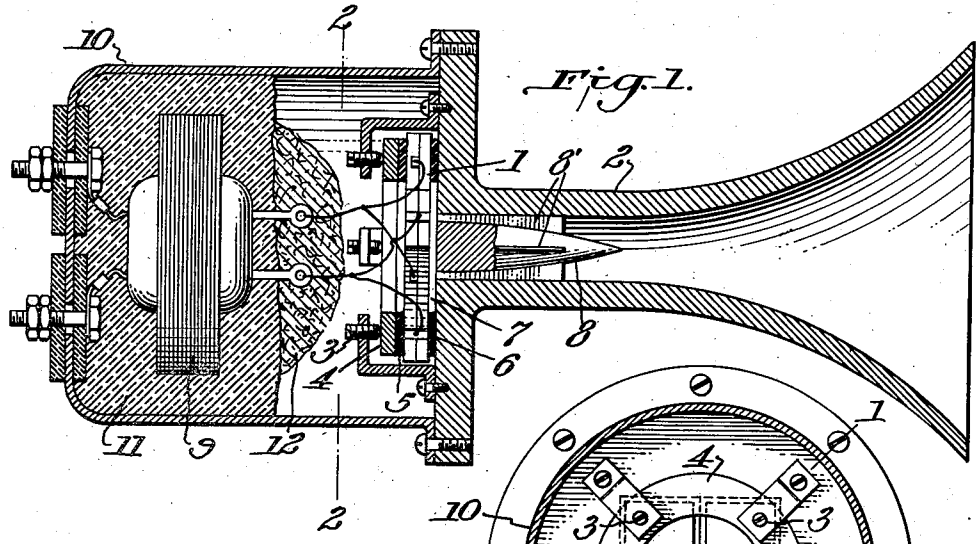
Dec. 21, 1937. S. BALLANTINE 2,102,668

PIEZOELECTRIC LOUDSPEAKER

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Fig. 1.



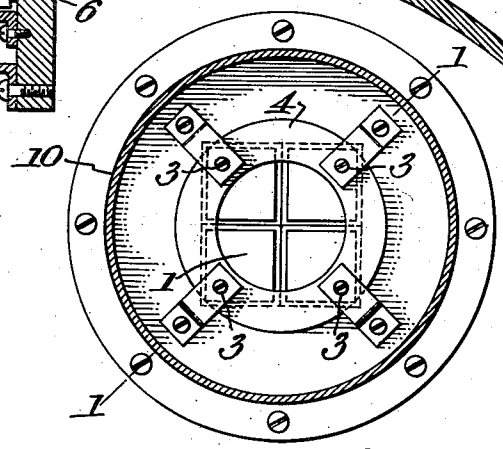


Fig. 2.

Fig. 3a.

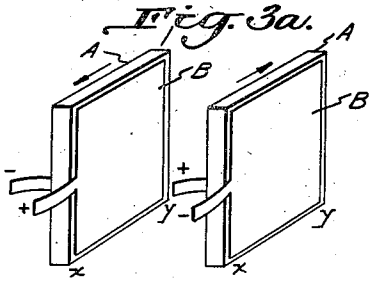
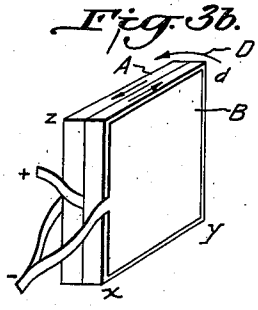
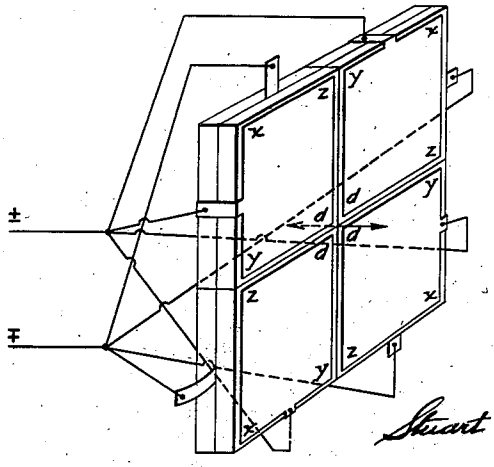


Fig. 4.

Fig. 3b.





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Fig. 5.

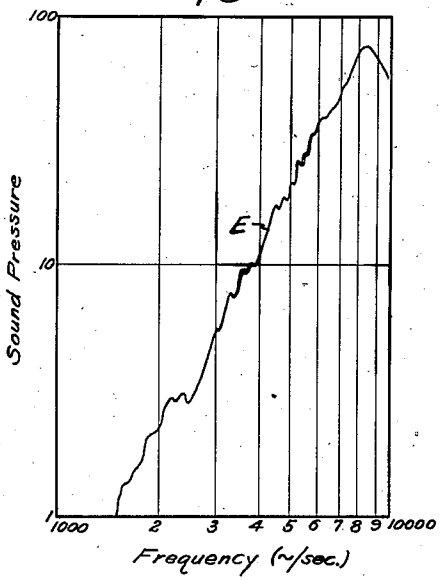


Fig. 7.

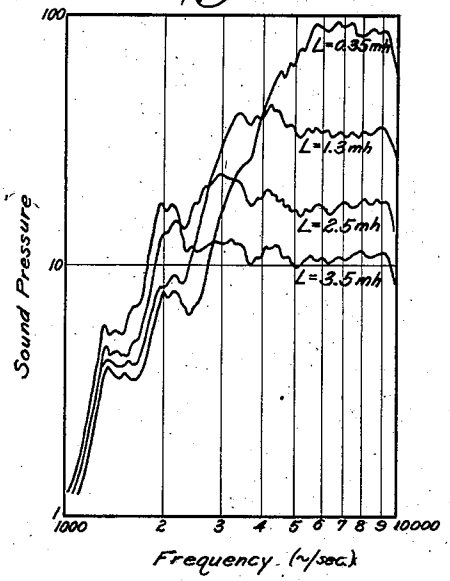


Fig. 6a.

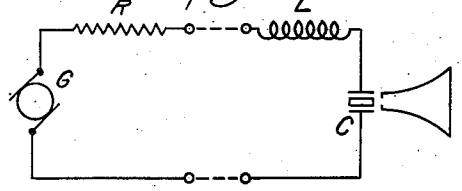


Fig. 6b.

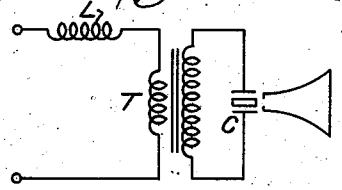
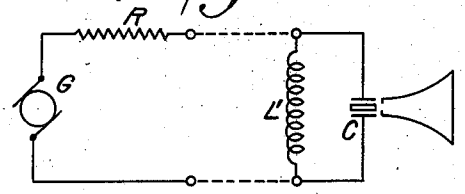


Fig. 6c.



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UNITED STATES PATENT OFFICE

2,102,668

PIEZOELECTRIC LOUDSPEAKER

Stuart Ballantine, Mountain Lakes, N. J., assignor, by mesne assignments, to Radio Corporation of America, New York, N. Y., a corporation of Delaware

Application June 14, 1933, Serial No. 675,834

11 Claims. (Cl. 179—110)

This invention relates to electroacoustic apparatus for the conversion of electrical energy into sound energy, and more particularly to electroacoustic apparatus of the type employing a piezoelectrically active crystal assembly.

An object of the invention is to provide electroacoustic apparatus of simplified construction and in which the active element is a piezoelectrically active diaphragm comprising a plurality of units, each unit comprising two crystal plates which have a torque response when a potential is impressed across the electrodes associated with the crystal plates. An object is to provide a loud speaker of the horn type, and driven by a piezoelectrically active crystal assembly of the type stated. A further object is to provide a loud speaker of the type stated, and in which the circuit or circuits supplying power to the speaker compensate for inequalities in the sound pressure-frequency response characteristic of the reproducer elements, thus rendering the combined characteristic of the electrical supply circuit and the reproducer elements more nearly uniform over the band of frequencies which is to be reproduced.

A further object is to produce a loud speaker of the above type which is particularly adapted for the reproduction of the higher audible frequencies.

These and other objects of the invention will be apparent from the following specification when taken with the accompanying drawings in which:

Fig. 1 is a longitudinal central section through a loud speaker embodying the invention, the section being taken substantially on line 1—1 of Fig. 2;

Fig. 2 is a transverse section substantially on line 2—2 of Fig. 1;

Figs. 3*a* and 3*b* are somewhat schematic views, in perspective, of crystal plate systems having shear sensitivity;

Fig. 4 is a similar view of the crystal plate diaphragm system of the speaker shown in Fig. 1;

Fig. 5 is a curve showing the sound pressure-frequency characteristic of a small piezoelectric loud speaker designed for the reproduction of the higher audio frequencies;

Figs. 6*a*, 6*b* and 6*c* are circuit diagrams of the loud speaker and associated circuits for supplying audio frequency voltages thereto, the circuits including inductance for altering the sound pressure-frequency characteristic; and

Fig. 7 is a curve sheet showing a series of curves which illustrate the compensating effect obtainable with a supply circuit such as shown in Fig. 6*b*.

In the drawings, the reference numeral 1 identifies a crystal plate diaphragm assembly which is clamped to the base of the horn 2 by means of screws 3 which bear against the annular metal ring 4, a compressible gasket 5 being arranged between ring 4 and the crystal assembly, proper clearance between the crystal faces and the horn base being provided by the annular spacer 6. The spacer ring 6 may be made of rubber or of any other suitable material capable of forming a seal to prevent the escape of air from the throat chamber 7. The throat of the horn is of uniform diameter out to the tip of the insert 8 which is approximately bullet-shaped to provide the desired exponential law of the increase in the cross-section of the horn.

The insert 9 provides an annular throat passage at the base of the horn, and thus reduces the average length of the paths from the various parts of the crystal diaphragm to the throat, thus bringing the phases of the air currents due to those various elements more nearly into agreement, with the result that the sound output at the higher frequencies is increased. The insert is held in place by four small longitudinal fins 8' which are cemented to the horn.

A transformer 9 may be secured within a protective cover 10 by means of a sealing compound 11, the cover 10 being secured to the base of the horn and, if necessary, sound absorbing material 12 being provided within the cover 10 to absorb the sound emanating from the rear of the crystal diaphragm 1.

The crystal diaphragm 1 comprises four square crystal plates cemented together at their edges to form a square assembly, as illustrated in Fig. 4. The method of operation of this assembly will be best understood by first considering the simpler crystal plate systems shown in Figs. 3*a* and 3*b*.

The plates A are cut from homogeneous Rochelle salt crystals with the flat faces of the crystals normal to the electrical or *a* axis and the sides parallel to the *b* and *c* axes. Electrodes B of metal foil are cemented to the faces of the crystals and, as is well known, the application of a potential difference between the electrodes tends to strain the crystal. When the corners *x*, *y* of the crystals are held immovable, the application of direct current potentials of the polarities indicated will tend to move the upper edges of the crystals in shear in the directions indicated by the arrows adjacent those edges.

It will be noted that the arrows point in opposite directions because the polarities of the foil electrodes on the two crystal plates are reversed. When the plates A are cemented together, as shown in Fig. 3b, and with the electrodes so energized that as one plate edge tends to move forward the other tends to move backward, the result will be a twisting or torque motion of the upper part of the assembly when the corners *x*, *y* are clamped. When one of the upper corners *z* is also clamped, the free corner *d* will move at right angles to the plane of the crystal plates, as shown by the arrow D. This method of securing torque sensitivity from shear plates is described by C. Baldwin Sawyer in "The Proceedings of the Institute of Radio Engineers", Nov. 1931, page 2025.

The crystal plate diaphragm of the present invention comprises four units of the type shown in Fig. 3, these units being cemented together at their edges to form the square assembly which is illustrated in Fig. 4. When this assembly is clamped to the horn base by the ring 4 and the screws 3, the corners *x*, *y* and *z* of each double plate unit of the composite diaphragm are substantially prevented from moving and the application of a potential difference between the electrodes causes the free corners *d* to move in and out in unison in a direction normal to the plane of the assembly. The whole assembly thus acts as a diaphragm and functions in the same manner for the generation of sound as the ordinary type of horn loud speaker.

To prevent the undesired escape or entrance of air into the throat chamber, the union of the four crystal plates at their edges must be carefully made so as to remain air tight. If cement is used, it is preferably of a plasticized resin type, such as cellulose nitrate cement containing castor oil, which will remain resilient after setting to avoid any constraint upon the free motions of the plates. It is not necessary to use cement, as the spaces between the plates may be calked, but, in general, the use of cement results in a better assembly mechanically.

As noted above, the gasket 5 is compressible to permit adjustment of the screws 3 to obtain that clamping pressure which affords the maximum and smoothest frequency response.

The four plates or double plates of the diaphragm are connected in parallel, as shown in Fig. 4, care being taken that the connections are so made that the motions of the four units are in phase. The clearance between the throat and the surfaces of the crystals was of the order of 0.010 inch.

The performance of a loud speaker of this type and designed for the reproduction of the higher audible frequencies is shown by curve E of Fig. 5. The data for this curve was obtained by measuring the pressure in the sound wave emanating from the horn for applied voltages of different frequencies. The same voltage was maintained across the crystals for all frequencies and the pressures were measured on the axis of the horn at a distance of three feet from the outer end. The dimensions of the crystals were so chosen that elastic resonance was obtained at a frequency approximately equal to the upper limit of the frequency range to be reproduced. As shown by curve E, the design was such that the resonant frequency was about 8000 cycles.

For many purposes, it is desirable to have a relation between sound pressure and applied voltage which is substantially uniform over an extended range of frequencies. This characteristic may be obtained with a horn having the inherent characteristic of Fig. 5 by an appropriate design of the circuit which transmits the voltage to the loud speaker.

As shown in Fig. 6*a*, the generator G or source of power supply is represented as having an internal resistance R, and the circuit completed between the terminals of the generator G and the loud speaker C includes the series inductance L which tunes the circuit to a frequency lower than the resonant frequency of the loud speaker. With this arrangement, the sound pressure response will be substantially uniform for all frequencies between the resonant frequency of the circuit and the resonant frequency of the horn. When it is desired to secure an impedance match with a generator of arbitrary internal resistance, the speaker C may be connected to the supply circuit through a transformer T, Fig. 6*b*, which transformer corresponds to the transformer 9 of Fig. 1. With this arrangement, the tuning inductance L may be inserted in the primary, as shown, or in the secondary circuit in series with the horn. It may also be built into the transformer, for example, as leakage inductance.

The circuit may also be resonated by means of a shunt inductance L', or equivalent reactance, as shown in Fig. 6*c*.

The effect of the series tuning inductance L upon the sound pressure characteristic is illustrated graphically in Fig. 7, the several curves being identified by legends "L=0.35 mh", etc., to indicate the value, in millihenries, of the inductance effectively included in the supply circuit when the data for a particular curve was obtained.

The electrical supply circuit may also be tuned to a frequency higher than the resonant frequency of the loud speaker. In this case the response tends to become more uniform above the diaphragm resonant frequency rather than below it.

Some control over the sound-pressure frequency characteristic may also be obtained without the tuning inductor L by adjusting the effective capacity reactance of the loud speaker relative to the internal resistance of the supply source. The most convenient way to do this is by means of a transformer inserted between the supply source and loud speaker. Increasing the secondary-primary turns ratio will in general cause an increase in the effective crystal capacity and a greater slumping off of voltage across the crystals with frequency.

The above data is given merely as an illustration of the operating characteristic of one particular embodiment, and it is to be understood that the invention is not limited to any particular frequency range of operation. By appropriate design of the diaphragm and the associated electrical system, the frequency range of reproduction may be located at another section of the audio frequency range, and it may be increased or decreased in width in accordance with the design requirements for a particular construction.

I claim:

1. In an electromechanical transducer, a flat assembly of four piezoelectrically active plate-shaped elements arranged in edge alinement and with corners of the said elements substantially meeting at a common central point of said assembly, each of said elements comprising a pair of superposed crystal plates having an electrode between their adjacent faces and electrodes at

their outer faces, and circuit connections between the several electrodes of said elements to produce like deflections of all elements at said common point when voltages are impressed across said electrodes or, alternatively, to produce like electrical responses between connected electrodes of all elements when pressure is applied to said common point of the assembly, and means introduced between the contiguous edges of said elements to prevent leakage of air past said contiguous edges, said means consisting of a resilient cement joining the adjacent edges of said elements to each other.

2. The invention as claimed in claim 1, in combination with means engaging marginal areas at opposed faces of said flat assembly of elements for limiting movement of the said engaged areas.

3. A loud speaker comprising a horn, a diaphragm comprising a plurality of piezoelectrically active crystal plates secured across the throat of said horn, and sealing means between and cooperating with said diaphragm and horn to form an air-tight throat chamber.

4. A loud speaker comprising a horn, a diaphragm comprising a plurality of piezoelectrically active crystal plates at the throat of the horn, a gasket cooperating with said throat and horn to form an air-tight throat chamber, and means clamping said diaphragm to said horn, said clamping means limiting movement of the periphery of the diaphragm.

5. A loud speaker as claimed in claim 4, wherein said diaphragm comprises four crystal units of rectangular form and arranged to form a rectangular diaphragm.

6. In a loud speaker, a horn and means at the base thereof defining an annular opening into the throat of the horn, a piezoelectrically active diaphragm positioned adjacent the throat of the horn, a gasket between said diaphragm and horn base, and means clamping said diaphragm against said gasket, whereby said gasket cooperates with said diaphragm and horn base to form an air-tight throat chamber.

7. A loud speaker as claimed in claim 6, wherein said diaphragm comprises a plurality of plate-shaped crystal units having their contiguous edges cemented to each other; each unit being piezoelectrically responsive normally to its plane surfaces.

8. In a loud speaker, a horn member, a piezoelectrically active diaphragm and means mounting the same at the base of the horn to form an air-tight throat chamber, an insert member within said horn member and cooperating therewith to define an annular opening into said throat chamber, and means comprising ribs projecting radially from one of said members for centering said insert member within said horn member.

9. In a loud speaker, a piezoelectrically active diaphragm, a horn provided with a throat chamber, said diaphragm constituting one wall of the throat chamber, and an insert in said horn defining an annular opening with the throat of said horn, said insert being centered in said horn by longitudinal fins integral with said insert.

10. A piezoelectric loud speaker comprising a horn member, a piezoelectrically active diaphragm and means mounting the same at the base of the horn to form an air-tight throat chamber, said diaphragm and horn member having an over-all resonant sound-pressure frequency characteristic, said resonant frequency being located at the upper end of the range of frequencies to be reproduced.

11. A piezoelectric loud speaker comprising a horn member, a piezoelectrically active diaphragm and means mounting the same at the base of the horn to form an air-tight throat chamber, said diaphragm and horn member having an over-all resonant sound-pressure frequency characteristic, said resonant frequency being located above 7,000 cycles.

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