

[54] TORSIONAL WAVE TRANSDUCER

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[58] Field of Search 333/30 R, 72, 71; 310/8.0, 310/8.3, 8.1, 8.5, 9.7, 9.8, 9.6

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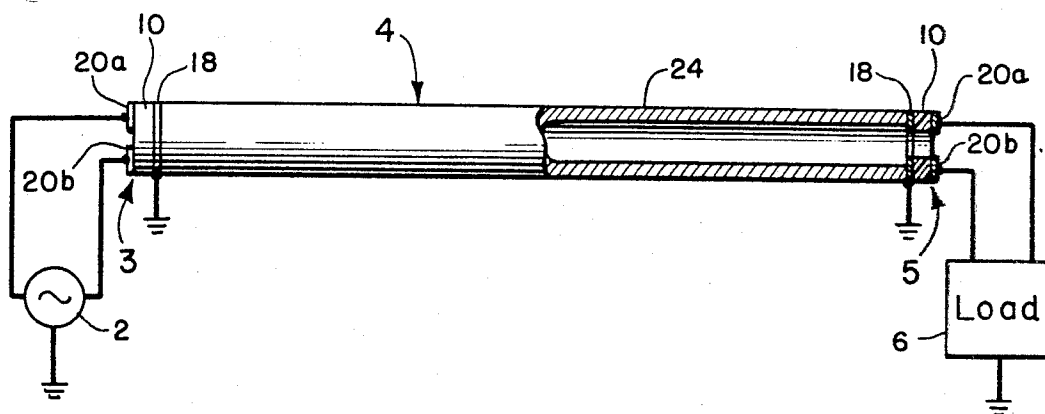
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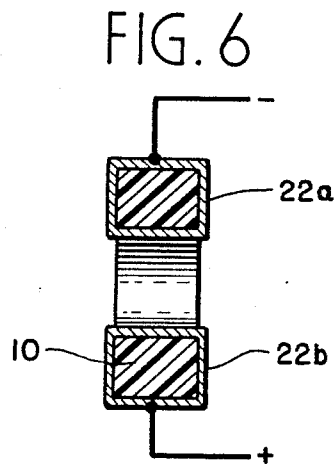
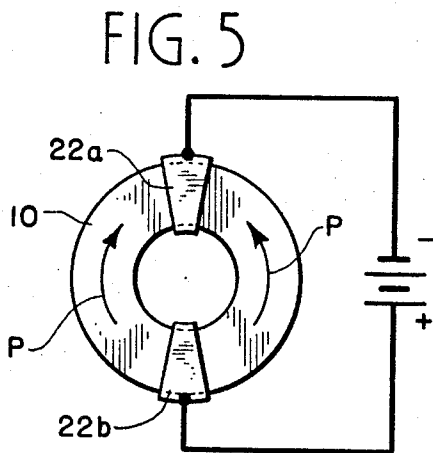
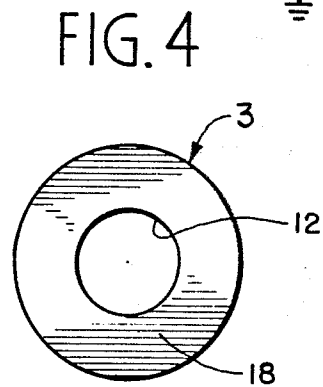
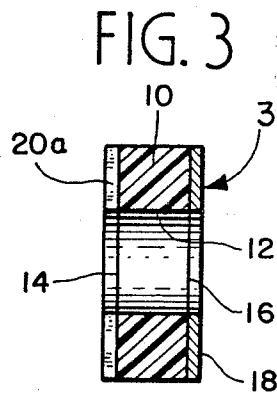
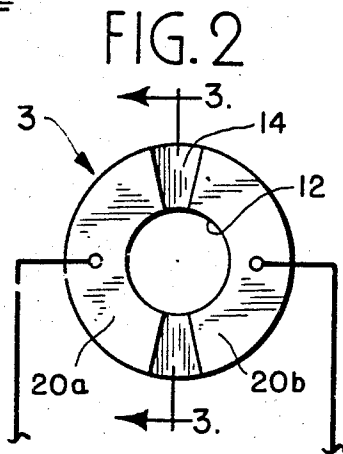
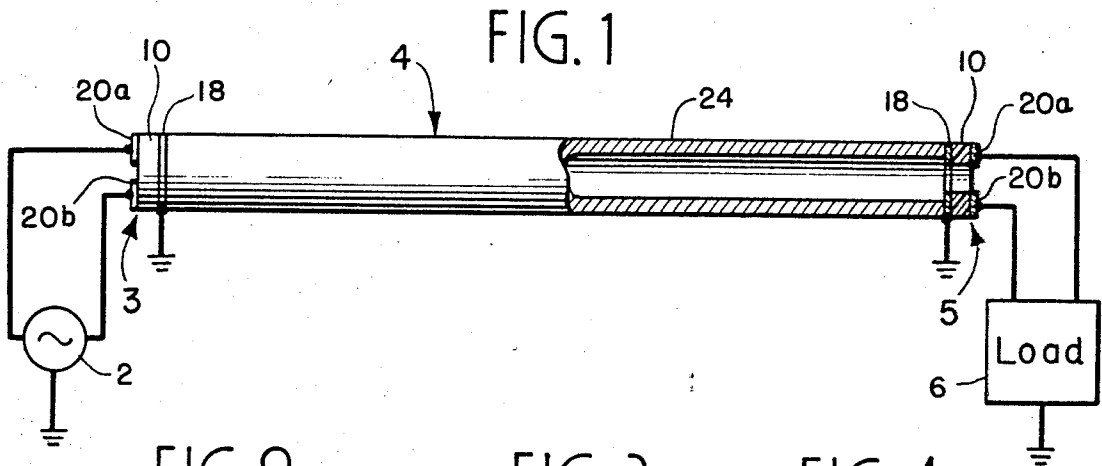
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ABSTRACT

A torsional-wave transducer is particularly suitable for use with torsional-mode delay lines. The transducer preferably takes the form of a washer-like annular disc of ferro-electric material which is electrically poled concentrically of the disc in two opposing directions. A unitary electrode is bonded to and overlies one end face of the disc. A pair of spaced driving electrodes are bonded to the opposite end face of the disc. In combination, a torsional-mode delay line in the form of an elongate hollow cylindrical tube has a pair of the transducers individually bonded to its respective opposite ends by the corresponding single electrodes. To make each transducer, a pair of narrow poling electrodes are first affixed to diametrically opposed locations on the disc, and a DC voltage then is applied across those poling electrodes. The latter are subsequently removed following which the unitary and driving electrodes are bonded in place.

7 Claims, 6 Drawing Figures





TORSIONAL WAVE TRANSDUCER

BACKGROUND OF THE INVENTION

The present invention pertains to torsional-mode transducers and methods for making the same. More particularly, it relates to transducer methods and apparatus suitable for the ultimate fabrication of a complete torsional-mode delay line.

The advantages of employing the torsional mode for wave transmission in delay lines have long been recognized. However, practical problems of construction have largely limited their employment to the laboratory. The primary advantages of the torsional mode are that it is truly non-dispersive and that it provides a greater delay per unit length than is obtained with other modes.

The basic problems involved in constructing a ferroelectric torsional-mode transducer arise primarily from the required configuration and the relatively minute physical dimensions required for operation at high frequencies. The necessary cylindrical configuration poses problems, because the exciting field must be applied perpendicular to the poling direction. In one technique for constructing transducers of this type, a hollow cylindrical tube is split axially and the two halves of the tube are then poled axially in opposite directions by use of poling electrodes temporarily attached to the opposite flat end faces of the tube segments. Driving electrodes are then placed on the two halves by applying an electrically conductive cement to the split surfaces to bond the two halves back into their assembled relationship. While a satisfactory transducer may be constructed by the foregoing technique, this approach has obvious drawbacks from the standpoint of quantity production. In addition, when such a transducer is used to drive a torsional transmission line made of electrically conductive materials such as a metal or alloy, the applied high-frequency field is shorted out, so that a special insulating section with carefully selected matching properties must be inserted.

OBJECTS OF THE INVENTION

A general object of the present invention is to provide a new and improved torsional-mode transducer in which at least some of these problems and drawbacks are reduced.

Another object of the present invention is to provide a new and improved method of manufacturing torsional-mode transducers.

A further object of the present invention is to provide a new and improved complete torsional-mode delay line.

In accordance with the present invention, a torsional-mode transducer is made by first bonding a pair of poling electrodes to a disc of ferro-electric material at spaced diametrically opposed sectors thereon of comparatively small circumferential extent. A DC voltage is applied across those electrodes to pole the disc circumferentially in mutually opposing directions in diametrically opposing halves of the disc. The poling electrodes are then removed, and a pair of exciting electrodes are bonded to one end face of the disc at spaced symmetrically disposed locations thereon. Finally, a unitary electrode is bonded to the other face of the disc. While the resulting structure is, in itself, a

feature of the invention, it is further contemplated to form a delay line by affixing such transducers to opposing ends of a cylindrical hollow tube propagative of torsional waves.

BRIEF DESCRIPTION OF THE DRAWING

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The organization and manner of operation of the invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings, in the several figures of which like reference numerals identify like elements, and in which:

FIG. 1 is a side-elevational view, partially schematic and partially in cross-section, of a delay line embodying the present invention;

FIG. 2 is a view of one end face of a torsional-mode transducer employed in the delay line of FIG. 1;

FIG. 3 is a transverse cross-sectional view taken along line 3—3 of FIG. 2;

FIG. 4 is a view of the opposite end face of the transducer of FIG. 2;

FIG. 5 is a diagram showing one method of poling a ferro-electric disc for use in the transducer of FIG. 2; and

FIG. 6 is a cross-sectional view taken along line 6—6 of FIG. 5.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 1, a signal source 2 drives an input transducer 3 in push-pull. Transducer 3 then induces torsional-mode waves in a delay line 4. Subsequently, those waves interact with an output transducer 5 to effect the development of delayed electrical signals that are fed in push-pull to a load 6.

As specifically illustrated, FIGS. 2-4 depict details of input transducer 3 and FIGS. 5 and 6 pertain to a step in its formation. It is to be understood, however, that all of FIGS. 2-6 apply as well to output transducer 5. Thus, transducer 3 includes an annular disc 10 of a ferro-electric material such as PZT. Disc 10 is of generally washer-like configuration, having a centrally located bore 12 and provided with flat parallel end faces 14 and 16. The thickness of disc 10 is such as to produce shear wave resonance at the nominal or center frequency of the signal from source 2. A unitary electrode 18, preferably a metallic film of gold or silver, is bonded to completely cover end face 16 of disc 10. A pair of driving electrodes 20a and 20b, which likewise may be a film of gold or silver, are bonded to the opposite end face 14 of disc 10 in spaced symmetrically disposed locations on opposite sides of an imaginary diametrical line on face 14 that would be along line 3—3.

Prior to its assembly into the completed transducer of FIGS. 2-4, disc 10 is electrically poled by the arrangement shown in FIGS. 5 and 6. Poling electrodes 22a and 22b are bonded to the disc on diametrically opposed sectors. Each of electrodes 22a and 22b is of relatively small circumferential extent and, as indicated in the cross-sectional view of FIG. 6, extends around both end faces of disc 10 and across both the inner and

outer cylindrical surfaces of the disc. By using comparatively narrow poling electrodes, a maximum of the ferro-electric material is utilized and the magnitude of strains produced in the material during poling is reduced. Advantageously, the width and shape of the poling electrodes are the same as those of the spaces between driving electrodes 20a and 20b.

Poling is accomplished by applying a relatively high DC voltage (e.g., 75,000 volts per inch) across electrodes 22a and 22b to induce circumferential polarization in disc 10 extending from sector 22a to sector 22b around the disc axis. Disc 10 thus is poled in mutually opposing directions in diametrically opposing halves of the disc. As indicated by the arrows P in FIG. 5, a major portion of each half of the disc is poled and the poling direction is clockwise in one half of the disc and counterclockwise in the other half. It will be recognized that each of the portions poled in one specific orientation corresponds to one of the two electrodes 20a and 20b in the completed transducer. After poling of disc 10 has been completed, poling electrodes 22a and 22b are removed from the disc by etching or the like, and electrodes 18, 20a and 20b then are applied. When electrodes 20a and 20b are used in a push-pull circuit as shown, the oppositely directed axial electric signal fields generated or picked up by these electrodes, in cooperation with the correspondingly opposed directions of polarization, couple to purely torsional strain in disc 10.

In principle, bore 12 may be omitted. During poling, however, this leads to the development of very high voltage stress in the center of disc 10 as a result of which arcing may occur between the poling electrodes. Even with bore 12, it is preferred during poling to immerse disc 10 in a highly-refined oil or other high-dielectric liquid medium.

Returning to FIG. 1, it will be observed that delay line 4 takes the form of an elongate hollow cylindrical metal rod 24 of a suitable material, such as stainless steel or Ni-Span-C alloy 902, that propagates the torsional waves. A transducer of the type shown in FIGS. 2-4 is bonded to each end of the tube by its unitary or solid electrode 18. An AC signal from source 2 is applied in push-pull to electrodes 20a and 20b of the transducer at the left-hand end of the tube as viewed in FIG. 1; that signal is transduced by transducer 3 into a torsional vibration which is applied to the left-hand end of rod 24. The torsional waves thus induced travel through the rod from left to right to induce a corresponding torsional vibration in transducer 5 at the right-hand end of tube 24. Transducer 5 converts that vibration into an electric signal which is applied in push-pull to load 6.

In practice for the production of a delay line operative at a nominal or center frequency of 3.58 MHz for use in a color-television receiver, typical parameters of the transducers may be: PZT having a low-frequency dielectric constant greater than 450, and effective shear coupling factor greater than 55 percent, surface parallelism better than 0.0001 inch, outside diameter of 0.256 inch, inside diameter of 0.180 inch and thickness of 0.016 inch. The latter, of course, is most critical; whatever the piezoelectric material used, the thickness should be one-half wavelength for shear waves in the material at the frequency of interest.

In use, it has been found that delay lines incorporating the transducers herein disclosed may be designed for a wide range of frequencies. The resulting signal field is axial, and the interposed unitary electrode provides complete electrical separation from the associated transmission line. Moreover, either the overall delay lines or the individual transducers are capable of economic mass production.

While particular embodiments of the present invention have been shown and/or described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects, and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. The method of making a torsional-wave transducer comprising the steps of:

bonding a pair of poling electrodes to a disc of ferro-electric material at spaced diametrically opposed sectors on said disc of comparatively small circumferential extent;

applying a DC voltage across said poling electrodes to pole said disc circumferentially in mutually opposing directions in diametrically opposing halves of the disc;

removing said poling electrodes;

bonding a pair of exciting electrodes to one end face of said disc at spaced symmetrically disposed locations thereon;

and bonding a unitary electrode to the other end face of said disc.

2. The method as defined in claim 1 in which said disc is of annular shape, and which includes the additional step of submerging said disc, during the application of said voltage, in a liquid medium presenting a high dielectric constant.

3. The method as defined in claim 2 in which said poling electrodes each constitute at least substantially a ring surrounding a radial cross-section of said disc.

4. A torsional wave transducer comprising:

2 disc of ferro-electric material of a thickness producing a shear wave resonance at a predetermined operating frequency, having flat parallel end faces with a major portion of each half of said disc being electrically poled circumferentially in mutually opposing directions in diametrically opposing portions of the disc;

a pair of electrodes bonded to one end face of said disc and symmetrically spaced on opposite sides of an imaginary diametrical line on said end face;

and a unitary electrode bonded to and overlying the other end face of said disc.

5. A transducer as defined in claim 4 in which said disc is of annular shape, having a concentrically located circular bore therethrough.

6. A torsional-wave delay line comprising:

an elongate cylindrical body propagative of torsional-mode waves;

a pair of circular discs, each having a thickness producing shear wave resonance at a predetermined frequency, of ferro-electric material with each being electrically poled circumferentially in mutually opposing directions in diametrically opposing halves of the disc;

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first and second electrode pairs individually bonded to respective one end faces of said discs with the electrodes of each pair disposed in registry with said diametrically opposed halves of the disc;
first and second unitary electrodes individually bonded to and overlying the respective other end faces of said discs;
and means for effectively bonding said discs in-

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dividually to the respective opposite ends of said body with said unitary electrodes individually engaging the respective ends of said body.

7. A delay line as defined in claim 6 which further includes means for applying an electric signal in push-pull across the individual electrodes of at least one of said pairs.

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