310-369 SR
XR 3,900,748
CROSS REFERENCE

United States Patent [19]
Adler
[11] 3,900,748
[45] Aug. 19, 1975

[54] TORSIONAL CERAMIC TRANSDUCER

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[73] Assignee: **Zenith Radio Corporation**, Chicago, Ill.

[22] Filed: **Jan. 31, 1972**

[21] Appl. No.: **222,201**

[52] **U.S. Cl.** **310/9.6**; 310/9.7
[51] **Int. Cl.**[2] **H01L 41/04**
[58] **Field of Search** 310/8, 8.2, 8.3, 8.6, 9.6, 310/9.7, 9.8

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Primary Examiner—Mark O. Budd
Attorney, Agent, or Firm—John H. Coult

[57] **ABSTRACT**

A transducer capable of large excursions in response to a signal takes the form of a coiled element of ferroelectric material. Shear stresses produced in opposite faces of the element oppose each other, so that each incremential portion of the element is subjected to a net torsional or twisting stress about its centerline, with resulting axial displacement of the coil. The element may be coiled either helically or spirally. Such axial movement may be used, for example, to drive the cone of a loudspeaker. In one general approach, a pair of electrodes, spaced side-by-side and helically wound on the outer surface of a coiled tube, are coupled across a signal source. In another form, the coiled element is composed of a pair of joined sections which carry symmetrically mirrored electrode pairs canted to the element centerline and embracing oppositely poled portions of the mating sections. The driving signals are coupled interdigitally to the electrode pairs. The transducers also may be operated in the reverse mode as generators.

12 Claims, 11 Drawing Figures

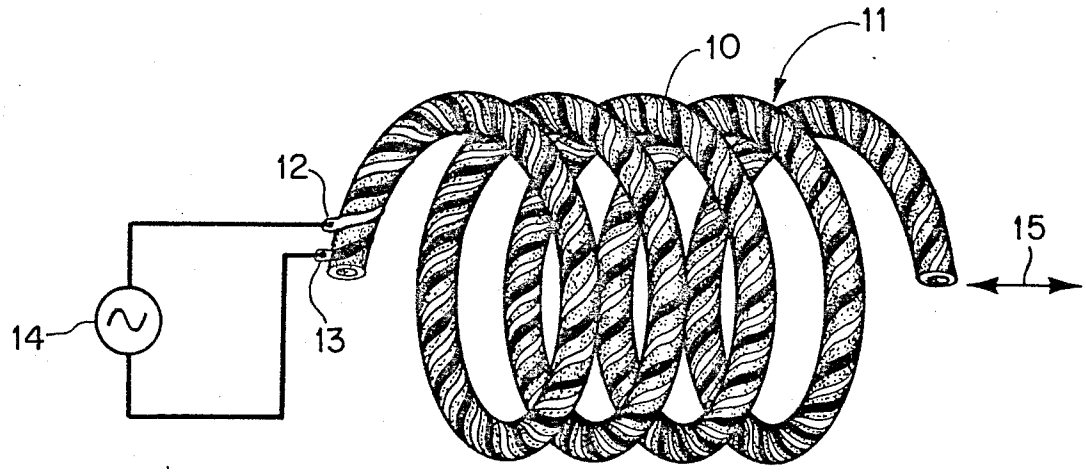


FIG. 1

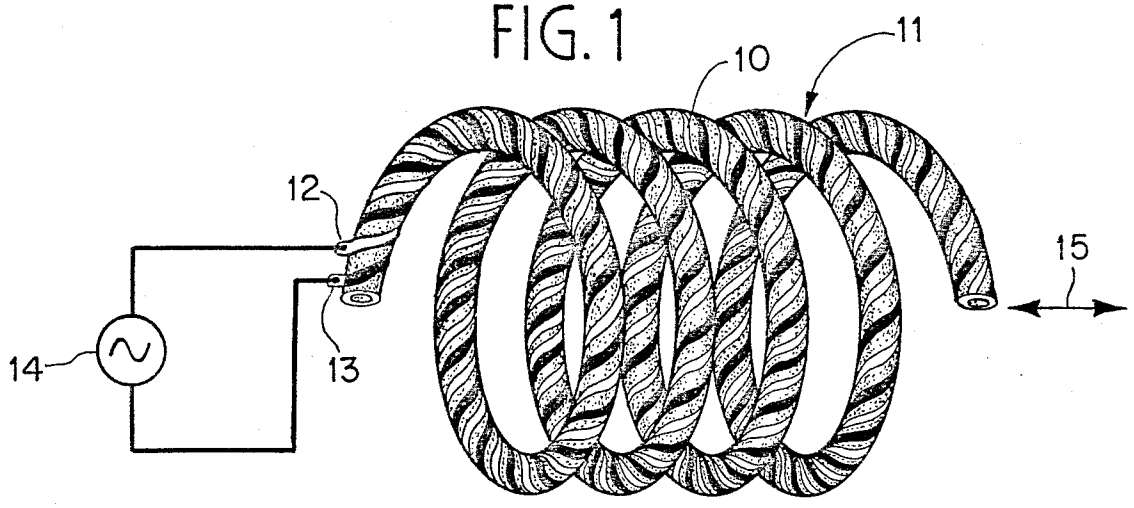


FIG. 1a

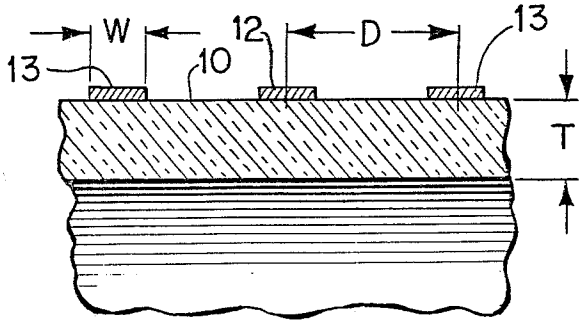


FIG. 2

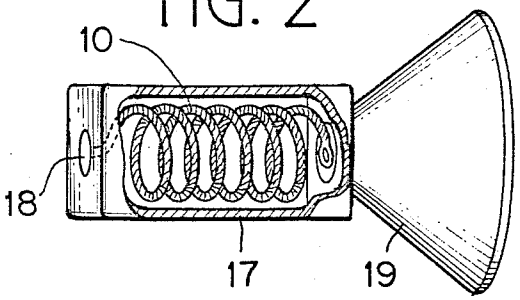


FIG. 3a

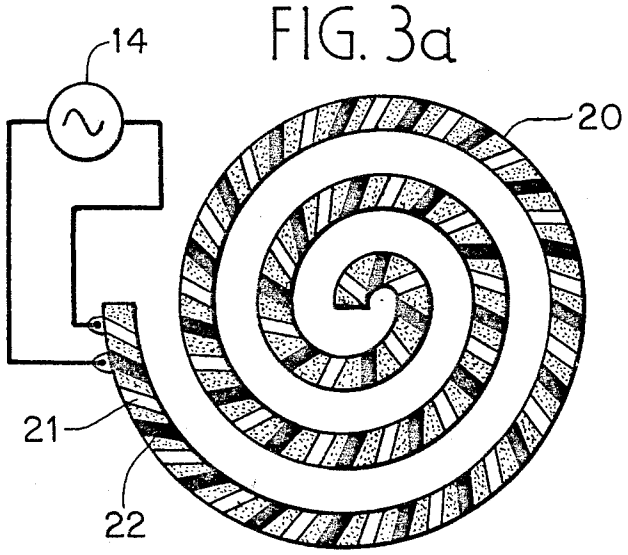


FIG. 3c

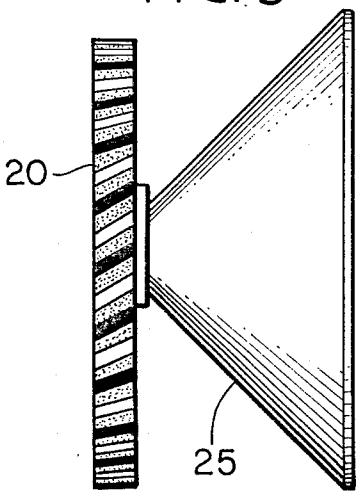


FIG. 3b

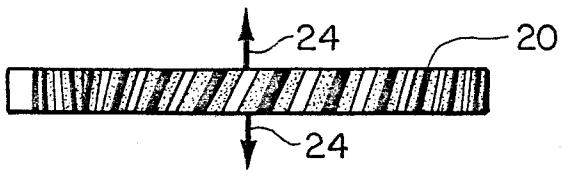


FIG. 4

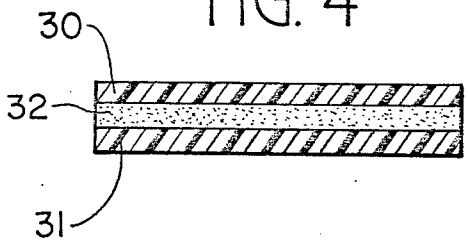


FIG. 5

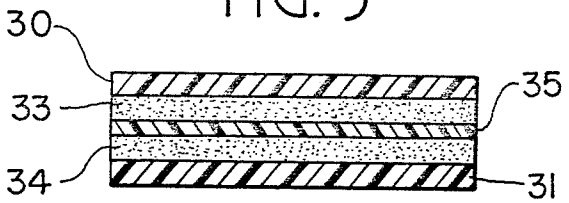


FIG. 6a

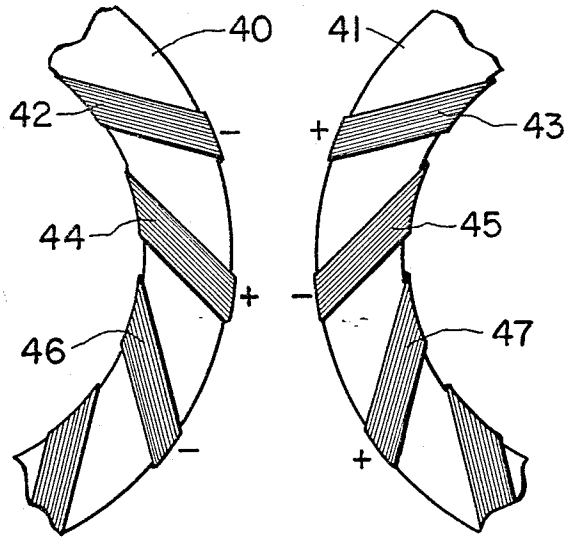
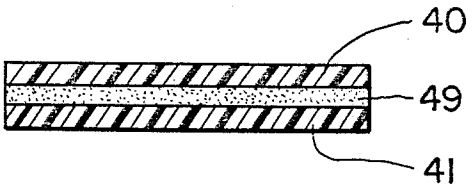


FIG. 6b



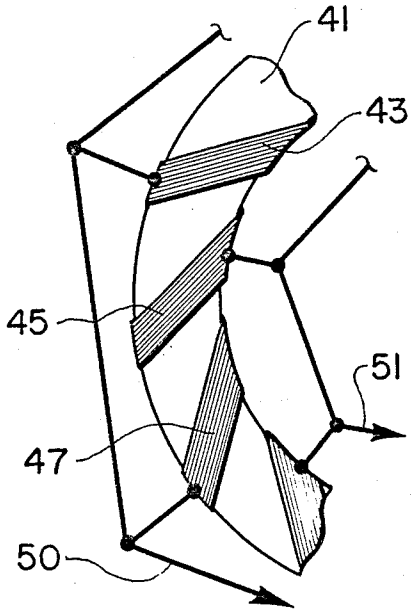


FIG. 6c

TORSIONAL CERAMIC TRANSDUCER

BACKGROUND OF THE INVENTION

The present invention pertains to transducers. More particularly, it relates to a ferroelectric transducer which is characterized by its high compliance.

Ferroelectric transducers have found a wide variety of uses. In some devices, as in a sound reproducer, the property of expansion and contraction in response to an applied signal is utilized. In others, the reverse application is employed wherein a voltage is generated in response to mechanical force applied to the transducer. In both types of device, various different modes of electro-mechanical action have been of interest. Some versions, utilizing a sandwich of two piezoelectric elements, feature a bending action. Others may respond with respect to a twisting action. For example, two oppositely-poled half cylinders of a ceramic material may be joined together in such a way as to provide a twist in response to an applied field, or vice-versa. In another arrangement, a tubular piezoelectric material has electrodes on its inner and outer surfaces. In response to an applied voltage, the vibratory action is partly radial and partly circumferential. Vibration in the torsional mode also may be induced by a pair of electrodes helically wrapped around a straight tube of piezoelectric ceramic material. The driving signal is applied between the two electrodes. Moreover, it is known that two flat plates of natural piezoelectric material, so cut that each is excited in face shear by means of suitable electrodes, may be mechanically joined so that a uniform electric field produces face shear stresses on two opposite faces which oppose each other and result in a twisting distortion.

It has also been known to arrange a tubular piezoelectric element into a coiled form, either of helical or a spiral character. A first electrode is coated on the inner external surface of the coil, while a second electrode is coated on its outer external surface. In response to an applied voltage, the element itself tends to increase or decrease its radius of curvature so that a free end is caused to move in a peripheral direction; a rod mechanically coupled to that free end by a rotor arm may then be caused to rotate for the purpose of operating an indicator, movable switch contacts or the like.

Particularly where very low-frequency sound reproduction is desired, piezoelectric elements have not found extensive usage. This is because a straight-line motion is required and, for such motions in the usual structural approach, the piezoelectric transducer exhibits insufficient compliance. Known linear-motion piezoelectric transducers do not exhibit sufficient excursion in response to a permissible level of applied signal voltage. While substantial excursions are obtained in the aforementioned helical or spiral arrangement, the resulting motion is rotational rather than along a straigt line.

Of course, torsional stress and strain have long been utilized in purely mechanical devices. By subjecting a helical or spiral spring to torsional stress throughout, linear displacement is obtained in an axial direction.

OBJECTS OF THE INVENTION

It is a general object of the present invention to integrate some of the features of the foregoing devices in order to provide a new and improved ferroelectric transducer.

Another object of the present invention is to provide a new and improved ferroelectric transducer particularly characterized by the property of exhibiting substantial straight-line excursions in response to a comparatively small applied signal voltage.

A further object of the present invention is to provide a new and improved ferroelectric transducer in which the mechanical compliance is high.

A still further object of the present invention is to provide such a transducer which conveniently may be formed of a ceramic piezoelectric material.

A transducer produced in accordance with the present invention includes a coiled element of ferroelectric material. A pair of electrodes are spaced apart on a surface of the coiled element and individually canted with respect to its centerline. In response to signals coupled to the electrodes, opposing stresses are created in opposite faces of the element. Torsional stress is induced about the coiled centerline of the element, and this results in concomitant change in elongation of the coil in the direction of its axis.

BRIEF DESCRIPTION OF THE FIGURES

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

FIG. **1** is a partially schematic perspective view of one embodiment of the present invention;

FIG. **1***a* is a fragmentary cross-sectional view of a linearly stretched-out portion of the device of FIG. **1**;

FIG. **2** is a side-elevational view, partly broken away, of a loud-speaker driven by a device like that in FIG. **1**;

FIG. **3** *a* is a partially schematic side-elevational view of another embodiment;

FIG. **3***b* is a plan view of the device of FIG. **3***a*;

FIG. **3***c* is a plan view of the device in FIG. **3***a* cooperatively associated with a loudspeaker cone.

FIG. **4** is a cross-sectional view of one modification of the principal element in the device of FIG. **3***a*;

FIG. **5** is a cross-sectional view of another modification of that element;

FIG. **6***a* is a fragmentary plan view of a still different modification of the same element, the latter being shown in separated form prior to assembly;

FIG. **6***b* is a cross-sectional view of the element of FIG. **6***a* after such assembly; and

FIG. **6***c* is a fragmentary plan view of the element of FIG. **6***b* together with a schematic representation of connecting circuitry.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. **1**, a transducer takes the form of a tube **10** of ferroelectric material wound into a coil **11**. A pair of elongated electrodes **12** and **13** are spaced side-by-side

on the external surface of tube **10** and are helically wound around that surface so as to be canted with respect to the centerline of the tubular element. In response to a signal from a source **14** coupled across respective terminals affixed to electrodes **12** and **13**, coil **11** expands or contracts in the direction of the axis around which its turns are formed, as indicated by arrow **15**. By reason of the configuration of the electrodes, they induce torsional stress about the coiled centerline of tube **10**. The torsional stress is the result of opposing shearing stresses produced in portions of the surface facing toward opposite directions along the coil axis. It is those stresses which, in turn, result in the axial displacement of the coil. Alternatively, axial deformation or change in elongation of the coil produces purely torsional stress in each portion of the tube as a result of which a potential is developed between electrodes **12** and **13**.

Tube **10** is formed of a conventional ceramic piezoelectric material such as barium titanate or PZT (lead titanate zirconate). The tube may be formed by extruding the material through a dye and forming it into the helically-coiled shape before the material is permitted or caused to harden. Subsequently, of course, the material is fired at a high temperature in order to cure it into a rigid structure. In principle, electrodes **12** and **13**, of a conductive material, may be deposited on the surface of the tube either before or after the firing step. In one approach, the electrodes are "painted" in place, as the tube emerges from the extrusion dye, by a machine head which revolves relative to the axis of the as yet uncoiled tube. The two spiralling electrodes could as well be coated on the inside surface of the tube or on both sides in corresponding positions. After the material has been cured and the electrodes formed, the material of the tube is poled in the conventional manner by applying a very high voltage for a short period of time between electrodes **12** and **13**.

As detailed in FIG. **1***a*, electrodes **12** and **13** each have a width W, tube **10** has a wall thickness T and the center-to-center spacing between electrodes **12** and **13** is D. For best operation, it is preferred that the spacing D between adjacent electrodes is substantially greater than the wall thickness T of tube **10**. At the same time, the width W of the electrode should be less than one-half spacing D. Further, width W also should be greater than or at least approximately equal to thickness T.

FIG. **2** generally illustrates the combination of the transducer of FIG. **1** with a loudspeaker that is driven thereby. Thus, coil **10** is contained within a cylindrical housing **17** and affixed at one end to a closure **18** of the housing. At its other end, coil **10** is mechanically coupled to the narrow end of a loudspeaker cone **19**. In operation, the very substantial excursions exhibited by coil **10**, in response to input signals of a permissible level, serve to drive cone **19** sufficiently even at very low frequencies.

In the alternative general form of FIGS. **3***a* and **3***b*, the ferroelectric element is in the form of a flat, ribbon-like element **20** coiled in this case into a spiral shape. As before, a pair of elongated electrodes **21** and **22** are spaced side-by-side and are helically wound on the external surface of element **20**. Signal source **14** again is coupled across terminals affixed to electrodes **21** and **22**. In response to a signal from source **14**, elemental portions of element **20** assume stress in the shear mode and the opposite surfaces of the coiled ribbon seek to shear in opposing directions. In consequence, a torsional stress again is induced about the coiled centerline of element **20**, and this results in a concomitant movement of the central portion (or free end) of the coiled ribbon again in an axial direction as indicated by arrows **24** in FIG. **4**. That movement again may be used to drive a speaker cone **25** as illustrated in FIG. **3***c*. Spiral element **20** may be formed by pressing it into its final shape.

As so far described, the embodiment of FIG. **3***a* is not very efficient. Because the electrodes run in different directions on the opposed major surfaces of a relatively thin strip, the poling produced is incomplete. For improved performance, the poling and electric fields are preserved independently in the respective regions underlying the opposing major faces of element **20**. To that end, element **20** is composed of a pair of ferroelectric strips **30** and **31** separated by a ribbon or layer **32** of cement as shown in FIG. **4**. Layer **32** exhibits a dielectric constant substantially lower than that of strips **30** and **31**, in order to isolate the respective electric fields from each other.

Because of the degree of electrical isolation between strips **30** and **31** is a function of the thickness of layer **32**, the modified arrangement of FIG. **5** is preferred. In this case, strips **30** and **31** are cemented by respective layers **33** and **34** to corresponding opposite sides of a solid insulating substrate **35** that exhibits a comparatively low dielectric constant. With the structure of either FIG. **4** or FIG. **5**, it is possible to pole strips **30** and **31** separately, after which they are assembled and connections are formed across the separation to complete the helical electrodes. That is, the portions of the ultimate helically disposed electrodes that lie on the exposed major surfaces of strips **30** and **31** are first affixed. A temporary counter-electrode then is disposed against each opposite major surface and the two strips are individually poled by the application of suitable potentials to the even and to the odd ones of the electrode portions and opposed in each case to the counter-electrode. After the strips have subsequently been assembled, the different external electrode portions are interconnected by disposition of additional portions across the sides of the assembly so as to complete the formation of a pair of continuous electrodes running helically around the assembly of the strips and other layer or layers. Alternatively, strips **30** and **31** are first cemented together about the intervening layer or layers, and the conductive helices are then deposited in final form. Thereafter, the two strips are simultaneously poled in the same manner as described above in connection with FIG. **1**.

An efficient and equivalent spiral structure is depicted in FIGS. **6***a*–**6***c*. Initially, a pair of flat spiral sections **40** and **41** are shaped to mate together and form an ultimate spiral coil. Each section is coated on one major surface with a plurality of electrode segments. Thus, segments **42**, **44** and **46** are spaced along section **40**, and segments **43**, **45** and **47** are spaced along section **41**. Moreover, the segments, which are canted relative to the longitudinal center lines of the sections, are symmetrically disposed as between the two sections so that one section becomes the mirror image of the other as shown in FIG. **6***a*.

Prior to assembly, sections **40** and **41** are individually poled. Alternate segments on each section are of opposite polarity and the order is such that, when subse-

quently mated, a negative portion will be opposite a positive portion. After poling, sections **40** and **41** are joined together by a layer **49** of cement as shown in FIG. 6*b*. Next, electrical interconnections are formed between the space-opposed electrode segments of each pair **42–43, 44–45,** and **46–47.** Finally, alternate ones of these electrode pairs are coupled individually to respective ones of terminal leads **50** and **51**; that is, the terminals are connected interdigitally to the different electrode pairs.

Within each pair, the respective electrodes embrace oppositely poled portions of the corresponding ferroelectric sections. In response to a signal, the individual electrodes once again induce opposing shear stresses in opposite faces of the composite spiral element, resulting in a torsional stress about the coiled centerline. Accordingly, the desired linear motion is produced axially of the center of the spiral with respect to its periphery.

In each of the embodiments, the helical electrodes preferably are wound at an angle of 45° with respect to the coiled centerline of the ferroelectric element itself. Moreover, at the cost of slight additional complexity of fabrication, more helical electrode pairs may be interleaved on the surface of the element. For example, four helical electrodes may be used, the signals being coupled across each adjacent two electrodes. In any event, a principal feature in all of the different embodiments of the resulting ferroelectric transducer is its comparatively high compliance. Any of the versions may alternatively be operated as a generator in response to physical movement. In all cases, a significantly large linear movement is available.

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

I claim:

1. A transducer comprising:

a coiled element of ferroelectric material;

means, including a pair of electrodes spaced apart on a surface of said element and individually canted with respect to the centerline of said element, for inducing torsional stress about the coiled centerline of said element;

and terminal means for coupling a signal source to the electrodes in said pair to create change in elongation of said coil in the direction of its axis.

2. A transducer as defined in claim **1** in which said element form a helix.

3. A transducer as defined in claim **1** in which said element forms a spiral.

4. A transducer as defined in claim **1** including a sound reproducing element mechanically coupled to one end of said element.

5. A transducer as defined in claim **1** in which said pair of electrodes are spaced side-by-side and helically wound on said surface of said coiled element,

and said terminal means serve to couple said signal source across the individual electrodes in said pair.

6. A transducer as defined in claim **5** in which the spacing between adjacent ones of said electrodes is substantially greater than the thickness of said element, the width of said electrodes is less than one-half said spacing, and said width is greater than or approximately equal to said thickness.

7. A transducer as defined in claim **5** in which said element is a hollow tube.

8. A transducer as defined in claim **5** in which said element is a ribbon-like strip.

9. A transducer as defined in claim **5** in which said element is composed of a pair of individual strips of ferroelectric material sandwiched about a ribbon of material exhibiting a dielectric constant substantially lower than that of said ferroelectric material.

10. A transducer as defined in claim **9** in which said ribbon is of an electrically insulating material.

11. A transducer as defined in claim **1** in which said element is composed of a pair of joined sections, additional pairs of said electrodes are spaced apart along said element with the individual electrodes of each pair being symmetrically disposed on respective ones of said sections, and said terminal means serve to couple said signal source between adjacent ones of said pairs.

12. A transducer as defined in claim **11** in which the respective electrodes in each of said pairs embrace oppositely poled portions of said sections, the individual electrodes in each of said pairs being mutually connected.

* * * * *