

Jan. 6, 1942.

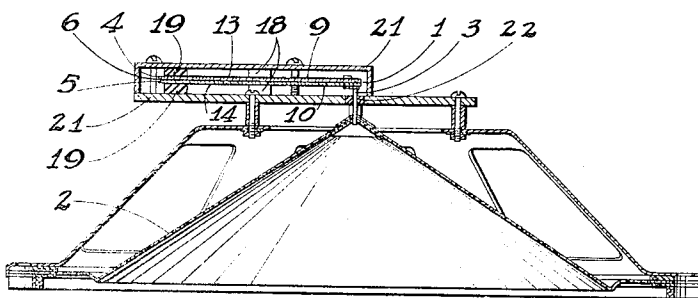
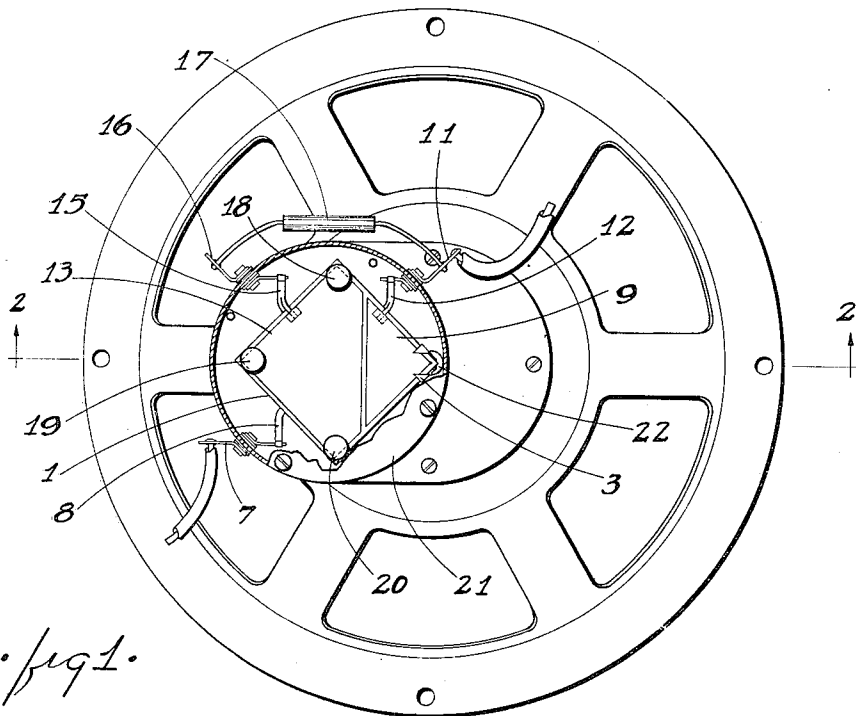
A. L. W. WILLIAMS

2,269,403

PIEZOELECTRIC UNIT

Filed Aug. 3, 1940

2 Sheets-Sheet 1



INVENTOR
• ALFRED L. W. WILLIAMS •

BY

E. G. Christensen
ATTORNEY

Jan. 6, 1942.

A. L. W. WILLIAMS

2,269,403

PIEZOELECTRIC UNIT

Filed Aug. 3, 1940

2 Sheets-Sheet 2

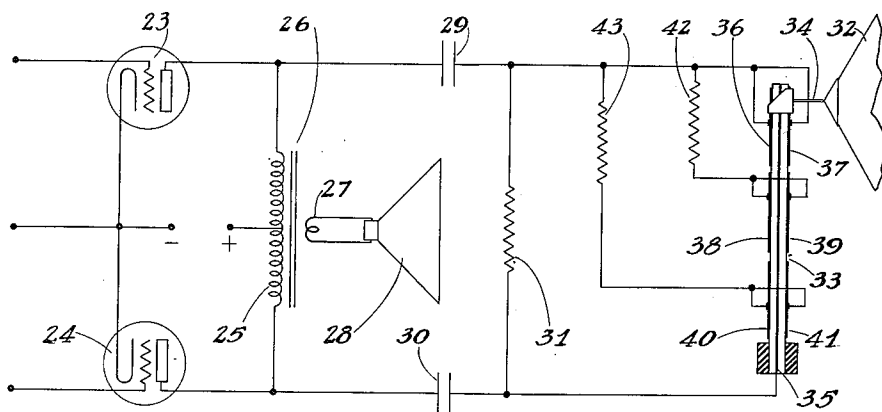


Fig. 3.

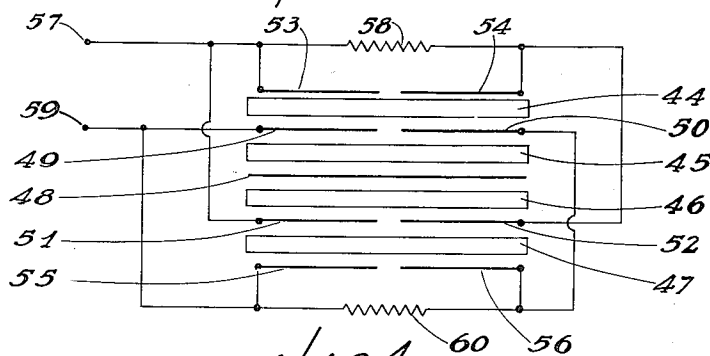


Fig. 4.

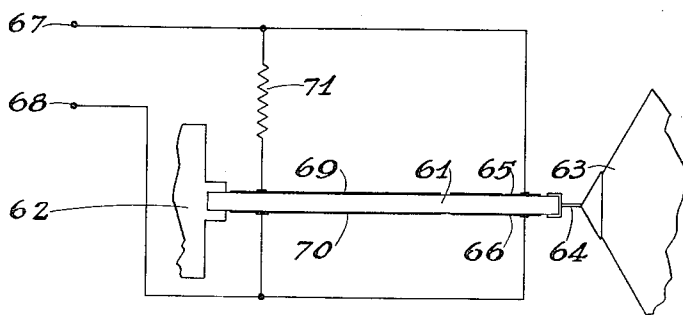


Fig. 5.

INVENTOR
ALFRED L. W. WILLIAMS

BY

G. B. Christensen
ATTORNEY

UNITED STATES PATENT OFFICE

2,269,403

PIEZOELECTRIC UNIT

Alfred L. W. Williams, Cleveland Heights, Ohio,
assignor to The Brush Development Company,
Cleveland, Ohio, a corporation of Ohio

Application August 3, 1940, Serial No. 350,845

18 Claims. (Cl. 171—327)

This invention relates to piezo-electric transducer units and relates more particularly to means for extending the frequency range of piezo-electric devices.

The principal object of this invention is to provide an improved type of a piezo-electric transducer unit that is capable of responding to a wide range of frequencies.

A secondary object of this invention is to increase the sensitivity of piezo-electric transducers.

Another object of this invention is to reduce the variation of the impedance of piezo-electric transducer units with changes in frequency.

Another object is to reduce the wave form distortion produced in power amplifiers used in conjunction with piezo-electric motor devices.

Another object of this invention is to extend the frequency range of piezo-electric motor devices.

One of the principal factors limiting the frequency range of piezo-electric transducers is mechanical resonance in the crystal unit itself. Since piezo-electric crystals have a high stiffness the first mechanical resonance can be made to occur at a reasonably high frequency, and therefore crystal devices are usually designed so that this resonance occurs near the high end of the useful frequency range. If a wide frequency range is desired, the dimensions of the crystal unit are chosen so that a high resonant frequency is obtained. However, when this is done, the sensitivity is comparatively low. In other words, in piezo-electric transducers constructed in accordance with the prior art methods, it has been necessary to make a rather definite compromise between frequency range and sensitivity. The sensitivity of prior art crystal devices is also further limited by the variation in impedance with frequency. The impedance of a crystal unit is predominantly capacitive reactance except at those frequencies at which the crystal is mechanically resonant, and therefore throughout the useful frequency range the impedance decreases as the frequency increases. Because of this variation in impedance it is necessary to operate a piezo-electric motor device from a relatively low resistance source or a source whose impedance is low for high frequencies in order to prevent a loss of high frequency response, and it is necessary to operate a piezo-electric generator device into a high resistance circuit or a circuit whose impedance is high for low frequencies in order to prevent a loss of low frequency response. In either case the overall sensitivity of the crystal

transducer and its associated circuit is limited because the impedances cannot be matched except for a very narrow band of frequencies. The variation in the impedance of a piezo-electric motor also reduces the handling capacity of an amplifier used to operate the device.

By constructing a piezo-electric transducer in accordance with this invention, it is possible to extend the frequency range without sacrificing sensitivity. This object is achieved by connecting suitable electrodes of the crystal unit to the associated circuit in a manner which permits the entire crystal unit to function at low frequencies while permitting only a part of the unit to function at the higher frequencies. That part of the crystal unit which is effective throughout the entire frequency range is preferably coupled most closely to the associated mechanical or acoustic system. In most types of piezo-electric transducers this coupling comprises a single drive pad or link or a torque drive wire, and so when a crystal unit constructed in accordance with this invention is used in such a device, the coupling to the mechanical or acoustic system is located at a point on the part of the unit which functions throughout the entire frequency range.

Although the invention is applicable to devices using various types of piezo-electric material it is particularly useful in piezo-electric transducers utilizing Rochelle salt crystals or other piezo-electric material having substantially the same characteristics. The invention will therefore be described with reference to devices of this type. For the purpose of illustrating the invention, applicant shows a structure which is capable of being used either as a loudspeaker or as a diaphragm microphone. It will be understood, however, that the invention is also applicable to numerous other motor or generator devices which are not illustrated such as earphones, record cutters, oscilloscopes, pen recorders and phonograph pickups, whether reversible or irreversible in their action.

In the drawings:

Fig. 1 is a rear view of a piezo-electric loudspeaker or diaphragm microphone embodying the invention, part of the case enclosing the crystal unit being broken away to show the interior construction.

Fig. 2 is a sectional side view of the loudspeaker or microphone taken along line 2, 2 of Fig. 1.

Fig. 3 is a schematic wiring diagram illustrating the manner in which a high frequency speaker, constructed in accordance with the invention may be connected to its driving amplifier.

Fig. 4 is an exploded diagram of a four ply piezo-electric unit embodying the invention.

Fig. 5 is a diagrammatic view of a loudspeaker illustrating the application of the invention to a single plate expander type piezo-electric unit.

In the reversible loudspeaker-microphone construction shown in Figs. 1 and 2 a piezo-electric unit 1 is connected to the diaphragm 2 by means of a drive link 3. This unit, which is of the torque "Bimorph" type of construction, comprises two plates 4, 5 of piezo-electric material of the Rochelle salt type cemented together face to face with an interior electrode 6 interposed between them. This inner electrode is preferably composed of finely divided conducting material such as powdered graphite, but metal foil or any other suitable electrode material could be used. The use of metal foil electrodes is described more fully in United States Patent No. 1,995,257 granted to C. B. Sawyer, and the method of applying graphite electrodes is disclosed in my United States Patent No. 2,106,143. Instead of having conventional outer electrodes the outer face of each is provided with two adjacent sectional electrodes which are constructed of any suitable material and insulated from each other. The inner electrode 6 is connected to one of the signal input terminals 7 by means of a flexible lead 8, and the outer sectional electrodes 9, 10 which are adjacent to the drive link 3 are connected directly to the other input terminal 11 through flexible lead 12. The other two outer sectional electrodes 13, 14 are connected through lead 15 to a third terminal 16, which is connected to the signal input terminal 11 through a resistor 17. The terminal 16 is not connected to any external circuit but is used to provide additional support for the resistor. The crystal unit is supported at three corners by means of mounting pads 18, 19, 20, which are preferably constructed of damping material, and the unit is entirely enclosed by the case 21. This method of mounting the crystal unit is disclosed in my United States Patent No. 2,105,011 and therefore forms no part of the present invention. The point at which the drive link extends through the wall of the case is sealed by means of the flexible bushing 22.

When this construction is used as a loudspeaker or microphone the crystal unit operates in substantially the same fundamental manner as a conventional "Bimorph" generator or motor unit, particularly at low frequencies. When it is used as a motor, the application of signal voltage to the electrodes produces an electrostatic field in a direction parallel to the electrical axis of the crystal, and this causes each plate to expand in one direction perpendicular to the electrical axis and contract in a direction perpendicular to the electrical axis and to the direction of expansion. Since the plates are oriented so that the direction of expansion of one is parallel to the direction of contraction of the other, they mutually constrain each other so that the unit bends about two axes of curvature disposed at right angles to each other on opposite sides of the unit and parallel to the faces of the unit. Conversely when the unit is bent or flexed mechanically a voltage appears between the electrodes of the unit. For a more complete discussion of the operation of piezo-electric "Bimorph" units of the Rochelle salt type reference may be made to United States Patents Nos. Re. 20,213 and Re. 20,680 granted to C. B. Sawyer. "Bimorph" units may also be constructed of other

types of piezo-electric material which have at least one axis of expansion and contraction which is at an angle to the electrical axis. When a signal voltage of low frequency is applied to the crystal unit of Figs. 1 and 2 through the terminals 7, 11, full voltage is applied to the electrodes contacting both sections of the unit, and therefore the entire crystal unit bends, or flexes, in the same manner as when conventional electrodes are used. However, when the signal voltage is of high frequency the full voltage is applied only to the electrodes that are adjacent to the drive link 3, and so the flexing is greatest at this part of the unit. This is accomplished by choosing the value of resistor 17 so that at high frequencies its resistance is high in comparison with the impedance of the section of the crystal unit that is contacted by the sectional electrodes 13, 14 which are adjacent to the mounting points. Of course, the resistance must also be low enough to be negligible in comparison with the impedance of this section of the unit at low frequencies. Since only part of the unit flexes appreciably at high frequencies the resonant frequency is raised without decreasing the sensitivity, and the useful range of the unit extended to above its resonant frequency. The use of the resistor in series with one section of the unit also reduces the variation of impedance with frequency, so that more efficient coupling to the source of signal voltage is obtained, particularly at the higher frequencies. Reducing the variation in impedance also improves the handling capacity of an amplifier used to supply signal voltage to the loudspeaker. In order to obtain a considerable reduction in the variation of impedance with frequency the portion of the unit which is effective throughout the entire frequency range must be made small, and therefore the effective area of the electrodes contacting this part of the unit should be small. In other words, to reduce the variation in impedance the area of the outer sectional electrodes 9, 10, which are adjacent to the drive link should be small in comparison with the area of the other two outer electrodes 13, 14. On the other hand, if the electrodes 9, 10, are made too small the high frequency response of the device will be reduced. Usually it will be found desirable to make the area of these electrodes one-half or one-third the area of the electrodes 13, 14 which are adjacent to the mounting pads. However, other proportions between about $\frac{1}{2}$ and 2 may be found desirable and in some cases improved results will be obtained by using more than two electrode sections. The most advantageous number of sections and proportions may be determined by experiment. For this purpose it is useful to construct an experimental unit having a relatively large number of small electrode sections which may be interconnected in various ways to obtain the effect of fewer larger electrodes, and various resistance values may be tried with the different arrangements until the desired results are obtained.

Without wishing to be limited by the theory expressed, it is my belief that when a sectional electrode crystal unit of the type here considered is used as a generator device it functions somewhat differently from a motor unit. For example, if the device of Fig. 1 is used as a microphone, the improvement in the high frequency response is not due to the comparatively high impedance at high frequencies as in the motor

device, but is due to the fact that only the portion of the unit which lies adjacent the drive point is effective at the high frequencies. At low frequencies the vibration of the diaphragm causes the crystal unit to vibrate in such a manner that the voltages generated in the two sections are approximately equal, and the operation is therefore substantially the same as when conventional electrodes are used. If, however, the frequency of the sound wave which actuates the diaphragm is high, conditions may be such that the inertia of the crystal unit causes the unit to flex most near the drive point. Then, of course, the greatest voltage is generated in this part of the unit while little if any voltage may be generated in other parts. The invention mitigates the adverse effects which would otherwise result from this condition since the high resistances which are in series with the various sectional electrodes prevent the comparatively inactive or unflexed parts of the unit from acting as an electrical load on the part where the flexing is greatest. For example, if the unit were of conventional construction and had conventional electrodes on it, that part of the crystal which flexes least would act substantially as a capacitive load on the part which flexes the most. The effect of this load would be to reduce the terminal voltage developed by the unit at high frequencies. When, however, the unit is constructed in accordance with the invention and is separated electrically into different parts by the use of sectional electrodes which are connected together through a circuit of high resistance, the inactive part of the unit is effectively disconnected from the part which is most active at the high frequencies. On this basis, it will be recognized that the efficiency of the unit as a generator should be maintained even at frequencies somewhat above the frequencies at which the unit is mechanically resonant, and such result has been found to occur when the invention is used on piezo-electric generators.

The schematic diagram shown in Fig. 3 illustrates a circuit arrangement in which a high frequency piezo-electric loudspeaker is connected to the output of an amplifier that is also feeding a dynamic type low frequency speaker. The high frequency speaker illustrated in this diagram embodies a modification of the invention in which the outer electrodes of the crystal device unit are divided into three sections. In this circuit the plates of the power type output tubes 23, 24 are connected to the primary winding 25 of an output transformer 26 in a manner well known. The secondary winding 27 of the output transformer is connected to the voice coil of the dynamic speaker 28, which is preferably designed to have its greatest efficiency in the low frequency range. If it is desired, a low pass filter may be connected between the secondary winding and the voice coil to prevent high frequency components of the signal voltage from exciting the low frequency speaker. The high frequency speaker is connected to the output circuit of the amplifier by means of blocking condensers 29, 30 which serve to isolate the speaker from the high direct current potential of the power supply circuit. The low frequency components of the signal are suppressed in the high frequency speaker circuit by means of these condensers 29, 30 and a resistor 31, which is connected in parallel with the speaker. Reducing the magnitude of the signal voltage applied to

the speaker at low frequencies reduces the possibility of the crystal unit being damaged by excessive voltage. The high frequency speaker consists primarily of a suitable sound radiating diaphragm 32, a piezo-electric "Bimorph" unit 33, and a light rigid drive link 34. The interior electrode 35, of the "Bimorph" unit 33 is connected to one side of the resistor 31, and the outer sectional electrodes are connected to the other side of this resistor. The sectional electrodes 36, 37 which are adjacent to the drive link 34 are connected directly, while the remaining remote electrodes 38, 39 and 40, 41 are connected through resistors 42 and 43 respectively. The values of these latter resistors are preferably chosen so that the part of the crystal unit that is farthest from the diaphragm driving link (the portion between electrodes 40 and 41) is excited only by components of the signal voltage that are in the medium frequency range, while the center part (the portion between electrodes 38 and 39) responds both to medium and moderately high frequencies, and the part of the unit adjacent to the drive link responds to all the useful medium and high frequencies. Dividing the electrode system into three sections instead of two gives a greater improvement in high frequency response and reduces still further the variation of impedance with frequency.

From the standpoint of ease of manufacture, the type of sectional electrode crystal unit illustrated in Figs. 1, 2 and 3 is probably the most satisfactory. However, instead of using a single-section inner electrode with divided outer electrodes, it is possible to use either conventional outer electrodes with a divided inner electrode, or divided outer and inner electrodes. It is also possible to divide the electrodes into sections of either equal or unequal area, and considerable variation in the frequency characteristic can be obtained in this manner. However, when a crystal unit constructed in accordance with the invention is used in a motor device the operation is essentially the same regardless of which of these types of electrode arrangement is used.

The application of the invention to a four-ply series-parallel "Bimorph" unit is illustrated in the exploded diagrammatic view of Fig. 4. This unit, which may be of either the torque or bend type, comprises four plates 44, 45, 46, 47 of piezo-electric material; a single-section electrode 48 interposed between the two inner plates 45, 46; two sectional electrodes 49, 50 between the inner plate 45 and the outer plate 44; two sectional electrodes 51, 52 between plates 46 and 47; and four outer sectional electrodes 53, 54, 55, 56. One set of connecting leads provides connections between terminal 57 and sectional electrodes 51 and 53. It will be noted that these electrodes are adjacent the outer piezo-electric plates 44 and 47 respectively. The corresponding sectional electrodes 52, 54 of these outer plates are connected to terminal 57 through a resistor 58. The other terminal 59 is connected directly to the inner sectional electrode 49 and the outer sectional electrode 55, and is also connected through a resistor 60 to the corresponding sectional electrodes 50, 56. The single section inner electrode 48 needs no connection to the external circuit since the two inner piezo-electric plates 45 and 46 of the unit are connected in series. The electrodes may be constructed of metal foil, graphite or other suitable material and may be applied by cementing, spraying or any other suitable

method. For a more complete description of the construction and operation of the four-ply series-parallel type of crystal unit reference may be made to my United States Patent No. 2,105,011. In assembling the unit the four slabs are first electroded and then secured together in the usual manner by means of a suitable cement. Although single layer inner electrodes are shown in Fig. 4 for the purpose of simplifying the illustration, crystal units of this type are more apt to be constructed with electrodes on both faces of each plate. It will be understood that the driving connection between the unit and its associated mechanical system should be located at the end of the unit which is directly connected to the terminals 57, 59.

The invention is applicable not only to multiple plate units but also to both single plate "Bimorphs" and expander type units. A simple "Bimorph" can be constructed by applying sectional electrodes to one face of a piezo-electric crystal and applying a relatively stiff metal constraining electrode to the opposite face; a single plate expander unit can be constructed by applying sectional electrodes to both faces or by using a conventional electrode on one face and sectional electrodes on the other.

A loudspeaker using a single plate expander type unit constructed in accordance with the invention is shown in diagrammatic form in Fig. 5. One end of the crystal plate 61 is fastened rigidly to a supporting member 62, and the other end is connected to a sound radiating diaphragm 63 by means of a rigid drive link 64. A two-section electrode is applied to each face. The two electrodes 65, 66 adjacent to the drive link are connected directly to the terminals 67, 68, while the other two electrodes 69, 70 are connected to these terminals through a resistor 71. When a low frequency signal voltage is applied to the terminals the substantially full voltage is applied to both sections of the electrode system, and so the expansions and contractions take place throughout the entire length of the unit. However, when a high frequency signal is applied the full voltage is applied only to the electrodes adjacent to the drive link, and therefore the maximum expansions and contractions occur in this part of the unit. In this manner it is possible to reduce the loss of high frequency response that would occur due to various regions vibrating out of phase with each other if conventional electrodes were used. Also the loss in high frequency response due to variation in the impedance is reduced. It will be appreciated that the expander type unit of Fig. 5 is reversible in its action and may be used as a generator instead of as a motor. Thus if diaphragm 63 were acted upon by sound waves, a signal voltage would be developed at terminals 67 and 68.

It is evident from the above description that the invention is applicable to crystal units comprising any desired number of plates, and it has already been shown that piezo-electric units constructed in accordance with the invention are applicable to either motor or generator devices. Furthermore such units can also be used in loudspeakers in which the crystal itself functions as the sound radiator and in microphones in which the crystal functions as the diaphragm. The sound cell is an example of a direct-radiating type of microphone. Such microphones are described in detail in United States Patent No. 2,105,010 to C. B. Sawyer and in my United States

Patent No. 2,126,436. A loudspeaker of the direct-radiating type is disclosed in United States Patent No. 2,102,668 granted to Stuart Ballantine.

While I have disclosed my invention by reference to certain specific embodiments thereof, it is to be understood that the invention is not limited thereto but that various omissions, substitutions and changes within the scope of the appended claims may be made therein without departing from the spirit of the invention.

What I claim is:

1. A piezoelectric transducer unit which comprises the combination of: a plate-like member of piezoelectric material; electrode means associated with said plate-like member, and comprising: a first pair of electrodes in register with each other and on opposite sides of the piezoelectric plate-like member, thereby effectively electroding a first portion of the latter; a second pair of electrodes in register with each other and on opposite sides of a second portion of said plate-like member, said second portion being distinct from said first portion; a low resistance circuit connecting said first pair of electrodes to a pair of terminals; a circuit connecting said second pair of electrodes to said terminals and including resistive impedance equal in magnitude to the impedance of said second portion when measured at a frequency which lies within the useful frequency range of said unit.

2. A piezoelectric unit as claimed in claim 1 wherein at least said first and second pairs of electrodes utilize a common electrode.

3. A piezoelectric unit as claimed in claim 1 wherein the effective area of said second pair of electrodes is between about $\frac{1}{2}$ and 5 times the effective area of said first pair of electrodes.

4. A piezoelectric transducer unit which comprises the combination of: a plate-like member of piezoelectric material adapted to be operatively coupled within a selected zone thereof to a mechanical system; electrode means associated with said member, and comprising: a first pair of electrodes in register with each other and disposed in the vicinity of said coupling zone and on opposite sides of a first portion of the said plate-like member, thereby effectively electroding said first portion; a second pair of electrodes distinct from said first pair and in register with each other and on opposite sides of a second portion of said plate-like member, said second portion being remote from said coupling zone; a low resistance circuit connecting said first pair of electrodes to a pair of terminals; a circuit connecting said second pair of electrodes to said terminals, and including resistive impedance equal in magnitude to the impedance of said second portion when measured at a frequency which lies within the useful frequency range.

5. A piezoelectric transducer unit which comprises the combination of: a flexible plate-like member having an electrical axis which intersects the faces of the plate, and being adapted to expand in a direction parallel to the faces of the plate when subjected to an electrostatic field of a given polarity substantially parallel to the said electrical axis and to contract in the said direction when the polarity of such field is reversed; constraining means adapted to oppose expansion and contraction of the flexible member and cause said member, when subjected to the action of an electrostatic field of given polarity, to bend and conversely, cause the establishment of such an electrostatic field when the member is mechanically bent; electrode means associated with

the said plate-like member and comprising: a first pair of electrodes in register with each and on opposite sides of a first portion of said piezoelectric plate-like member, thereby effectively electroding said first portion; a second pair of electrodes in register with each other and on opposite sides of a second portion of said plate-like member, said second portion being distinct from said first portion; a low resistance circuit connecting said first pair of electrodes to a pair of terminals; a circuit connecting said second pair of electrodes to said terminals and including resistive impedance equal in magnitude to the impedance of said second portion when measured at a frequency which lies within the useful frequency range of said unit.

6. A piezoelectric transducer as claimed in claim 5 wherein said constraining means include a flexible plate-like body secured to a face of the said plate-like member.

7. A piezoelectric transducer unit as claimed in claim 5 wherein said plate-like member is adapted to be coupled within a selected coupling zone thereof to a mechanical system, and wherein at least a portion of said coupling zone coincides with said first portion.

8. A piezoelectric transducer unit comprising the combination of: a piezoelectric member; and an electrode system which includes a pair of terminals and means for subjecting at least two different portions of the member to substantially the same voltage at substantially the same time when an alternating test voltage having a frequency selected from the low end of the useful frequency range of the unit is applied to the terminals, and for subjecting said two portions to different voltages at substantially the same time when said test voltage has a frequency selected from the high frequency end of the said useful frequency range.

9. A piezoelectric transducer unit comprising the combination of: a piezoelectric member; and an electrode system which includes a pair of terminals and means for subjecting at least two different portions of the member to substantially the same voltage at substantially the same time when an alternating test voltage having a frequency selected from the low end of the useful frequency range of the unit is applied to the terminals, and for subjecting said two portions to different voltages at substantially the same time when said test voltage has a frequency selected from the high frequency end of the said useful frequency range, said means comprising a pair of electrodes in register with one of said portions, and another pair of electrodes in register with the other portion, one pair of electrodes being connected to the other pair through resistive impedance.

10. A piezoelectric transducer unit comprising the combination of: a piezoelectric member adapted to be coupled within a selected coupling zone thereof to a mechanical system; and an electrode system which includes a pair of terminals and means for subjecting at least a portion of said coupling zone and a different portion of said member to substantially the same voltage at substantially the same time when an alternating test voltage having a frequency selected from the low end of the useful frequency range of the unit is applied to said terminals, and for subjecting said portion of the coupling zone and said different portion of the member to different voltages at substantially the same time when

said test voltage has a frequency selected from the high end of said useful frequency range.

11. A piezoelectric transducer unit comprising the combination of: a piezoelectric member adapted to be coupled within a selected coupling zone thereof to a mechanical system; and an electrode system which includes a pair of terminals and means for subjecting at least a portion of said coupling zone and a different portion of said member to substantially the same voltage at substantially the same time when an alternating test voltage having a frequency selected from the low end of the useful frequency range of the unit is applied to said terminals, and for subjecting said portion of the coupling zone and said different portion of the member to different voltages at substantially the same time when said test voltage has a frequency selected from the high end of said useful frequency range, said means comprising a first pair of electrodes in register with said portion of the coupling zone, and a second pair of electrodes in register with said different portion, one of said pairs of electrodes being connected to the other pair through resistive impedance.

12. A piezoelectric transducer unit comprising the combination of: a piezoelectric member adapted to be coupled within a selected coupling zone thereof to a mechanical system; and an electrode system which includes a pair of terminals and means for subjecting at least a portion of said coupling zone and a different portion of said member to substantially the same voltage at substantially the same time when an alternating test voltage having a frequency selected from the low end of the useful frequency range of the unit is applied to said terminals, and for subjecting said portion of the coupling zone and said different portion of the member to different voltages at substantially the same time when said test voltage has a frequency selected from the high end of said useful frequency range, said means comprising a first pair of electrodes in register with said portion of the coupling zone, and a second pair of electrodes in register with said different portion, said first pair being connected to said terminals, and said second pair being connected to said first pair through resistive impedance.

13. A piezoelectric transducer unit comprising the combination of: a piezoelectric member; and an electrode system which includes a pair of terminals and means for subjecting a first portion of said member to a voltage of desired magnitude and simultaneously to subject a second portion to a lesser voltage when an alternating test potential having a frequency selected from the high frequency end of the useful frequency range of the unit is applied to said terminals.

14. A piezoelectric transducer unit comprising the combination of: a piezoelectric member; and an electrode system which includes a pair of terminals and means for subjecting a first portion of said member to a voltage of desired magnitude and simultaneously to subject a second portion to a lesser voltage when an alternating test voltage having a frequency selected from the high frequency end of the useful frequency range of the unit is applied to said terminals, said means comprising a first pair of electrodes in register with said first portion on opposite sides thereof, and a second pair of electrodes in register with said second portion and on opposite sides thereof, said first pair being connected to said terminals, and said second pair being con-

nected to the terminals through a circuit having sufficient resistance therein to establish the desired voltage differential between said first and second portions.

15. A piezoelectric transducer unit comprising the combination of: a plate-like member of piezoelectric material having an electrical axis which intersects the faces of the member, and adapted to expand in a direction parallel to the faces of said member when said member is subjected to an electrostatic field of given polarity along said electrical axis, and to contract in said direction when the polarity of said field is reversed; an electrode system which includes a pair of terminals, and means for subjecting a first portion of said member to a voltage of desired magnitude and simultaneously to subject a second portion to a lesser voltage when an alternating test voltage having a frequency selected from the high frequency end of the useful frequency range of the said unit is applied to said terminals, said means comprising a first pair of electrodes in register with said first portion on opposite sides thereof, and a second pair of electrodes in register with said second portion on opposite sides thereof, said first pair being connected to said terminals, said second pair being connected to the terminals through a circuit having sufficient resistance therein to establish the desired voltage differential between said first and second portions; and constraining means adapted to oppose the said expansion and contraction of said member, whereby said member is caused to bend when a voltage is applied to said terminals, and conversely is caused to generate a voltage at said terminals when it is mechanically bent.

16. A piezo-electric transducer unit comprising the combination of: a multiple assembly which includes a pair of plate-like members of piezo-electric material having an electrical axis which intersects the faces of the member, and adapted to expand in a direction parallel to the faces of said member when said member is sub-

jected to an electrostatic field of given polarity along said electrical axis, and to contract in said direction when the polarity of said field is reversed; an electrode system which includes a pair of terminals, and means for subjecting a first portion of each member to a voltage of desired magnitude and simultaneously to subject a second portion of each member to a lesser voltage when an alternating test voltage having a frequency selected from the high frequency end of the useful frequency range of the said unit is applied to said terminals, said means comprising for each member a first pair of electrodes in register with said first portion on opposite sides thereof, and a second pair of electrodes in register with said second portion on opposite sides thereof, said first pairs being connected to said terminals, said second pairs being connected to the terminals through a circuit having sufficient resistance therein to establish the desired voltage differential between said first and second portions; means securing said pair of plates together face to face with their respective first and second portions in substantial register with each other, and with the said respective directions of expansion and contraction in substantial alignment, the mutual orientation of said members being effective to cause each member to oppose the expansion and contraction of the other, whereby said assembly is caused to bend when a voltage is applied to said terminals, and conversely is caused to generate a voltage at said terminals when it is mechanically bent.

17. A piezo-electric unit as claimed in claim 16 wherein the first and second pairs of electrodes of each member utilize a common electrode.

18. A piezo-electric transducer unit as claimed in claim 16 wherein said assembly is adapted to be coupled within a selected coupling zone thereof to a mechanical system, and wherein at least a portion of said coupling zone coincides with said registering first portions.

ALFRED L. W. WILLIAMS.