems.

These advances in acoustic technology suggest that complete ultrasonic information handling systems might be constructed which operate at frequencies of tens of megacycles up into the microwave range. It is possible, for instance, that a microwave system could be arranged to accept propagated electromagnetic energy, convert these high frequency radio signals into acoustical energy, and then modulate, detect, switch or amplify this acoustical energy as desired. Following these operations, the resulting ultrasonic signals could be converted 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, "unbounded" solids may sustain two types of elastic wave motion; (1) longitudinal (compressional) and (2) transverse (shear). It is with the latter class of waves that the present invention is concerned. With transverse waves, the particles within the solid vibrate along paths perpendicular to the direction of propagation—and these vibrations are "polarized."

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

A further object of the invention is to effect the polarization discriminative generation, absorption, and detection of acoustical waves.

In a principal aspect, the present invention takes the form of acoustical transmission apparatus which, depending upon the nature of the external circuit connections, may be used as an acoustical isolator, modulator, or circulator.

According to the invention, polarized, elastic shear waves are transmitted through an acoustical transmission channel wherein the polarization of the waves is rotated in a nonreciprocal sense with respect to the two possible directions of travel. One feature of the invention resides in the use of a pair of piezoelectric transducers acoustically coupled to one end of the channel, the two transducers generating and being responsive to acoustical vibrations of different polarizations.

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

FIG. 1 is a cross-sectional representation of an embodiment of the invention;

FIG. 2 shows an electrical equivalent circuit for the transducers employed in the present invention;

FIG. 3 illustrates the relative orientation of the transducers employed in the invention as well as the nature of polarization rotation experienced by the acoustical waves as they pass through the nonreciprocal rotator;

FIG. 4 is a simple schematic diagram which illustrates the manner in which the embodiment of FIG. 1 may be used as a circulator;

FIG. 5 shows the use of the embodiment of FIG. 1 as an isolator;

FIG. 6 illustrates the manner in which the invention may be used as a modulator; and

FIG. 7 depicts the manner in which modulation is achieved by the arrangement shown in FIG. 6.

The embodiment of the invention pictured in FIG. 1 of the drawings comprises an acoustical transmission channel which includes a cylinder of gyromagnetic material **10**. The cylinder **10** is sandwiched between a pair of quartz rods **11** and **12**, each being coupled to the cylinder by an appropriate acoustical bonding material such as a silicon compound or a metallic layer. A pair of transducers is affixed to the free end of the quartz rod **11**. Each transducer comprises a disc-shaped block of piezoelectric material flanked on each side by a conductive plating. The piezoelectric material **14** is bonded to the rod **11** by a metalllic plating **15** and the piezoelectric disc **13** in turn is fastened to the disc **14** by a second metallic plating **16**. The unattached circular face of the piezoelectric disc **13** is similarly plated with an electrically conductive metallic coating **17**. Electrical output conductors **18**, **19** and **20** are connected to the metallic platings **15**, **16** and **17**, respectively. A similar input-output arrangement, comprising the discs of piezoelectric material **21** and **22** and the electrical conductors **23**, **24** and **25**, is affixed to the free end of the quartz rod **12**.

As may be seen, each of the piezoelectric discs **13**, **14**, **21** and **22** is flanked on both sides by a metallic plating to which is attached an electrical conduuctor. Whenever an electrical potential is applied across the connected conductors, an electrical field parallel with the longitudinal axis **26** is set up across the piezoelectric disc causing shear stress in the disc.

Each of these piezoelectric discs is oriented such that, when subjected to a high frequency oscillatory electric field, polarized shear waves are launched into the attached quartz rod. The appropriate orientation of the piezoelectric material depends upon the particular characteristics of the material used. In the case of quartz, any "Y-cut" crystal will generate shear waves. Among

these, the "AC" rotated Y-cut is preferred due to its superior freedom from coupling to other modes of acoustical vibration. With the rotated Y-cut quartz crystal transducer, the mechanical waves launched into the acoustic path will have a particle displacement which is parallel to the X-axis of the crystal. A detailed exposition of the characteristics of various forms of suitable piezoelectric materials is contained in W. P. Mason's treatise, Piezoelectric Crystals and Their Application to Ultrasonics, D. Van Nostrand, Inc., (1950).

When it is desired to operate an embodiment of the present invention at an especially high frequency, some difficulty will be experienced with the conventional transducers discussed above. These transducers work most efficiently when their thickness is approximately equal to a half-wavelength of sound. Hence, at very high frequencies they must be extremely thin. For instance, the velocity of sound in Y-cut quartz is 3.2×10^5 cm./sec. At 200 mc./sec. the required disc would be only 0.008 mm. thick and very difficult to fabricate and handle. Although it is possible to operate these standard transducers at overtone frequencies (with reduced efficiency), a better solution is to be found in the recently developed "resistive layer" transducers. Several high-frequency transducers of this class have been invented by D. L. White. These include the "depletion layer" transducer described in U.S. application Serial No. 64,808, filed October 25, 1960, now Patent No. 3,185,935; the epitaxial transducer disclosed in U.S. application Serial No. 147, 282, filed October 21, 1962, now Patent No. 3,155,781; and the "diffusion layer" transducer described in U.S. application Serial No. 208,185, filed July 3, 1962. The principal advantage of these new transducers is that the piezaelectrically active region, whether it be a depletion layer, an epitaxially grown layer, or a diffusion layer, can be made very thin, less than a micron. At the same time, the crystal on which the layer is formed is thick enough to be easily handled. The resistive layer transducers achieve electromechanical energy conversion in the same manner as the more conventional transducers and the same considerations in selecting and orienting the piezoelectric material apply.

The transducers employed in the present invention are not only capable of generating shear waves of a selected polarization, they are also polarization selective detectors. That is, each of these transducers is responsive to only those components of the acoustical vibration which are parallel to a given axis. For example, with a rotated Y-cut quartz transducer, only those vibrational components which are parallel to the X-axis of the quartz crystal cause electrical oscillations to appear at the connected conductors. In contrast, those elastic vibration components which are perpendicular to the X-axis of the crystal are not transformed into electrical energy. That is to say, the transducers themselves are reciprocal devices.

Since the transducers employed in the present invention are used in conjunction with a connected electrical circuit, it will be helpful to describe their behavior by means of an equivalent electrical circuit. Such an electrical analog is shown in simplified form in FIG. 2 of the drawings. The circuit includes a source of electrical oscillations **30** connected in series with a source impedance **31**. A matching inductor **32** is connected in parallel with the source **30** and source impedance **31**.

A resistance **33** which represents electrical heating losses is connected in series with a capacitor **34**, this series combination being in parallel with the matching inductor **32**. The capacitor **34** represents the ordinary capacitance between the metal platings which flank the piezoelectric crystal. This capacitance, which is termed the "clamped capacitance," would exist even if the material were not piezoelectric. A transformer having windings **35** and **36** is included in the electrical circuit to represent the

coupling between the electrical and mechanical forms of energy. The winding **35** is connected in parallel with the clamped capacitance **34**. Winding **36** is connected in series with capacitor **37**, inductance **38** and resistance **39**. The series tuned circuit formed by the capacitor **37** and inductance **38** represents the mechanical resonance of the transducer while resistance **39** represents the mechanical losses. The source **40** and resistance **41** are also connected in series with the winding **36** and the series circuit which forms the electrical analog of the mechanical response for the transducer.

As is well known in circuit theory, the maximum power is transmitted to a load when the impedance of the load is the complex conjugate of the source impedance. Accordingly, a matching section is included between the transducer and the electrical source or load. The parallel inductance **32** anti-resonates the capacitance **34** of the transducer while the load resistance and the source resistance are selected to be of an appropriate value such that they are matched through the coupling transformer.

It is important to note that the coefficient of coupling, φ, is dependent upon the polarization of the acoustical waves. That is:

$$\varphi=\varphi_{\max.}\cos\alpha$$

where $\varphi_{\max.}$ is the coefficient of coupling which exists when the vibrations are parallel to axis of maximum response, and where α is the angle the vibrations make with the axis of maximum response.

By means of the equivalent circuit for the transducer shown in FIG. 2 of the drawings, it may be noted that if the acoustical source **40** is generating waves which are of the appropriate polarity to cause maximum coupling between windings **36** and **35**, then a maximum electrical signal is delivered to the electrical load **31**. Similarly, if the source **30** delivers an electrical signal to the transducer, then an acoustical signal is delivered to the acoustical load **41**, this signal being comprised of elastic shear waves which are polarized parallel with the axis of maximum transducer response. If the source **40** generates an acoustical wave having a polarization perpendicular to the axis of maximum response, the coupling coefficient φ is zero, and no electrical signal is delivered to the load **31**. This polarization selective feature of the transducer is used in the present invention to provide the new and useful results to be described below.

Each of the four transducer crystals **13**, **14**, **21** and **22** shown in FIG. 1 of the drawings has its axis of maximum response or displacement polarization oriented in a particular manner relative to the other transducers. FIG. 3 of the drawings illustrates this relative orientation. If the crystal **13** is taken as a reference and has a vertical displacement polarization A, then the transducer crystal **14** is arranged to have a horizontal displacement polarization C. The two transducer crystals **21** and **22** are also polarized perpendicular to one another, the displacement polarization of transducer **21** being oriented parallel to the vector B as shown in FIG. 3 and the displacement polarization of transducer crystal **22** being parallel to the vector D.

Excepting the case where the embodiment shown is used as a modulator, the displacement polarization of transducers **13** and **21** are at an angle to one another which is equal to the angle of polarization rotation experienced by the acoustical waves as they pass through the gyromagnetic material **10**. As will be more clearly understood after considering the description to follow, this angle preferably equals 45° in several useful cases.

In this embodiment of the invention, the gyromagnetic material preferably comprises an yttrium-iron-garnet crystal whose crystal axis of circular symmetry is parallel to the longitudinal axis **26** of the cylinder. An electrical current from source **28** flows through magnetizing winding **27** to create a magnetic field parallel to the longi-

tudinal axis **26**. The magnetic moment of the yttrium-iron-garnet crystal which is substantially aligned with the magnetic field applied by magnetizing winding **27** and the acoustical vibrations interact causing the displacement of the elastic wave within the yttrium-iron-garnet crystal **10** to rotate at an angle to the original displacement 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. The amount of rotation may thus be varied by adjusting the magnitude of current from source **28**. For yttrium-iron-garnet, a field strength of the order of 1000 oersteds is appropriate for achieving the approximate desired rotation at a frequency of 500 mc. This "acoustogyric 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 Messrs. H. Matthews and R. C. LeCraw in an experiment described in the Physical Review Letters, volume 8, pp. 397–399, May 1962.

The rotation of the acoustic wave polarization while passing through the gyromagnetic material is nonreciprocal; that is, if the polarization of the acoustic waves were rotated in a clockwise sense (as viewed from the transmitting end) while traveling in a first direction through the gyromagnetic material **10**, the polarization would continue to be rotated in a clockwise direction (again as viewed from the transmitting end) if the wave were reflected back through the material. FIG. 3 of the drawings may be noted to illustrate this rotation. If a high-frequency electrical potential is applied across conductors **19** and **20**, transverse vibrations having the displacement polarization A as shown in FIG. 3, are propagated down the quartz rod **11** and into the gyromagnetic material **10**. As these waves pass through the gyromagnetic material **10**, their direction of vibration rotated in a clockwise direction to assume the displacement polarization B. These vibrations, which are manifested in the quartz rod **12** as particle displacements along a path parallel to the vector B in FIG. 3, pass through the transducer crystal **22** (which is unresponsive to vibrations of this polarization due to its orientation) and enter the crystal **21**, inducing an electrical potential across conductors **24** and **25**. If, on the other hand, high-frequency electrical energy is applied across conductors **24** and **25**, acoustical waves are launched into the quartz rod **12** by the transducer crystal **21**. These transverse ultrasonic waves have the displacement polarization B. As the wave is propagated through gyromagnetic material **10**, it is rotated in a clockwise direction to the new displacement polarization C. Since the particle displacements are horizontal, an electrical output voltage appears across conductors **18** and **19**. The transducer crystal **13**, having vertical polarity, is unresponsive to the horizontally polarized waves.

Through the use of the gyromagnetic material as discussed above, the polarization of the acoustic wave is rotated in a nonreciprocal manner with respect to the two possible directions of travel along the longitudinal axis **26**. Another, less preferred method for achieving nonreciprocal rotation of acoustic waves is described in U.S. Patent 2,872,994 which issued to W. E. Kock on February 10, 1959. The use of a nonreciprocal rotator in combination with the novel input-output arrangement contemplated by the present invention may be used as a "circulator." This arrangement, which achieves a commutation of power from one transmission terminal to another, is schematically pictured in FIG. 4 of the drawings. The numerals used to designate the input-output terminals of the circulator shown in FIG. 4 are the same as the numerals which designate like terminals of the device shown in FIG. 1.

As shown in FIG. 4, input power applied across terminals **19** and **20** passes through the circulator in the direction indicated by the curved arrow and emerges across terminals **24** and **25**. Likewise, power inserted at terminals **24** and **25** proceeds through the circulator and appears at terminals **18** and **19**; power applied at terminals **18** and **19** next appears at terminals **23** and **24**; and power inserted at terminals **23** and **24** finally appears back at terminals **19** and **20**. Further, it should be noted that if no electrical load is connected to any one of the input-output terminals of such a circulator, those terminals are effectively by-passed. Thus, if neither terminals **24** and **25** nor **18** and **19** are connected to a load, power inserted across terminals **19** and **20** emerges first at terminals **24** and **25**, is reflected, emerges again at terminals **18** and **19**, is again reflected and, if terminals **23** and **24** are connected to a load, the input power is finally absorbed there. As discussed with regard to FIG. 2 of the drawings, an inductor or other electrical matching section should be connected across each of the input-output terminals to insure proper matching.

The device pictured in FIG. 1 of the drawings may also be used as an "isolator," so named because it can be used to isolate one transmission element from reflections arising from succeeding elements. The external circuit elements used in conjunction with the embodiment shown in FIG. 1 to form an isolator are connected as shown in FIG. 5 of the drawings. Like reference numerals have been used to designate those components which are common to both FIG. 1 and FIG. 5.

In FIG. 5 a matching inductance is shown connected across each of the input-output terminals. The inductance **42** is connected between terminals **19** and **20**, the inductance **43** is connected between terminals **18** and **19**, inductance **44** is connected between terminals **23** and **24**, and an inductance **45** is connected between terminals **24** and **25**. The transducer **13** forms the input to the isolator and accordingly a source of electrical oscillations **46** is connected across the terminals **19** and **20**. The transducer **14** is provided with an electrical load **47** which is connected between terminals **18** and **19** such that the transducer **14** operates as a polarization selective absorber. The transducer **22** is similarly arranged as an absorber and accordingly is provided with a load resistance **48** connected across terminals **23** and **24**. The transducer **21** is the output transducer and a load circuit **50** is connected across terminals **24** and **25**.

In FIG. 5 electrical input power from the source **46**, when applied to the terminals **19** and **20**, causes acoustical waves to be emitted from the transducer **13**. These waves, which are launched into the transducer crystal **14**, have a particle displacement direction which is parallel to the displacement vector A shown in FIG. 3. The transducer crystal **14**, being responsive only to components of the elastic waves which are parallel to the displacement vector C, passes these acoustical waves without substantial attenuation. Similarly, after passing through the gyromagnetic rotator **10** and being rotated to the new polarization B, these same waves are passed through the loaded transducer crystal **22**. Transducer **22**, however, absorbs only those components of the acoustical wave which are parallel to the vector D and allows the waves to pass unattenuated. Transducer **21** does respond to waves of polarity B and converts them into electrical energy which is delivered to the load **50**.

Should the load **50** possess an impedance which is not correct for properly matching the output impedance of the transducer **21**, some portion of the electrical energy from the transducer **21** will be reflected and cause acoustical waves to be launched back into the acoustical channel from the output transducer **21**. Due to the nonreciprocal nature of the rotation in the rotator **10**, however, these waves will continue to be rotated in a clockwise direction upon passing through the rotator the second time. Hence, the reflected waves will have a particle displace-

ment direction parallel to the vector C upon reaching the transducer crystal **14**. Consequently, these reflected waves will be absorbed in the transducer **14** so that the source **46** is substantially isolated from the reflected energy. Thus, it may be seen that the device pictured in FIG. 1, when connected as shown in FIG. 5, may be used to allow the free transmission of signals in one direction, while suppressing their transmission in the other direction.

Still further, the acoustic device pictured in FIG. 1 of the drawings may be used as a modulator. The external circuit connections for this application are shown in FIG. 6 of the drawings. The circuit of FIG. 6 is similar to that of FIG. 5 with the following exceptions: the load **48** of FIG. 5 is replaced with an output circuit load **53** which is connected across terminals **23** and **24**, the load **50** of FIG. 5 is replaced with a single load resistance **54** so that the transducer **21** is a polarization selective absorber, and the fixed source of magnetizing current **28**, shown in FIG. 5, is replaced with the combination of a source of biasing current **55** and a source of modulating current **56**.

It will be remembered from the discussion above that the amount of polarization rotation experienced by an acoustical wave in passing through the gyromagnetic material **10** is in part dependent upon the magnitude of the magnetizing current. Since the crystal transducers are responsive only to that component of an acoustical wave which is parallel with a particular axis of the crystal, varying the amount of rotation causes a consequent variation in the electrical signals delivered to the output transducers terminals. FIG. 7 of the drawings illustrates the manner in which modulation is achieved. The electrical energy from source **46** is converted into acoustical energy by transducer **13**. These elastic waves travel through the loaded transducer crystal **14** which insures that any components of the acoustical shear wave launched by crystal **13** other than those of polarization A are absorbed and further that any subsequently reflected waves will be absorbed. The source of biasing current **55** is of an appropriate magnitude to cause the polarization of the waves passing through the gyromagnetic material **10** to be rotated to polarity B when no additional current is contributed by the signal source **56**. The transducer **22** is the output transducer and converts those components of the rotated wave having a polarity parallel with the vector D shown in FIG. 7 into electrical energy which is delivered to the output load **53**. The output transducer **21** is loaded such that it absorbs those components of the transmitted wave which are parallel with the vector B. If the magnitude of the magnetizing current is varied such that the rotated wave makes an angle θ with the vector D, the axis of maximum output, the signal E_{out}, which is applied to the output load **53** may be related to the input signal E_{in}, from source **46** by the following relation:

$$E_{out}=E_{in}r\ \mathrm{Cos}\theta$$

Where "*r*" is a constant which represents the loss mechanisms within the device. Since θ is a function of the total magnetizing current from the biasing source **55** and the signal source **56**, it is apparent that E_{out}, the magnitude of the high-frequency signal appearing at the terminals of load **53**, may be varied or modulated by varying the magnitude of the magnetizing current.

It is to be understood that the above described arrangements are merely illustrative of the principles of the invention. Other arrangements may be 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 with an acoustic transmission channel, first and second piezoelectric transducers acoustically coupled to one end of said channel, each of said transducers generating and being responsive to linearly polarized transverse acoustical waves, said first transducer oriented with respect to said second transducer such that said transducers are most responsive to waves of different polarizations.

2. In combination, an acoustical transmission channel having first and second ends, first and second electromechanical transducers acoustically coupled to said first end of said channel, a source of an oscillatory electrical voltage connected to said first transducer for causing said transducer to launch transverse elastic waves into said channel, said waves having a first direction of polarization, and an electrical load connected to said second transducer for causing said second transducer to absorb acoustical energy residing in waves having a second direction of polarizaiton, said first and said second transducer being oriented such that said first and said second directions of polarization are substantially perpendicular to one another.

3. In combination, an acoustical transmission channel having first and second ends and including means for rotating the direction of polarization of transverse acoustical waves passing therethrough in a nonreciprocal sense, first and second transducers acoustically coupled to said first end, at least a third transducer acoustically coupled to said second end, said first, second, and third transducers being oriented to generate and respond to transverse acoustical waves of first, second, and third direction of polarization respectively, said first and said second directions being essentially perpendicular to one another, and said first and said third directions being at an angle to one another which is essentially equal to the angle of rotation experienced by said waves as they pass through said channel.

4. A combination as set forth in claim **3** including a source of an oscillatory voltage connected to said first transducer, a load impedance connected to said second transducer, and an electrical output circuit connected to said third transducer.

5. A combination as set forth in claim **3** wherein said means for rotating the direction of polarization of said waves comprises a block of gyromagnetic material interposed along said acoustical channel, and means for establishing an electromagnetic field parallel to the direction of wave travel through said material.

6. In combination, a two-ended acoustic channel adapted for the transmission of transverse elastic vibrations along its longitudinal axis, said channel including in series relation therewith a block of gyromagnetic material, means for establishing a magnetic moment within said material directed along a path substantially parallel with said longitudinal axis, a pair of piezoelectric transducers coupled to one end of said channel, each of said transducers generating and being responsive to linearly polarized transverse acoustical waves, said first transducer being oriented at an angle to said second transducer such that said transducers are responsive to waves of different polarities, and acoustical wave detecting means connected to the other end of said channel.

7. A combination as set forth in claim **6** including a source of alternating-current electrical energy connected to said first transducer and an electrical load connected to said second transducer.

8. In combination, a two-ended acoustical channel adapted for the transmission of polarized transverse ultrasonic waves in either direction along its longitudinal axis, said channel including means for rotating the direction of polarization of said waves in a nonreciprocal sense with respect to the two directions of wave travel, a first piezoelectric transducer acoustically coupled to one end of said channel, an electrical load connected to said first transducer such that said first transducer absorbs those wave components parallel with a first direction of polarization, a second transducer coupled to said first transducer for launching transverse waves having a second direction of polarization through said first transducer into

said channel, and an acoustical wave detector coupled to the other end of said channel.

9. A combination as set forth in claim 8 wherein said acoustical wave detector comprises a third transducer oriented to be responsive to acoustical waves having a third direction of polarization, said second and said third directions of polarization being at an angle to one another which is essentially equal to the angle of polarization rotation experienced by waves passing through said channel.

10. In combination, a two-ended acoustic channel adapted for the transmission of transverse elastic vibrations along its longitudinal axis, said channel including in series relation therewith a block of gyromagnetic material, means for establishing a variable magnetic moment within said material directed along a path substantially parallel with said longitudinal axis, said last-named means including a magnetizing winding and means for applying a variable current to said winding, a first piezoelectric transducer acoustically coupled to one end of said channel, an electrical load connected to said first transducer such that said first transducer absorbs those wave components parallel with a first direction of polarization, a second transducer coupled to said first transducer for launching transverse wave having a second direction of polarization through said first transducer into said channel, and a polarization selective acoustic wave detector connected to the other end of said channel.

No references cited.

CHESTER L. JUSTUS, *Primary Examiner.*