# United States Patent [19]
de Klerk

[11] 3,769,615
[45] Oct. 30, 1973

[54] TAPPED PRAETERSONIC BULK DELAY LINE

[75] Inventor: **John de Klerk**, Pittsburgh, Pa.
[73] Assignee: **Westinghouse Electric Corporation**, Pittsburgh, Pa.

[22] Filed: **June 28, 1972**
[21] Appl. No.: **266,950**

[52] **U.S. Cl.** ........................ **333/30,** 333/72, 310/8.2
[51] **Int. Cl.** ........................ **H03h 7/30**
[58] **Field of Search** ........................ 333/30, 72; 310/8.2, 310/9.8

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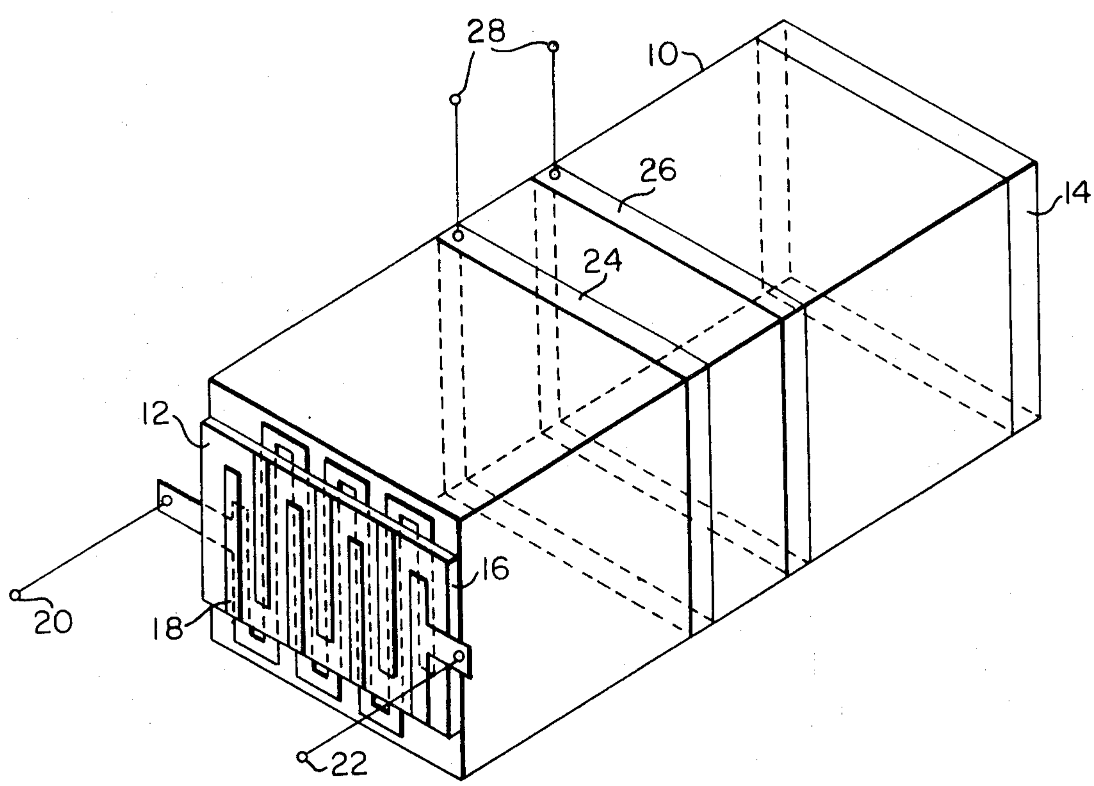
*Primary Examiner*—Rudolph V. Rolinec
*Assistant Examiner*—Saxfield Chatmon, Jr.
*Attorney*—F. H. Henson et al.

[57] **ABSTRACT**

Praetersonic delay line means comprising transducer means for converting input electromagnetic wave energy to bulk sonic wave energy and for causing the bulk wave energy to traverse a body of piezoelectric material, together with electromagnetic antenna means positioned along the body at a point removed from the transducer means for converting the bulk sonic wave energy back to output electromagnetic wave energy which is delayed with respect to the input wave energy by an amount equal to the time required for the bulk sonic wave energy to travel from the transducer means to the antenna means.

**8 Claims, 6 Drawing Figures**



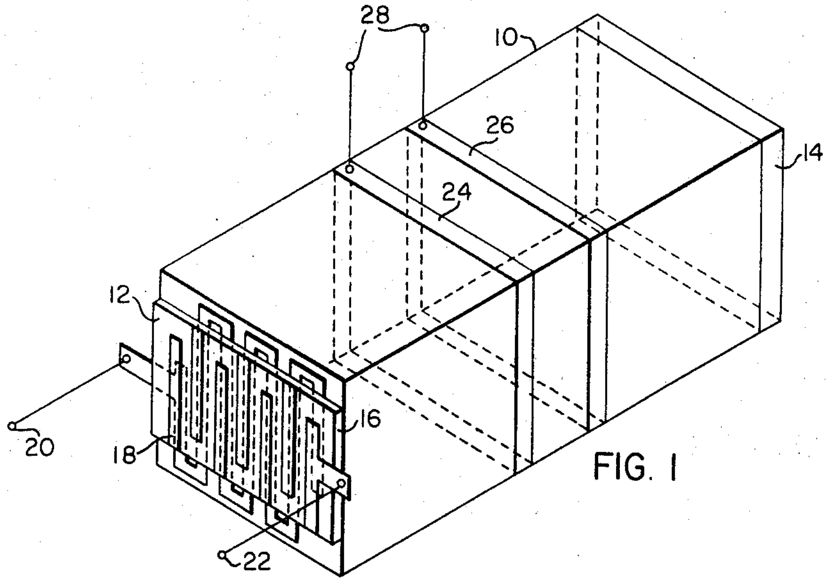



FIG. 1

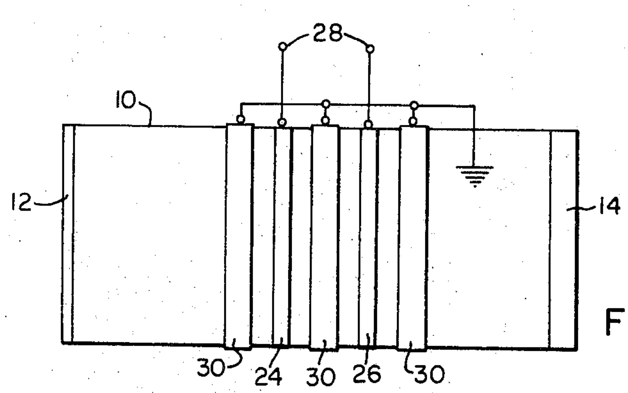



FIG. 2

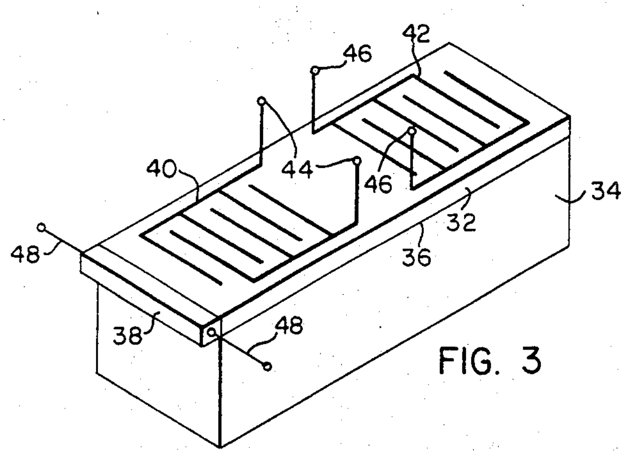



FIG. 3

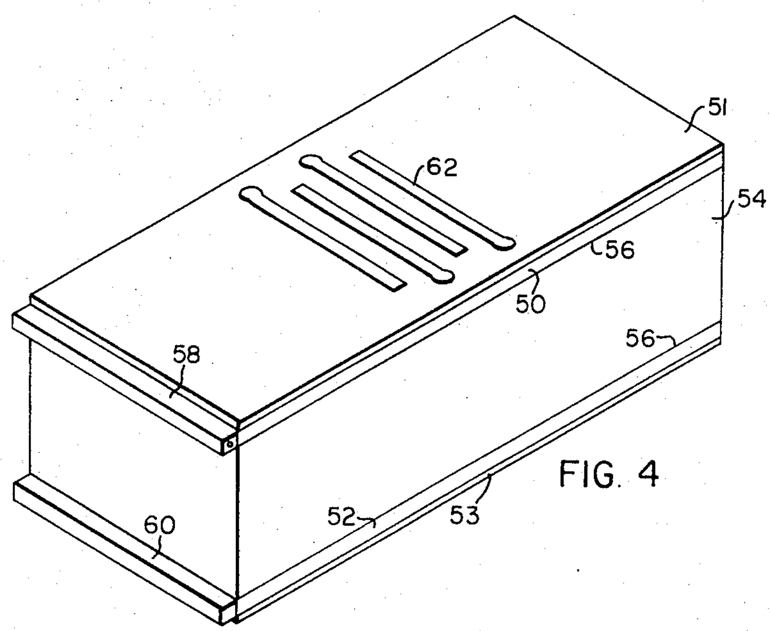



FIG. 4

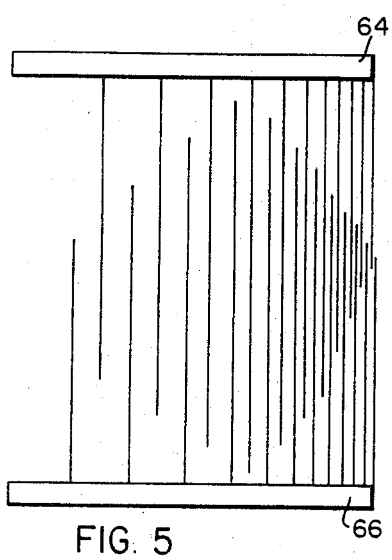



FIG. 5

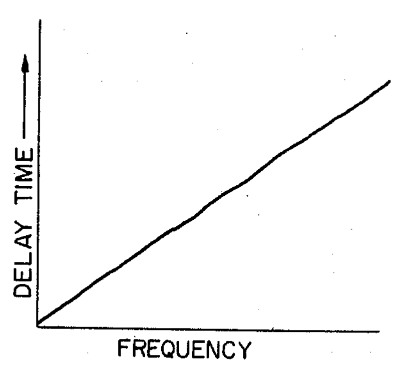



FIG. 6

## TAPPED PRAETERSONIC BULK DELAY LINE

### BACKGROUND OF THE INVENTION

As is known, signal processing at microwave frequencies frequently requires a tapped delay line, with delay times per tap ranging from a few nanoseconds to possibly a few tens of microseconds. Although delays up to 100 nanoseconds can be achieved using conventional electromagnetic coaxial cable or strip lines, both approaches are bulky. Longer delays can be achieved using elastic surface waves. The properties and applications of elastic surface waves are described, for example, in an article by de Klerk appearing in the Jan. 1971 issue of *Ultrasonics*. While such elastic surface waves can be used in certain applications, their use at gigahertz frequencies requires the use of scanning electron microscope techniques; and large insertion losses are inevitable due to acoustic scattering losses as well as electrical series resistance losses.

The acoustic as well as the electrical losses can be greatly reduced by employing praetersonic bulk waves rather than surface waves. Acoustic losses for bulk waves are at least an order of magnitude less than surface wave losses at one gigahertz and approximately four orders less at 10 gigahertz. Furthermore, electrical losses for bulk waves can be made comparably lower than those encountered with surface waves.

### SUMMARY OF THE INVENTION

In accordance with the present invention, a new and improved acoustic delay line is provided employing praetersonic bulk waves rather than surface waves whereby the acoustic and electrical losses of the device can be minimized.

Specifically, there is provided a delay line comprising a body of piezoelectric crystal material having a piezoelectrically active direction extending from one side of the body to the other. A piezoelectric transducer is in contact with one side of the body at one end of the active direction for converting electromagnetic wave energy into bulk sonic wave energy and for causing the bulk sonic wave energy to traverse the body along the active direction. Electromagnetic antenna means are provided adjacent at least one side of the body at a point spaced from the transducer for converting the bulk acoustic wave energy back into electromagnetic wave energy which is delayed with respect to the original electromagnetic wave energy applied to the transducer by an amount equal to the time required for the bulk wave energy to travel from the transducer to the antenna means.

The bulk waves can be caused to traverse a solid body of piezoelectric material or, alternatively, a thin layer of piezoelectric material can be affixed to one surface of a substrate, preferably of crystalline material. The antenna means can take the form of a simple loop or dipole and can comprise interdigital grids with finger lengths and spacing weighting. In the latter case, the time delay becomes a function of the frequency of the input signal.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIG. **1** is an isometric view of one embodiment of the invention wherein bulk praetersonic wave energy is transmitted through a solid block of piezoelectric crystal material;

FIG. **2** is a side view of the device of FIG. **1**;

FIG. **3** is an illustration of another embodiment of the invention wherein the piezoelectric crystal material is mounted on a substrate;

FIG. **4** is an illustration of still another embodiment of the invention wherein piezoelectric crystal material is mounted on opposite sides of a substrate and the antenna means is in the form of spaced dipoles which provide for different time delays;

FIG. **5** is an illustration of an interdigital grid to be used as the antenna means of the invention with finger lengths and spacing weighting to achieve a time delay dependent upon frequency; and

FIG. **6** is a graph of frequency versus delay time showing the manner in which the time delay decreases as frequency increases with the embodiment of FIG. **5.**

With reference now to the drawings, and particularly to FIG. **1,** the delay line shown includes a block **10** of piezoelectric material having an ultrasonic transducer **12** at one end and an acoustic absorber **14** at the other end. The transducer **12** may be of the type shown and described in copending application Ser. No. 71,094, filed Sept. 10, 1970. Essentially, it consists of a substrate upon which is deposited a first electrode pattern of a plurality of individual electrodes over which is deposited a single layer of piezoelectric material **16,** followed by a thin layer of silicon monoxide. A second electrode pattern **18** overlies the other side of the piezoelectric layer **16** with selective interconnections between the electrode pattern **18** and the first-mentioned electrode pattern on the opposite side of the piezoelectric layer **16.** Electromagnetic wave energy to be converted to praetersonic wave energy is applied to terminals **20** and **22,** the terminal **20** being connected to an electrode on one side of the piezoelectric layer **16** and the terminal **22** being connected to an electrode on the other side of the piezoelectric layer. Further details of the transducer can be obtained by reference to the aforesaid copending application Ser. No. 71,094.

When the piezoelectric transducer **12** at one end of the block of piezoelectric material **10** is excited by electromagnetic wave energy, the bulk praetersonic waves will be caused to traverse the block **10** in a piezoelectrically active direction from the transducer **12** to the acoustic absorber **14.** When an acoustic or elastic wave of this type propagates along a piezoelectrically active direction in a piezoelectric crystal, the elastic wave acts as a moving source of electromagnetic energy. The resulting electromagnetic alternating current fields can be readily detected by means of an electromagnetic antenna. In the embodiment of FIG. **1,** the antenna comprises a pair of loops or taps **24** and **26** which extend around the four sides of the block **10** of piezoelectric material and are provided with output terminals **28** from which electromagnetic wave energy can be derived, the electromagnetic wave energy on the respective terminals **28** being delayed with respect to that applied to the transducer **12** via terminals **20** and **22** by virtue of the delay encountered in the acoustic wave traveling through the block **10.**

In the operation of the invention, bulk compressional waves are launched in the block **10** by the transducer **12**; while the loops **24** and **26** detect the traveling electromagnetic waves. The spacing, $d$, between loops is determined by the delay time, $t$, per tap, and the acoustic velocity, $v$. That is,

$$d = vt.$$

Consider, for example, that the block **10** is formed from $LiNbO_3$ and assume that delay steps of five nanoseconds are required. The distance between taps would then be:

$$d = 7.3 \times 10^5 \times 5 \times 10^{-9} \text{ cm.}$$
$$= 36.5 \times 10^{-4} \text{ cm.}$$

where, of course,

$$v = 7.3 \times 10^5 \text{ cm/sec}^{-1}.$$

The acoustic wavelength of compressional bulk waves in $LiNbO_3$ at one gigahertz is given by:

$$v = f\lambda$$

or

$$\lambda = v/f = 7.3 \times 10^5)/10^9 \text{ cm.}$$

and

$$\lambda = 7.3 \times 10^4 \text{ cm.}$$

If each delay tap loop **24** or **26** is made one wavelength wide, the electromagnetic field at both edges of the loop would be in phase. This would result in the generation of an electromagnetic signal. Successive loops spaced $36.5 \times 10^{-4}$ cm. apart would result in dealy steps of five nanoseconds. Coded tapped delay lines could also be fabricated using this design. In this aPplication, the spacing between taps could be varied to generate or detect the desired code, simply by arranging the relative phases of the tapped signals to conform to the desired codes. It is preferable that the loops **24** and **26** be electrically shielded from one another by, for example, grounded metal strips **30** as shown in FIG. **2.**

In FIG. **3**, another embodiment of the invention is shown wherein a thin film of piezoelectric material, such as $LiNbO_3$, is supported on a substrate **34** which may comprise fused quartz or any other suitable material. A metalized grounded surface **36** separates the substrate of quartz **34** and the layer **32** of piezoelectric material. Again, a thin film mosaic bulk wave transducer **38**, such as transducer **12** shown in FIG. **1**, is provided at one end of the thin film of piezoelectric crystal material **32.** The antenna means in this case comprises interleaved grids **40** and **42** spaced along the length of the piezoelectric crystal **32** and ach provided with output terminals **44** and **46**, respectively. In this manner, the electromagnetic wave energy appearing at terminals **46** will be delayed by a greater amount than that appearing at terminal **44.** Again, however, the basic principle of the invention is the same. Electromagnetic wave energy applied to terminals **48** of the transducer **38** is converted into bulk praetersonic wave energy which travels through the piezoelectric layer **32**, the resultant moving source of electromagnetic wave energy being detected by the antenna means **40** and **42** at different points in time.

In FIG. **4**, still another embodiment of the invention is shown wherein layers **50** and **52** of low loss, high velocity non-piezoelectric crystal material are deposited on opposite sides of a substrate **54** of fused quartz or the like, the layers **50** and **52** being separated from the substrate **54** by means of ground planes or metalizations **56.** The non-piezoelectric material may, for example, comprise ruby, sapphire or silicon. Piezoelectric transducers **58** and **60** for converting electromagnetic wave energy into bulk praetersonic wave energy are provided at one end of each of the layers **50** and **52.** These, again, serve to induce bulk praetersonic wave energy which travels along the crystals **50** and **52.** Deposited on top of the layers **50** and **52** are layers **51** and **53** of piezoelectric material such as that described above. These piezoelectric layers **51** and **53** sense the elastic waves traveling along the non-piezoelectric layers **50** and **52.** The antenna means in this case comprises interleaved dipoles **62** which can be provided on both piezoelectric films **51** and **53** at spaced points to achieve different time delays.

In FIG. **5**, an interdigital grid with finger length and spacing weighting is shown which can be applied to a surface of the piezoelectric body to achieve a time delay dependent upon the frequency of the input signal. The output terminals **64** and **66** of the grid of FIG. **5** are on opposite sides of the interleaved fingers of the grid. Note that the interleaved fingers at the left end of the grid of FIG. **5** are more widely spaced apart than those at the right side, the spacing gradually decreasing from left to right. With an arrangement of this sort, the grids shown in FIG. **5** respond to the lowest input frequencies at the left-hand side and to the highest frequencies at the right-hand side. Assuming, therefore, that the grid of FIG. **5** is deposited on the surface of a piezoelectric crystal and that bulk wave energy is caused to traverse the piezoelectric crystal from left to right, a frequency response will be achieved as shown in FIG. **6** wherein the lowest frequencies have the shortest time delay and the highest frequenices have the greatest time delay. Further details of the manner in which the grid of FIG. **5** can be fabricated are found in the aforesaid article by John de Klerk appearing in the Jan. 1971 issue of *Ultrasonics*.

Although the invention has been shown in connection with certain specific embodiments, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention.

What is claimed is:

**1.** Delay line means comprising transducer means for converting input electromagnetic wave energy to bulk compressional wave energy and for causing said bulk wave energy to traverse a body of piezoelectric material, and electromagnetic antenna means positioned along said body at a point removed from the transducer means for converting said bulk compressional wave energy back to output electromagnetic wave energy which is delayed with respect to the input wave energy, said antenna means comprising at least two parallel line electrodes on at least one face of said body.

**2.** The delay line means of claim **1** wherein said bulk compressional wave energy traverses said body of piezoelectric material along a piezoelectrically active direction.

**3.** The delay line means of claim **1** wherein said antenna means comprises a loop extending around said body of piezoelectric material in a plane extending transverse to the direction of movement of said bulk compressional wave energy through the piezoelectric body.

**4.** The delay line means of claim **1** wherein said antenna means comprises interleaved grids.

**5.** The delay line means of claim **4** wherein said interleaved grids are such as to produce output electromagnetic wave energy having a time delay dependent upon the frequency of the input electromagnetic wave energy.

**6.** Delay line means comprising a body of piezoelectric crystal material having a piezo-electrically active direction extending from one side of the body to the other, a piezoelectric transducer in contact with said one side of the body for converting electromagnetic wave energy to bulk compressional wave energy and for causing said bulk compressional wave energy to traverse the body along said active direction, and electromagnetic antenna means on at least one side of the body for converting said bulk compressional wave energy back to electromagnetic wave energy which is delayed with respect to the electromagnetic wave energy applied to said transducer, said antenna means comprising at least two parallel line electrodes on said one side of the body.

**7.** The delay line means of claim **6** wherein said body of piezoelectric crystal material is deposited on a substrate.

**8.** The delay line means of claim **6** including an acoustic absorber at the end of said piezoelectric body opposite said piezoelectric transducer.

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