

June 11, 1963

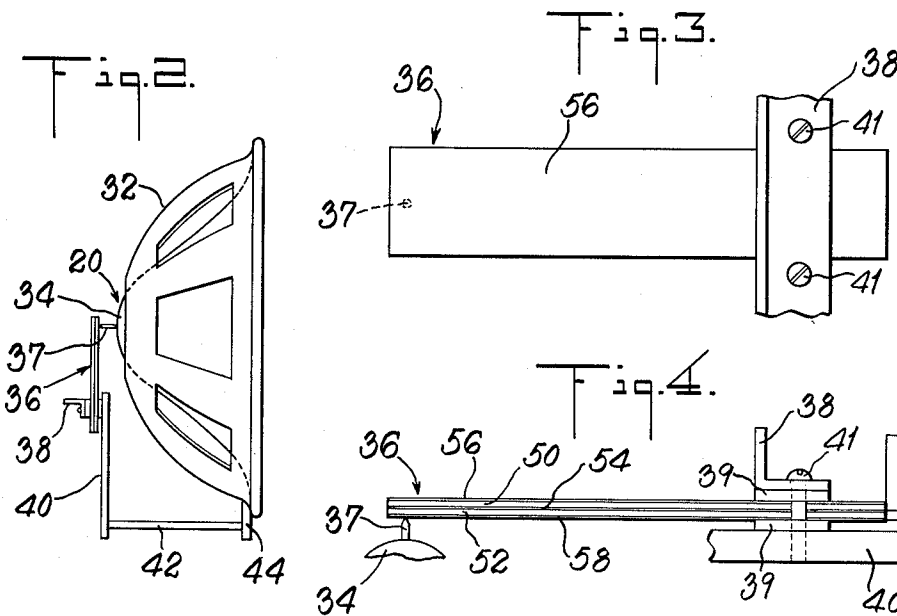
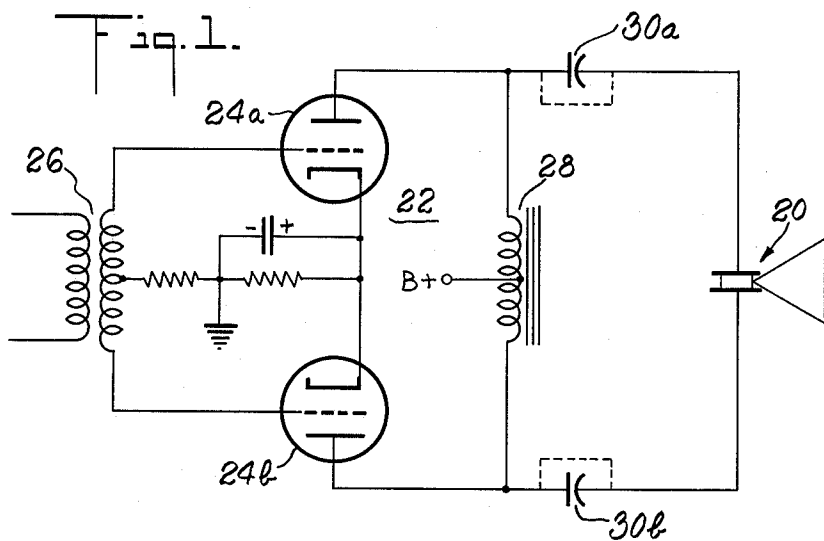
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3,093,710

PIEZOELECTRIC ELECTROMECHANICAL TRANSDUCER

Filed July 6, 1959

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

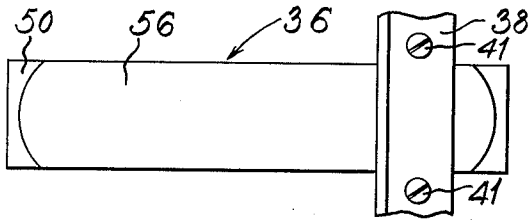


Fig. 5.

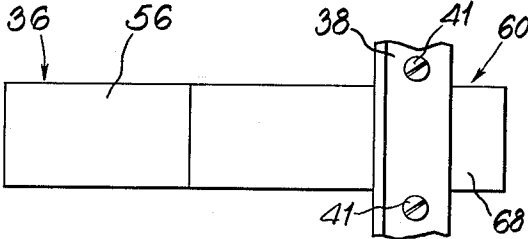


Fig. 6.

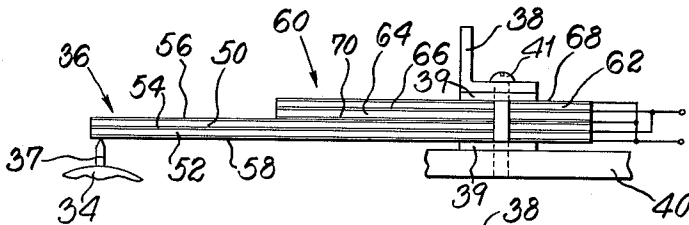


Fig. 7.

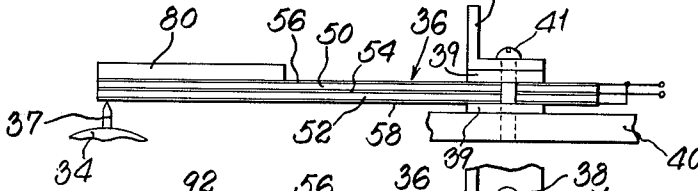


Fig. 8.

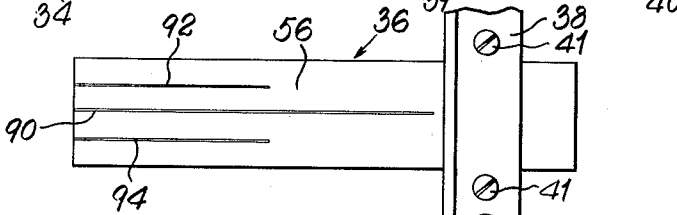


Fig. 9.

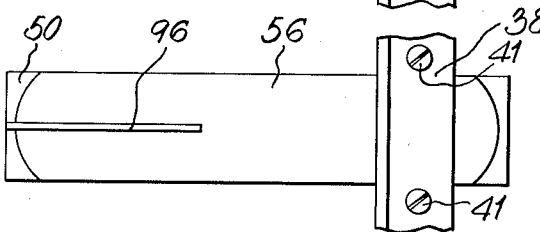


Fig. 10.

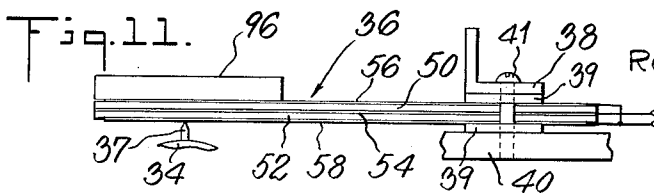


Fig. 11.

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PIEZOELECTRIC ELECTROMECHANICAL  
TRANSDUCER

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Filed July 6, 1959, Ser. No. 825,361  
16 Claims. (Cl. 179—110)

This application is a continuation-in-part of my application Serial Number 803,524, filed April 1, 1959 now abandoned.

My invention relates to electromechanical devices and in particular to those devices which require a reasonably flat frequency response over the audible range. More particularly, my invention is directed toward providing an electromechanically sensitive ceramic transducer for driving such devices. While I shall describe my invention in terms of driving a loudspeaker with such a transducer, it should be clearly understood that the transducers of my invention may be used for driving any electromechanical devices such as meters, servo valves, record cutters (both stereo and monaural), and relays.

In the prior art there have been many attempts to produce loudspeakers which were driven by ceramic transducers. However, all of them lacked low frequency response and as a result their use was confined to the high frequency element in multispeaker arrays. Since the use of a piezoelectrically driven loudspeaker will eliminate the need for an output transformer, there is a definite demand for such a speaker with a fuller frequency range.

Accordingly, it is an important object of my invention to provide an electromechanical device driven by a piezoelectric ceramic transducer which possesses a reasonably flat frequency response over the audible range.

It is a further object of my invention to provide a loudspeaker with the foregoing properties which is simple to fabricate and produce.

It is a still further object of my invention to provide a ceramic transducer capable of driving such a device.

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

FIGURE 1 is a schematic diagram of a preferred output circuit used in conjunction with loudspeakers of my invention,

FIGURE 2 is an elevational view of a preferred embodiment of my invention showing the connection of the driving transducer to the diaphragm,

FIGURE 3 is a plan view of the transducer of FIGURE 2,

FIGURE 4 is an elevational view of the transducer of FIGURE 3,

FIGURE 5 is a view similar to FIGURE 3 showing a transducer wherein only a portion of each of the outer surfaces is covered by an electrode,

FIGURE 6 is a view similar to FIGURE 3 showing a transducer to the upper surface of which there is affixed a second transducer,

FIGURE 7 is a view similar to FIGURE 4 showing a second transducer bonded to the upper surface of the transducer of FIGURE 3,

FIGURE 8 is a view similar to FIGURE 4 showing an electromechanically inert thin strip bonded to the upper surface of the transducer of FIGURE 3,

FIGURE 9 is a view similar to FIGURE 3 wherein a plurality of thin cuts have been made in the upper surface of the transducer of FIGURE 3,

FIGURE 10 is a view similar to FIGURE 3 wherein

an electromechanically inert element is mounted edge-wise on the transducer of FIGURE 5, and

FIGURE 11 is a view similar to FIGURE 4 of the assembly of FIGURE 10.

In the drawings, wherein, for the purpose of illustration, are shown preferred embodiments of the loudspeaker of my invention, the numeral 20 designates the loudspeaker generally. Loudspeaker 20 is fed from amplifier 22 which comprises push-pull electron tubes 24a and 24b, input transformer 26, output inductor 28 and isolating capacitors 30a and 30b. Capacitors 30a and 30b may be dispensed with, as shown by the dotted lines in FIGURE 1, but under such conditions the plate voltage appears on the transducer of loudspeaker 20 and presents some shock hazard to the user of the equipment.

Loudspeaker 20 (FIGURE 2) is seen to comprise frame 32, diaphragm 34, transducer 36, transducer clamp 38, driving pin 3, mounting plate 40, mounting strut 42 and mounting frame 44. Clamp 38 is held to mounting plate 40 by means of screws 41 and an insulator 39 of polyethylene plastic or similar material is placed between the transducer and the clamp and another is placed between the transducer and the mounting plate to obtain electrical isolation of the transducer from the mounting assembly. Frame 32 is sometimes referred to as the basket and diaphragm 34 is often referred to as the cone. It should be noted, however, that diaphragm 34 in loudspeakers of my invention need not be circular in the plane at which it is joined to frame 32. Any other shape such as ellipses, polygons or any other closed figure may be used equally effectively. The diaphragm must be tapered so that its widest opening is in the plane at which it is joined to the frame.

I have found it best to fashion transducer 36 in the form of a ceramic sandwich wherein there are two ceramic thin strips 50 and 52 bonded together with a thin brass shim 54 between them in a manner well-known in the art. Electrodes 56 and 58 are suitably affixed to strips 50 and 52 in any manner well-known in the art such as by reduction, electrodeposition or other means. Driving pin 37 is affixed to transducer 36 and to diaphragm 34 by bonding cement such as the radio service cement manufactured by General Cement Co. Clamp 38 is preferably made of steel and is affixed to mounting plate 40, which is made of brass, by means of screws 41, as shown in the figures. I choose to make clamp 38 of angle iron to achieve greater rigidity and to eliminate the bowing which is present when a flat, thin piece is used for the clamp. However, if a heavy enough material which will not bow or buckle under pressure of the bolts, is used, angle iron is unnecessary. Mounting stud 42 and mounting frame 44 serve to anchor clamp 38 so that there is no mechanical interaction between the frame and the diaphragm.

I have found that I obtain good frequency response using loudspeakers of my invention when the transducer is formed of lead titanate-zirconate and has the following dimensions:

Length:  $3\frac{3}{4}$ " to  $4\frac{1}{2}$ "

Width:  $\frac{5}{8}$ " to  $\frac{7}{8}$ "

Thickness of each ceramic element of the sandwich: .028" to .032".

I have also found that I can obtain equally good results if pin 37 is located at positions along the longitudinal dimension of transducer 36 so long as it is at least halfway between clamp 38 and the free end of transducer 36. Moreover, I have found it best to have some overhang of the transducer behind the clamp. This overhang should be between approximately  $\frac{1}{4}$  inch and  $\frac{1}{2}$  inch.

While I have obtained satisfactory results using a single sandwich such as is illustrated in FIGURES 3 and 4 wherein the two ceramic elements 50 and 52 are polarized in the thickness mode and in the same direction and are fed as indicated in FIGURE 4, it is also possible to polarize the two ceramic elements in opposite directions in the thickness mode and feed the two outer electrodes. In such a case, the transducer has its elements driven in series, has an impedance four times that of the parallel feed shown in the figures and requires twice the driving voltage.

Improved frequency response is obtained by making the modifications discussed below. For example, some undesired resonances of transducer 36 are damped out by removing some of electrode 56 as shown in FIGURES 5 and 10. The response of the transducer is also improved by cutting thin grooves 90, 92 and 94 in the upper surface of ceramic element 50 as shown in FIGURE 9. I have also found that a single thin groove also produces improvement in the response of the transducer over that of FIGURES 3 and 4.

Similar improvements in frequency response are obtained when using the modifications of FIGURES 6, 7, 8, 10 and 11. FIGURE 6 is a horizontal plan view of the embodiment of FIGURE 7. In FIGURE 7 there is shown a second transducer 60 of the same shape and material as transducer 36 but shorter in length. Transducer 60 is made up of ceramic elements 62 and 64, central brass shim 66 and outer electrodes 68 and 70. Transducer 60 is bonded to transducer 36 by means of bonding cement and is fed in parallel therewith as shown in FIGURE 7. I have found that transducer 60 should not extend beyond half the free or driving length of transducer 36.

In FIGURE 8, there is shown a still further modification of transducer 36 for driving loudspeakers of my invention. Strip 80 is formed of phenolic, laminated melamine glass or similar material and is bonded to the upper surface of transducer 36 by means of bonding cement and the transducer is driven as described heretofore. Generally, strip 80 should not occupy more than half the free end of transducer 36.

In FIGURES 10 and 11 there is shown a still further embodiment of transducer of my invention. The removal of portions of the electrodes as shown in FIGURE 5 improves the frequency responses over that of the transducer of FIGURE 4 and the mounting of a thin, plastic strip edgewise on one surface of the transducer results in additional improvement over the embodiment of FIGURE 4. I have found that the unwanted, undesired resonances are damped out when this embodiment is used to drive a loudspeaker diaphragm in loudspeakers of my invention. I have obtained excellent results when the length of the electromechanically inert plastic strip is approximately one half the length of the driving end of the transducer and the junction of the inert strip and the transducer is parallel to the longitudinal edges of the transducer.

It should be noted that I have found that better results are obtained if the contact between the transducer and pin 37 is as thin as possible, essentially a knife edge contact, as shown in the figures.

In operation, audio signal is applied to transformer 46 whose secondary is connected in push-pull to the grids of tubes 24a and 24b. The plates of tubes 24a and 24b are also connected in push-pull and B+ is applied to the plates through the center tap of inductor 28. The output of the push-pull amplifier is fed to loudspeaker 20 through capacitors 30a and 30b. Capacitors 30a and 30b serve to keep the high, positive plate voltage off the transducer of loudspeaker 20. The circuit shown in FIGURE 1 and described herein is one example of an amplifier which may be used to drive loudspeakers of my invention. Any other amplifier, which produces audio frequency output voltage sufficient to drive the transducer, may also be employed in carrying out the teachings of my invention.

Ceramic transducers of my invention deliver relatively high amplitudes with reasonably flat response over the audible frequency range. These transducers may be connected to a cutting stylus or phonograph pickup needle in pairs at an angle of 90° and used for stereo recording. A single such transducer may be used for monaural recording. A plurality of such transducers may be used for reed relays and similar devices and a single such transducer or a plurality of them may be used as the sensitive element in servo valves, meters and other devices requiring a reasonably flat frequency response.

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. An electromechanical device comprising mounting means, an elongated electromechanically sensitive ceramic transducer clamped adjacent one end to said mounting means and including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, mechanical operating means connected to the free end of said transducer for operation thereby, and means on and adjacent to the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range.

2. An electromechanical device comprising, an elongated electromechanically sensitive ceramic transducer including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, mounting means, means for clamping said elongated transducer near one end thereof to the mounting means so that the active free end of the elongated transducer is approximately  $2\frac{1}{2}$  times as long as the opposite end beyond the point of clamping, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, mechanical operating means connected to the free end of said transducer for operation thereby.

3. An electromechanical device comprising, an elongated electromechanically sensitive ceramic transducer including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, mounting means, means for clamping said elongated transducer near one end thereof to the mounting means so that the active free end of the elongated transducer is approximately  $2\frac{1}{2}$  times as long as the opposite end beyond the point of clamping, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, mechanical operating means connected to the free end of said transducer for operation thereby, and means adjacent the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range.

4. An electromechanical device comprising mounting means, an elongated electromechanically sensitive ceramic transducer clamped adjacent one end to said mounting means and including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, mechanical operating means connected to the free end of said transducer for operation thereby, said electrodes of said elongated transducer terminating short of the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range.

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5. An electromechanical device comprising mounting means, an elongated electromechanically sensitive ceramic transducer clamped adjacent one end to said mounting means and including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, mechanical operating means connected to the free end of said transducer for operation thereby, and means on and adjacent to the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range, said last mentioned means including an electromechanically inert strip affixed to said transducer adjacent the free end thereof.

6. An electromechanical device comprising mounting means, an elongated electromechanically sensitive ceramic transducer clamped adjacent one end to said mounting means and including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, mechanical operating means connected to the free end of said transducer for operation thereby, and means on and adjacent to the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range, said last mentioned means including a thin strip of electromechanically inert material affixed at one of its longer edges to said transducer adjacent the free end thereof and parallel to the longitudinal axis of the transducer.

7. An electromechanical device comprising mounting means, an elongated electromechanically sensitive ceramic transducer clamped adjacent one end to said mounting means and including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, mechanical operating means connected to the free end of said transducer for operation thereby, and means on and adjacent to the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range, said last mentioned means including an electromechanically inert strip affixed to said transducer adjacent the free end thereof for approximately one half the driving length of said transducer.

8. A electromechanical device comprising mounting means, an elongated electromechanically sensitive ceramic transducer clamped adjacent one end to said mounting means and including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, mechanical operating means connected to the free end of said transducer for operation thereby, and means on and adjacent to the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range, said last mentioned means including at least one cut in at least one surface of the transducer adjacent the free end thereof and parallel to the longitudinal axis of the transducer.

9. A loudspeaker comprising a frame, a flexible diaphragm affixed to said frame, mounting means carried by said frame, an elongated electromechanically sensitive ceramic transducer clamped adjacent one end to said mounting means and including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for driv-

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ing said transducer in bending mode including electrical connections to said conductor strip and electrodes, means for mechanically connecting the free end of said transducer to said flexible diaphragm for flexing the same, and means on and adjacent to the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range.

10. A loudspeaker comprising a frame, a flexible diaphragm affixed to said frame, mounting means carried by said frame, an elongated electromechanically sensitive ceramic transducer including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for clamping said elongated transducer near one end thereof to the mounting means so that the active free end of the elongated transducer is approximately  $2\frac{1}{2}$  times as long as the opposite end beyond the point of clamping, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, means for mechanically connecting the free end of said transducer to said flexible diaphragm for flexing the same.

11. A loudspeaker comprising a frame, a flexible diaphragm affixed to said frame, mounting means carried by said frame, an elongated electromechanically sensitive ceramic transducer including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for clamping said elongated transducer near one end thereof to the mounting means so that the active free end of the elongated transducer is approximately  $2\frac{1}{2}$  times as long as the opposite end beyond the point of clamping, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, means for mechanically connecting the free end of said transducer to said flexible diaphragm for flexing the same, and means adjacent the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range.

12. A loudspeaker comprising a frame, a flexible diaphragm affixed to said frame, mounting means carried by said frame, an elongated electromechanically sensitive ceramic transducer clamped adjacent one end to said mounting means and including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, means for mechanically connecting the free end of said transducer to said flexible diaphragm for flexing the same, said electrodes of said elongated transducer terminating short of the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range.

13. A loudspeaker comprising a frame, a flexible diaphragm affixed to said frame, mounting means carried by said frame, an elongated electromechanically sensitive ceramic transducer clamped adjacent one end to said mounting means and including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, means for mechanically connecting the free end of said transducer to said flexible diaphragm for flexing the same, and means on and adjacent to the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range, said last mentioned means including an electromechanically inert strip affixed to said transducer adjacent the free end thereof.

14. A loudspeaker comprising a frame, a flexible dia-

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phragm affixed to said frame, mounting means carried by said frame, an elongated electromechanically sensitive ceramic transducer clamped adjacent one end to said mounting means and including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, means for mechanically connecting the free end of said transducer to said flexible diaphragm for flexing the same, and means on and adjacent to the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range, said last mentioned means including a thin strip of electromechanically inert material affixed at one of its longer edges to said transducer adjacent the free end thereof and parallel to the longitudinal axis of the transducer.

15. A loudspeaker comprising a frame, a flexible diaphragm affixed to said frame, mounting means carried by said frame, an elongated electromechanically sensitive ceramic transducer clamped adjacent one end to said mounting means and including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, means for mechanically connecting the free end of said transducer to said flexible diaphragm for flexing the same, and means on and adjacent to the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range, said last mentioned means including an electromechanically inert strip affixed

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to said transducer adjacent the free end thereof for approximately one half the driving length of said transducer.

16. A loudspeaker comprising a frame, a flexible diaphragm affixed to said frame, mounting means carried by said frame, an elongated electromechanically sensitive ceramic transducer clamped adjacent one end to said mounting means and including a pair of polarized piezoelectric thin ceramic strips and a conductor strip forming a unitary sandwich and a pair of electrodes on the outer surfaces of said thin ceramic strips, means for driving said transducer in bending mode including electrical connections to said conductor strip and electrodes, means for mechanically connecting the free end of said transducer to said flexible diaphragm for flexing the same, and means on and adjacent to the free end of the transducer for damping the same to provide a substantially flat frequency response over the audible range, said last mentioned means including at least one cut in at least one surface of the transducer adjacent the free end thereof and parallel to the longitudinal axis of the transducer.

#### References Cited in the file of this patent

##### UNITED STATES PATENTS

|           |            |               |
|-----------|------------|---------------|
| 2,045,403 | Nicholides | June 23, 1936 |
| 2,166,326 | Riesz      | July 18, 1939 |
| 2,223,537 | Sykes      | Dec. 3, 1940  |
| 2,269,403 | Williams   | Jan. 6, 1942  |
| 2,352,311 | Di Toro    | June 27, 1944 |
| 2,510,811 | Gale       | June 6, 1950  |
| 2,587,684 | Bauer      | Mar. 4, 1952  |
| 2,640,165 | Howatt     | May 26, 1953  |

##### FOREIGN PATENTS

|         |               |               |
|---------|---------------|---------------|
| 698,989 | Great Britain | Oct. 28, 1953 |
|---------|---------------|---------------|