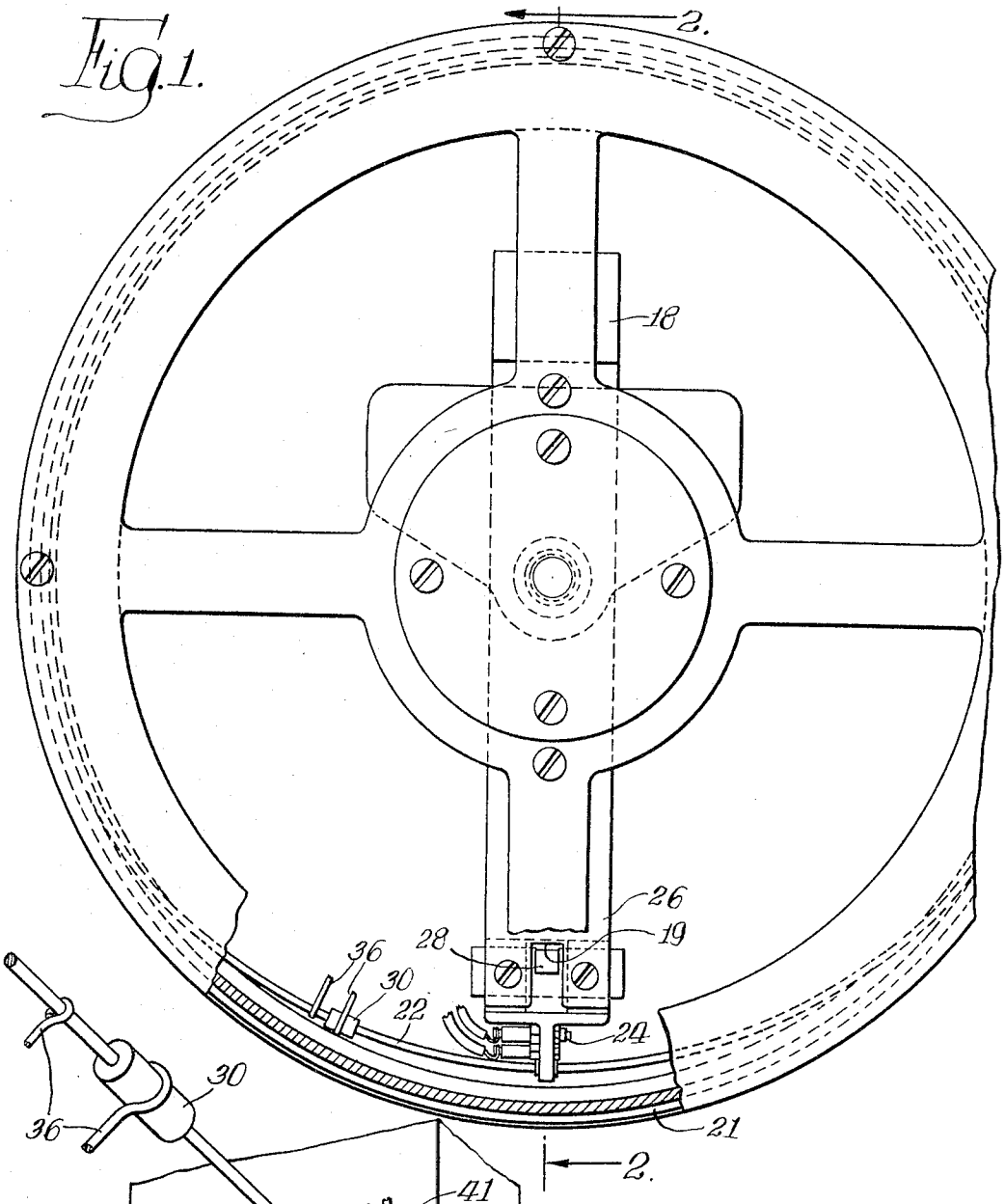
Nov. 1, 1966 E. A. KELLER 3,283,270

WIRE DELAY LINE COMPRISING TWO TRANSDUCERS, ONE RELATIVELY MOVEABLE WITH RESPECT TO THE OTHER

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Fig. 1.



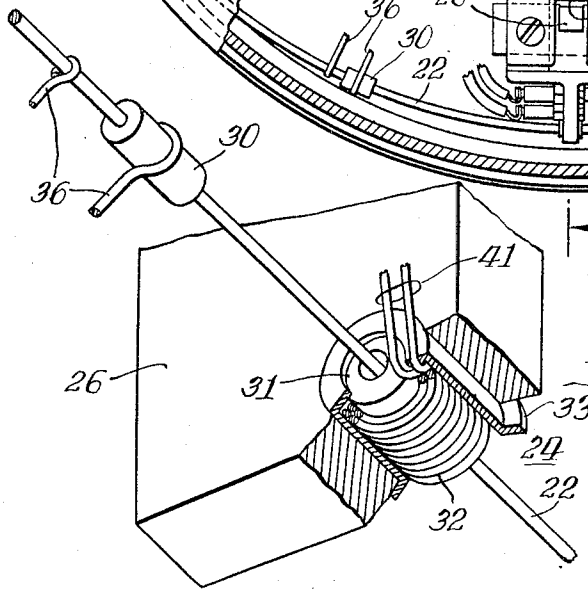


Fig. 3.

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Fig. 2.

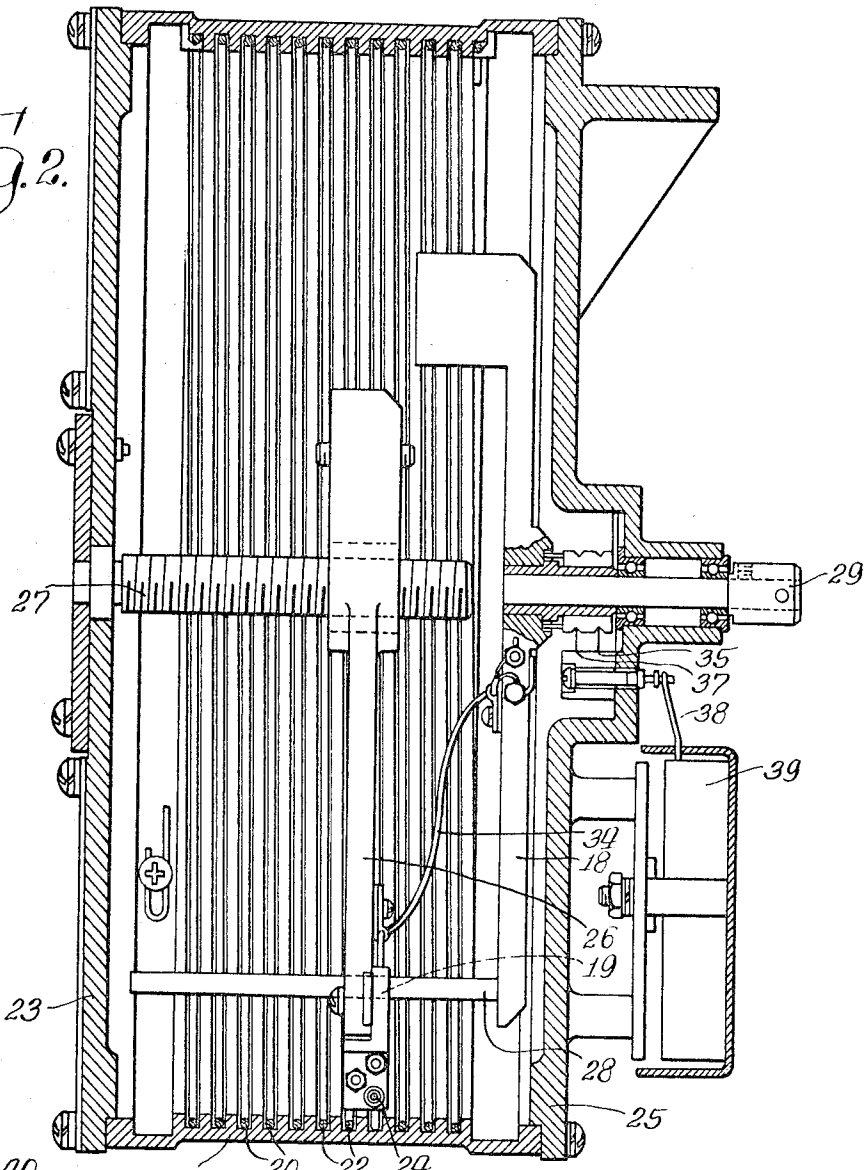


Fig. 4

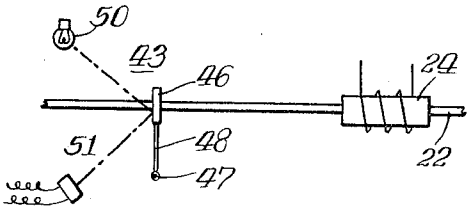


Fig. 5.

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WIRE DELAY LINE COMPRISING TWO TRANSDUCERS, ONE RELATIVELY MOVEABLE WITH RESPECT TO THE OTHER

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This invention relates to a variable delay line in which the delay is accomplished by propagating a pressure wave in a wire, and in particular to means for variably spacing input and output transducers with respect to each other, which permits very close spacing to provide short minimum delay times, and wherein energy is coupled between the transducers only through the delay in line wire.

In many electrical devices it is desirable to delay signals for periods of times longer than feasible using purely electrical circuits. One way in which this has been accomplished has been to introduce a pressure wave, corresponding to the electrical signal to be delayed, into a wire by means of an electromagnetic transducer. A second electromagnetic transducer coupled to the wire receives the pressure wave and generates an electric signal therefrom. Since the propagation of the pressure wave along the wire is considerably slower than the propagation of an electric signal, large time delays can be developed in this manner.

This system works well for relatively long time delays in which the receiving and transmitting transducers are spaced relatively far apart. However, when it is desired to produce a short time delay using this method, energy from the transmitting transducer can be coupled to the receiving transducer through the magnetic field produced by the transmitting transducer. Since the time of transmission from the transmitting transducer to the receiving transducer by means of the magnetic field is considerably shorter than the desired delay, the signal at the receiving transducer will be distorted and errors in the time delay can result. Thus the minimum delay time possible is restricted to a time corresponding to a distance which avoids magnetic coupling between the transducers. This distance is considerably greater than the physical dimensions of the electromagnetic transducer would permit, even if proper magnetic shielding between the transducers is used.

Accordingly, it is an object of this invention to provide an improved variable delay line which is effective to provide delays of signals extending over a wide range from short delays to very long delays.

Another object of the invention is to provide electrical delay apparatus having input and output tranducers coupled to a wire in which a pressure wave is propagated to produce a delay, and in which energy is transferred between the transducers only through the medium of the delay line wire.

A feature of this invention is the provision of a variable delay line having receiving and transmitting transducers and in which the transmitting transducer operates on a different physical principle than the receiving transducer to isolate the same from each other.

Another feature of this invention is the provision of a variable delay line including transmitting and receiving transducers coupled to a wire which delays the wave applied thereto, in which one of the transducers is a magnetostrictive device and the other transducer is either a piezoelectric, mechano-resistive or mechano-optical device.

The invention is illustrated in the drawings wherein:

FIG. 1 is a drawing of a variable delay line structure;

FIG. 2 is a cross sectional view of the structure shown in FIG. 1;

FIG. 3 is an enlarged view illustrating the relationship between the input and output transducers and the delay line wire;

FIG. 4 illustrates the combination of a magnetostrictive transducer with a mechano-resistive transducer; and

FIG. 5 illustrates the combination of a magnetostrictive transducer with a mechano-optical transducer.

In practicing this invention a variable delay line is provided consisting of a hollow cylindrical drum having a spiral rectangular groove cut on the inside. A delay line wire made from a nickel alloy such as Elenvar and having magnetostrictive properties is coiled in the groove to form a helix. An input transducer, consisting of a coil of wire wound around a hollow cylindrical jewel through which the delay line wire passes, is moved along the inside surface of the drum. As the input transducer is moved along the inside surface of the drum, the delay line wire is removed from the groove, passes through the jewel and is returned to the groove. Electrical signals coupled to the input transducer cause it to generate a magnetic field which develops a pressure wave in the delay line wire using magnetostrictive principles. This pressure wave is propagated along the delay line wire until it contacts a receiving transducer. The receiving transducer can be a crystal device operating upon the piezoelectric or mechano-resistive principles, or a mechano-optical device. The receiving transducer converts the pressure wave applied thereto to an electrical signal corresponding to the input electrical signal but delayed in time.

Since the receiving transducer and the transmitting transducer operate on different physical principles, the transmitting transducer can be placed in close proximity to the receiving transducer without coupling energy directly to the receiving transducer. If, for example, the receiving transducer were a second coil of wire operating upon the magnetostrictive principle, undesired coupling through the magnetic field would be possible. By using transmitting and receiving transducers having different physical principles the energy applied to the transmitting transducer is coupled to the receiving transducer only through the delay line wire and it is possible to place the two transducers in close proximity thereby achieving very short delay times.

A delay line incorporating the features of this invention is shown in FIGS. 1 and 2. Similar portions of the two figures have the same identifying numerals. The delay line includes a circular drum **21** having a rectangular spiral groove **20** on the inside surface. A delay line wire **22** formed of a nickel alloy such as Elenvar and having magnetostrictive properties, rests within the groove forming a helix. An end plate **23** is secured to drum **21** and supports a threaded rod **27** centrally positioned within drum **21**. One end of an arm **26** is threaded on rod **27** while the other end of arm **26** supports a transmitting transducer **24**. The pitch of the threads or rod **27** is the same as the pitch of spiral groove **20** so that as arm **26** is rotated the end of arm **26** supporting transducer **24** advances along the inside surface of drum **21** with transducer **24** always opposite groove **20**. Arm **26** is rotated by rod **28** which passes through opening **19** in arm **26**. Rod **28** is connected to an external shaft **29** by arm **18**. Shaft **29** is mounted on end plate **25** which is secured to drum **21**. Rotating shaft **29** causes arm **26** to rotate and move transducer **24** along the surface of drum **21**. Transducer **24** is connected to amplifier **39** through cable **34**, slip rings **35** and **37** and cable **38**. A piezoelectric receiving transducer **30** is rigidly fixed to delay line wire **22**.

An enlarged view of arm **26**, transmitting transducer **24**, and receiving transducer **30** is shown in FIG. 3. The transmitting transducer **24** consists of a hollow cylindrical jewel **31** through which the delay line wire **22** passes. Jewel **31** provides a bearing surface for delay

line wire 22. A coil of wire 32 is wound around bearing 31 and is coupled to a source of electrical signals by wires 41. An electrical signal applied to the coil of wire 32 generates a magnetic field which imparts a pressure wave to the delay line wire 22 by means of the magnetostrictive effect. A mu-metal shield 33 is provided to minimize the external field produced by coil 32.

A receiving transducer 30 consisting of a hollow cylindrical piezoelectric crystal surrounds delay line wire 22. The crystal is mechanically and electrically bonded to delay line wire 22. The pressure wave received by transducer 30 deforms the crystal and thereby produces an electrical output signal. This signal is coupled to an output amplifier by means of wires 36.

In operation an input signal to be delayed is applied to transmitting transducer 24 from amplifier 39. The signal applied to transducer 24 creates a pressure wave in delay line wire 22 by means of the magnetostrictive effect. This pressure wave is propagated along delay line wire 22 to the receiving transducer 30 where it is converted to an output signal, corresponding to the input signal, by transducer 30 using the piezoelectric effect. The delay duration between the input and output signals is determined by the length of wire 22 extending between transmitting transducer 24 and receiving transducer 30.

FIG. 4 illustrates a second embodiment of this invention in which transmitting transducer 24 operates on the magnetostrictive principle while the receiving transducer 42 can be a strain gauge operating on the mechano-resistive principle. An input signal applied to magnetostrictive transducer 24 provides a pressure wave in delay line wire 22 as described above. The pressure wave is propagated along delay line wire 22 to the receiving transducer 42. The pressure wave distorts the receiving transducer 42 thereby changing its resistance and causing the current flowing through the transducer to change. The current change in transducer 42 produces an output signal corresponding to the input signal but delayed in time. This output signal is coupled to an output amplifier by means of wire 40. Again, since the transmitting and receiving transducers operate by different physical principles energy is not coupled between them directly but only by means of delay line wire 22 connecting the two transducers.

FIG. 5 shows another embodiment of this invention in which the transmitting transducer 24 is a device operating upon the magnetostrictive principle while the receiving transducer 43 operates on the mechano-optical principle. Receiving transducer 43 consists of a reflecting mirror 46 mechanically connected to delay line wire 22. Mirror 46 is mounted on a torsion wire welded at right angles to the magnetostrictive wire to transfer the longitudinal mechanical motion into a rotary motion, used to deflect the right beam from light source 50 to photocell 51. Again, since the principles upon which the two transducers operate is different only energy transmitted through delay line wire 22 can be coupled from the transmitting transducer 41 to the receiving transducer 43.

Thus a simple variable delay line structure has been shown in which short delay times can be obtained by using input and output transducers operating on different physical principles. The different transducers can be placed in close proximity to each other without the energy in the transmitting transducer being coupled to the receiving transducer, except through the delay line wire connecting the two transducers.

I claim:

1. Delay line apparatus wherein a time delay is established between first and second electrical signals and including in combination, a hollow cylinder having a spiral groove on the inside surface thereof, said groove being substantially rectangular in cross section, a wire located within and adjacent to the bottom of said groove and forming a helix, magnetostrictive transducer means adapted to be moved along said inside surface, said transducer means including a coil about said wire, and means for removing a portion of said wire from within said groove, said magnetostrictive transducer means being responsive to the first electrical signal to develop a stress wave in said removed portion of said wire by means of the magnetostrictive effect, piezoelectric transducer means mechanically coupled to said wire and responsive to the stress wave therein to develop the second electrical signal by means of the piezoelectric effect whereby energy is transferred with a time delay from said magnetostrictive transducer means to said piezoelectric transducer means only through said wire.

2. A delay line wherein a time delay between first and second electrical signals is established by propagating a stress wave along a wire and including in combination, magnetostrictive transducer means coupled to the wire and responsive to the first electrical signal to develop a stress wave within the wire, optical transducer means including a mirror coupled to the wire, a light source and a photocell, said mirror being responsive to said stress wave to deflect light from said source to said photocell for developing the second electrical signal, means coupled to one of said transducer means for moving the same along the wire relative to the other of said transducer means, the length of the time delay between the first and second electrical signals being determined by the length of said wire between said transducers.

3. Delay line apparatus wherein a time delay is established between first and second electrical signals and including in combination a hollow cylinder having a spiral groove on the inside surface thereof, said groove being substantially rectangular in cross section, a wire located within and adjacent to the bottom of said groove and forming a helix, magnetostrictive transducer means adapted to be moved along said inside surface for removing a portion of said wire from within said groove, said magnetostrictive transducer means being responsive to the first electrical signal to develop a stress wave in said removed portion of said wire by means of the magnetostrictive effect, mechano-optical transducer means mechanically coupled to said wire and responsive to the stress wave therein to develop the second electrical signal by means of the mechano-optical effect, whereby energy is transferred with a time delay from said first transducer to said second transducer only through said wire.

4. Delay line apparatus wherein a time delay is established between first and second electrical signals and including in combination a hollow cylinder having a spiral groove on the inside surface thereof said groove being substantially rectangular in cross section, a wire located within and adjacent to the bottom of said groove and forming a helix, magnetostrictive transducer means adapted to be moved along said inside surface for removing a portion of said wire from within said groove, said magnetostrictive transducer means being responsive to a first electrical signal to develop a stress wave in said removed portion of said wire, optical transducer means mechanically coupled to said wire and including a mirror coupled to the wire, a light source and a photocell, said mirror being responsive to the stress wave within said wire to deflect light from said source to said photocell for developing the second electrical signal, whereby energy is transferred with a time delay from said first transducer to said second transducer only through said wire.

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