Nov. 26, 1963 S. YANDO 3,112,414

ACOUSTIC TRANSFORMER

Filed March 15, 1961 2 Sheets-Sheet 1

Fig. 1

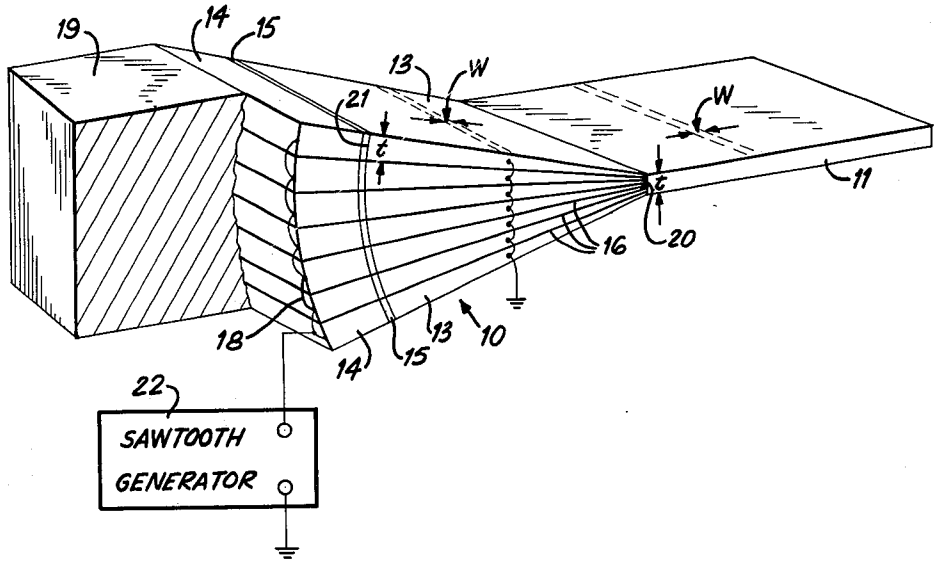
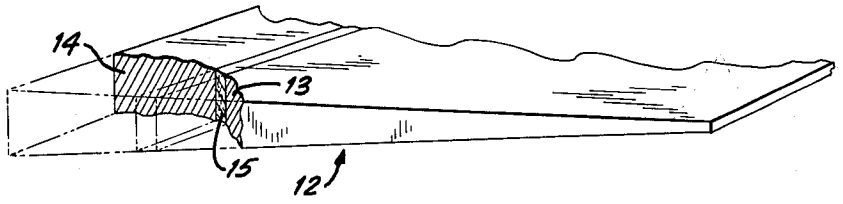


Fig. 1a



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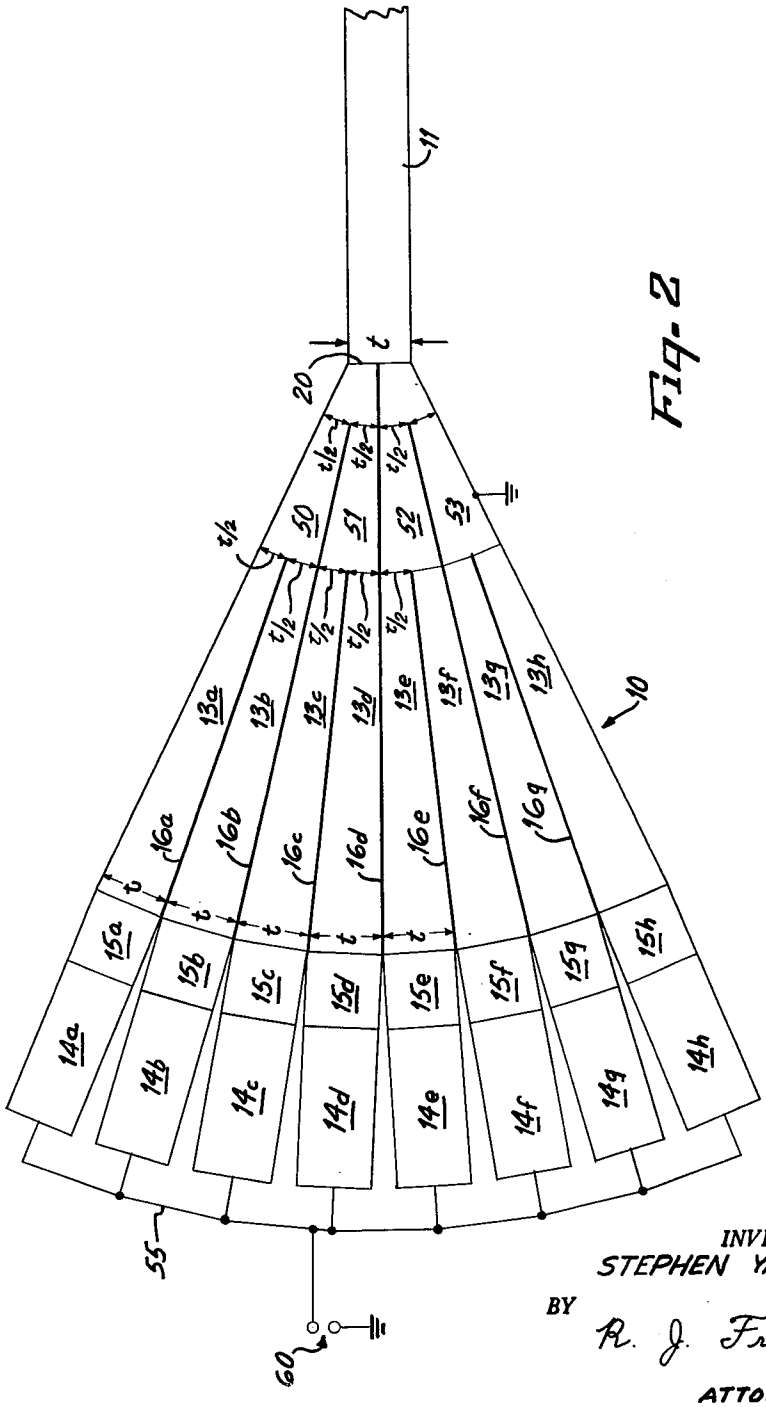


Fig. 2

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ACOUSTIC TRANSFORMER

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4 Claims. (Cl. 310—8.3)

This invention relates to acoustic transformers.

Acoustic waves are employed in various kinds of electrical apparatus including ultrasonic delay lines and display devices of the type disclosed in my patent application Serial No. 855,419 filed November 25, 1959. In these devices a localized mechanical strain is produced in a suitable transmission media (such as a sheet of piezoelectric material) by applying a voltage across electrodes affixed to opposite surfaces of the sheet. As the strain changes, a disturbance in the form of an elastic wave or pulse is propagated along the sheet away from the electrodes. When the width of the electrodes is small compared to the thickness of the piezoelectric sheet, the width of the pulse, as measured in the direction of propagation, is determined by the thickness of the sheet; a thick sheet transmitting only relatively wide pulses and a thin sheet being capable of propagating much narrower pulses.

In order to transmit a maximum amount of information, the acoustic pulses must be narrow and, therefore, the piezoelectric sheet should be as thin as possible. However, for a given excitation voltage, the minimum thickness of the sheet is limited by the voltage gradient that can be impressed on the sheet without causing dielectric breakdown. Thus, when the excitation voltage is applied directly across the sheet, the magnitude of the acoustic pressure that can be obtained with a given voltage is limited to a relatively low value.

Accordingly it is an object of my invention to provide an acoustic transformer for coupling high magnitude acoustic pulses to an acoustically transmitting material without the application of a voltage directly across the material.

Another object is to provide an acoustic transformer suitable for the transmission of relatively narrow acoustic pulses.

Still another object is to provide an acoustic transformer suitable for propagating high magnitude pulses by the use of relatively low excitation voltages.

A further object is to provide an acoustic transformer for propagating high magnitude pulses in a piezoelectric media having relatively low dielectric strength.

Yet another object is to provide an acoustic transformer having a characteristic impedance which matches the characteristic impedance of the acoustic medium.

In the present invention a wedge-shaped acoustic transformer composed of a plurality of adjacent wedge-shaped members is provided. Each of the wedge-shaped members consists of first and second acoustic wave-propagating sections with a transducer section interposed between adjacent edges of the two wave-propagating sections. An acoustically isolating medium extends between the surfaces of the adjacent wedge-shaped members.

The transducer sections are electrically connected in parallel. When a voltage is applied across the transducers, each of the wedge-shaped members is strained mechanically. The mechanical strain causes disturbances in the form of elastic waves, or pulses, to be transmitted down each of the wave-propagating sections, the magnitudes of the pulses being proportional to the rate of change of the mechanical strain. If the edge of a sheet of piezoelectric material or other acoustically transmitting medium is placed in contact with the narrow edge of the acoustic transformer the pulse is transferred into and propagated down the sheet. When the thickness of the sheet, the thickness of the narrow edge of the transformer, and the thickness of each transducer section are substantially equal, maximum energy transfer between the transformer and the sheet is obtained with minimum pulse width.

In one embodiment of the invention, each of the wedge-shaped members comprising the transformer is completely isolated acoustically from the adjacent members. Thus, the pulses travel down the individual wave-propagating sections and do not reenforce each other until they meet in the piezoelectric sheet. The ratio of the acoustic pressure applied to the sheet to the pressure applied to each transducer is substantially equal to the square root of the number of wedge-shaped members.

In another embodiment of the invention, the wedge-shaped members are acoustically isolated from each other only in the regions where the thickness of adjacent members is greater than one-half the thickness of the transducer sections. Toward the narrow end of the transformer the wave-propagating sections are conductively joined in such a manner that the distance between the acoustic isolators is never greater than the thickness of the transducer section.

The above objects of and the brief introduction to the present invention will be more fully understood and further objects and advantages will become apparent from a study of the following description in connection with the drawings, wherein:

FIG. 1 is a perspective view of one embodiment of the invention;

FIG. 1*a* is a sectional view of one of the wedge-shaped members comprising the embodiment of FIG. 1; and

FIG. 2 is an elevation view of another form of the invention.

Referring to FIG. 1, there is shown a wedge-shaped acoustic transformer 10 placed in intimate contact with a sheet 11 of a material capable of sustaining an acoustic wave. Sheet 11 is composed of a piezoelectric material, lead titanate-lead zirconate, but may be formed of any other material having desired acoustic propagation characteristics. The lead titanate-lead zirconate sheet is a piezoelectric ceramic consisting of a solid solution composed of 47 mole percent lead titanate and 53 mole percent lead zirconate.

Transformer 10 consists of a plurality of adjacent wedge-shaped members 12 (FIG. 1*a*). Each member 12 is divided into first and second wave-propagating sections 13 and 14 respectively and a transducer section 15 cemented to adjacent edges of sections 13 and 14 by a conductive epoxy cement. The wave-propagating sections 13 and 14 are made of zinc, zinc having substantially the same acoustic characteristic impedances as the lead-titanate-lead zirconate comprising sheet 11. The transducer sections 15 are formed from a lead titanate-lead zirconate solid solution.

The wedge-shaped members 12 are separated from each other by acoustic isolators 16 made of a suitable insulating material such as Teflon. Jumpers 17 electrically connect all of the first wave-propagating sections 13 while jumpers 18 electrically connect all of the second wave-propagating sections 14. A lead termination 19 may be attached to the wide end of transformer 10 to prevent undesired reflections.

In order to assure maximum energy transfer and to minimize reflections at the junction between transformer 10 and sheet 11, the sheet is acoustically matched to the transformer by making its thickness equal to that of the narrow edge 20 of transformer 10. This thickness is designated by the letter *t* in the drawings. Similarly, the thickness of the edge 21 of transducer section 15 ad-

jacent the wide end of wave-propagating section 15 is also equal to *t*.

When a saw-tooth voltage having a rapid rise time is applied across the transducer sections 15 by generator 22, the transducer sections are mechanically strained causing an elastic wave or pulse to be transmitted down each of the wave propagating sections 13. The magnitudes of these pulses are proportional to the rate of change of the mechanical strain. The width W of the pulses travelling down each of the sections 13 is a function of the thickness *t* of edges 21 of transducers 15, a thin edge producing a narrow pulse and a thick edge a wide pulse. Since a narrow pulse corresponds to maximum bandwidth, the dimension *t* is given the smallest value which permits wave-propagation to take place without voltage or mechanical breakdown of the transducer members 12.

As the acoustic pulses travel down the wedge-shaped sections 13, the thickness of each section gradually decreases and the acoustic pressures in each of the sections 13 increase accordingly. At the edge 20 between transformer 10 and sheet 11, the individual pulses emerging from each of the sections 13 reenforce each other producing an acoustic pressure in sheet 11 which is proportional to the square root of the number of wedge-shaped members 12 in transformer 10 times the pressure applied at the wedge 21 of transducers 15 by the sawtooth voltage. Thus, if the voltage applied across transducer sections 15 produces a pressure P_1, the pressure P_2 transmitted to sheet 11 is approximately equal to $P_1\sqrt{n}$, where *n* is the number of wedge-shaped sections 12 in transformer 10. For example, with *t* equal to 0.75 millimeter and an applied sawtooth voltage having a peak-to-peak magnitude of 100 volts volts and a rise time of 0.3 microsecond, the acoustic pressure P_1 applied to each of the wave-propagating sections 13 at edge 21 is about 0.35 newton per square millimeter. Under these conditions, the acoustic pressure P_2 applied to the sheet 11 at edge 20 is approximately 1.0 newton per square millimeter. The duration of the propagated pulse is approximately 1.0 microsecond and, therefore, in a lead titanate-lead zirconate sheet having a propagation velocity of 3600 meters per second, W equals about 3.6 millimeters.

It shall be noted that if the wedge-shaped members 12 were not acoustically isolated, the pressure wave would extend through the entire thickness of the transformers and a single, very wide pulse (corresponding to a narrow bandwidth) would be generated.

Acoustic waves also travel through wave-propagating sections 14 but these are absorbed by lead termination 19. In some application it may be desirable to eliminate termination 19 and utilize the signals reflected from the ends of sections 14.

In FIG. 2 there is shown a view in elevation of a form of the invention which is somewhat simpler to construct than that shown in FIG. 1. In this embodiment, wave-propagating sections 13*a* and 13*b* are acoustically isolated from each other by isolator 16*a* only in those regions in which the thickness of wedge-shaped sections 13*a* and 13*b* are greater than *t*/2. Similarly, sections 13*c* and 13*d*, 13*e* and 13*f*, 13*g* and 13*h* are acoustically isolated by isolators 16*c*, 16*e* and 16*g* respectively in the regions where their thicknesses are greater than *t*/2. In the regions designated 50, sections 13*a* and 13*b* are soldered together and, in the same way, sections 13*c* and 13*d* are joined to form region 51, sections 13*e* and 13*f* to form region 52, and sections 13*g* and 13*h* to form region 53. Regions 50 and 51 and sections 13*b* and 13*c* are separated by acoustic isolator 16*b* wherever their total thicknesses are greater than *t*/2 but are conductively joined at the narrow end of the transformer 10. Similarly, regions 52 and 53 and sections 13*f* and 13*g* are separated by acoustic isolator 16*f* and are conductively joined at the narrow end of the transformer. Isolator 16*d* extends almost to the edge 20 between transformer 10 and sheet 16, a slight conductive gap being left to provide a smoother transition

and to permit grounding section 13*a*–13*h* without using jumpers. A jumper wire 55 is used, however, to electrically connect sections 14*a*–14*h*. Acoustic isolators 16*a*–16*g* may be made of Teflon spacers as in the transformer of FIG. 1. In some cases, it may be desirable to withdraw the spacers after the transformer is assembled, the remaining air space providing sufficient acoustic isolation between the members.

The transformer is energized by applying a sawtooth voltage between terminal 60 and ground thereby exciting transducers 15*a*–15*h*. The excitation of transducers 15*a*–15*h* produces separate pressure waves in each of the eight wave propagating sections 13*a*–13*h*. These pressure waves merge into sections 50–53 and converge upon edge 20. As in the embodiment shown in FIG. 1, the ratio of the pressure at edge 20 to that at each of the transducers 15*a*–15*h* is the square root of the number of wave-propagating sections 13*a*–13*h*. Thus, using eight sections, as shown in FIG. 2, this ratio is approximately equal to the $\sqrt{8}$.

Since the sections 13*a*–13*h* are separated where their combined thicknesses are equal to the transducer thickness *t* and conductively joined for lesser thicknesses, the transitions are smooth and the pressure builds up uniformly as the pulses travel down the transformer.

Pulses are also transmitted from the transducers 15*a*–15*h* into sections 14*a*–14*h*. The reflection of these pulses may be used to produce a second pulse across sheet 11 or a termination may be provided to absorb the energy as shown in FIG. 1.

As many changes could be made in the above construction and many different embodiments could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In combination with a sheet of material of thickness *t* having acoustic wave transmitting properties, a wedge-shaped acoustic transformer having a narrow edge of thickness *t* in contact with one edge of said sheet, said acoustic transformer comprising a plurality of adjacent wedge-shaped members, each of said wedge-shaped members consisting of first and second wave propagating sections and a transducer section interposed therebetween, the thickness of the edge of said first wave propagating section adjacent said transducer section being substantially equal to *t*; acoustic isolating means separating adjacent surfaces of said wedge-shaped members, said isolating means extending between the surfaces of said wedge-shaped members in the region where the thicknesses of adjacent wedge-shaped members are greater than one-half *t*; means for coupling a voltage source across the transducer section of each of said plurality of wedge-shaped members.

2. A wedge-shaped acoustic transformer having a narrow edge of thickness *t* comprising a plurality of adjacent wedge-shaped members, each of said wedge-shaped members consisting of a wedge-shaped acoustic wave propagating section having a narrow edge forming a part of the narrow edge of said acoustic transformer, a transducer section having one end affixed to the wide edge of said wedge-shaped section, the thickness of the wide edge of said wedge-shaped section being substantially equal to *t*, and means electrically joining the other edges of each of said transducer sections; means separating adjacent surfaces of said wedge-shaped members, said means including an acoustically isolating medium extending between portions of the adjacent surfaces of said wedge-shaped members, and means for coupling a voltage source across each of said transducer sections.

3. A wedge-shaped acoustic transformer having a narrow edge of thickness *t* comprising a plurality of adjacent wedge-shaped members, each of said wedge-shaped members consisting of a first wedge-shaped acoustic wave

propagating section having a narrow edge forming a part of the narrow edge of said acoustic transformer, a second wedge-shaped acoustic wave propagating section, and a transducer section interposed between said first and second wave propagating sections, the edge of said first wave propagating section adjacent said transducer having a thickness substantially equal to *t*; means separating adjacent surfaces of said wedge-shaped members, said means including an acoustically isolating medium extending between adjacent surfaces of said wedge-shaped members and means for coupling a voltage source across each of said transducer sections.

4. A wedge-shaped acoustic transformer having a narrow edge of thickness *t* comprising a plurality of wedge-shaped acoustic wave propagating sections, each section having a narrow edge and a wide edge; a plurality of transducer sections each conductively joined to the wide edge of a corresponding wave propagating section, the wide edge of each of said wave propagating sections having a thickness substantially equal to *t*; acoustic isolating means separating adjacent surfaces of said wave propagating sections, said isolating means extending between the surfaces of said wave propagating sections in the region where the thicknesses of adjacent sections are greater than one-half *t*, said wave propagating sections being conductively joined in the regions where the thicknesses of adjacent sections are less than one-half *t*; and means for coupling a voltage source across said plurality of transducers.

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