March 4, 1952 B. B. BAUER 2,587,684

DIRECTIONAL MICROPHONE

Filed Oct. 13, 1948 2 SHEETS—SHEET 1

Fig. 1

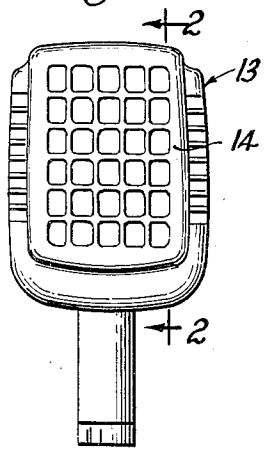


Fig. 2

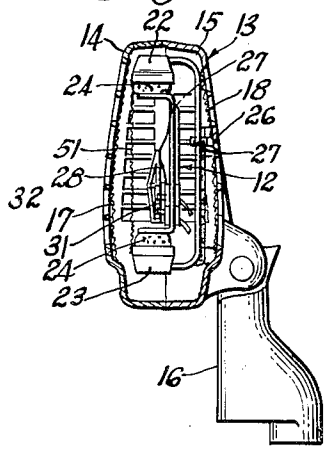


Fig. 3

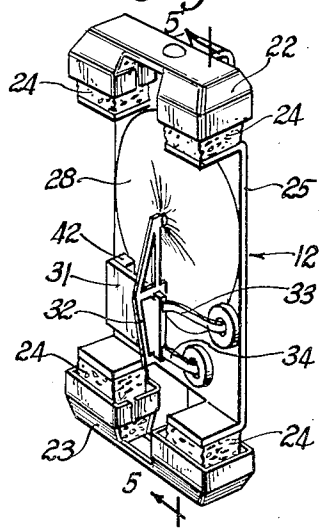


Fig. 4

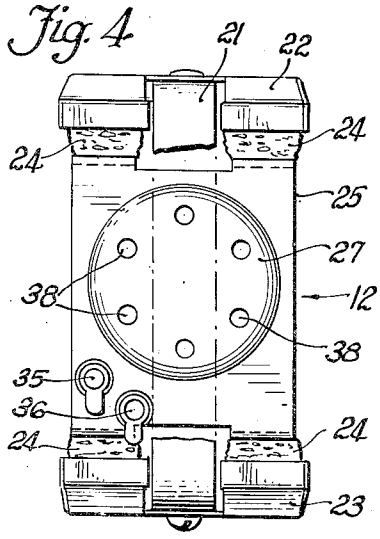


Fig. 5

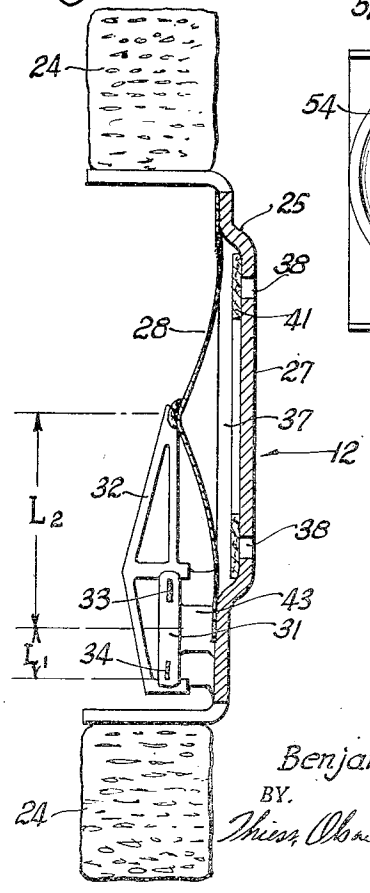
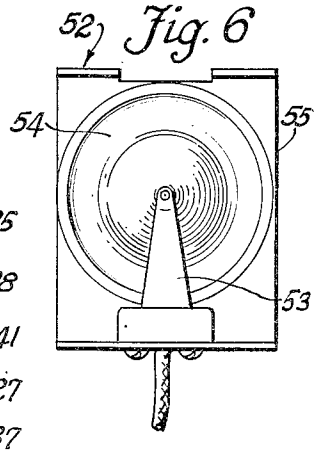


Fig. 6



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DIRECTIONAL MICROPHONE

Filed Oct. 13, 1948 2 SHEETS—SHEET 2

Fig. 7

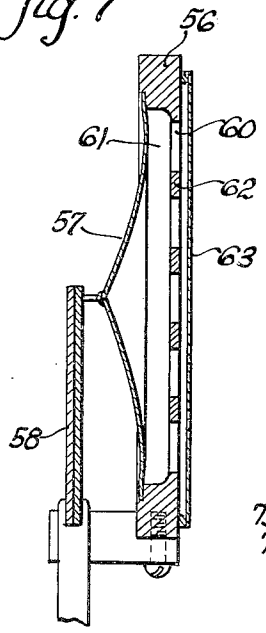


Fig. 9

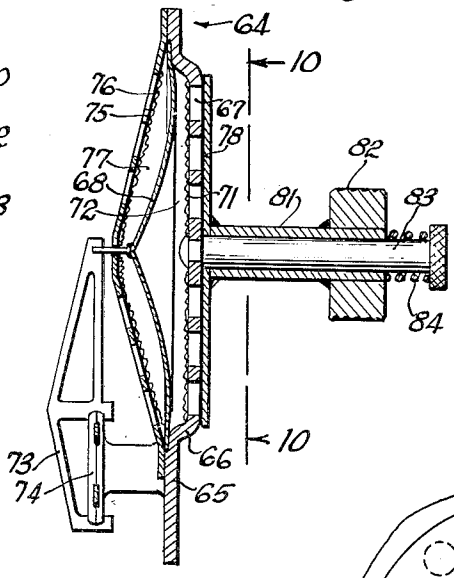


Fig. 10

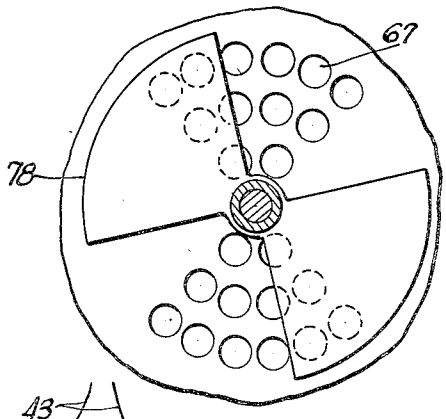
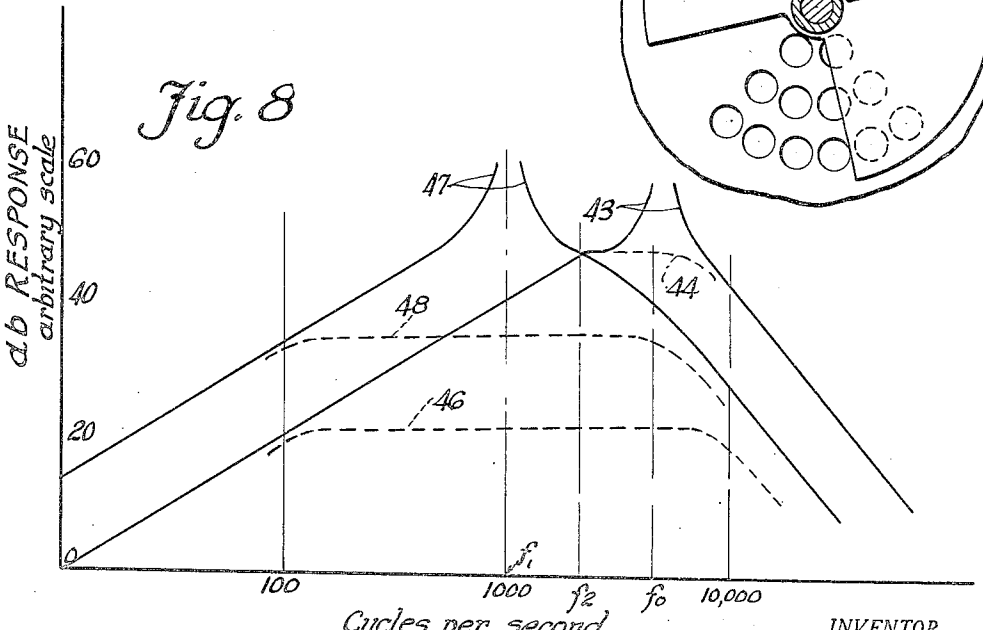


Fig. 8



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UNITED STATES PATENT OFFICE

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DIRECTIONAL MICROPHONE

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Application October 13, 1948, Serial No. 54,221

23 Claims. (Cl. 179—110)

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This invention relates to directional sound translating devices, more particularly to directional microphones having displacement responsive sensitive elements, and it is an object of the invention to provide improved microphones of this character.

Directional microphones, that is, microphones which have greater response for sound received from one direction than from another and which utilize displacement responsive elements such as piezoelectric crystals are well known. One form of such microphones wherein a single transducer or piezoelectric crystal is used and produces its output through sound effects from two points in space is described and claimed in the Patent No. 2,237,298 to Benjamin Baumzwieger, now by judicial change of name Benjamin B. Bauer, assigned to the same assignee as the present invention. Microphones of the character described in the patent utilizing a single sound translating element, such as a diaphragm which is acted upon by sound from two points in space, are essentially pressure difference type microphones and when the diaphragm thereof drives a displacement responsive element, such as a piezoelectric crystal, an output or response is obtained which increases with increasing frequency. This occurs because the pressure difference between the two points in space increases with frequency and the dominant factor in controlling movements of the crystal is its stiffness.

Crystals have natural frequencies of vibration or free resonances at which the amplitude of vibration is large. In prior constructions (such as described in the patent referred to) the crystal dimensions have been chosen so that the natural frequency of vibration of the crystal and diaphragm is in the upper range of the frequencies to be translated. Thus, for the normal frequency spectrum of about 100 cycles per second to 10,000 cycles per second, the natural frequency of vibration may be in the vicinity of 4,500 to 6,000 cycles per second. Such crystals are quite stiff, thereby requiring a relatively large driving force per unit output voltage with consequent relatively low output or sensitivity.

The rise in response at resonance (natural frequency) in the prior devices is compensated for by providing a relatively small amount of damping such as a cloth placed in close association with the diaphragm. Flat or uniform response over substantially the whole useful frequency range despite the rising response with increasing frequency is produced by utilizing an electrical compensating circuit or network which introduces attenuation increasing in proportion to the frequency increase. While such a circuit maintains flat response, it produces a loss in over-all output and keeps the output at the low level determined by the circuit despite the higher output available. At the higher frequencies the circuit loses its effect but the output remains substantially the same due to diffraction effects.

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The damping or resistance used in connection with crystals and diaphragms of the prior microphones has been small and only prevented the rise in output at resonance, higher damping to obtain flat response over a greater frequency range being avoided because of the resultant low microphone output obtained and the difficulty of making physical structures having the necessary acoustical properties.

Accordingly, it is a further object of the invention to provide an improved microphone of the character indicated having improved response or output level.

It is a further object of the invention to provide an improved microphone of the character indicated wherein flat or uniform response at a higher output level is obtained and the compensating network is eliminated.

Microphones of the character described have been made directional through the use in each unit of a phase shifting network which applied a force to one side of the microphone diaphragm. While such a phase shift network has resistance or damping associated therewith, it does not have any substantial effect in controlling the amplitude of diaphragm vibration at its natural frequency, this being done by a separate damping element as already described.

Accordingly, it is a further object of the invention to provide an improved directional microphone which performs damping of the diaphragm amplitude at its natural frequency and provides the phase shift network resistance in a single element of the phase shift network.

It is a further object of the invention to provide an improved microphone of the character described having high output level wherein the dominant element in controlling the diaphragm movements is the damping component of the phase shift network.

According to one form of the invention, a directional microphone for a range of frequencies is provided comprising, a diaphragm adapted to be substantially exposed on one side to sound waves in a medium, a phase shifting network including resistance and a cavity or compliance between the other side of the diaphragm and sound waves

in the medium, piezoelectric means external to the cavity for producing an output, lever means coupling the diaphragm to the piezoelectric means, the natural frequency of the system including the piezoelectric means, and the diaphragm being in the upper range of the frequencies to be translated, the lever means producing a natural frequency of the moving system including the piezoelectric means, the diaphragm and the lever approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance or damping of the phase shift network being approximately equal to the reactance of the moving system at the lower range of frequencies to be translated.

For a better understanding of the invention, reference should be had to the accompanying drawings in which:

Figure 1 is a front elevational view of the outer casing of a microphone embodying the invention;

Fig. 2 is a sectional view taken substantially along lines 2—2 of Fig. 1;

Fig. 3 is a perspective view of the microphone unit of Fig. 2 on a larger scale embodying the invention;

Fig. 4 is a rear elevational view partly broken away of the unit shown in Fig. 3;

Fig. 5 is a sectional view on a larger scale taken substantially in the direction of arrows 5—5 of Fig. 3;

Fig. 6 is a front elevational view of a modified microphone unit embodying the invention;

Fig. 7 is a sectional elevational view of a modified microphone unit embodying the invention;

Fig. 8 is a series of response curves for microphone units useful in explaining the invention;

Fig. 9 is a sectional elevational view of a modified microphone unit embodying the invention, and

Fig. 10 is a rear elevational view partially broken away taken substantially in the direction of arrows 10—10 of Fig. 9.

Referring to the drawings, the invention is shown embodied in a microphone unit 12 held in a grillwork casing 13 which comprises front and rear grill sections or halves 14 and 15, respectively, held together by screws for example, not shown, and a swivel 16 pivoted to the rear grill section. A stand (not shown) may be attached to the swivel and connecting leads may pass therethrough to the active part of the microphone unit. The casing and the grillwork may have any desired configuration, and attached to the inside thereof are relatively porous cloth pieces 17 and 18 to provide wind shielding.

Microphone unit 12 is held to casing 13 by means of a strap 21 and a screw 26, the strap being attached at its respective ends to transverse members 22 and 23 which have pieces of sponge rubber 24 cemented or otherwise attached at their ends and in turn attached to brackets of base 25.

The microphone unit comprises a base 25 including a rearwardly formed (such as by punching) portion 27, a generally conical curved diaphragm 28, a piezoelectric crystal 31 cemented to the base, and a lever 32 connecting the crystal and the apex of the diaphragm, leads 33 and 34 extending from the crystal for bringing out the electrical output to terminals 35 and 36 (Fig. 4) respectively.

Diaphragm 28 is sealed around its edges to base member 25 thereby forming, together with depressed portion 27, a cavity 37, the diaphragm being made of thin material such as aluminum, stiff paper or the like. The edge of the diaphragm is made quite resilient or flexible so that it vibrates easily, but the diaphragm in general, including its apex, is quite rigid so that the diaphragm tends to vibrate as a whole and has sufficient rigidity to actuate (deflect) the crystal. The diaphragm rigidity, while the diaphragm is light, obtains mainly because of the curved conical form.

Extending through depressed portion 27 is a series of holes 38 whereby sound waves at the rear of the base 25 may enter into cavity 37 and thus act on the rear side of the diaphragm. Cloth 41 or other sound permeable material is placed over each of the holes for a purpose to be described subsequently in this specification. In place of cloth which may be, for example, silk with very fine interstices, other material having acoustic resistance and inertance such as slits, diaphragms and the like may be used.

Crystal 31 is of the torsion type wherein an output is produced by twisting thereof, one end of the crystal being relatively rigidly supported across its full width on a block of material 42 cemented to the base and crystal. The other end of the crystal is relatively free so that torsional movements may take place, but this end is lightly supported on a second member 43 which may be a resilient material introducing no substantial resistance to crystal movement. Torsion of the crystal is produced by lever 32 in transmitting movements of the diaphragm apex.

Lever 32 may be of any suitable shape and of any light material such as metal (magnesium, for example) or plastic, and is shown in the form of a truss to lend the necessary rigidity. One end of the lever is coupled to the diaphragm apex by any suitable means such as cementing and the other is attached to both sides of the crystal such as by having the crystal received in notches, as seen best in Fig. 5. Hence as diaphragm 28 vibrates back and forth the right end of the crystal is twisted back and forth, the twisting taking place about the center line of the crystal.

Crystal 31 may have a natural frequency when vibrating by itself above the highest frequency to be translated, but when coupled to a diaphragm, the natural frequency of the moving system including the crystal, diaphragm, and coupling structure may be in the upper range of sound frequencies to be translated. For example, in a well known microphone, such as described in the patent referred to, the natural frequency of the crystal alone has been in the vicinity of 15,000 to 18,000 cycles per second and the natural frequency of the crystal, diaphragm, etc. has been in the vicinity of 4,500 to 6,000 cycles per second. When such a microphone operates on the principle of pressure difference, it has a relatively low output since the forces available for actuation are small.

In Fig. 8 there is drawn a curve 43 showing the response or output of a pressure difference type crystal microphone such as where the natural frequency is in the vicinity of 4,500 cycles per second, the frequency being shown on a logarithmic scale and the response being given in decibels (db.) with reference to an arbitrary output level. It will be seen that the response rises uniformly as the frequency increases until in the vicinity of f_2 where diffraction effects cause the pressure difference to become constant the response levels off, the response rises sharply in the vicinity of f_0=4,500 cycles per second due to the natural frequency, and the response falls off rapidly above resonance. The frequency f_2 depends on the

transverse dimension (outside diameter) of the unit and in the vicinity of f_2 where the transverse dimension is equal to one-quarter wavelength of sound the pressure tends to become constant. The sharp rise at resonance may be prevented by a relatively small amount of damping or resistance and results in the response curve following the dotted portion 44. The curve 43, 44 is one such as might be obtained with the microphone shown in Fig. 6 of the Patent No. 2,237,298 where the stiff crystal is coupled directly to the diaphragm. With such a microphone a flat response may be obtained by using an electrical attenuating circuit or network which begins functioning at some low frequency such as 100 cycles per second. Using such a circuit, a response following curve 45 may be obtained which, while flat over the frequency range, is at a low output level compared to that at 4,500 cycles without the network. Curve 46 corresponds to the upper curve of Fig. 9 of the patent referred to.

The apparent stiffness of the crystal 31 and consequently the natural frequency of vibration of the moving system may be reduced by lever 32, the ratio of frequencies without and with the lever being equal to the lever ratio. That is

$$\frac{f_0}{f_1}=\frac{L_2}{L_1}$$

See Fig. 8 where f_0 is the natural frequency of the moving system without the lever, and f_1 is the natural frequency of the moving system with the lever. L_1 and L_2 represent the lengths of the lever arms, as may be seen from Fig. 5. It is a relatively simple matter to choose a lever ratio such that the natural frequency of the moving system is reduced from 4,500 cycles per second to 1,000 cycles per second or from and to other values. The moving system includes in each unit the crystal, the diaphragm and the lever or other coupling structure.

Changing the resonant frequency by changing the stiffness reflected on to the diaphragm results in a response curve for an undamped crystal, diaphragm and coupling structure which follows curve 47 of Fig. 8. Utilizing a lever as shown produces a greater deflection of the crystal for the same pressure exerted on the diaphragm and thus the output or response is increased below resonance over the case where no lever is used. The response also increases with increasing frequency. At resonance there is a sharp increase in response, and above resonance the response falls at one rate since the pressure difference available is still increasing. This continues up to f_2 where diffraction effects cause the pressure difference to become constant and the response falls off at a more rapid rate.

By providing the resistance material 41 having acoustic resistance equal to the reactance of the moving system at a low frequency, for example 100 cycles per second, the response curve following curve 48 may be obtained which is substantially flat over the range from 100 cycles to 10,000 cycles per second, i. e. substantially the useful frequency range. The response or output shown by curve 48 is considerably above that of curve 46 and is accomplished through damping alone and without an attenuating network. It has been found that an average increase in response of 10 db. or more over the whole frequency range may be obtained in this fashion.

It has been found that the preferred results are obtained when the natural or resonant frequency of the moving system is placed approximately at

the geometric mean frequency of the frequency range to be translated, the geometric mean frequency being the square root of the product of the lowest and highest frequencies to be translated. Thus if the lowest and highest frequencies to be translated are respectively 100 and 10,000 cycles per second, the geometric mean frequency is equal to $\sqrt{100\times10,000}$ or 1,000 cycles per second. It has likewise been found that good results are obtained to a considerable range on each side of the geometric mean frequency such as down to one-half thereof and up to twice thereof. It is also to be understood that the frequencies of 100 and 10,000 chosen for the lower and upper limits may be varied over considerable range as desired.

In the Patent No. 2,237,298, it has been shown that a microphone having a diaphragm coupled to a crystal wherein a phase shifting network transmits a force to the rear side of the diaphragm, a cardioid directional response pattern is obtained when the volume of the cavity and the resistance and inertance comprising the network are chosen so that

$$\frac{d}{C_v}=RC;\text{ and }L=\frac{CR^2}{2}$$

where

d=the effective distance from the front of the diaphragm to the network entrance in centimeters.

C_v=the velocity of sound in centimeters per second.

R=the network resistance in acoustic ohms.

C=the compliance of the cavity in acoustic farads.

L=the network inertance in acoustic henrys.

The phase shifting network comprises the cavity 37 and the resistance and inertance of cloth 41, and couples the rear side of the diaphragm to the sound pressure waves existing at the perforations 38. The delay or phase shift introduced by the network combined with the force at the front surface of the diaphragm produces the directional pattern. When the phase shift produced by the network is equal to that experienced by sound travelling the effective distance from the front of the diaphragm to the network inlet for normal front incidence, cardioid response is obtained.

In the instant application, referring to Fig. 5, d is the effective distance in centimeters from the front of diaphragm 28 to the openings 33, and is closely approximated by the diameter of the diaphragm plus the thickness of case 25; C_v is as defined; C is the compliance of cavity 37; R and L are the resistance and inertance of material 41 in units as specified. While material 41 has inertance and resistance, it is principally resistance to produce the proper phase shift.

When the constants are chosen in accordance with the formulas given, a cardioid directional response pattern is obtained in the subject invention similar to that of the patent.

In the structure of the patent the resistance of the network entered mainly into shifting the phase of the force available at the rear network, the diaphragm being damped at its natural frequency by resistance material placed at the front thereof. Furthermore, the crystal was mounted inside of the cavity making it advisable to have the cavity large. Accordingly, the product RC was chosen equal to

$$\frac{d}{C_v}$$

but with R small and C large relatively. Then because of the rising response with increasing frequency, the attenuating network was used to obtain a flat response over the frequency range.

It has been found that when the natural frequency of the moving system is approximately at the geometric mean frequency of the frequency range to be translated, the resistance R of the phase shift network may be so chosen relative to the volume of the cavity (which determines the compliance C) that the phase shift for directional operation and for damping the diaphragm at its natural frequency are obtained from the same element. That is, the resistance R of material 41 may be chosen to accomplish both damping and, in combination with the cavity and inertance of material 41, phase shifting.

This in accomplished by choosing the product RC equal to

$$\frac{d}{C_v}$$

choosing R in acoustic ohms equal to the reactance of the moving system at the low frequency to be translated and then choosing C to complete the relationship. The reactance of the moving system depends on its mass and stiffness and is relatively large at low frequencies. Hence the resistance component R is relatively large and in effect it becomes the dominant element in controlling the diaphragm movements. That is, the moving system may be said to be resistance controlled. Consequently from the frequency at which R equals the reactance of the moving system the response of the microphone is flat over the frequency range selected.

The quotient

$$\frac{d}{C_v}$$

is readily found for any construction. C_v, the velocity of sound in centimeters per second, is known, and d in units consistent with C_v, for example centimeters, can be measured from the physical dimensions of the structure.

To obtain resistances and reactances of the proper values, various samples of these elements are tested until elements of the proper values are found according to generally known formulas and procedures.

Acoustical impedance in ohms may be defined as the complex quotient of the alternating pressure applied to the system and the resulting volume current. See for example Elements of Acoustical Engineering, by Olson, page 73, second edition, published 1947 by D. Van Nostrand Company, Inc. The real part of this quotient is the resistance, and the imaginary part is the reactance. The definition of acoustical impedance is sometimes stated as a quotient of sound pressure and particle velocity. See for example an article entitled "An acoustic transmission line for impedance measurement" published in The Journal of the Acoustical Society of America, volume 11, July 1939, page 142.

In the case of openings such as slits or the interstices of cloth, the resistance R is a function of the dimensions of the openings or interstices. In slits which may have precise dimensions, the resistance may be fairly well calculated by the expression

$$R=\frac{12ul}{t^3L}$$

as given in the Patent No. 2,305,597, Benjamin B. Bauer, entitled "Conversion of Wave Motion into Electrical Energy" and assigned to the same assignee as the present application. In this expression:

R is the acoustic resistance in ohms,
u is the viscosity coefficient of the medium,
l is the passage length in centimeters in the direction of flow,
t is the passage thickness in centimeters, and
L is the peripheral length of the passage.

See also The Journal of the Acoustical Society, July 1931, volume 3, page 49.

When the resistance is cloth, the same formula applies, but there is a practical difficulty in determining the dimensions of the cloth interstices. For this reason the resistance may be measured by forcing a stream of air, for example, through a sample of the material and measuring the pressure drop thereacross and the volume current therethrough. The resistance R in acoustic ohms may be given by the expression

$$R=\frac{p}{v}$$

where

p is the pressure drop in dynes per square centimeter, and
v is the flow in cubic centimeters per second.

In the publication The Design and Construction of Anechoic Sound Chambers, a Report of October 15, 1945, to the Office of Scientific Research and Development (O. S. R. D. No. 4190) by the Electro-Acoustic Laboratory of Harvard University, a practical method for measuring the acoustic resistance is described in Appendix II at page 105. In the method described air, for example, is forced through a sample of the material and the resistance is determined according to the formula

$$R=\frac{Ap}{\frac{V}{t}}$$

where

A is the area of sample in square centimeters,
p is the pressure drop in dynes per square centimeters,
$\frac{V}{t}$ is the volume velocity in cubic centimeters per second.

In the article referred to as published in volume 11 of The Journal of the Acoustical Society of America, the impedance of an element may be determined by utilizing the element to terminate an already calibrated tube and supplying the tube with sound pressure of a particular frequency. The impedance Z may be determined by the expression

$$Z=Z_0 \coth\left[\left(\coth^{-1}\frac{P_{max}}{P_{min}}\right)+j\left(n\pi-\frac{2\pi L}{\lambda}\right)\right]$$

where

Z_0 is the characteristic impedance of the tube,
P_{max} is the maximum pressure in the tube,
P_{min} is the minimum pressure in the tube,
j is the symbol $\sqrt{-1}$,
λ is the wave length in centimeters,
n is the frequency in cycles per second, and
L is the distance from the source of the sound to the point of pressure maximum in centimeters.

The real part of the formula is the resistance and the imaginary part is the reactance. The

method described may also be used for determining the impedance of cloth, but since it is known that cloth is primarily resistance, the method described in the O. S. R. D. publication may be used also.

Acoustical reactance of the mechanical components at any frequency of the crystal **31**, the lever **32** or other coupling structure, and the diaphragm **28** may be obtained by constructing such a combination and testing it according to the procedure outlined in volume 11 of The Journal of the Acoustical Society of America.

Acoustical reactance is a function of the stiffness or rigidity (or the inverse thereof, compliance) of the diaphragm, crystal and coupling, the mass of these elements and the frequency of the sound. If the combined elements are very stiff or rigid, then little sound will be transmitted thereby and the impedance is high. Likewise, if the mass of these elements is great, little sound will be transmitted thereby and the impedance is high. Conversely, if the combined elements are very flexible or compliant and of a very small mass, substantially all of the sound incident will be transmitted and the reactance is low.

Experience has shown in general what dimensions of crystal to use in order to obtain sufficient electrical output and the physical dimensions and characteristics of a diaphragm to drive the crystal. It is not believed necessary to set out these criteria here. A particular selection of crystal, diaphragm and coupling may be made and the impedance thereof determined according to the procedure set out in the article in The Journal of the Acoustical Society of America, volume 11. While the procedure there outlined will give both resistance and reactance, it is known that the resistance of such a mechanical system is very largely negligible compared to its reactance. The reactance having been determined at the lower frequency to be translated, a cloth having the requisite resistance may be selected having this same value.

The resonant or natural frequency of the combined crystal, coupling and diaphragm may be obtained by exposing the structure to sound of varying frequency and noting the frequency at which maximum vibration amplitude occurs.

In Fig. 8, curve **48** represents the case described, it having been assumed that the resistance is equal to the reactance at about 100 cycles per second. Having chosen a resistance of this value, the resonant rise at 1,000 cycles per second is eliminated, the response is flat over substantially the whole frequency range, and the directional pattern is that of a cardioid up to where the transverse dimensions of the casing are equal to one-quarter wavelength of the frequency being translated. Thereafter diffraction effects maintain the directivity. Comparing curves **48** and **49**, the output obtained by shifting the natural frequency of the system and using the resistance of the phase shift circuit for damping is much higher and flat response is obtained without the use of an attenuating network.

While in the case described a cardioid directional pattern was assumed, it is understood that any other directional pattern from pressure response to bi-directional or cosine law response may be obtained by choosing the product RC in known fashion relative to

$$\frac{d}{C},$$

and thereafter choosing R to obtain the necessary damping and C in conformance therewith. In the Patent No. 2,305,596 to Bauer, assigned to the same assignee as the present invention, the relationship between

$$\frac{d}{C},$$

and RC for other directional patterns is disclosed. It has equal application here and thus is not given in detail.

As seen best in Fig. 2, a second layer of cloth **51**, which may be silk having relatively fine interstices, may be placed across the front of the unit to improve the shielding out of wind sound, etc. The support blocks **24** of sponge rubber or the like prevent substantially the transmission of mechanical vibrations to the unit.

Obtaining a moving system having a natural frequency at the relatively low frequency of the geometric mean of the frequency range to be translated may be obtained by using a very thin or flexible crystal and applying stresses to it directly without the use of a lever. In Fig. 6 there is shown a microphone unit **52** having a crystal **53** of this character. In other respects, that is, the diaphragm **54**, the base **55**, the cavity and the cloth material (not shown), unit **52** may be substantially identical to unit **12**. Crystal **53** is thin and is placed under bending stress rather than torsion, as may also be seen from the construction of Fig. 7 showing a modification having a similar crystal but differing in other respects. The crystal, being thin, has a low natural frequency of vibration in combination with the diaphragm, but is quite fragile compared to the stiffer crystals already described.

The resistance component for damping the diaphragm as well as for phase shifting may be obtained by sound permeable means other than cloth. In Fig. 7 there is shown a structure wherein the resistance components R is obtained by the resistance to flow of air, the microphone unit having a case **56**, a diaphragm **57**, and a crystal **58**. The cavity **61** and diaphragm **57** may be the same as described for the other embodiments and crystal **58** may be the same as described for the embodiment of Fig. 6. The back of casing **56** includes a series of openings or perforations **60** between which there are elements of solid material **62**. Spaced rearwardly from elements **62** is a thin membrane **63** held so spaced by any suitable means such as by cementing to a circular ridge, as shown.

Membrane **63** is a thin flexible member through which sound is transmitted without significant decrease in pressure over the frequency range desired and may be made of foils of metals, plastic materials, rubber, and the like. As the membrane moves back and forth under sound waves, air or other gas between the back surface of members **62** and the front of the membrane is forced to flow in and out. Due to the viscosity of such air or gas, its movement introduces resistance and inertance as is understood in this art and provides the phase shift and damping.

In this embodiment, the cavity, the resistance produced as described, together with the equivalent inertance introduced by the membrane, form the phase shift network. The membrane is an inlet to sound waves since with proper choice of characteristics it will transmit sound pressure over a substantial range of frequencies without any significant reduction in the pressure magnitude.

In Figs. 9 and 10 there is shown an embodiment of the microphone wherein different directional response patterns may be obtained and the output is substantially the same irrespective of which directional pattern is chosen. In these figures the microphone unit 64 includes a base member 65 having a rearwardly depressed portion 66 provided with a series of perforations 67. Closing the front end of depressed portion 66 is a diaphragm 68, and placed across the inside of perforations 67 is porous material 71 having acoustic resistance and inertance. Diaphragm 68 and depressed portion 66 define a cavity 72 which, together with the resistance and inertance of porous material 71, provides a network for shifting the phase of pressure before it acts on the rear surface of the diaphragm in like manner to the embodiments already described.

Coupled to the apex of diaphragm 68 is one end of a lever 73 having its other end connected to a stationarily arranged crystal 74, also as already described. Spaced away from the front surface of diaphragm 68 is a perforated metal supporting member 75 having porous material 76 defining acoustic resistance and inertance attached to the inside surface thereof, the space between the porous material and the diaphragm defining a cavity 77.

Associated with the rear surface of depressed portion 66 is a shutter 78 shaped, for example, as shown in Fig. 10, the perforations 67 being arranged in a similar pattern. Shutter 78 is connected to a tube 81 which in turn is connected to a knob 82 by means of which shutter 78 may be rotated. A stud 83 is firmly attached to the back of base 65 to form a support for member 81 and a spring 84 is arranged as shown to hold shutter 78 firmly against the back of the casing.

Assuming in one instance that the front support member 75 and acoustic material 76 are not present, the microphone unit is similar to that shown in Fig. 5 except that the number of perforations forming an inlet into the microphone unit at the rear may be varied. This construction may be such that when all of the perforations are open, the microphone has a cardioid directional pattern, and when shutter 78 completely closes all of the perforations the microphone is pressure responsive. By suitably choosing the number and size of perforations 67, a virtually continuous variation between these two patterns is obtainable.

When acoustic material 76 is being held adjacent the front surface of diaphragm 68, a second phase shifting network is added to the microphone unit, this phase shifting network including the cavity 77 and the resistance and inertance of material 76. The constants of this network may be so chosen that they are equal to the constants of the network at the rear of the diaphragm whenever shutter 78 is completely open. Under these conditions the same phase shift is produced by the two networks and a cosine law or bi-directional response microphone results. As the shutter 78 is closed, the phase shift produced by the rear network increases thereby producing a different directional pattern until when shutter 78 is completely closed a pressure response microphone is had. This variation may be virtually continuous or in discreet steps, depending on the size and number of the perforations chosen.

In accordance with the teachings of this invention, the volume of cavities 72 and 77 and the resistance of porous materials 71 and 76 may be so chosen that the dominant factors in the control of the diaphragm movements are the resistance components. By utilizing lever 73 the natural frequency of the moving system may be substantially at the geometric mean frequency of the frequency range to be translated.

Assuming, as previously, that the geometric mean frequency of the frequency range is 1000 cycles per second and the lower frequency is 100 cycles per second, the resistance of materials 71 and 76 may be chosen to be substantially equal to the reactance of the moving system at the lower frequency. Approximately one-half of the resistance so obtained may be placed in each of the resistance materials. The reactance of the moving system being relatively high at this low frequency, the resistance values will be high and thus the volumes of cavities 72 and 77 may be made quite small. Consequently, the resistance of both materials becomes the dominating element in controlling the movements of the diaphragm, the rise in response at the resonant frequency of 1,000 cycles per second is eliminated, and a substantially flat response over the whole frequency range is obtained.

When the shutter 78 completely closes all of perforations 67 and the microphone is pressure responsive, the natural frequency of the moving system is consideraly increased over that when the shutter is open. This follows from the fact that when shutter 78 is closed the air in cavity 72 acts as a greater stiffness (due to no escape through the perforations) which, in association with the diaphragm, the crystal and the lever, results in the moving system having a frequency approximately 4,000 to 6,000 cycles per second, whereas when shutter 78 is open the natural frequency of the system may be 1,000 cycles per second. When the microphone is operating as a pressure microphone, the resistance of material 76 acts to damp out the rise in response at resonance and tends to produce a flat response over the frequency range, the response being about at the same level as that for the bi-directional case. It has been found that the same general level of output is obtained with other directional patterns, that is, for positions of shutter 78 between fully open and fully closed.

Throughout this specification and claims the following definitions and concepts obtain.

Where constants of the microphone are referred to, and relationships between the constants governing the operation are given, it is understood that the values thereof are in a consistent system of units, such for example as acoustic units.

A displacement responsive element is one producing an output proportional to its displacement or deflection from a normal or equilibrium position. Thus the voltage of crystal which is one form of displacement responsive element is proportional to its deformation.

Where phase shift networks and the transmission of sound pressures are referred to, it will be understood that the pressure does not change significantly in magnitude.

An acoustic phase shift network is one which shifts the phase of acoustic pressure without regard to the character of the elements producing the phase shift. A network utilizing acoustic components is one where the components are gaseous elements such as cavities and physical passages.

While particular embodiments of the invention have been shown, it will be understood, of course, that the invention is not limited thereto since many modifications may be made, and it is, therefore, contemplated by the appended claims to cover any such modifications as fall within the true spirit and scope of the invention.

Having thus described the invention, what is claimed and desired to be secured by Letters Patent is:

1. A directional sound translating device for a range of frequencies comprising, a translating unit adapted to be exposed to sound pressure along one portion thereof for producing an output proportional to displacement, a sound pressure phase shifting network including resistance and compliance for coupling another portion of said translating unit to sound pressure, said translating unit having a natural frequency of approximately the geometric means frequency of the range to be translated, and the resistance of said network being approximately equal to the reactance of said translating unit at the lower end of the frequency range to be translated.

2. A directional sound translating device for a range of frequencies comprising, a translating element adapted to be substantially exposed to sound waves in a medium on one side thereof, a sound pressure phase shifting network including resistance and compliance between the other side of said translating element and sound waves in said medium, transducing means producing an output proportional to displacement thereof, means coupling said transducing means to said translating element, said transducing means, said translating element and the associated coupling structure having a natural frequency approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said network being approximately equal to the reactance of the translating element, the transducing means coupled thereto, and the associated coupling structure at the lower end of the frequency range to be translated, thereby to effect substantially constant output from said transducing means over said frequency range.

3. A directional sound translating device for a range of frequencies comprising, a diaphragm adapted to be substantially exposed to sound waves in a medium on one side thereof, a sound pressure phase shifting network including resistance and compliance between the other side of said diaphragm and sound waves in said medium, transducing means producing an output proportional to displacement thereof, means coupling said transducing means to said diaphragm, said transducing means, said diaphragm and the associated coupling structure having a natural frequency approximately equal to the geometric mean frequency of the frequency range to be translated, the resistance of said network being approximately equal to the reactance of the diaphragm, the transducer coupled thereto, and the associated coupling structure at the lower end of the frequency range to be translated.

4. A directional sound translating device for a range of frequencies comprising, a diaphragm adapted to be substantially exposed to sound waves in a medium on one side thereof, a sound pressure phase shifting network having acoustic compliance and acoustic resistance between the other side of said diaphragm and sound waves in said medium, transducing means producing an output proportional to displacement thereof, means coupling said transducing means to said diaphragm, said transducing means, said diaphragm and the associated coupling structure having a natural frequency approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said network being approximately equal to the reactance of said transducing means, the transducing means coupled thereto, and the associated coupling structure at the lower end of the frequency range to be translated, thereby to effect substantially constant output from said transducing means over said frequency range.

5. A directional sound translating device for a range of frequencies comprising, a diaphragm adapted to be substantially exposed to sound waves in a medium on one side thereof, a sound pressure phase shifting network having acoustic compliance and acoustic resistance between the other side of said diaphragm and sound waves in said medium, piezoelectric means for producing an output, means for coupling said piezoelectric means to said diaphragm, said piezoelectric means, said diaphragm and the associated coupling structure having a natural frequency approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said network being approximately equal to the reactance of said piezoelectric means, said diaphragm and said associated coupling structure at the lower end of the frequency range to be translated.

6. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, a sound pressure phase shifting network including acoustic resistance and acoustic compliance between the other side of said diaphragm and sound waves in said medium, transducing means for producing an output proportional to the displacement thereof, means for connecting said transducing means substantially directly to the apex of said diaphragm, said transducing means, said connecting means and said diaphragm having a natural frequency approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said network being approximately equal to the reactance of the transducing means and the diaphragm at the lower end of the frequency range to be translated.

7. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, a sound pressure phase shifting network including resistance and compliance between the other side of said diaphragm and sound waves in said medium, transducing means for producing an output proportional to the displacement thereof, said transducing means and diaphragm having a natural frequency within the higher range of frequencies to be translated, lever means coupling the apex of said diaphragm to said transducing means, said lever means producing a natural frequency of the moving system including said transducing means, said diaphragm and said lever means approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said network being approximately equal to the reactance of said moving system at the lower end of the frequency range to be translated.

8. A directional sound translating device for a range of frequencies comprising, a diaphragm in-

cluding an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, a sound pressure phase shifting network including acoustic resistance and acoustic compliance between the other side of said diaphragm and sound waves in said medium, transducing means for producing an output proportional to the displacement thereof, said transducing means and diaphragm having a natural frequency within the upper range of frequencies to be translated, lever means coupling the apex of said diaphragm to said transducing means, said lever means producing a natural frequency of the moving system including said transducing means, said diaphragm and said lever means approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said network being approximately equal to the reactance of said moving system at the lower end of the frequency range to be translated.

9. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, a sound pressure phase shifting network including acoustic resistance and acoustic compliance between the other side of said diaphragm and sound waves in said medium, piezoelectric means for producing an output, said piezoelectric means and diaphragm having a natural frequency within the upper range of frequencies to be translated, lever means coupling the apex of said diaphragm to said piezoelectric means, said lever means producing a natural frequency of the moving system including said piezoelectric means, said diaphragm and said lever means approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said network being approximately equal to the reactance of said moving system at the lower end of the frequency range to be translated.

10. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, a sound pressure phase shifting network including acoustic resistance and acoustic compliance between the other side of said diaphragm and sound waves in said medium, piezoelectric means for producing an output, said piezoelectric means having a natural frequency within the higher range of frequencies to be translated, lever means coupling the apex of said diaphragm to said piezoelectric means, said lever means producing a natural frequency of the moving system including said piezoelectric means, said diaphragm and said lever means approximately between one half of and twice the geometric mean frequency of the frequency range to be translated, and the resistance of said network being approximately equal to the reactance of said moving system at the lower end of the frequency range to be translated.

11. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, structure at the other side of said diaphragm forming a cavity, a sound inlet to said cavity, acoustic resistance means associated with said inlet, said cavity and said resistance means comprising a phase shift network for sound pressure, transducing means for producing an output having a natural frequency within the upper frequency range to be translated, lever means coupling the apex of said diaphragm to said transducing means, said lever means producing a natural frequency of the moving system including said transducing means, said diaphragm and said lever means approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said resistance means being approximately equal to the reactance of the moving system at the lower end of the frequency range to be translated.

12. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, structure at the other side of said diaphragm forming a cavity, a sound inlet to said cavity, acoustic resistance means associated with said inlet, said cavity and said resistance means comprising a phase shift network for sound pressure, transducing means for producing an output having a natural frequency within the upper frequency range to be translated, lever means coupling the apex of said diaphragm to said transducing means, said lever means producing a natural frequency of the moving system including said transducing means, said diaphragm and said lever means approximately between one half of and twice the geometric mean frequency of the frequency range to be translated, and the resistance of said resistance means being approximately equal to the reactance of said diaphragm, said transducing means, and said lever means at the lower end of the frequency range to be translated thereby to effect substantially constant output from said transducing means over said frequency range.

13. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, structure at the other side of said diaphragm forming a cavity, a sound inlet to said cavity, acoustic resistance means associated with said inlet, said cavity and said resistance means comprising a phase shift network for sound pressure, transducing means external to said cavity for producing an output having a natural frequency within the upper frequency range to be translated, lever means coupling the apex of said diaphragm to said transducing means, said lever means producing a natural frequency of the moving system including said transducing means, said diaphragm and said lever means approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said resistance means being approximately equal to the reactance of said diaphragm, said transducing means, and said lever means at the lower end of the frequency range to be translated thereby to effect substantially constant output from said transducing means over said frequency range.

14. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, structure at the other side of said diaphragm forming a cavity, a sound inlet to said cavity, acoustic resistance means associated with said inlet, said cavity and said resistance means comprising a phase shift network for sound pressure, piezoelectric means external to said cavity for producing an output having a natural fre-

quency within the upper frequency range to be translated, lever means coupling the apex of said diaphragm to said piezoelectric means, said lever means producing a natural frequency of the moving system including said piezoelectric means, said diaphragm and said lever means approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said resistance means being approximately equal to the reactance of said diaphragm, said piezoelectric means, and said lever means at the lower end of the frequency range to be translated thereby to effect substantially constant output from said piezoelectric means over said frequency range.

15. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, structure at the other side of said diaphragm forming a cavity, a sound inlet to said cavity, acoustic resistance means associated with said inlet, said cavity and said resistance means comprising a phase shift network for sound pressure, piezoelectric means for producing an output having a natural frequency within the upper frequency range to be translated, lever means coupling the apex of said diaphragm to said piezoelectric means, said lever means producing a natural frequency of the moving system including said piezoelectric means, said diaphragm and said lever means approximately between one half of and twice the geometric mean frequency of the frequency range to be translated, and the resistance of said resistance means being approximately equal to the reactance of said diaphragm, said piezoelectric means, and said lever means at the lower end of the frequency range to be translated thereby to effect substantially constant output from said piezoelectric means over said frequency range.

16. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, structure at the other side of said diaphragm forming a cavity, sound permeable means forming an inlet to said cavity and defining acoustic resistance and inertance, the compliance of said cavity and the resistance and inertance of said permeable means forming a phase shifting network for sound pressure, piezoelectric means external to said cavity for producing an output, said piezoelectric means having a natural frequency within the upper frequency range to be translated, lever means coupling the apex of said diaphragm to said piezoelectric means, said lever means producing a natural frequency of the moving system including said piezoelectric means, said diaphragm and said lever means approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said sound permeable means being approximately equal to the reactance of said diaphragm, said piezoelectric means, and said lever means at the lower end of the frequency range to be translated thereby to effect substantially constant output from said piezoelectric means over said frequency range.

17. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, structure at the other side of said diaphragm forming a cavity, passage means into said cavity, porous material defining principally acoustic resistance covering said passage means, piezoelectric means external to said cavity for producing an output, said piezoelectric means having a natural frequency within the upper frequency range to be translated, lever means coupling the apex of said diaphragm to said piezoelectric means, said lever means producing a natural frequency of the moving system including said piezoelectric means, said diaphragm and said lever means approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said porous material being approximately equal to the reactance of said diaphragm, said piezoelectric means, and said lever means at the lower end of the frequency range to be translated thereby to effect substantially constant output from said piezoelectric means over said frequency range.

18. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, structure at the other side of said diaphragm forming a cavity, sound permeable means forming an inlet to said cavity and defining acoustic resistance and inertance, the compliance of said cavity and the resistance and inertance of said permeable means forming a phase shifting network for sound pressure, the resistance and inertance of said sound permeable means and the compliance of said cavity being chosen so that the phase shift produced thereby is substantially equal to the phase change produced in sound pressure between said one side of said diaphragm and said inlet for normal front sound incidence, piezoelectric means external to said cavity for producing an output, lever means coupling the apex of said diaphragm to said piezoelectric means, said lever means producing a natural frequency of the moving system including said piezoelectric means, said diaphragm and said lever means approximately equal to the geometric mean frequency of the frequency range to be translated, and the resistance of said sound permeable means further being approximately equal to the reactance of said moving system at the lower end of the frequency range to be translated thereby to effect substantially constant output from said piezoelectric means over said frequency range.

19. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, structure at the other side of said diaphragm forming a cavity, sound permeable means forming an inlet to said cavity and defining acoustic resistance and inertance, the compliance of said cavity and the resistance and inertance of said permeable means forming a phase shifting network for sound pressure, piezoelectric means external to said cavity for producing an output, said piezoelectric means having a natural frequency within the upper range to be translated, lever means coupling the apex of said diaphragm to said piezoelectric means, said lever means producing a natural frequency of the moving system including said piezoelectric means, said diaphragm and said lever means approximately equal to the geometric mean frequency of the frequency range to be translated, means for varying said sound permeable means thereby to effect different output directional patterns, and the resistance of said sound permeable means be-

ing approximately equal to the reactance of said diaphragm, said piezoelectric means, and said lever means at the lower end of the frequency range to be translated thereby to effect substantially constant output from said piezoelectric means over said frequency range.

20. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex adapted to be substantially exposed to sound waves in a medium on one side thereof, structure at the other side of said diaphragm forming a cavity, a thin diaphragm forming sound inlet to said cavity, a perforated plate closely spaced to said thin diaphragm, said thin diaphragm having equivalent inertance and air movement between said thin diaphragm and perforated plate defining acoustic resistance, the compliance of said cavity and said resistance and inertance forming a phase shifting network for sound pressure, piezoelectric means external to said cavity for producing an output, said piezoelectric means having a natural frequency within the upper range to be translated, lever means coupling the apex of said diaphragm to said piezoelectric means, said lever means producing a natural frequency of the moving system including said piezoelectric means, said diaphragm and said lever means approximately equal to the geometric mean frequency of the frequency range to be translated, and said resistance being approximately equal to the reactance of said diaphragm, said piezoelectric means, and said lever means at the lower end of the frequency range to be translated thereby to effect substantially constant output from said piezoelectric means over said frequency range.

21. A directional sound translating device for a range of frequencies comprising, a diaphragm including an apex, first porous material having acoustic resistance and inertance spaced from one side of said diaphragm, second porous material having acoustic resistance and inertance spaced from the other side of said diaphragm, said first and second porous materials defining first and second cavities and with said respective porous materials defining first and second sound pressure phase shifting networks having approximately equal phase shift values, piezoelectric means external to said cavities for producing an output, said piezoelectric means having a natural frequency within the upper frequency range to be translated, lever means coupling the apex of said diaphragm to said piezoelectric means, said lever means producing a natural frequency of the moving system including said piezoelectric means, said diaphragm and said lever means approximately equal to the geometric mean frequency of the frequency range to be translated, the total resistance of both said porous materials being approximately equal to the reactance of said moving system at the lower end of the frequency range to be translated, and means for varying said second network from phase shift equality with said first network to closing off the other side of said diaphragm.

22. The invention as defined in claim 21 wherein the phase shift of said second network may be varied substantially continuously.

23. The invention as defined in claim 21 wherein the phase shift of said second network may be varied in discrete steps.

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