Sept. 9, 1947. F. MASSA 2,427,062

VIBRATIONAL ENERGY TRANSMITTER OR RECEIVER

Filed June 2, 1944 5 Sheets-Sheet 1

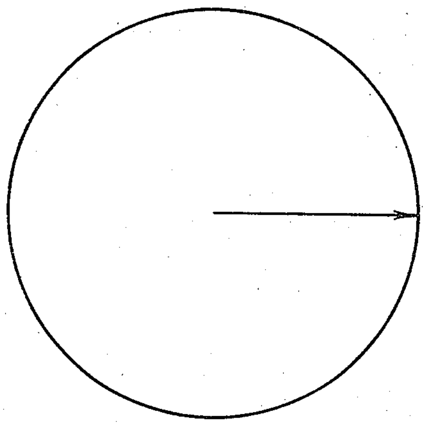

FIG. 1

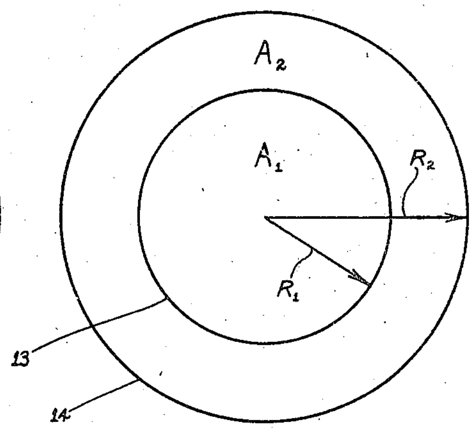


FIG. 2

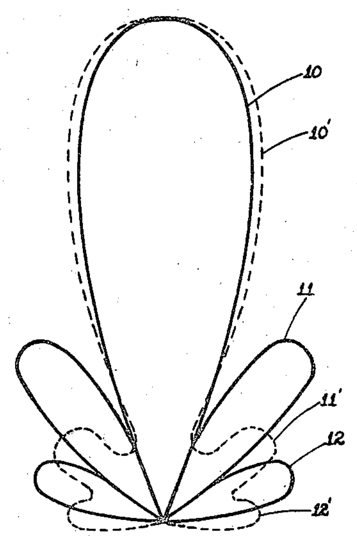


FIG. 3

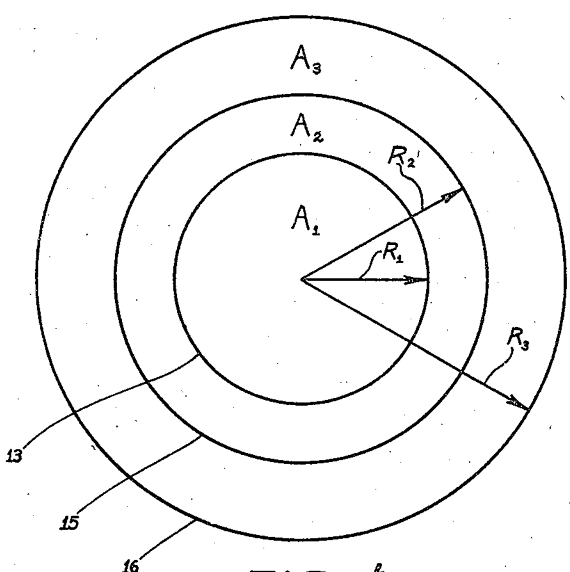


FIG. 4

INVENTOR.
FRANK MASSA
BY
Elmer J. Hyde
ATTORNEY

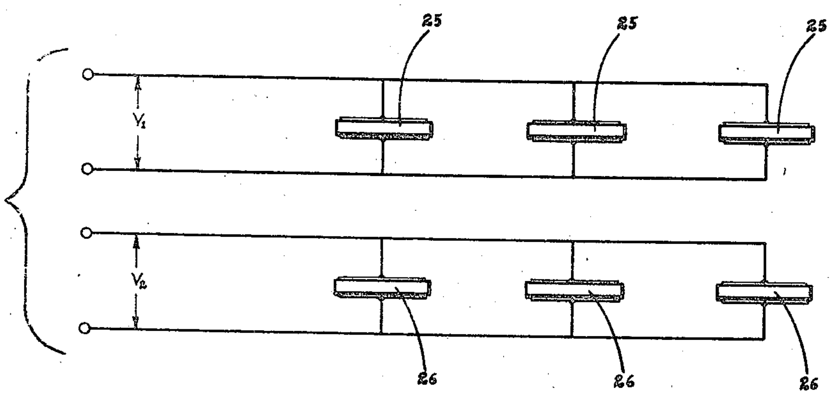


FIG. 5

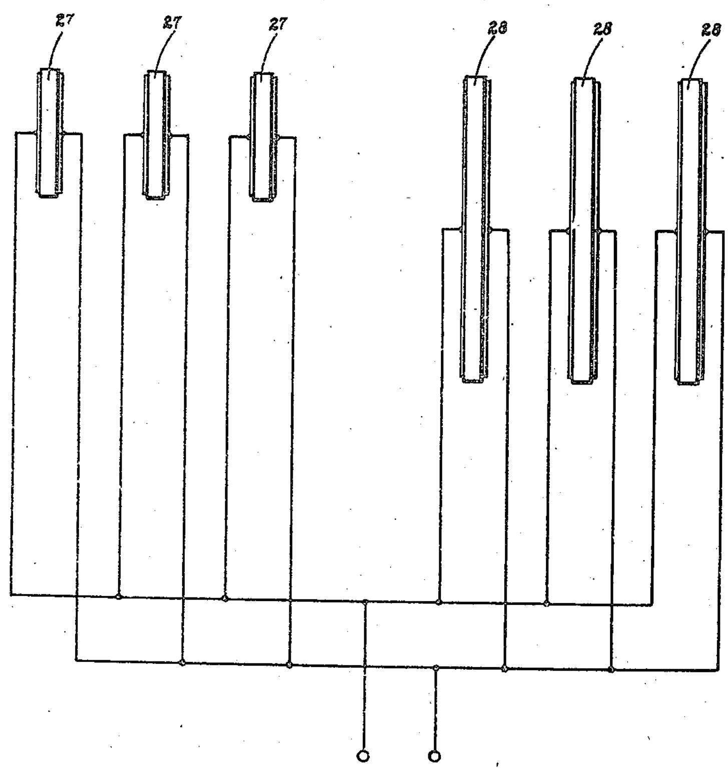


FIG. 6

INVENTOR.
FRANK MASSA
BY
Elmer J. Hyde
ATTORNEY

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VIBRATIONAL ENERGY TRANSMITTER OR RECEIVER

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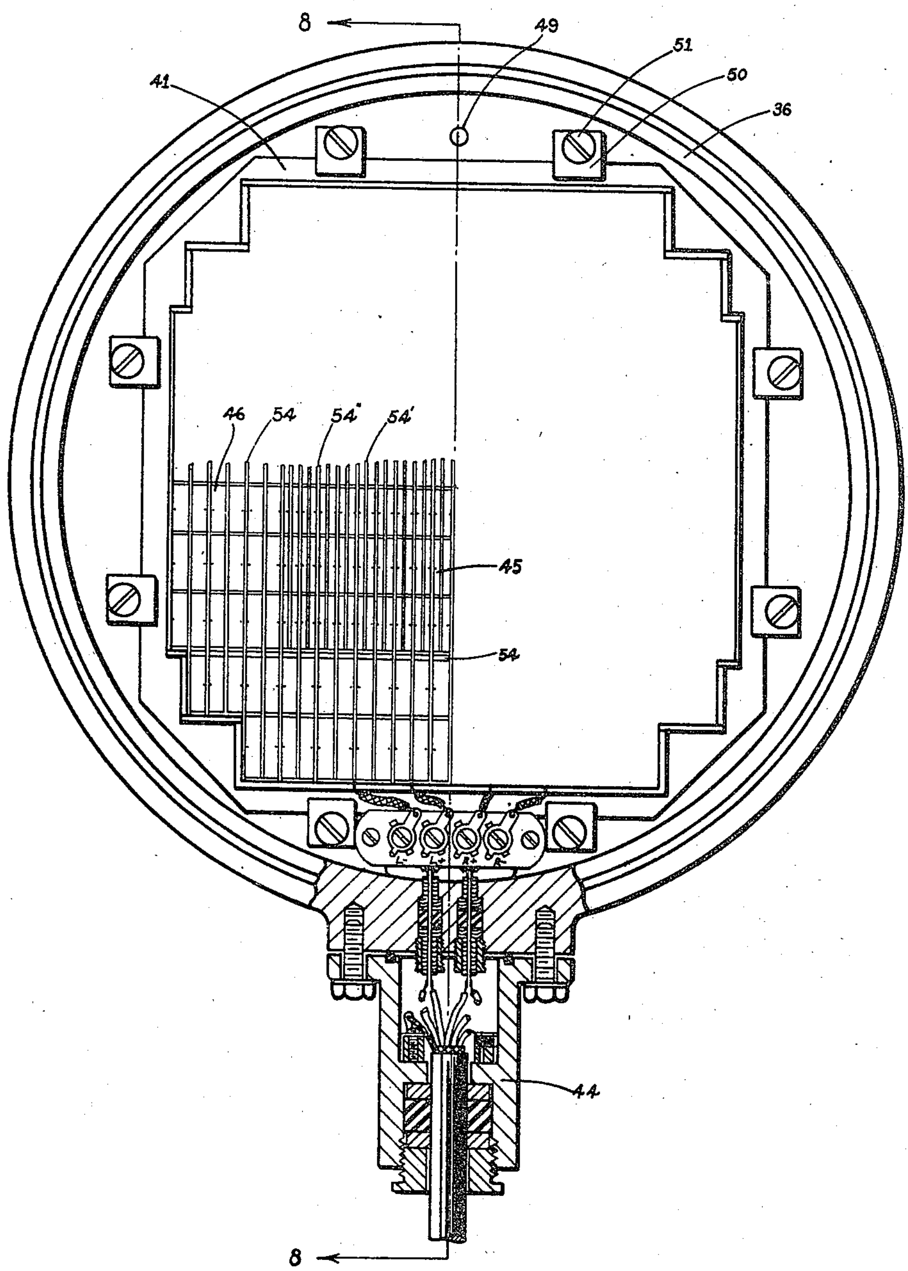


FIG. 7

INVENTOR.
FRANK MASSA
BY
Eber J. Hyde
ATTORNEY

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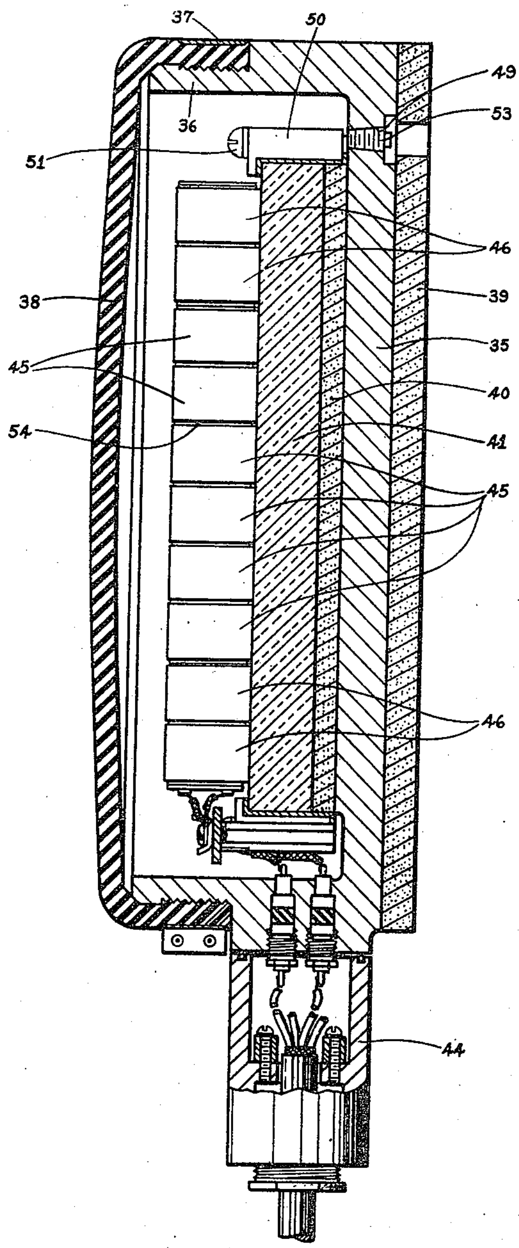


FIG. 8

INVENTOR.
FRANK MASSA
BY
Eber J. Hyde
ATTORNEY

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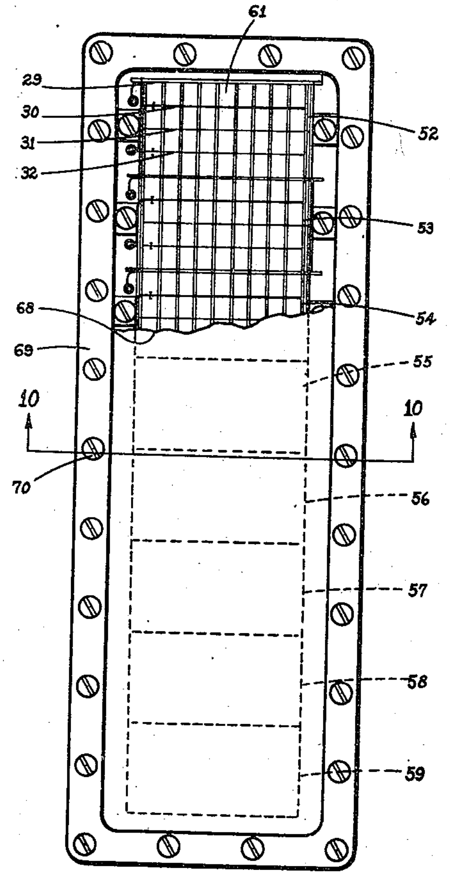


FIG. 9

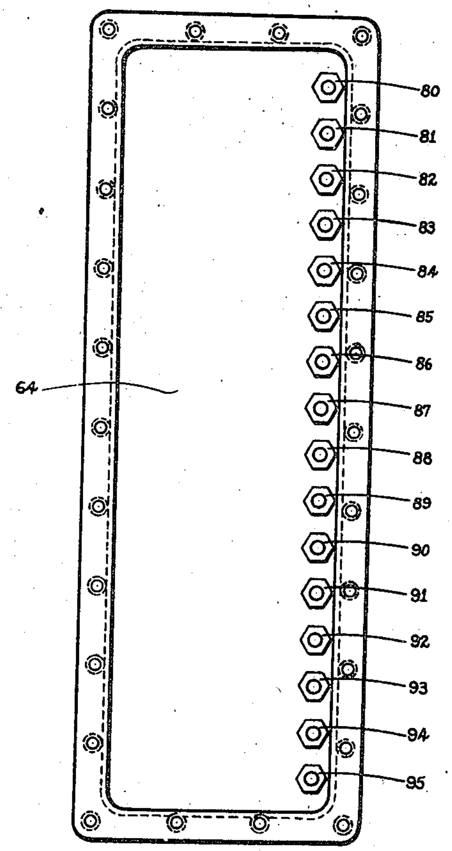


FIG. 11

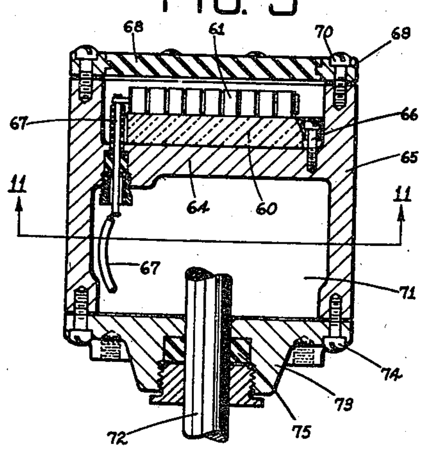


FIG. 10

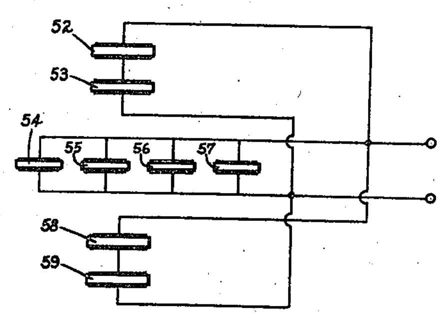


FIG. 12

INVENTOR.
FRANK MASSA

BY

ATTORNEY

Patented Sept. 9, 1947 2,427,062

# UNITED STATES PATENT OFFICE

2,427,062

## VIBRATIONAL ENERGY TRANSMITTER OR RECEIVER

Frank Massa, Cleveland Heights, Ohio, assignor to The Brush Development Company, Cleveland, Ohio, a corporation of Ohio

Application June 2, 1944, Serial No. 538,469

8 Claims. (Cl. 177—386)



My invention pertains to transducers for radiating and/or receiving vibrational energy and more particularly to transducers having a composite piston surface vibrating with a plurality of amplitudes whereby the ratio of the vibrational energy in the main lobe of its directional pattern to the vibrational energy in the minor lobes of the pattern is a maximum.

An object of my invention is to provide a transducer for radiating and/or receiving vibrational energy which has a directional pattern comprised of a main and minor lobes in which the ratio of the vibrational energy in the main lobe to the vibrational energy in the minor lobes is maximum.

Another object of my invention is to provide new and novel piezoelectric transducers.

It is also an object of my invention to provide a transducer whose directional pattern may be easily changed.

A further object of my invention is to provide a transducer of simple, practical construction yet which closely approximates certain optimum conditions which are obtainable only with more complicated and expensive construction.

Other objects and a fuller understanding of my invention may be had by referring to the specification, claims, and drawings in which:

Figure 1 diagrammatically represents a circular vibrating piston.

Figure 2 diagrammatically represents a composite piston comprised of a circular piston surrounded by an annular piston.

Figure 3 represents by a solid line the directional pattern of the vibrating piston of Figure 1, and by a dotted line the directional pattern of the vibrating composite piston of Figure 2.

Figure 4 diagrammatically represents a vibrating piston comprised of a circular piston and two concentric annular pistons surrounding the circular piston.

Figure 5 is a circuit diagram showing one form of my invention.

Figure 6 is a circuit diagram showing another form of my invention.

Figure 7 is a plan view, with the cover removed, of the piezoelectric transducer which is illustrated in Figure 8.

Figure 8 is a cross-sectional view taken along line 8—8 of Figure 7.

Figure 9 is a plan view of another type of piezoelectric transducer wherein a number of separate transducer units are assembled in a common housing, with a portion of the vibration transmitting cover broken away.



Figure 10 is a cross-sectional view taken along line 10—10 of Figure 9, and

Figure 11 is a view of the back of the transducer illustrated in Figures 9 and 10, with the back cover portion removed.

Figure 12 is a circuit diagram of one of a variety of possible electrical connections for the separate transducer units of Figures 9–11.

In the past it has been general practice to design transducers for receiving and/or transmitting vibrational energy in the form of a circular piston which vibrates with substantially the same amplitude and phase throughout its area. Such a piston is diagrammatically illustrated by Figure 1 and it has a directional response pattern which is illustrated by the solid lines in Figure 3 and comprised of a main lobe 10, a secondary lobe 11 and a tertiary lobe 12. Other minor lobes may be present but for the purpose of illustrating my invention showing them in the figures might only lead to confusion.

I have found that in order to obtain a better response pattern than is obtainable from a single vibrating piston (Fig. 1), the effect of a composite piston comprised of a central circular piston with an annular piston surrounding it should be obtained, and certain relationships should exist between the radii and amplitudes of vibration of the several parts of the composite piston. This effect may be obtained by utilizing separate piston surfaces, such as will later be described in detail, or a single piston surface may be driven with a plurality of amplitudes.

I have found when a certain ratio of amplitudes of motion of the circular and annular pistons exists and when a certain ratio of radii of the circular and annular pistons exists, it is possible to obtain a maximum in the ratio of vibrational energy in the main lobe compared to the vibrational energy in the minor lobes.

In Figure 2 there is shown a circular vibrating piston 13 of radius $R_1$ and an annular vibrating piston 14 having an inner radius $R_1$ and an outer radius $R_2$. If the annular piston 14 vibrates through an amplitude $A_2$ which is less than the amplitude $A_1$ of vibration of the circular piston 13 the main lobe of the polar distribution pattern will be somewhat broadened as is shown by the dotted line 10′ in Figure 3, and at the same time the secondary lobes as illustrated by the reference characters 11′ and

12' will be materially reduced in sensitivity. The optimum design for a transducer having a composite vibrating surface comprised of the circular piston 13 and one annular piston 14 is as follows: The ratio of the amplitude of movement $A_1$ of the circular piston 13 to the amplitude of movement $A_2$ of the annular piston 14 should be about 2.4. The ratio of the radius $R_1$ of the circular piston to the radius $R_2$ of the annular piston 14 should be about .607. When these two ratios exist the vibrational energy in the main lobe 10' of the directional pattern of the transducer compared to the vibrational energy in the minor lobes 11', 12' of the directional pattern is a maximum. For example, if the directional pattern 10, 11, 12 has an 18 db reduction between its main lobe 10 and its secondary lobe 11, the directional pattern 10', 11', 12' obtained from a transducer having the optimum design ratios will have approximately 32 db reduction between the peak of its main lobe 10' and the peak of its secondary lobe 11'.

The three-section piston surface diagrammatically illustrated by Figure 4 should have the following ratios of radii and amplitude of movement in order to obtain the best directional pattern. The ratio between the amplitude $A_1$ of movement of the circular piston 13 and the amplitude $A_2$ of movement of the first annular piston 15 should be about 1.9, and the ratio of the amplitude $A_1$ of movement of the circular piston 13 to the amplitude $A_3$ of movement of the second annular piston 16 should be about 5.8. The ratio of the radius $R_1$ of the circular piston to the radius $R_2$ of the first annular piston should be about .676; and the ratio of the radius $R_1$ to the radius $R_3$ of the second annular piston 16 should be about .476. When these ratios exist there will be approximately 38 db reduction in signal intensity between the peak of the main lobe and the peak of the secondary lobes.

It is also possible to design transducers having more than two annular piston portions and a slightly better directional pattern will be obtained. However, the improvement over the three-section composite piston surface is not such as to warrant the added manufacturing cost of such a unit unless special results are desired.

The improvement arises from the main lobes of the response patterns of the circular and annular pistons reinforcing each other while the secondary lobe of the response pattern of the circular piston and the tertiary lobe of the response pattern of the annular piston tend to cancel each other as they are out of phase. Thus, in order to obtain the maximum improvement the magnitude of the secondary lobe of the response pattern of the circular piston should be the same as the magnitude of the tertiary lobe of the response pattern of the annular piston. The secondary lobe of the response pattern of the annular piston is reduced in magnitude to a point below the peak of the secdnary lobe of the response pattern of the composite piston as the main lobe of the response pattern of the circular piston is out of phase with the secondary lobe of the response pattern of the annular piston and partially cancels it.

I have given the optimum ratios for a two and a three section composite piston and I will illustrate by mathematics the method of designing a two-section composite piston. A person skilled in the art will then be able to design a composite piston having more than two sections.

The amplitude of a sound wave at a point P distant from a sound source making an angle $\theta$ with the normal to the plane of the circular piston may be expressed by the following well-known equation:

Amplitude at

$$P=A_1r_1^2\left(\frac{J_1(kr_1 \sin\theta)}{kr_1 \sin\theta}\right)$$

and the amplitude of a sound wave at the point P distant from the sound source making the angle $\theta$ with the normal to the plane of the annular piston may be expressed by the following well-known equation:

Amplitude at

$$P=A_2\left(r_2^2\frac{J_1(kr_2 \sin\theta)}{kr_2 \sin\theta}-r_1^2\frac{J_1(kr_1 \sin\theta)}{kr_1 \sin\theta}\right)$$

Where

$A_1$ = the amplitude of movement of the circular piston
$r_1$ = the radius of the circular piston
$A_2$ = the amplitude of movement of the annular piston
$r_2$ = the radius of the annular piston
$J_1$ = Bessel function
$k=\frac{2\pi}{\lambda}=\frac{2\pi f}{c}$

where

$f$ = frequency
$c$ = velocity of sound in the medium

The amplitude of the sound wave at point P due to the composite piston therefore is:

Eq. (1):

Amplitude at

$$P=A_1r_1^2\left(\frac{J_1(kr_1 \sin\theta)}{kr_1 \sin\theta}\right)+A_2\left(r_2^2\frac{J_1(kr_2 \sin\theta)}{kr_2 \sin\theta}-r_1^2\frac{J_1(kr_1 \sin\theta)}{kr_1 \sin\theta}\right)$$

Eq. (2):

Amplitude at

$$P=(A_1-A_2)r_1^2\frac{J_1(kr_1 \sin\theta)}{kr_1 \sin\theta}+A_2r_2^2\frac{J_1(kr_2 \sin\theta)}{kr_2 \sin\theta}$$

From Bessel function tables $J_1$

$$\frac{(Z)}{Z}$$

has maxima for $Z=0$; $1.638\pi$; $2.666\pi$; $3.694\pi$.

The first term in Eq. (2) will have its secondary maxima at $kr_1 \sin\theta=1.638\pi$ or

$$\sin\theta=\frac{1.638\pi}{kr_1}$$

The second term in Eq. (2) will have its tertiary maximum at $kr_2 \sin\theta=2.666\pi$ or

$$\sin\theta=\frac{2.666\pi}{kr_2}$$

To reduce the secondary maximum of the response pattern of the composite piston source as much as possible I make the secondary maximum of the response pattern of the circular piston coincide in space with the tertiary maximum of the outer annulus which is out of phase with the secondary maximum. This means that we must make the angles coincide or, expressed mathematically:

$$\frac{1.638\pi}{kr_1}=\frac{2.666\pi}{kr_2}$$

Eq. (3):

$$\frac{r_2}{r_1}=\frac{2.666}{1.638}=1.629$$

or

$$\frac{r_1}{r_2}=.61$$

Another condition which must be satisfied is that the ratio of the combined amplitudes of the Bessel functions at angle zero to the combined amplitudes at the angle at which the secondary and tertiary maxima coincide shall be a maximum.

From Bessel tables we find:

$$J_1(1.638\pi) = -.3401$$
$$J_1(2.666\pi) = +.2702$$

Substituting in Eq. (2):

$$\left((A_1-A_2)r_1^2\frac{-.3401}{1.638\pi}+A_2(1.629r_1^2)\frac{.2702}{2.666\pi}\right)=0$$

Eq. (4):

which gives

$$\frac{A_2}{A_1}=.42$$

or

$$\frac{A_1}{A_2}=2.38$$

My invention contemplates utilizing any means for vibrating the several sections of a composite piston, but one of the best is to utilize piezoelectric crystal elements.

I have found that expander crystals are highly successful, and there are several ways of obtaining the desired different amplitudes of motion of the several sections of the piston.

One of the best is illustrated by Figures 7 and 8 wherein the crystal elements which comprise the center circular piston and the crystal elements which comprise the annular ring portion have the same length and width but the thickness between their electrodes which are connected to their major faces varies inversely as the desired amplitudes of motion, and the same voltage is applied across each crystal element whereby the voltage gradient in the crystal elements which are to vibrate with greater amplitude is greater than the voltage gradient in the crystal elements which are to vibrate with a smaller amplitude.

Another method, illustrated diagrammatically by Figure 5 is to utilize similar crystal elements and to subject those crystals which are to vibrate with a greater amplitude to a higher voltage than the other crystal elements. Within certain limits the amplitude of motion of a crystal element is directly proportional to the voltage applied. Thus, in Figure 5, the elements **25** and **26** are similar, and the ratio of $V_1$ to $V_2$ is the same as the desired ratio between $A_1$ and $A_2$, i. e., for a two-section composite piston 2.4. For a three-section composite piston another voltage source and another bank of crystal elements would be necessary and $V_1$ to $V_2$ would be 1.9 and $V_1$ to $V_3$ would be 5.8.

The required voltage ratios may be obtained by suitably series-paralleling banks of crystal plates with the number of plates in each group adjusted to produce the required percentage of the total voltage drop; or the correct voltage can be derived in other ways: for example; from separate amplifiers which have their inputs connected together and which have their gains adjusted to produce the required voltage output.

Figure 6 diagrammatically illustrates still another method of obtaining the desired amplitude of motion utilizing the same voltage on each group of crystal elements. The ratio of the length of crystal elements **27** to the length of crystal elements **28** should be the same as the ratio of the amplitude of motion, i. e., if it is desired that the center section vibrate with an amplitude 2.4 times the amplitude of the annular section then the crystal elements which form the center section should be 2.4 times as long as the crystal elements which form the annular section. A transducer utilizing this method of obtaining different amplitudes of motion is not as good as a transducer utilizing either of the other two methods if the transducer is to operate at resonance.

It is to be realized that these three methods of obtaining the desired amplitude of motion of the central and annular portions are not the only methods which may be utilized, as, for instance, any combination of the three may also be used; that is, the elements in the two banks of crystals may be of different length, different thickness, and have different voltages impressed thereon, but these three factors may be so correlated that the desired result is obtained.

While I describe my invention primarily in connection with a loudspeaker wherein a voltage is applied across the crystal elements to obtain a vibration which is transmitted to a fluid or liquid medium, my invention is equally applicable to a microphone wherein vibrating waves in air or liquid establish a voltage in the piezoelectric crystal elements which may be utilized for controlling an amplifier, and analogous means may be used for obtaining the requisite voltage ratios.

In the theoretical description of my invention I have utilized a circular piston and annular rings. However, when making a practical embodiment of my invention such as is shown in Figures 7 and 8 it is not essential that the inner piston be absolutely circular nor that the outside ring be truly annular, as the approximation illustrated by Figure 7 gives very satisfactory results and is much less complicated to make.

For ease of manufacture it is usually preferable to have all of the crystal elements in a composite transducer the same length. When this is desired the differential amplitude of vibration is obtained by having a higher voltage gradient on those crystals which are to vibrate with a greater amplitude. Several methods may be utilized for obtaining a higher voltage gradient on one type of crystal than on another. One is to utilize crystals of the same thickness and to apply greater voltage to those crystals which are to vibrate with a greater amplitude. Another method, which is illustrated in Figures 7 and 8, is to utilize the same voltage across all the crystal elements and to make the crystals which are to vibrate with greater amplitude thinner in the dimension between the electrodes. This means that the voltage gradient across the thinner crystals is greater than the voltage gradient across the thicker crystals and if the thickness ratio of the crystals is inversely proportional to the desired amplitude of motion then the desired vibrational characteristics will be obtained. In other words, when it is desired that the crystals comprising the circular diaphragm portion vibrate 2.4 times the amplitude of vibration of the crystals in the annular diaphragm portion, and if they are the same length and have the same voltage across them, then each crystal in the annular portion should be 2.4 times as thick as each crystal in the circular portion.

The transducer illustrated in Figures 7 and 8 may be either a microphone or a loudspeaker. However, it will be described as a loudspeaker. It comprises a housing **35** having an upstanding edge portion **36** to which a cover portion **38** is connected by means of a steel clamping band **37**.

The cover portion as shown is a rubber vibration transmitting member and does not comprise a true diaphragm although a diaphragm in contact with the ends of the crystal elements may be utilized. Connected to the bottom of the housing **35** is a vibration isolating pad **39** which materially reduces the vibrational energy transmitted or received through the back of the unit. Within the housing 35 and connected to the bottom portion thereof is a second vibration isolating pad **40** which, like pad 39, may be formed of rubber impregnated cork, corprene, or any other such material having a bulk modulus of elasticity which is low compared to that of the housing material which may be cast iron or the like. Mounted on one face of the vibration isolating pad **40** is an assembly base **41** to which is affixed a first group of electroded crystal elements **45** and a second group of electroded crystal elements **46**. These crystal elements may be of Rochelle salt or primary ammonium phosphate or any other suitable piezoelectric crystalline material and are of the expander type which means that when an electrostatic field is impressed across the crystal in a direction between the electrodes and parallel to the electric axis of the crystalline material, (which in the drawing is parallel to the plane of the base **41**) each of the crystal elements will expand in a direction normal to the plane of the base **41**. The dots on the edges of the crystal elements in Figure 7 indicate the major faces of the elements upon which is developed a charge of a given polarity for a given exciting force. The base **41** should have sufficient mass and it should be so connected to the housing 35 that it is not materially vibrated by the vibration of the crystal elements. Electrical leads are brought in through an entrance **44** which includes means (not described in detail) for preventing moisture from entering the housing 35.

The method of assembling the unit is as follows: The assembly base **41**, formed of some material such as glass which may be ground flat, is provided. To a flat face of this base **41** is connected a plurality of piezoelectric crystal elements 45, 46, either one crystal element at a time or in previously assembled strips of crystals.

Thin strips of corprene **54** or the like extend between the faces of the several crystal elements and between the several strips of elements in order to reduce the effect of expansion and contraction in a direction perpendicular to the desired direction of expansion and contraction, and in order that unreasonably small manufacturing tolerance need not be maintained. For a more detailed description of the vibration decoupling feature reference may be made to my patent applications, Serial No. 669,761 and Serial No. 519,069.

These piezoelectric elements may be connected to the base by means of a thin film of suitable adhesive material. Then, in order that all of the crystal elements be of the same length the assembly comprised of the base **41** and the affixed crystal elements is placed with the ends of the crystal elements against a sheet of fine sandpaper or emery cloth. Relative motion between the sandpaper or emery cloth and the crystal assembly is effected until the ends of the crystal elements define a plane surface. The assembly is then mounted in the housing **35** by means of a number of clamps 50 which are screwed into the base of the housing **35** by means of screws **51**. The electrical leads, which are brought through the opening **44** in the housing, are then connected to the crystal leads and electrodes. The rubber cover **38** is clamped onto the upstanding edge portion **36** of the housing **35** by means of the clamping band **37**. Air is then evacuated through the opening **49** in the bottom of the housing **35** and replaced by castor oil. When all of the air has been replaced by castor oil a pipe plug **53** is utilized for sealing the opening **49**. The bottom vibration isolating pad **39** is then affixed to the outside face of the base of the housing.



When utilizing crystal elements **45** and **46** of different thickness to obtain the desired amplitude differential, I have found it convenient from a practical manufacturing view point to so design the corprene strips **54'** which contact the major faces of the thinner crystal elements that they are .4 times as thick as the thinner crystal elements. The thicker crystal elements **46** have corprene strips **54''** running between them and in contact with their major faces, and these corprene strips may be of any practical thickness. These strips **54''** also extend between some of the thinner crystal elements **45**, and those elements **45** which are not separated by strips **54''** are separated by strips **54'**. If the total thickness of two of the thinner elements **45** and one strip of corprene **54'** is made equal to the thickness of one of the crystal elements **46**, then the strips **54''** on either side of the two thinner elements **45** will extend in a straight line between those thin elements and their next adjacent elements. In order to achieve this construction and maintain the desired ratio between the crystal element thickness of 2.4, the corprene strips **54'** should be made .4 as thick as one of the thin crystal elements.

Figures 9, 10, 11 illustrate another type of unit which may approximate the optimum conditions previously set forth.

In this construction a glass base plate **60** is provided. The piezoelectric crystal elements **61** preferably are assembled into strips **29, 30, 31, 32** and then into units such as **52, 53, 54, 55, 56, 57, 58, 59**. The units are then affixed by means of an adhesive to the base plate **60**.

Each of the eight units **52** to **59** has its own pair of terminals on the partition **64**, and all of the crystal elements **61** in each unit are connected in parallel. In all, eight such units **52—59** are connected to the glass base. The assembly is then inverted onto an emery cloth and the ends of the crystal elements are ground until a plane is defined by the faces. The ground crystal assembly is then connected to a partition **64** within the housing **65** by means of screws **66**. The electric leads **67** for the piezoelectric crystal elements extend through a hole in the partition **64** and are connected to the element leads and electrodes. A vibration transmitting rubber cover **68** is connected to the housing **65** such as by being molded into a metal ring **69** which is connected to the housing **65** by means of the screws **70**. Air is evacuated from the crystal element chamber and replaced with castor oil or the like. The housing **65** has a chamber **71** wherein an amplifier (details of which are not shown) may be mounted. The leads **67** are connected to the amplifier, and a cable **72** which is brought in through the base **73** is also connected to the amplifier. The base **73** is connected to the housing **65** by means of the several screws **74** and water-tight means **75** may be provided between the cable **72** and the base **73** of the housing.

Each of the crystal units **52** to **59** has its own pair of terminals on the base of the housing **65**, thus the terminal **80** is the positive terminal for unit 52 and the terminal 81 is the negative terminal for the unit 52. The terminal 82 is the positive terminal for the unit 53. Terminal 83 is the negative terminal for the unit 53, etc. By inter-connecting two or more of the crystal units together by means of their terminals on the back of the housing 65 various different directional patterns may be obtained.

Although the optimum reduction in the magnitude of the secondary lobes of a directional pattern is obtained for a two-section composite piston when the amplitude ratio is about 2.4 and the diameter ratio is about .61, it may be desirable to sacrifice some of the reduction in the secondary lobes to gain advantages such as mechanical simplicity and flexibility of operation. Such a device is illustrated by Figures 9, 10, and 11 wherein the mechanical structure is simple, particularly due to utilizing crystal elements which are uniform in size, and flexibility is gained by the range of possible connections which can be made.

Figure 12 illustrates how the eight similar crystal units 52 to 59 may be interconnected to approximate the optimum results. In Figure 12 the plurality of individual crystal elements 61 which form a unit are symbolized by a single crystal.

The center four units, 54, 55, 56, and 57 are connected in parallel and form a first group, the units 52, 53 at one end are connected in series and form a second group, and the units 58, 59 at the other end are connected in series and form a third group. The three groups are then connected across the same voltage source, as shown. Thus, each crystal element in the second and third groups will have half the voltage gradient that each crystal element in the first group has thereby establishing an amplitude ratio of 2.0, and the ratio of "diameters" will be .5. A substantial reduction in the magnitude of the secondary lobes will result.

When a piezoelectric crystal element is electroded a margin is usually provided between the edge of the electrode and the edge of the crystal element, as is shown in Figures 5, 6, and 12. Primarily this is to prevent electrical leakage paths over the surface of the element between the electrodes. If an electroded crystal were mounted on a metallic base plate and several hundred volts were applied to it (as in a speaker) a short-circuit between the electrode and the metallic base plate would be apt to be established unless a very wide electrode margin were employed. Wide electrode margins are not desirable as they reduce the effectiveness of a given amount of crystalline material. Thus it is important in transducers, especially of the vibration transmitting type, that the base 41 be of glass or some other insulating material.

While I have described my invention with a certain degree of particularity it is to be understood that the illustrated means are by way of example, and that changes may be made in the construction and arrangement of parts without departing from the spirit and scope of my invention.

I claim as my invention:

1. In a transducer for radiating and/or receiving vibrational energy and having main and secondary directional lobes, a substantially circular piston of radius $R_1$, and a substantially annular piston of inner radius $R_1$ and outer radius $R_2$ surrounding and lying in the same plane as said circular piston, said circular piston being adapted to vibrate at a given frequency and with an amplitude $A_1$, and said annular piston being adapted to vibrate in phase with said circular piston with an amplitude $A_2$, the ratio of $R_1$ to $R_2$ being substantially .61, and the ratio of $A_1$ to $A_2$ being substantially 2.4 whereby the ratio of the main lobe energy radiated substantially normal to the plane of the said pistons to the secondary lobe energy is maximum.



2. In a transducer for radiating and/or receiving vibrational energy and having main and secondary directional lobes, a first group of similar piezoelectric crystal elements of the expander type arranged to define substantially a circle of radius $R_1$ and having planar free ends adapted to vibrate in unison, a second group of similar piezoelectric crystal elements of the expanded type but different than the piezoelectric crystal elements of the said first group, the crystal elements in said second group being arranged to define substantially an annulus of outside radius $R_2$ surrounding the said first group and having free ends lying in the plane of the free ends of the crystal elements in the substantially circular group, said first and second groups of crystal elements being adapted to vibrate in phase, first and second electrical circuits connected respectively to said first and second groups of crystal elements, the ratio of $R_1$ to $R_2$ being substantially .61, and the ratio of the amplitude of effective movement of the crystal elements in said first group to the amplitude of effective movement of the crystal elements in said second group being substantially 2.4 whereby the ratio of the vibrational energy in the main lobe to the vibrational energy in the secondary lobe is maximum.

3. In a transducer as set forth in claim 2, the further characterization that the length and the width of each crystal element in the first group of crystal elements is substantially the same, respectively, as the length and the width of each crystal element in the second group of crystal elements, and the thickness of each crystal element in the second group is about 2.4 times the thickness of each crystal element in the first group.

4. In a transducer for radiating and/or receiving vibrational energy and having main and secondary directional lobes, a first group of piezoelectric crystal elements of the expander type arranged to define substantially a circle of radius $R_1$ and having planar free ends adapted to vibrate in unison, a second group of piezoelectric crystal elements of the expander type arranged to define substantially an annulus of outside radius $R_2$ surrounding said first group and having free ends lying in the plane of the free ends of the crystal elements in the substantially circular group, the crystal elements in said first and said second groups being adapted to vibrate in phase, circuit means for impressing a voltage on each of the crystal elements in said first group, circuit means for impressing a voltage on each of the crystal elements in said second group, the voltage across the thickness dimension of each crystal element in said first group and the voltage across the thickness dimension of each element in said second group and the thickness of the crystal elements in said first and second groups being so related that the voltage gradient per unit thickness on each crystal element in said first group is about 2.4 times the voltage gradient per unit thickness on each crystal element in said second group, and the ratio of $R_1$ to $R_2$ being substantially .61 whereby the ratio of the main lobe vibrational energy normal to the plane of the free

ends of the crystal elements to the secondary lobe vibrational energy is maximum, and means comprising a housing for substantially enclosing the piezoelectric crystal elements.

5. In a transducer for radiating and/or receiving vibrational energy and having main and secondary directional lobes, a flat base plate, a first group of piezoelectric crystal elements of the expander type mounted on said base plate and arranged to form substantially a circle of radius $R_1$ and arranged to expand and contract in unison in a direction substantially normal to the plane of said base plate, a second group of piezoelectric crystal elements of the expander type mounted on said base plate and arranged to form substantially an annulus of outer radius $R_2$ surrounding said first group of crystal elements and each said crystal element being adapted to expand and contract in unison with each other and in phase with each of the crystal elements of said first group, the dimension of each of the crystal elements in the said first and second groups in a direction normal to the plane of the flat base plate being substantially the same, electrode means on each of said crystal elements, circuit means connected to the electrode means of said first and second groups of crystal elements and so arranged and related to the thickness dimension of said crystal elements that the voltage gradient per unit thickness between the electrode means on the crystal elements of said first group is about 2.4 times the voltage gradient per unit thickness on each crystal element in said second group, and the ratio of $R_1$ to $R_2$ being substantially .61 whereby the ratio of the main lobe vibrational energy substantially normal to the plane of the said flat base plate to the secondary lobe vibrational energy is maximum, and means comprising a housing for substantially enclosing the piezoelectric crystal elements.

6. In a transducer as set forth in claim 5, the further characterization that the circuit means is arranged for substantially equal voltage across all of the crystal elements in the said first and second groups, and the thickness dimension between the electrode means on the crystal elements of the said second group is about 2.4 times the thickness dimension between the electrode means on the crystal elements of the said first group.

7. In a transducer, a housing having a vibration transmitting portion, piezoelectric crystal element means including electrode means within



and connected to a portion of said housing, and lead means extending through said housing and connected to the electrode means of said piezoelectric crystal element means; said piezoelectric crystal element means comprising a first group of crystal elements each element thereof having a given length and a given width in directions respectively parallel to the two directions of piezoelectric expansion and contraction and having a given thickness between its electrode faces, and a second group of crystal elements each element thereof having the same given length and width as the crystal elements in said first group and having a given thickness between its electrode faces which is related to the thickness of the elements of said first group by the factor 2.4, said first group of crystal elements forming substantially a circle of radius $R_1$ and being surrounded by said second group of crystal elements which forms substantially an annulus of outside radius $R_2$, the ratio of $R_1$ to $R_2$ being about .61.

8. In a transducer as set forth in claim 5, the further characterization that the crystal elements in the first and second groups are substantially the same in thickness and the voltage applied to the said first group is substantially 2.4 times the voltage applied to the said second group.

FRANK MASSA.


## REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

| Number | Name | Date |
|---|---|---|
| 2,324,024 | Ream | July 13, 1943 |
| 2,181,132 | Kallmeyer | Nov. 28, 1939 |
| 2,138,036 | Kunze | Nov. 29, 1938 |
| 2,063,950 | Steinberger | Dec. 15, 1936 |
| 1,802,781 | Sawyer et al. | Apr. 28, 1931 |
| 1,980,957 | Parry | Nov. 13, 1934 |
| 2,405,605 | Goodale et al. | Aug. 13, 1946 |
| 2,407,271 | Hart | Sept. 10, 1946 |
| 2,407,329 | Turner | Sept. 10, 1946 |
| 2,407,643 | Batchelder | Sept. 17, 1946 |

FOREIGN PATENTS

| Number | Country | Date |
|---|---|---|
| 279,878 | Great Britain | Mar. 8, 1928 |

OTHER REFERENCES

Ser. No. 382,084, Menges (A. P. C.), pub. May 18, 1943.