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[54] COMPOSITE SURFACE-WAVE TRANSDUCER

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[51] Int. Cl.H01v 7/00

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333/30 R, 72

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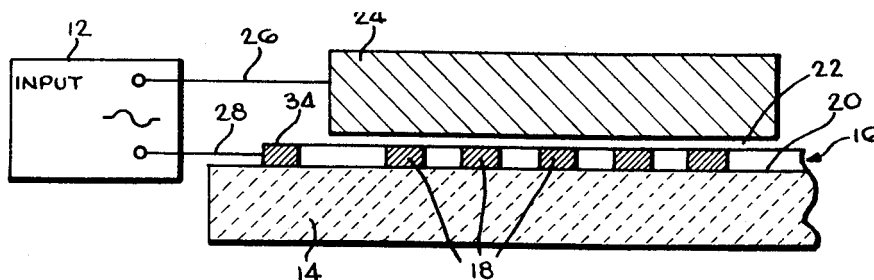
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[57]

ABSTRACT

A transducer for generating and detecting surface elastic waves in a piezoelectric material may include a metallic grating on the material forming one electrode of the transducer and a counter-electrode separated from the grating by a dielectric layer.

16 Claims, 4 Drawing Figures



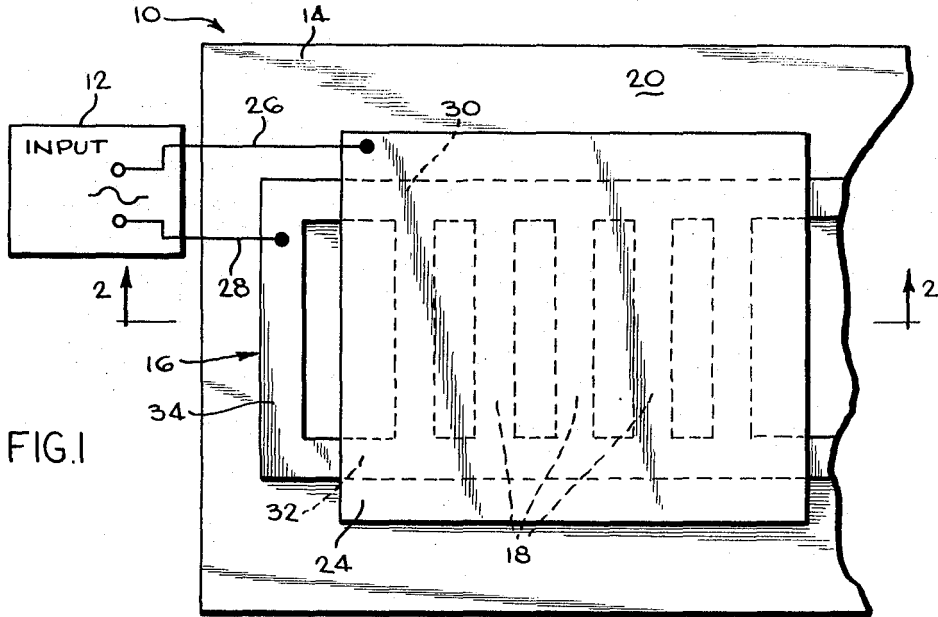


FIG. 1

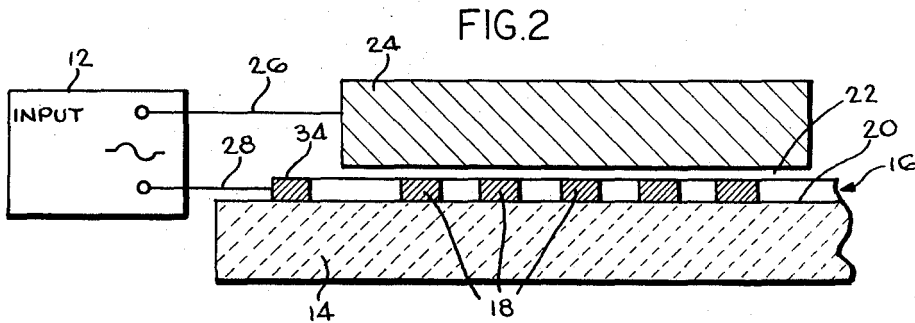


FIG. 2

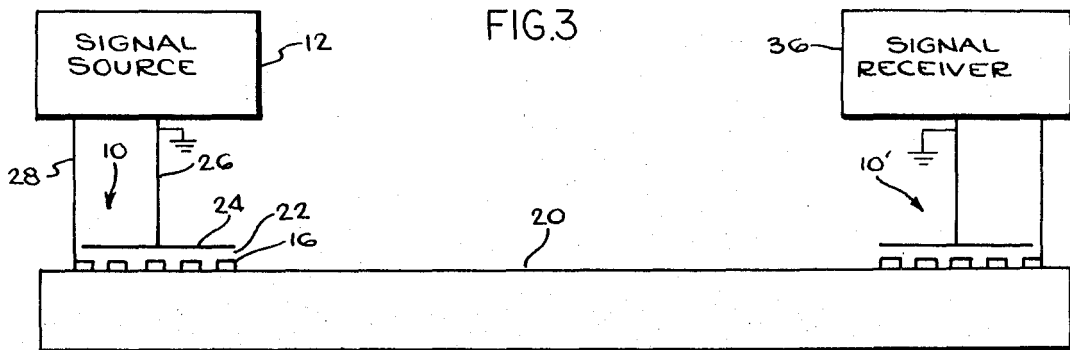


FIG. 3

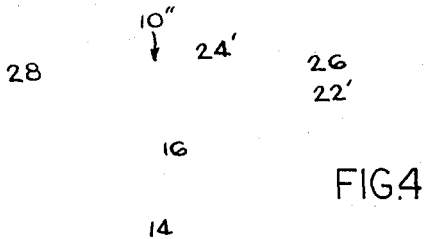


FIG. 4

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COMPOSITE SURFACE-WAVE TRANSDUCER

The present invention relates to devices for transducing signals between an electrical mode in an electric circuit and a mechanical or elastic surface-wave mode on a piezoelectric material, and more particularly to acoustic surface-wave piezoelectric transducers.

Heretofore, two general types of transducers have been commonly employed for generating and detecting surface-waves in piezoelectric crystals, and these are the so-called interdigital transducer and the single phase grating transducer. The interdigital transducer generally comprises a pair of electrodes disposed on the surface of a piezoelectric crystal where the electrodes are each in the general form of a comb with the "teeth" or projection lines of the respective comb electrode structures interdigitated in opposed relation to define a grating. The conductive projection lines of both comb structures are disposed normal to the direction of wave propagation along the crystal and the comb structures are respectively connected to opposite polarity terminals of a circuit. A first pair of such comb electrodes are utilized to generate a surface-wave on the crystal by having an electrical signal applied across the electrodes, and a similar pair of interdigital electrodes are typically disposed on another portion of the same surface of the piezoelectric crystal, spaced from the first pair, for detection of the propagated surface-waves and transduction back to electrical signals.

The single phase transducer typically comprises a single grating electrode in the form of a ladder or comb which is disposed on a surface of a piezoelectric crystal and forms one electrical terminal adapted for connection to a circuit. The conductive lines of the ladder or comb are disposed normal to the direction of wave propagation along the crystal. A metal counter-electrode is commonly disposed across the opposing or "dead" surface of the piezoelectric crystal and forms the other terminal adapted for connection to the circuit. A signal applied across the grating and counter-electrode causes elastic surface-wave generation in the crystal. Another grating electrode of like structure is typically disposed on the same surface of the crystal, spaced from the first grating, to form the detection transducer which is adapted for connection to a further circuit for receiving the output signal from the surface-wave device. This output signal is taken across the second grating and the metal counter-electrode extending continuously across the entire opposite surface of the crystal.

The single phase transducer has an advantage over the interdigital transducer of twice the fundamental resonant frequency for the same electrode spacing, and an additional advantage in that any short circuits between neighboring or adjacent lines of the grating do not inactivate the entire transducer. This latter advantage is particularly significant at high frequencies, which necessitate extremely small line spacings within the grating electrode arrays. On the other hand, however, the performance of the single phase transducer is much lower than that of the interdigital, and for this reason the single phase transducer has not found wide use.

It has also been heretofore proposed to construct a surface-wave transducer employing interdigital electrode arrays which are maintained in close, but non-contacting relationship to the piezoelectric crystal. However, such constructions also give rise to the previously discussed problems associated with close spacing of opposite polarity electrodes, especially at high frequencies.

It is thus an object of the present invention to provide a surface-wave transducer structure which will retain all of the advantages of the single phase transducer, but which will also have an efficiency and performance much greater than that of the single phase transducer, and comparable to that of the interdigital transducer.

It is a further object of the present invention to provide such an improved surface-wave transducer which may be easily and economically manufactured.

These and other objects of the invention are specifically set forth in the following detailed description, and in the accompanying drawings, wherein:

FIG. 1 is a plan view illustrating the structure of a surface-wave transducer on a portion of a piezoelectric substrate in accordance with an embodiment of the present invention;

FIG. 2 is a sectional view taken along line 2—2 of FIG. 1 in the direction of the arrows;

FIG. 3 is a schematic illustration generally showing a surface-wave delay line employing a pair of transducers, each having the construction shown in FIGS. 1 and 2; and

FIG. 4 is a schematic illustration generally showing a portion of a surface-wave device employing a transducer in accordance with a further embodiment of the invention.

Referring to FIGS. 1 and 2, there is generally illustrated a device 10 for transducing signals between an electric circuit, illustrated schematically as the input signal source 12, and a mechanical or elastic surface-wave mode on a piezoelectric crystal 14, which may be utilized in a surface-wave delay line, or other surface-wave device, as shown in FIG. 3. The transducer 10 comprises a first conductor 16 in the form of a ladder grating electrode having a plurality of spaced apart line portions 18 disposed on a planar surface 20 of the piezoelectric crystal 14; a layer of dielectric material, illustrated as merely an air layer 22, disposed over the spaced apart line portions 18 of the grating electrode 16; and a second conductor in the form of a solid or continuous counter-electrode plate 24 disposed over the layer of dielectric material 22. Any suitable conducting means 26 and 28 respectively connect the counter-electrode 24 and the grating electrode 16 to the signal source 12, the counter-electrode typically being grounded and forming a ground plane with respect to the crystal 14.

More particularly, the grating electrode 16 may be formed by plating a uniform layer of conductive material, such as aluminum or other metal, on the upper planar surface 20 of the piezoelectric crystal 14. Then portions of the metal are etched away by using standard photo-resist and thin-film techniques to leave a ladder array comprising the narrow, elongated and coplanar strips 18 extending transversely to the intended direction of wave propagation along the crystal surface 20. Thus, the strips 18 form acoustically separate electrodes which are electrically joined together in an integral fashion by side rails or strips 30 and 32, and by a terminating strip 34 joining the corresponding terminal ends of the side rails 30 and 32.

The counter-electrode 24 comprises a metal plate which is preferably substantially thicker than the plated grating electrode 16 for rigidity, and which is supported and maintained a predetermined distance above the upper surface of the grating electrode 16 to provide the air layer dielectric 22 between the grating and the counter-electrode. The counter-electrode 24 may be supported by any suitable means, such as insulated spacer members which bridge or straddle the active region of the device, or by being suspended from the device housing in any suitable manner. Alternatively, a solid dielectric material may be deposited on the grating electrode 16 and utilized to space and support the counter-electrode 24, but this is generally less advantageous as compared to the use of merely an air dielectric.

The crystal 14 may be formed of any suitable ultrasonic surface-wave supporting or propagating material having piezoelectric properties, such as for example, suitably cut quartz crystal, cadmium sulfide, sodium potassium niobate, lithium niobate, barium titanate, etc. Any of these materials may typically be formed as a rectangularly cross-sectioned bar for use, for example, as the simple delay line illustrated in FIG. 3, or other surface-wave device.

The delay line of FIG. 3 has a transmitting or generating transducer 10 formed in accordance with the construction illustrated in FIGS. 1 and 2 on the left-hand end of the crystal 14 for launching a wave of ultrasonic energy. This energy is propagated as a Rayleigh surface-wave along a path adjacent and substantially parallel to the surface 20 of the crystal in response to the signal from the electrical source 12. A receiving transducer 10' of identical construction to the transmitting transducer 10 is positioned at the right-hand end of the crystal 14 for detecting the delayed propagated Rayleigh surface-

waves and supplying a corresponding electrical signal to the receiver circuit 36. The distance or spacing between the grating electrode lines 18, as well as their various dimensions depend on the signal frequencies to be used and on the particular nature of the device with which the transducer of the invention is to be employed. These parameters may be readily determined in the known manners applicable to conventional single phase transducer devices.

Since the transducer structures in accordance with the principles of the present invention include a dielectric layer as well as a piezoelectric substrate, they may be termed "composite dielectric-piezoelectric transducers," or merely "composite" transducers. In operation, when the composite transducer 10 is utilized as a generator, the r.f. voltage (or other a.c. signal) from the signal source 12 is applied between the grating electrode 16 and the counter-electrode 24, and a spatially periodic fringing electric field is coupled to the piezoelectric substrate 14 which generates a traveling surface-wave along the surface 20 of the substrate. Since there is an electric field which extends outside the piezoelectric crystal associated with the elastic surface-wave propagating on the piezoelectric substrate, this external field produces a potential difference between the metallic grating electrode and the counter-electrode at the detection transducer 10' at the other end of the crystal, and hence power is delivered to the load at the receiver 36.

Referring to FIGS. 1 and 2, the conductive lines 18 of the grating electrode 16 may, if desired, be extended to the right across the surface 20 of the crystal 14 toward the detecting transducer in a delay line such as is generally shown in FIG. 3, and an adjustably controllable delay may then be obtained by selectively positioning the counter-electrode 24 along the length of the substrate relative to the position of the detecting transducer on the crystal. Where, for example, a solid dielectric is employed, the counter-electrode may be merely moved thereon to obtain the desired delay. In constructions having an air dielectric, a sliding insulated spacer may be used to support the counter-electrode 24, and the spacer may, for example, be in the form of a carriage resting on the crystal surface 20 but bridging the grating electrode region thereon.

Turning now to considerations of the performance, it is known that the performance of conventional single phase surface-wave transducers improve as the ratio of the piezoelectric substrate thickness to the wavelength of the operating frequency (h/λ) decreases. However, the minimum ratio of h/λ for practical structures equals approximately ten due to the inherent limitations on substrate thickness, and with this ratio, the performance (measured by the product of efficiency times the fractional bandwidth) of the single phase grating structure is still about 20 times less than that of the interdigital transducer.

In accordance with the principles of the present invention, however, the counter-electrode is moved from the underside of the crystal to a position above a conventional single phase grating, being separated from the grating by a dielectric layer. In this case, the ratio h/λ is the ratio of the height of the ground plane (i.e., the counter-electrode) above the grating to the wavelength at the operating frequency, and this can be decreased to any desired value since it is not limited by the minimum thickness requirements of the piezoelectric crystal (although there are limiting considerations as discussed hereinafter).

To verify the operation of the composite transducer according to the principles of the invention, two interdigital transducers and one composite transducer were fabricated on single crystal quartz. The transducers were resonant at a fundamental frequency of 12.4MHz. One of the interdigital transducers was excited at the fundamental frequency and the outputs obtained from the composite and the other interdigital transducer were compared. The dielectric layer was composed of glass 0.002 inch in thickness, equaling 0.2λ at 12.4MHz. The output of the composite transducer was found to be only about 2 or 3 times lower than that of the interdigital trans-

ducer, which is considerably superior to the performance of conventional single phase grating transducers. Similarly, when the composite transducer was used to generate or excite surface-waves, its performance was found to be generally comparable to that of the interdigital transducer relative to the typical performance of single phase transducers.

Such composite transducer structures according to the invention may also be capable of greater efficiency than the interdigital transducer. This may be achieved by suitable selection of the capacitive reactance which may be readily controlled to provide an optimum ratio of reactance to radiation resistance for a fixed number of electrodes and a given piezoelectric crystal surface. This cannot be done with the interdigital transducer because, under the same conditions, the ratio of these parameters is constant. In particular, and referring to FIG. 4, the input capacitance of the composite transducer 10'' may be reduced by reducing the overall area of the upper or counter-electrode, such as by forming it as a grating 24' similar to the lower grating electrode 16 on the crystal surface, but with the conductive elements or lines disposed over the areas located between the conductive lines of the lower grating so that they are staggered relative thereto. While the capacitance of the transducer will also decrease with increasing thickness of the dielectric layer, the degree of coupling to the crystal surface will decrease too (as will the ratio of λ/h). Thus, optimum dielectric layer thickness may be determined empirically for any specific device structure, or may be calculated from the mathematical relationships defining the relative rates of change of these functions for a particular device structure.

By way of example, the dielectric layer 22' is shown as a solid material such as glass to conveniently support the counter-electrode grating 24', but of course an air layer may alternatively be employed to provide a lower dielectric constant.

The composite transducer in accordance with the principles of the present invention may be utilized with various typed of surface-wave devices other than merely a simple delay line. For example, a multiple-tap matched filter for a 255 bit pseudo random code was fabricated using the present composite approach and designed for a center frequency of 30MHz. The fractional bandwidth was 100 percent and satisfactory operation was obtained. Binary coding is accomplished by varying the respective positions of the taps, and various weightings to the tap outputs may be achieved by suitably shaping the counter-electrode. Multiple code options may be provided by moving a relatively small ground plane electrode over a relatively long set of spatially coded transverse electrode strips.

Additionally, the composite transducer may be employed as a linear mixer wherein the counter electrode is excited with a given frequency to modulate the amplitude of an input signal at this frequency, resulting in an intermediate frequency output. Alternatively, mixing may be achieved by modulating the dielectric constant of the insulating layer by any suitable means.

Thus, a transducer structure has been described that has all the advantages of the single phase transducer array, while also having performance characteristics relatively comparable to those of the interdigital transducer and, in addition, has a selectively controllable input impedance.

Although specific embodiments of the present invention have been illustrated and described, various modifications thereof will be apparent to those skilled in the art; accordingly, the scope of the invention should be defined only by the claims, and equivalents thereof.

Various features of the invention are set forth in the following claims.

What is claimed is:

1. A device for transducing signals between an electrical mode in an electric circuit and an elastic surface-wave mode on a piezoelectric material, comprising a first conductor having a plurality of spaced apart portions disposed on a surface of the piezoelectric material, a layer of non-piezoelectric

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dielectric material disposed over said spaced apart portions of said first conductor, a second conductor disposed over said layer of dielectric material and spaced from said surface of the piezoelectric material, and means for coupling said first and second conductors to the electric circuit.

2. The device of claim 1 wherein said spaced apart portions of said first conductor form discrete elongated strips disposed transversely to the direction of surface-wave propagation on said piezoelectric material.

3. The device of claim 1 wherein said first conductor has a grating configuration.

4. The device of claim 1 wherein said dielectric material is air.

5. The device of claim 1 wherein said dielectric material is a solid.

6. The device of claim 5 wherein said solid dielectric is glass.

7. The device of claim 1 wherein said first conductor is a grating electrode and said second conductor is a continuous plate.

8. The device of claim 7 wherein said grating electrode has a ladder configuration.

9. The device of claim 2 wherein said second conductor comprises a plurality of spaced apart portions.

10. The device of claim 9 wherein the spaced apart portions of said second conductor form elongated strips parallel to the strips of said first conductor and are each disposed over respective areas of said piezoelectric material between said elongated strips of said first conductor.

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11. The device of claim 1 wherein said second conductor forms a ground plane relative to the surface of the piezoelectric material.

12. A surface-wave transducer comprising a piezoelectric substrate capable of supporting elastic surface-wave propagation on a surface thereof, a first conducting electrode having a plurality of spaced apart portions disposed on said surface, a non-piezoelectric dielectric layer disposed over said spaced apart portions of said first electrode, and a second conducting electrode disposed over said dielectric layer and spaced from said surface.

13. The transducer of claim 12 wherein said spaced apart portions of said first conductor are discrete members depending from a common conductive member, said discrete members being coplanar and defining a plane parallel to said surface of the piezoelectric substrate, and said dielectric layer being in a plane parallel to the plane of said discrete members and having an area at least coextensive with the overlying portions of said second electrode and said discrete members.

14. The transducer of claim 13 wherein said discrete members are elongated and are each disposed on said surface transversely to the direction of surface-wave propagation.

15. The transducer of claim 14 wherein said second conducting electrode comprises a plurality of spaced apart coplanar discrete members defining a plane parallel to said surface of the piezoelectric substrate.

16. The transducer of claim 12 wherein said dielectric layer is composed of air.

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