

June 23, 1964

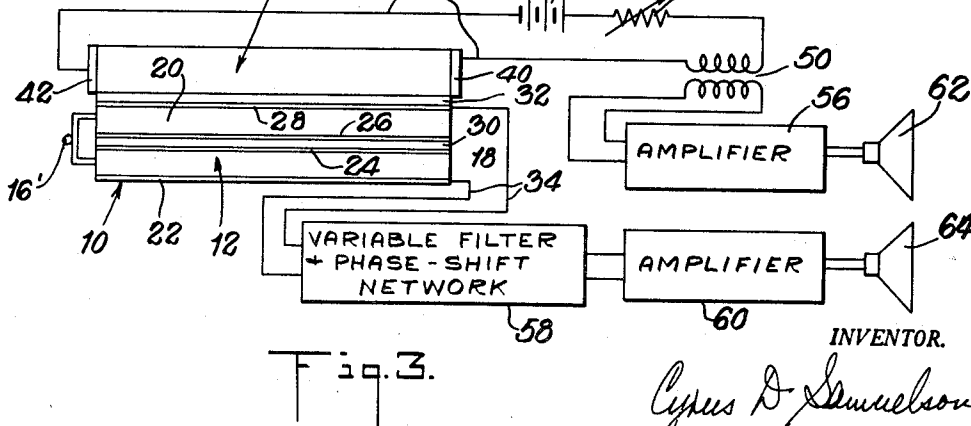
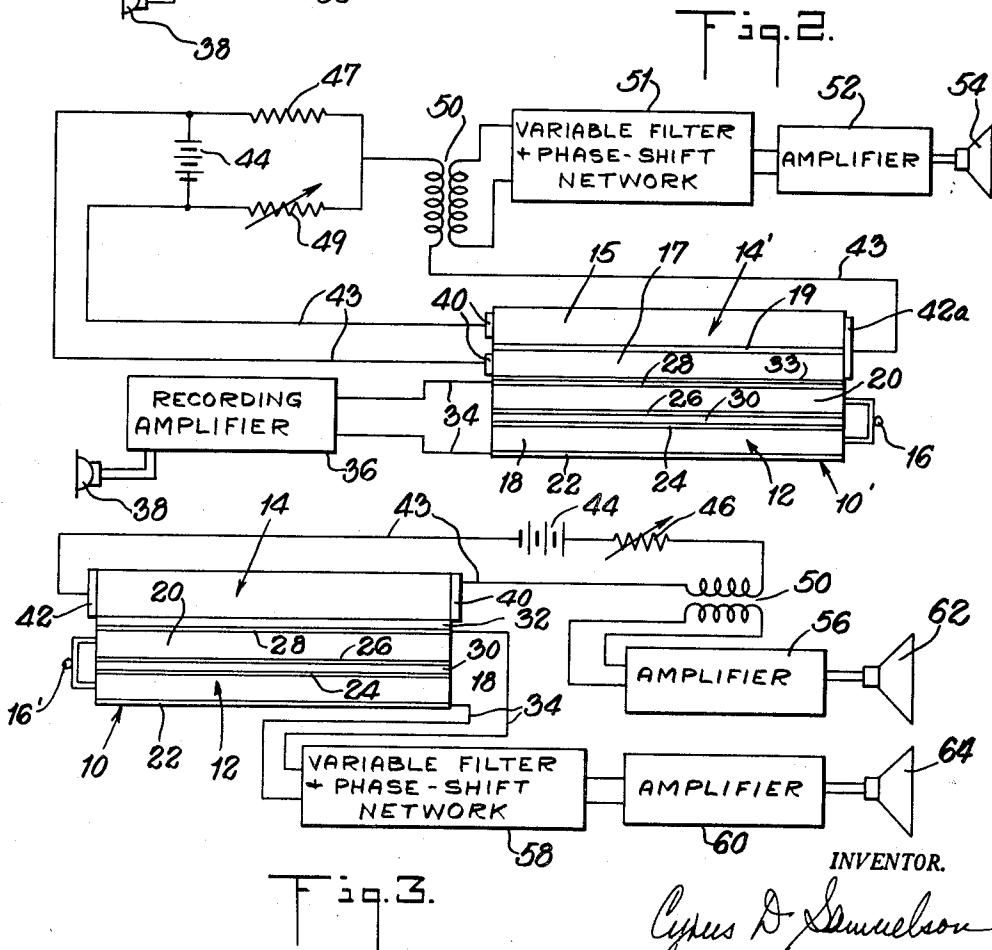
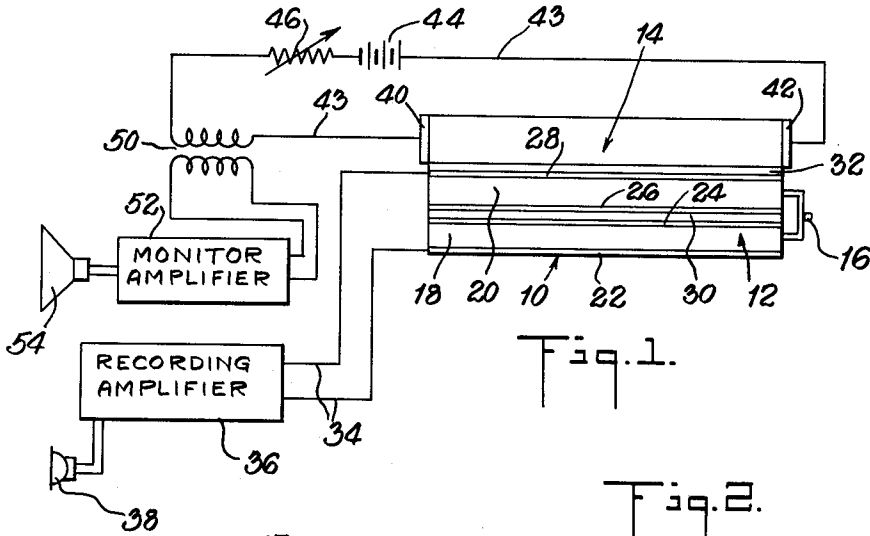
C. D. SAMUELSON

3,138,726

TRANSDUCER

Filed Nov. 17, 1960

2 Sheets-Sheet 1



INVENTOR.

Cyrus D. Samuelson

June 23, 1964

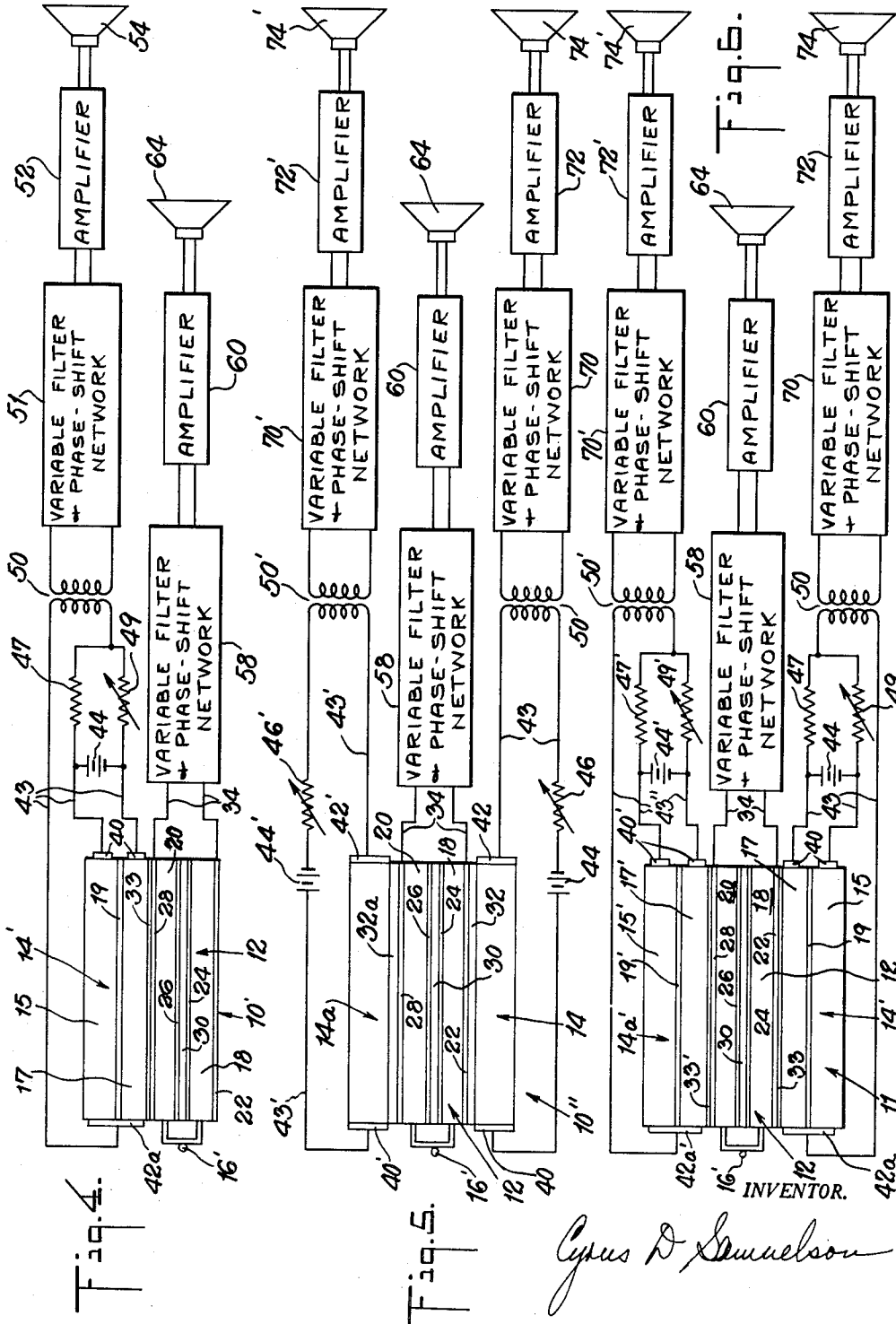
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3,138,726

TRANSDUCER

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12 Claims. (Cl. 310—8.1)

My invention relates to transducers and in particular to those transducers having more than one output and which are comprised of more than one piezosensitive element.

In the prior art, it has been usual to manufacture transducers of a single type of piezosensitive element. Such transducers have been described in the literature and in many patents. Presently known transducers are made, for example, with various types of elements such as quartz, Rochelle salts, ferroelectric ceramics, magnetostrictives, piezoresistives and electromechanically sensitive materials.

By an "electromechanically sensitive material" I mean one which changes one of its electrical and/or one of its magnetic characteristics when subjected to mechanical stress and by a "piezosensitive element" I mean one which changes one of its electrical characteristics when subjected to mechanical stress. Some electromechanically sensitive materials and some piezosensitive elements are reversible, that is, an electrical and/or magnetic signal applied thereto will produce a mechanical stress therein. Other such materials are not reversible. For example, transducers or ferroelectric ceramic are reversible and those of other materials are not reversible, that is, no mechanical movement is produced when an electrical signal is applied. I choose to designate these latter materials and elements as "single-ended" or "passive" piezosensitive or electromechanically sensitive materials. I choose to further designate the reversible piezosensitive materials as "active" piezosensitive or electromechanically sensitive materials.

Examples of single-ended or passive piezosensitive materials are P-type and N-type silicon semiconductors such as have been described in U.S. Patent No. 2,905,771 to Fred P. Burns, issued September 22, 1959. The semiconductors described by Burns are called piezoresistives because their resistance changes when mechanical stress is applied. It should be noted that there are many other piezoresistive materials other than those described by Burns and in the present application and the teachings of my invention apply as well to these other piezoresistive materials. Moreover, other piezosensitive materials may be used in practicing the invention. These other piezosensitive materials are any of those wherein one of the electrical characteristics changes when the material is subjected to a mechanical stress.

Piezoelectric materials such as quartz, Rochelle salt, polarized ferroelectric ceramics are active piezosensitive materials and are designated as piezoelectric because they generate an electric voltage when subjected to a mechanical stress. Piezoresistive materials, which are passive, are designated as piezoresistive because the resistance of the material changes when it is subjected to a mechanical stress. Examples of piezoresistive materials are P-type or N-type silicon.

I have discovered that improved results can be obtained from phonograph pickups, microphones, accelerometers and similar electromechanical devices when a plurality of outputs are obtained from a single mechanical stress. There are many advantages to such devices since, for example, it is possible to obtain different electrical output characteristics from the same mechanical stress. By applying suitable phase and frequency shifts to one or more of the outputs with respect to each other, it is pos-

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sible to produce stereophonic effects from a single microphone or phonograph pickup. This phonograph pickup stereo effect is obtained from the common monaural type records when using a pickup of my invention and associated electronic equipment. Accelerometers made in accordance with my invention have multiple outputs in a single unit so that if one output fails, measurements may still be made. This is particularly important in missiles, rockets and similar devices in which space is at a premium.

It is an important object of my invention to provide a transducer in which more than one electromechanically sensitive element is used.

It is a further object of my invention to provide such a transducer wherein one of the several electromechanically sensitive elements is used to produce a mechanical stress from an electrical signal and another of the elements produces an electrical signal from the mechanical stress.

It is a still further object of my invention to provide such a transducer wherein there are a plurality of usable electrical outputs available from a single mechanical stress.

These and other objects, advantages, features and uses will be apparent during the course of the following description when taken in conjunction with the accompanying drawings wherein:

FIGURE 1 is a plan view of a preferred embodiment of my invention used as a directly-monitored phonograph recorder and wherein the associated circuits are shown in block schematic,

FIGURE 2 is a view similar to that of FIGURE 1 of a further embodiment of my invention used as a directly-monitored phonograph recorder,

FIGURE 3 is a view similar to that of FIGURE 1 showing an embodiment similar to that of FIGURE 1 used as a stereophonic phonograph reproducer,

FIGURE 4 is a view similar to that of FIGURE 1 showing an embodiment similar to that of FIGURE 2 used as a stereophonic phonograph reproducer,

FIGURE 5 is a view similar to that of FIGURE 1 showing a three channel stereophonic phonograph reproducer using a piezoelectric element and two single piezoresistive elements, and

FIGURE 6 is a view similar to that of FIGURE 1 showing a three channel stereophonic phonograph reproducer using a piezoelectric element and two double piezoresistive elements.

In the drawings, wherein, for the purpose of illustration, are shown several embodiments of devices of my invention, the numeral 10 generally designates a transducer used as a combined phonograph recorder and pickup. Transducer 10 is seen to comprise piezoelectric element 12, piezoresistive element 14, and stylus 16. Piezoelectric element 12 is preferably formed of ferroelectric ceramic such as barium titanate, lead titanate-zirconate, each with or without additives but may be formed of any other natural or artificial piezoelectric material so long as application of an electrical signal thereto will produce motion of stylus 16. Piezoresistive element 14 is preferably formed of P-type silicon cut in the 1,1,1 direction. The designation 1,1,1 is in accordance with the so-called Miller indices which are commonly used in the crystallographic art. However, other piezoresistive materials such as N-type silicon, P-type and N-type germanium, P-type and N-type indium antimonide and similar materials may also be used. Moreover, piezosensitive materials other than the piezoresistives may be used in the position of piezoresistive element 14.

Stylus 16 is affixed to the combination in accordance with the technique taught by Glenn N. Howatt in his United States Patent 2,640,165, issued May 26, 1953. Piezoelectric element 12 is seen to comprise ceramic strips 18 and 20 to which are affixed electrodes 22, 24, 26 and

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28 in a manner such as is taught in the aforementioned patent to Glenn N. Howatt. In accordance with the said patent's teachings, ceramic strips 18 and 20 are suitably affixed to flexible reinforcing plate 30 which is formed of copper or similar material. Piezoresistive element 14 is affixed to flexible reinforcing plate 32 by means of an epoxy resin and ceramic strip 20 is affixed to flexible reinforcing plate 32, which is formed of similar material to that of plate 30, in the same manner as ceramic strips 18 and 20 are affixed to flexible reinforcing plate 30. Ceramic strips 18 and 20 are oppositely polarized if they are to be used connected in series as shown in FIGURE 1 and are polarized in the same direction if they are to be used connected in parallel.

Electrical connection is made between piezoelectric element 12 and recording amplifier 36 by means of leads 34. Amplifier 36 has the appropriate gain and power output necessary to stress piezoelectric element 12 when an acoustic wave is applied to microphone 38. Electrodes 40 and 42 are painted on piezoresistive element 14 and leads 43 are suitably affixed thereto. Battery 44, variable resistor 46 and the primary of audio transformer 50 are connected in series with piezoresistive element 14 through electrodes 40 and 42. It can readily be seen that a change in the resistance of piezoresistive element 14 will produce a change in current flow in the primary of transformer 50. This change in current flow in the primary of transformer 50 causes an A.-C. voltage to be induced in the secondary of transformer 50 which voltage is amplified in monitor amplifier 52. Amplifier 52 has sufficient gain and power output to amplify the signal from the secondary of transformer 50 and to deliver enough power to drive loudspeaker 54 or a similar device such as a pair of headphones.

In operation, the user of the transducer of FIGURE 1 may monitor the signal applied to the recording medium by stylus 16 and thereby know of any failure instantaneously. Program is fed, for example, into microphone 38. The signal is amplified in recording amplifier 36 whose output is applied to piezoelectric element 12. This causes piezoelectric element 12 to stress and thus moves stylus 16. The movement of stylus 16 on the recording medium thereby records the acoustic signal from the microphone. The movement of piezoelectric element 12 also causes piezoresistive element 14 to stress in synchronism with the movement of piezoelectric element 12.

As a result of this movement, the resistance of piezoresistive element 14 is changed and an A.-C. signal is induced in the secondary of transformer 50. This A.-C. signal is amplified in monitor amplifier 52 and heard in loudspeaker 54. It should be noted that any other type of electroacoustic input may be substituted for microphone 38. For example, a phonograph pickup, tape playback or the audio output of a radio or television set may be used. Moreover, multiple audio inputs may be mixed ahead of the recording amplifier in any manner well-known in the art.

The transducer of FIGURE 3 is similar to that of FIGURE 1 but is connected as a phonograph pickup which produces a stereophonic output from a standard monaural record. The output of piezoresistive element 14 is connected in series with battery 44, variable resistor 46 and the primary of transformer 50 through leads 43 and electrodes 40 and 42. The secondary of transformer 50 is connected to the input of amplifier 56 and thence to loudspeaker 62. The output of piezoelectric element 12 is fed through leads 34 to variable filter and phase-shift network 58. The output of variable filter and phase-shift network 58 is connected to the input of amplifier 60 whose output is connected to loudspeaker 64.

If desired, another variable filter and phase-shift network may be connected between the secondary of transformer 50 and the input of amplifier 56. In this manner, certain frequencies can be confined to one channel and other frequencies can be confined to the other channel. High pass, low pass or band pass filters may be used and

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the phase difference between the two channels may be adjusted to produce the most pleasing effect for the listener. Standard phase-shift circuits, which are well-known in the art, may be used to accomplish the desired results. Moreover, the variable filter and phase-shift network may be connected at the output of the piezoresistive element instead of at the output of the piezoelectric element.

In operation, stylus 16' is moved by the grooves in the record being reproduced thereby causing transducer 10 to stress. As a result of this stress, piezoelectric element 12 and piezoresistive element 14 are stressed. An electrical signal appears at the input of amplifier 56 due to the change in resistance of piezoresistive element 14 and a second electrical signal appears at the input of variable filter and phase-shift network 58 due to the piezoelectric effect in piezoelectric element 12. By judicious location of loudspeakers 62 and 64 in the room and adjustment of variable filter and phase-shift network 58, I have been able to produce excellent stereophonic effects from monaural recordings.

It should be noted that the transducers of my invention are the so-called benders, that is, the end opposite the stylus is clamped to the pickup arm and the device is caused to bend while the clamped end remains fixed. Plates 30 and 32 serve to strengthen the transducers and thereby materially reduce the likelihood of cracking of the ceramic or the crystal.

In FIGURE 2, there is shown a further embodiment of transducer of my invention which is designated as 10' and wherein the piezoresistive element is designated as 14'. Piezoresistive element 14' comprises P-type silicon elements 15 and 17 cut in the 1,1,1 direction and a central, flexible plate 19. Plate 19 serves to strengthen the combination and elements 15 and 17 are bonded thereto by means of an epoxy resin. Electrodes 40 are painted to elements 15 and 17 at one end thereof and electrode 42a is applied to the other end of elements 15 and 17 and is common to both elements 15 and 17. Elements 15 and 17 are connected in a bridge circuit with fixed resistor 47 and variable resistor 49 by means of leads 43. Power is supplied to the bridge by battery 44 and the varying output due to the change in resistance of elements 15 and 17 is applied to the primary of transformer 50. To give mechanical strength to the transducer 10', piezoelectric element 12 and piezoresistive element 14' are affixed to flexible reinforcing plate 33 by means of an epoxy resin or similar adhesive. Plate 33 is formed of copper or similar material and is similar to reinforcing plates 30 and 32. The secondary of transformer 50 is connected to the input of variable filter and phase-shift network 51. The output of variable filter and phase-shift network 51 is connected to the input of amplifier 52 whose output is connected to loudspeaker 54. I have shown variable filter and phase-shift network 51 in FIGURE 2 in order to demonstrate the flexibility obtainable when using transducers of my invention. It should be noted that the embodiment of FIGURE 2 may be used without the variable filter and phase-shift network 51.

The operation of the transducer of FIGURE 2 is similar to that of the transducer of FIGURE 1. Piezoresistive element 14' is formed of two elements connected in a bridge circuit to thereby produce greater sensitivity than can be obtained from the single element of piezoresistive 14. When the embodiment of FIGURE 2 is used without variable filter and phase-shift network 51, the signal from microphone 38 is monitored in loudspeaker 54. When the variable filter and phase-shift network is used, special filter effects may be obtained in loudspeaker 54 even though a normal audio input is applied to microphone 38. By way of example but not by way of limitation, it is possible to produce telephone long line transmission quality at the loudspeaker or to otherwise limit or accentuate certain frequencies in the audio range.

The transducer of FIGURE 2 may be connected as a stereophonic pickup as shown in FIGURE 4. The opera-

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tion of the transducer is the same as that of FIGURE 3 except for the bridge circuit which is used in connection with elements 15 and 17 instead of the series circuit which is used in connection with element 14. It is to be noted that one variable filter and phase-shift network may be used instead of the two shown in the figure in the manner I have described in connection with the embodiment of FIGURE 3.

In FIGURE 5, there is shown a still further embodiment of transducer of my invention in which there are three active elements. Transducer 10" is seen to comprise piezoelectric element 12 and two piezoresistive elements 14 and 14a. Plates 30, 32 and 32a serve to strengthen the combination as has been described above in connection with the embodiments of FIGURES 1 through 4. Electrodes 40 and 42 are painted on piezoresistive element 14 and electrodes 40' and 42' are painted on piezoresistive element 14a. Battery 44, variable resistor 46 and the primary of transformer 50 are connected in series with piezoresistive element 14 by means of leads 43. Battery 44', variable resistor 46' and the primary of transformer 50' are connected in series with piezoresistive element 14' by means of leads 43'.

The secondary of transformer 50 is connected to variable filter and phase-shift network 70. The output of variable filter and phase-shift network 70 is connected to the input of amplifier 72 whose output is connected to loudspeaker 74. The secondary of transformer 50' is connected to variable filter and phase-shift network 70'. The output of variable filter and phase-shift network 70' is connected to the input amplifier 72' whose output is connected to loudspeaker 74'. The output of piezoelectric element 12 is fed to variable filter and phase-shift network 58 by means of leads 34. The output of variable filter and phase-shift network 58 is connected to the input of amplifier 60. The output of amplifier 60 is connected to loudspeaker 64.

I have found that better stereo effects are obtained from a three channel system such as is illustrated in FIGURE 5 than from the two channel systems illustrated in FIGURES 3 and 4. The three speakers may be placed in the room and the filter and phase-shift networks adjusted so that the maximum of audio presence is obtained. Moreover, the flexibility of adjustment permits the user to vary the reproduction of the monaural records to suit his own taste.

In FIGURE 6, transducer 11 is seen to comprise piezoelectric element 12 and piezoresistive elements 14' and 14a'. Piezoresistive elements 14' and 14a' are similar to piezoresistive element 14' of FIGURES 2 and 4. Piezoresistive element 14' comprises piezoresistive elements 15 and 17 and plate 19 and piezoresistive element 14a' comprises piezoresistive elements 15' and 17' and plate 19'. Electrodes 40 and 42a are applied to piezoresistive element 14' and electrodes 40' and 42a' are applied to piezoresistive element 14a'. Resistor 47 and variable resistor 49 are connected in a bridge circuit with piezoresistive elements 15 and 17 by means of leads 43. Battery 44 supplies power to the bridge and its output is connected to the primary of transformer 50. Resistor 47' and variable resistor 49' are connected in a bridge circuit with piezoresistive elements 15' and 17' by means of leads 43'. Battery 44' supplies power to the bridge and its output is connected to the primary of transformer 50'.

The secondary of transformer 50 is connected to variable filter and phase-shift network 70 whose output is connected to the input of amplifier 72. The output of amplifier 72 is connected to loudspeaker 74. The secondary of transformer 50' is connected to variable filter and phase-shift network 70' whose output is connected to the input of amplifier 72'. The output of amplifier 72' is connected to loudspeaker 74'. The output of piezoelectric element 12 is fed by means of leads 34 to variable filter and phase-shift network 58 whose output is con-

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nected to the input of amplifier 60. The output of amplifier 60 is connected to loudspeaker 64.

The embodiment of FIGURE 6 has increased sensitivity over that of FIGURE 5 and is operated as a three channel system with results which are similar to those described for the embodiment of FIGURE 5.

While I have shown the filter and phase-shift network as a single element placed between the electromechanically sensitive element and the amplifier in all the illustrations, it is also within the contemplation of my invention to use separate filter and/or phase-shift networks at any suitable place in the system.

While I have disclosed my invention in relation to specific examples and in specific embodiments, I do not wish to be limited thereto, for obvious modifications will occur to those skilled in the art without departing from the spirit and scope of my invention.

Having thus described my invention, I claim:

1. A transducer comprising a pair of thin strips of piezoelectric ceramic, a metal strip, an electrode applied to each surface of each of said thin strips of piezoelectric ceramic, said thin strips of piezoelectric ceramic being affixed to said metal strip such that electrical and mechanical contact is made between an electrode on each of said thin strips of piezoelectric ceramic and said metal strip, a thin strip of piezoresistive material, a pair of electrodes applied to said thin strip of piezoresistive material, said thin strip of piezoresistive material being affixed to one of said thin strips of piezoelectric ceramic on the surface thereof opposite that affixed to said metal strip, means for making electrical connection to the electrodes applied to said thin strips of piezoelectric ceramic, and means for making electrical connection to the electrodes applied to said thin strip of piezoresistive material.
2. A transducer comprising a pair of thin strips of piezoelectric ceramic, a first metal strip, an electrode applied to each surface of each of said thin strips of piezoelectric ceramic, said thin strips of piezoelectric ceramic being affixed to said first metal strip such that electrical and mechanical contact is made between an electrode on each of said thin strips of piezoelectric ceramic and said first metal strip, a pair of thin strips of piezoresistive material, a pair of electrodes applied to each of said thin strips of piezoresistive material, a second metal strip, said thin strips of piezoresistive material being affixed to each surface of said second metal strip such that said second metal strip is mounted between said thin strips of piezoresistive material, one outer surface of one of said thin strips of piezoelectric ceramic being affixed to one outer surface of one of said thin strips of piezoresistive material, means for making electrical connection to the electrodes applied to said thin strips of piezoelectric ceramic, and means for making electrical connection to the electrodes applied to said thin strips of piezoresistive material.
3. An electromechanical device comprising a pair of thin strips of piezoelectric ceramic, a metal strip, an electrode applied to each surface of each of said thin strips of piezoelectric ceramic, said thin strips of piezoelectric ceramic being affixed to said metal strip such that electrical and mechanical contact is made between an electrode on each of said thin strips of piezoelectric ceramic and said metal strip, a thin strip of piezoresistive material, a pair of electrodes applied to said thin strip of piezoresistive material, said thin strip of piezoresistive material being affixed to one of said thin strips of piezoelectric ceramic on the surface thereof opposite that affixed to said metal strip, means for making electrical connection to the electrodes applied to said thin strips of piezoelectric ceramic, means for making electrical connection to the electrodes applied to the thin strip of piezoresistive material, means for applying mechanical stress to the combination, a first amplifier connected to the electrodes applied to said thin strips of piezoelectric ceramic, a source of voltage, a resistor, and a second amplifier, said source of voltage, said resistor and said second amplifier being

connected to the electrodes applied to said thin strip of piezoresistive material such that said thin strip of piezoresistive material is in series with said source of voltage, said resistor and the input of said second amplifier.

4. An electromechanical device as described in claim 3 including phase-shifting means connected to the input of said second amplifier.

5. An electromechanical device as described in claim 3 including filter means connected to the input of said second amplifier.

6. An electromechanical device comprising a pair of thin strips of piezoelectric ceramic, a metal strip, an electrode applied to each surface of each of said thin strips of piezoelectric ceramic, said thin strips of piezoelectric ceramic being affixed to said metal strip such that electrical and mechanical contact is made between an electrode on each of said thin strips of piezoelectric ceramic and said metal strip, a thin strip of piezoresistive material, a pair of electrodes applied to said thin strip of piezoresistive material, said thin strip of piezoresistive material being affixed to one of said thin strips of piezoelectric ceramic on the surface thereof opposite that affixed to said metal strip, means for making electrical connection to the electrodes applied to said thin strips of piezoelectric ceramic, means for making electrical connection to the electrodes applied to the thin strip of piezoresistive material, means for applying electrical excitation to said thin strips of piezoelectric ceramic connected to the electrodes applied to said thin strips of piezoelectric ceramic and amplifying means connected to the electrodes applied to the thin strip of piezoresistive material.

7. An electromechanical device comprising a pair of thin strips of piezoelectric ceramic, a first metal strip, an electrode applied to each surface of each of said thin strips of piezoelectric ceramic, said thin strips of piezoelectric ceramic being affixed to said first metal strip such that electrical and mechanical contact is made between an electrode on each of said thin strips of piezoelectric ceramic and said first metal strip, a pair of thin strips of piezoresistive material, a pair of electrodes applied to each of said thin strips of piezoresistive material, a second metal strip, said thin strips of piezoresistive material being affixed to each surface of said second metal strip such that said second metal strip, is mounted between said thin strips of piezoresistive material, one outer surface of one of said thin strips of piezoelectric ceramic being affixed to one outer surface of one of said thin strips of piezoresistive material, means for making electrical connection to the electrodes applied to said thin strips of piezoelectric ceramic, means for making electrical connection to the electrodes applied to said thin strips of piezoresistive material, means for applying mechanical stress to the combination, a first amplifier connected to the electrodes applied to said thin strips of piezoelectric ceramic, a source of voltage, a first resistor, a second resistor and a second amplifier, said source of voltage, said first resistor, said second resistor, and said second amplifier being connected to the electrodes applied to said thin strip of piezoresistive material such that said thin strips of piezoresistive material form two arms of a bridge circuit and said first resistor and said second resistor form the other two arms of said bridge circuit, said source of voltage being connected to two opposite terminals of said bridge circuit and the input of said second amplifier being connected to the other two terminals of said bridge circuit.

8. An electromechanical device as described in claim 7 including phase-shifting means connected between the bridge circuit and the input of said second amplifier.

9. An electromechanical device as described in claim 7 including filter means connected between the bridge circuit and the input of said second amplifier.

10. An electromechanical device comprising a pair of thin strips of piezoelectric ceramic, a first metal strip, an

electrode applied to each surface or each of said thin strips of piezoelectric ceramic, said thin strips of piezoelectric ceramic being affixed to said first metal strip such that electrical and mechanical contact is made between an electrode on each of said thin strips of piezoelectric ceramic and said first metal strip, a pair of thin strips of piezoresistive material, a pair of electrodes applied to each of said thin strips of piezoresistive material, a second metal strip, said thin strips of piezoresistive material being affixed to each surface of said second metal strip such that said second metal strip is mounted between said thin strips of piezoresistive material, one outer surface of one of said thin strips of piezoelectric ceramic being affixed to one outer surface of one of said thin strips of piezoresistive material, means for making electrical connection to the electrodes applied to said thin strips of piezoelectric ceramic, means for making electrical connection to the electrodes applied to said thin strips of piezoresistive material, means for applying electrical excitation to said thin strips of piezoelectric ceramic connected to the electrodes applied to said thin strips of piezoelectric ceramic and amplifying means connected to the electrodes applied to the thin strip of piezoresistive material.

11. A transducer comprising a pair of thin strips of piezoelectric ceramic, an electrode applied to each surface of said thin strips of piezoelectric ceramic, a metal strip, said thin strips of piezoelectric ceramic being affixed to said metal strip such that electrical and mechanical contact is made between an electrode on each of said thin strips of piezoelectric ceramic and said metal strip, a pair of thin strips of piezoresistive material, a pair of electrodes applied to each of said pair of thin strips of piezoresistive material, one of said pair of thin strips of piezoresistive material being affixed to the outer surface of one of said thin strips of piezoelectric ceramic, the other of said pair of thin strips of piezoresistive material being affixed to the outer surface of the other of said thin strips of piezoelectric ceramic, means for making electrical connection to the electrodes applied to said thin strips of piezoelectric ceramic, and means for making electrical connection to the electrodes applied to said pair of thin strips of piezoresistive material.

12. A transducer comprising a pair of thin strips of piezoelectric ceramic, a first metal strip, an electrode applied to each surface of each of said thin strips of piezoelectric ceramic, said thin strips of piezoelectric ceramic being affixed to said first metal strip such that said first metal strip is mounted between said pair of thin strips of piezoelectric ceramic and such that said first metal strip makes electrical and mechanical contact with the electrodes on the inner surfaces of said thin strips of piezoelectric material, two pairs of thin strips of piezoresistive material, a pair of electrodes applied to each of said thin strips of piezoresistive material, a second metal strip, a third metal strip, one of said pairs of thin strips of piezoresistive material being affixed to said second metal strip such that said second metal strip is mounted therebetween, the other of said pairs of thin strips of piezoresistive material being affixed to said third metal strip such that said third metal strip is mounted therebetween, said pairs of thin strips of piezoresistive material being affixed to said pair of thin strips of piezoelectric ceramic such that said pair of thin strips of piezoelectric ceramic are mounted between said pairs of thin strips of piezoresistive material, means for making electrical connection to the electrodes applied to said thin strips of piezoelectric ceramic, and means for making electrical connection to the electrodes applied to said thin strips of piezoresistive material.

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