

May 22, 1951

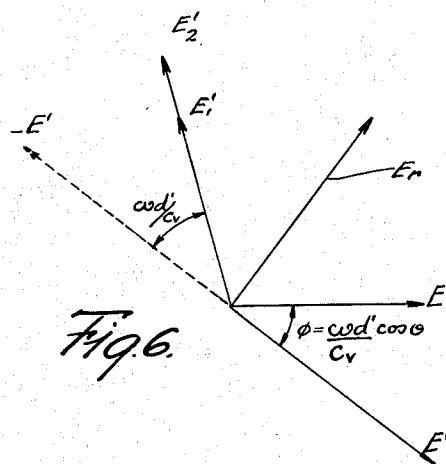
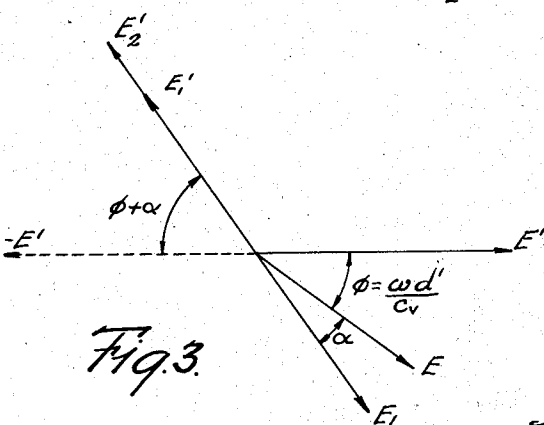
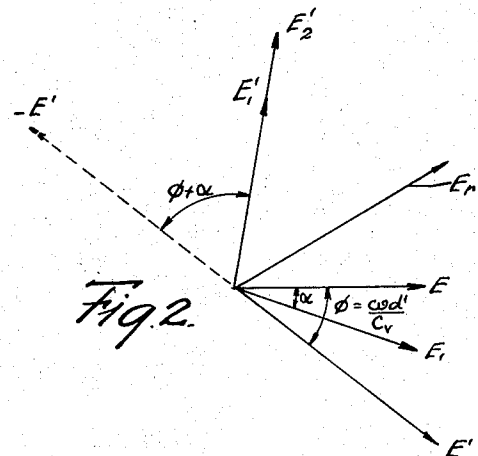
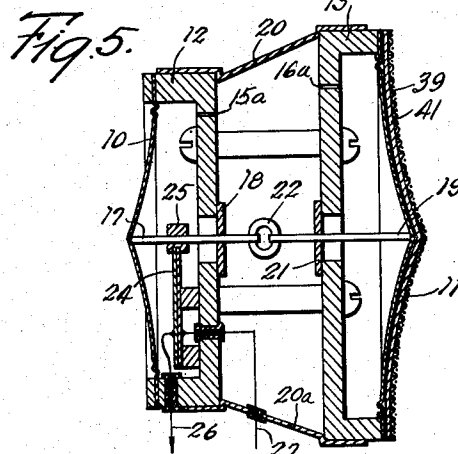
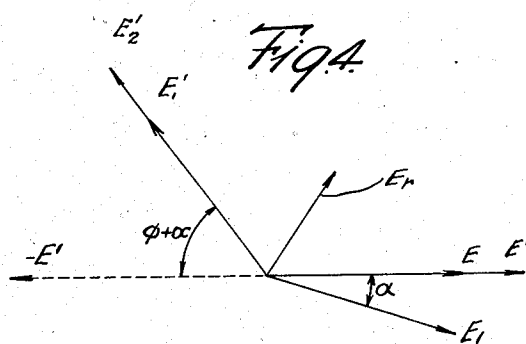
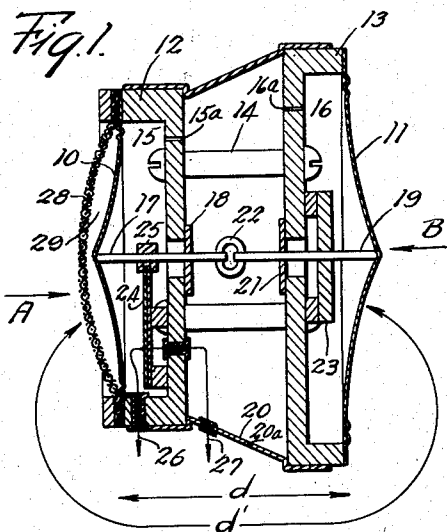
B. B. BAUER

2,553,539

DIRECTIONAL MICROPHONE WITH A COMPLIANT LINK
INTERCONNECTED BETWEEN THE TWO DIAPHRAGMS

Filed June 16, 1947

2 Sheets-Sheet 1



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DIRECTIONAL MICROPHONE WITH A COMPLIANT LINK
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2 Sheets-Sheet 2

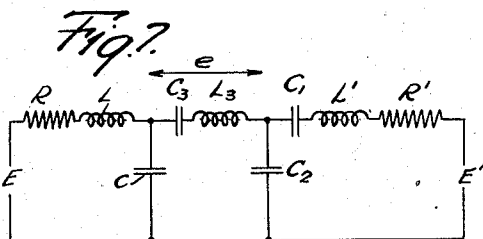
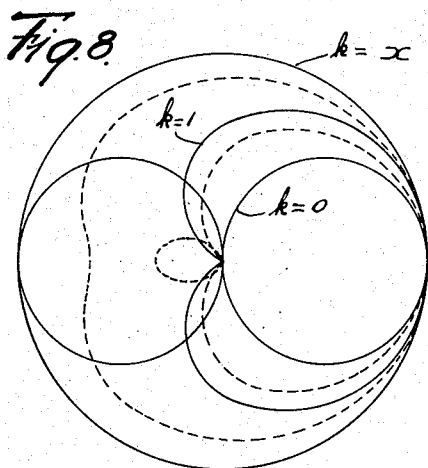


Fig. 9.



Fig. 10.

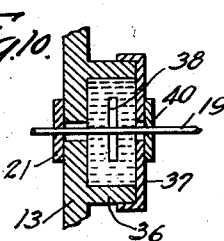


Fig. 11.

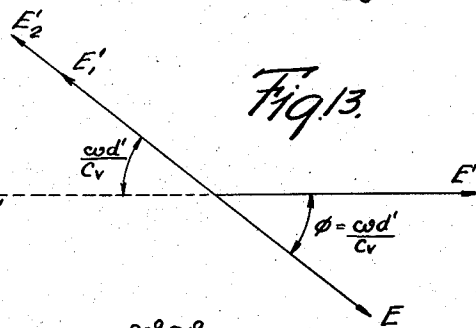
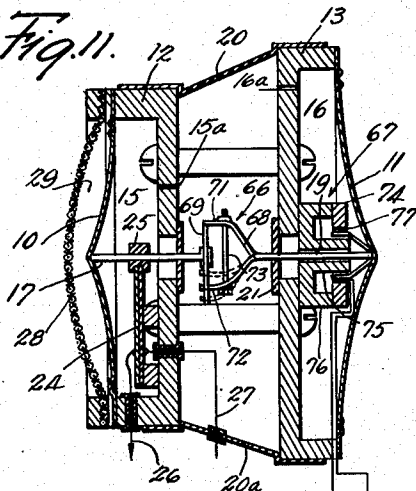


Fig. 12.

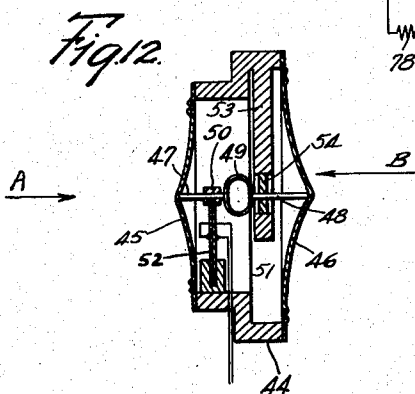


Fig. 14.

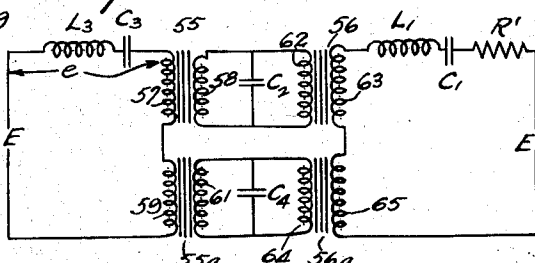
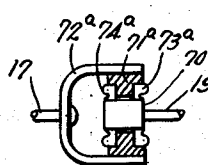


Fig. 15.



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UNITED STATES PATENT OFFICE

2,553,539

DIRECTIONAL MICROPHONE WITH A
COMPLIANT LINK INTERCONNECTED
BETWEEN THE TWO DIAPHRAGMSBenjamin B. Bauer, Oak Park, Ill., assignor to
Shure Brothers Inc., Chicago, Ill., a corpora-
tion of Illinois

Application June 16, 1947, Serial No. 754,798

24 Claims. (Cl. 179—139)

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This invention relates to apparatus for the conversion of wave motion of one character into wave motion of a different character, such for example as changing sound waves into electrical waves in microphones and the converse in loud speakers. More particularly, it relates to apparatus of this character which is of a directional nature, i. e., the instrument is active preferentially in one or more directions throughout an extensive range of frequencies and is relatively inoperative or less operative in other directions, it being an object of the invention to provide improved apparatus of this character.

While the invention is disclosed and described in connection with microphones, it will be understood by those skilled in this art that it may also be applied to sound reproducing means such as loud speakers without departing from the spirit and scope of the invention.

In many acoustical applications, it is desirable or necessary that a microphone have directional properties. For example, in a public address system involving the use of a microphone and one or more loud speakers the sound emanating from the loud speakers may, by one or more reflections, be transmitted to the microphone and hence pass through the amplifying system with resulting disturbances. Similarly in an instance where there are numerous sounds present in addition to the voice of an announcer, as for example an announcer speaking from a crowded room or platform where the announcer's voice may have very little more intensity than the voices of the people surrounding him, the sound picked up by the microphone will have a large number of extraneous components in it. In these instances, if the microphone is directional such that it discriminates very largely in favor of sounds coming to it from a particular area, from directly in front, for example, the amount of extraneous sound passing through the system will be much decreased.

It is well known to construct microphones of a unidirectional character having a pair of transducing elements, one of which is responsive to the pressure component of a sound wave and another of which is responsive to the pressure gradient of a sound wave, the outputs of the two transducers being combined by means of an electrical network. Microphones having directional characteristics may be constructed by using a single transducing element which is arranged to have two sound stimuli transmitted to it, the two stimuli being derived from the same functional component of a sound wave but with an acoustical network combining them. Such microphones

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may be constructed with different directional characteristics through a suitable choice of design constants as well as units whose directional characteristics may be varied by proper manipulation of their structure. Thus one may construct a unit having maximum response from the front and zero response from the rear or one hundred and eighty degrees displaced therefrom, this being the cardioid type of response; a unit having maximum response from the front and rear or one hundred and eighty degrees displaced from each other and zero response at right angles, this being the bidirectional or cosine law type of response; a unit having maximum response from the front, a lesser but not zero response from the rear, and zero or greater than zero response from some other direction; a unit having no directivity; or a unit whose directional characteristic may be varied from any one of the foregoing patterns to any other one.

It is a further object of the invention to provide an improved directional sound translating device eliminating electric circuits interconnecting the transducing elements.

It is a further object of the invention to provide an improved directional sound translating device comprising a pair of sound translating elements coupled by compliant means.

It is a further object of the invention to provide an improved directional sound translating device comprising a pair of sound translating elements coupled by impedance means.

It is a further object of the invention to provide an improved sound translating device with a directional response pattern obtained by the action of sound wave effects at two points in a sound wave and compliant means coupling the sound wave effects on a single transducing element.

It is a further object of the invention to provide, in a directional sound translating device embodying a pair of flexibly supported diaphragms coupled by compliant means, improved means for compensating for the diaphragm supporting or edge stiffness over the useful frequency range.

It is a further object of the invention to provide an improved type of network interrelating the sound wave effects obtained from two points in a sound wave which is relatively unaffected by atmospheric pressure and temperature.

In carrying out the invention in one form, a directional sound translating device is provided comprising a pair of spaced apart diaphragms adapted to vibrate, means for transforming the vibrations into electrical variations, compliant

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means interrelating the vibrations of the diaphragms for producing a resultant vibration, and means for transmitting the resultant vibration to the transforming means. More particularly, the compliant means may include gaseous as well as mechanical elements singly or in combination.

For a more complete understanding of my invention, reference should now be had to the accompanying drawing in which:

Figure 1 is a sectional elevational view of a microphone embodying my invention;

Fig. 2 is a diagram of forces for the microphone of Fig. 1 for sound of front incidence;

Fig. 3 is a similar diagram of forces for sound of rear incidence;

Fig. 4 is a similar diagram of forces for sound of right angle incidence;

Fig. 5 is a sectional elevational view of a modified form of the invention;

Fig. 6 is a diagram of forces for the microphone of Fig. 5 for sound of front incidence;

Fig. 7 is an electrical circuit analogous to the structure of Fig. 1 for explaining the operation of the invention;

Fig. 8 is a series of polar patterns indicating the different response patterns of the microphone obtainable according to the invention;

Fig. 9 is a fragmentary sectional view of a modified form of the invention shown in Fig. 1;

Fig. 10 is a fragmentary sectional view of another modified form of the invention shown in Fig. 1;

Fig. 11 is a sectional elevational view of another embodiment of the invention;

Fig. 12 is a sectional elevational view of another embodiment of the invention;

Fig. 13 is a diagram of forces for sound of rear incidence for the embodiment of Fig. 12;

Fig. 14 is an equivalent electrical circuit diagram analogous to the structure of Fig. 12 for explaining the operation of the invention embodied in Fig. 12; and

Fig. 15 is a fragmentary sectional view of another modified form of the invention.

Certain subject matter relating to mechanical damping means for diaphragms shown in the various figures is claimed in the continuation-in-part application Serial No. 222,747, Benjamin B. Bauer, entitled "Mechanical Damping Means for the Diaphragms of Microphones, Speakers and the Like," filed April 25, 1951.

Referring more particularly to the drawings, the invention is shown in Fig. 1 as comprising a microphone including a pair of diaphragms 10 and 11 adapted to vibrate and separated from each other by a distance d . The diaphragms may be made of any suitable material, such as thin aluminum or paper, for example, and are generally conical or curved in form so as to be relatively stiff whereby the diaphragms, in their movements, act largely as pistons. At their edges the diaphragms are resiliently supported and form the closures for casings 12 and 13 made of any sound impermeable material, casings 12 and 13 being separated from each other and relatively rigidly held together by means of spacers 14 thereby holding diaphragms 10 and 11 spaced apart. Diaphragms 10 and 11 are placed opposing each other for a purpose to be described subsequently in this specification. This spacing may vary and in some instances the spacers 14 may be eliminated to provide a common wall between casings 12 and 13. A circular case 20 may surround casings 12 and 13 to minimize perturbations of the sound field. Dia-

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phragm 10 with casing 12, and diaphragm 11 with casing 13 define cavities or chambers 15 and 16 filled with air, diaphragm 11 being shown larger in area than diaphragm 10 to compensate for the stiffness of diaphragm 11, but it will be made clear that under certain conditions the diaphragm areas may be equal. The case 20, as well as cavities 15 and 16, may be provided, if needed, with a small or high resistance vent 20a, 15a and 16a to the atmosphere to equalize the inside and outside pressure.

At the center or apex of diaphragm 10, a drive unit 17 is firmly attached by cementing, for example, the drive unit extending through an opening in the rear of casing 12, which opening is sealed by a seal 18 made of rubber, paper, or some other flexible material which will permit small mechanical vibrations of the drive unit without allowing sound waves to enter cavity 15. Similarly, a drive unit 19 is firmly attached to the center or apex of diaphragm 11, the drive unit extending through an opening in the rear of casing 13 which opening is sealed by a seal 21 also permitting small vibrations of the drive unit without permitting sound waves to enter cavity 16. The rear ends of drive units 17 and 19 are brought relatively close to each other and are joined by means of a compliant link 22 made of some springy material such, for example, as rubber, mechanical springs or one of the compounds known as elastomers. Consequently diaphragms 10 and 11 are not rigidly but resiliently connected to each other, and vibrations of one diaphragm are transmitted to the other as modified in one respect by compliant link 22. Stationarily fixed to the rear of casing 13 within cavity 16 there is a damping or dissipative element 23 attached to drive unit 19 so as to move therewith and introduce a resistance to the motion thereof, the dissipative element being made, for example, of the compounds known as elastomers. Many elastomers have the ability to absorb energy as well as springiness and hence may combine dissipation with compliance, examples of suitable elastomers being materials available as "Viscoloid" and "Flexiglass." In the event that an elastomer is used for link 22, the diaphragms are coupled by an element having both compliance and dissipation and thus are coupled by an impedance.

In order to derive an electrical output from the movements of the diaphragms, a piezoelectric crystal 24 is mounted inside of cavity 15 and is relatively rigidly connected at one end through a collar 25 to drive unit 17 whereby movements of drive unit 17 produce deformations of the crystal with a resultant voltage output. Conductors 26 and 27 extending from crystal 24 lead outwardly through casing 12 for supplying the voltage generated to a suitable amplifier or other apparatus.

Spaced directly in front of diaphragm 10 is an acoustical screen 28 which may be constituted of a suitable wire screen support having one or more thicknesses of cloth thereon forming acoustical resistance and inductance, screen 28 being spaced from diaphragm 10 and defining therewith a cavity or volume 29.

Assuming that the structure of Fig. 1 is placed in air and sound waves approaching in the direction of the arrow A impinge thereon, the sound waves will come into contact with screen 28 and after a slight delay will contact diaphragm 10. At some instant later, determined by the effective distance d' between screen 28 and dia-

phragm 11, and the sound frequency, the sound waves will come into contact with diaphragm 11. The effective distance d' differs from the linear distance between screen 28 and diaphragm 11 because sound waves must bend around the barriers provided by the casings, the effective distance being greater. Because of this effect the sound wave pressures across the screen 28 and diaphragm 11 are not constant. Consequently, the effective distance d' is equal to the distance d plus an average or effective distance from the edges of the structure to the apex of diaphragm 11 and screen 28. In instances where the distance d is relatively small compared to the diameters of the casing, the effective distance d' may approximate three quarters of the distance from the center of screen 28 and the center of diaphragm 11. As the distance d increases relative to the casing diameter, the effective distance approaches the center to center distance and becomes very nearly equal to it for large values of d . A sound wave, being in one aspect thereof a varying pressure wave traveling through the air, exerts varying pressure when it contacts the diaphragms, the sound pressure being converted into a mechanical force thereby. Sound pressure waves contacting diaphragm 10, after permeating the screen 28, will cause this diaphragm to exert a mechanical force on crystal 24, the phase of this force being determined by the resistance and inductance of screen 28 and the compliance of cavity 29, since the combined mass of the diaphragm and its drive unit, its mechanical resistance to movement or friction, the stiffness of the diaphragm mounting as well as the stiffness or resilience of the air within cavity 15 are sufficiently small compared to corresponding characteristics of the crystal that they may be considered part thereof. Sound pressure waves contacting diaphragm 11 exert a force thereon. This mechanical force is shifted in phase by the combined mass of diaphragm 11 and drive unit 19, its resistance to movement or friction, the stiffness of the diaphragm mounting, the stiffness of the air within cavity 16, the damping or resistance of dissipative element 23, and the compliance of link 22, link 22 serving to transmit a function of this force to crystal 24. The effects of seals 18 and 21 are made negligible.

A directional microphone discriminates in favor of sound coming from a particular direction or directions. One form of such directivity and the one treated in detail in the following paragraphs is the one in which a microphone has maximum response where sound falls on it directly from the front (direction of arrow A), has minimum or zero response where sound falls on it directly from the rear (direction of arrow B), and has a response varying between maximum and zero where sound falls on it from directions in between front and rear (i. e., cardioid response of Fig. 8, $k=1$). In the microphone shown in Fig. 1 the response thereof for any direction of sound incidence is the voltage generated by crystal 24 for sound of that direction. The voltage generated by a crystal being proportional to its deformation, and since its deformation is proportional to the applied force, the cardioid form of response is obtained when the force acting on crystal 24 through collar 25 is a maximum for front sound incidence, is zero for rear sound incidence, and has values intermediate maximum and zero for intermediate direction of sound incidence.

force acting on crystal 24, transmitted to

it through collar 25, is the resultant of two forces. The first of these forces is that arising by virtue of sound waves falling upon diaphragm 10 through screen 28 and transmitted directly to crystal 24 through drive unit 17, and the second is a result of sound waves falling on diaphragm 11 and transmitted to drive unit 17 through compliant link 22, it being necessary to place the diaphragms in opposition so that the forces arising directly therefrom oppose each other. The force arising from diaphragm 11 is transmitted to crystal 24, only after having its phase shifted by a phase shift network including mechanical damping of element 23, the mechanical mass of diaphragm 11 and drive unit 19, the resilience (compliance) of the air within cavity 16, the resilience (compliance) of mounting of diaphragm 11, and the resilience of link 22. To produce zero response for sound of rear incidence, the force from diaphragm 10 and the force transmitted through link 22 must be equal in value and opposed to each other.

The functioning of the various elements to produce the necessary forces which, when combined to act on crystal 24 for producing cardioid or unidirectional response, may best be understood by considering the force diagrams Figs. 2, 3 and 4 in connection with Fig. 1.

Considering first Figs. 1 and 2 (normal front incidence of sound waves as indicated by the direction of arrow A), sound of pressure P falling upon screen 28 will pass therethrough and fall on diaphragm 10 to exert a pressure P_1 thereon giving rise to a force E_1 equal to the product P_1A where A is the area of diaphragm 10. The characteristics of screen 28 and cavity 29 are chosen as subsequently pointed out so that the numerical values of P_1 and P are equal throughout a substantial frequency range. Screen 28 and cavity 29 produce a phase shift designated by the angle α between the sound pressure in front of screen 28 and the sound pressure exerted on diaphragm 10. Hence the force E available in front of screen 28 may be considered to be PA and is equal to the force E_1 , differing only in phase throughout the unidirectional range of the network. This same sound wave, before reaching diaphragm 11, travels the effective distance d' through the atmosphere to exert a pressure P' on diaphragm 11 giving rise to the force E' equal to the product $P'A'$ where A' is the diaphragm area. The force E' differs in phase angle from the force E by an angle ϕ determined by the time necessary for sound to travel the effective distance d' , and is larger than force E or E_1 since the area of diaphragm 11 is greater than the area of diaphragm 10. The phase angle ϕ may be designated the external phase angle. Since the effective distance d' normally is small, P and P' are substantially equal in magnitude. The diaphragms 10 and 11 being connected in opposition, the force E' on the front diagram must be reversed to $-E'$. The force transmitted to drive unit 17 from diaphragm 11 may be designated E_1' and differs from $-E'$ by a phase angle made (or designed to be) equal to the sum of the phase angles introduced by screen 28 and cavity 29, and the effective distance d' , i. e. $(\phi+\alpha)$ produced by the phase shifting network. The angle $(\phi+\alpha)$ may be termed the internal phase angle. The force E_1' is also less than the force $-E'$ or E' since a portion of the force E' is consumed in deforming diaphragm 11 and compressing the air in cavity 16. E_1' is made equal to force E_1

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by a proper choice of diaphragm areas as will be pointed out subsequently in this specification. The resultant vector combination of E_1' and E_1 designated as E_r acts on crystal 24 to produce the voltage output or response.

Considering next Figs. 1 and 3 (normal rear incidence of sound waves as indicated by the direction of arrow B), the force on diaphragm 11 due to the sound pressure is E' and has a magnitude the same as in Fig. 2. Due to the time necessary for this sound wave to travel the effective distance d' to screen 28, the force E available there differs from source E' by an angle ϕ equal in value to that in Fig. 2 since sound is traveling the same distance d' , the forces E in the two figures being also equal in magnitude since the same instrument is involved. The relative position of E' and E in the two figures is reversed since sound strikes the rear diaphragm first for rear sound incidence. The sound waves after striking screen 28 pass through and exert a pressure on diaphragm 10 giving rise to the force E_1 which differs from force E by the phase angle α . In Fig. 3 also, since the diaphragms are opposed in direction, the force E' is reversed to $-E'$. The force E_1' transmitted to drive unit 17 from diaphragm 11 differs from force $-E'$ by a phase angle $\phi + \alpha$, equal in value to that of Fig. 2, produced by the phase shifting network. Since E_1 is at an angle $(\phi + \alpha)$ clockwise from E' , and E_1' is at an angle $(\phi + \alpha)$ clockwise from $-E'$, E_1 and E_1' are opposed to each other and since they are equal in magnitude due to a proper choice of diaphragm areas the resultant force on crystal 24 is zero. Hence for rear sound incidence the microphone has zero response.

Fig. 4 shows the force diagram for an instance where sound falls on the microphone from the side or at right angles to directions A and B. Since the sound in this case strikes the screen 28 and diaphragm 11 at the same time, the phase angle ϕ between the forces E and E' is zero, E' being greater than E as previously. Due to screen 28 the force E_1 has a phase angle α relative to force E . The force E' is reversed to $-E'$ and the force E_1' has a phase angle $(\phi + \alpha)$ which has the same value as for Figs. 2 and 3, relative to force $-E'$ since the sound in passing through the network experiences the same phase shift irrespective of the direction of sound incidence. Combining E_1 and E_1' vectorially, the resultant E_r gives the force tending to deform crystal 24 or the microphone response for this direction of sound incidence. Comparing E_r from Figs. 2, 3 and 4, it is evident that the response for front incidence is greatest, and that for right angle incidence has a value between this and zero.

By constructing a series of force diagrams for different directions of sound incidence the total response may be obtained, the phase angle ϕ between the forces E and E' or between any two points in a sound wave spaced apart by an effective distance d' being given by the expression

$$\phi = \frac{\omega d'}{C_s} \cos \theta$$

where

ϕ is the phase angle between E and E' in radians;
 ω is $2\pi f$ where f is the sound frequency in cycles per second;

d' is the effective distance between screen 28 and diaphragm 11 in centimeters;

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C_s is the velocity of the sound wave in centimeters per second;

θ is the angle between the incident sound and normal front incidence (the direction of arrow A).

Since the velocity of sound is a constant under fixed atmospheric conditions, ω is a constant for some arbitrary frequency and d' may be fixed in the microphone construction, it is evident that the phase angle ϕ is proportional to $\cos \theta$. For θ equal to zero, i. e. sound is incident directly from the front $\cos \theta = 1$ and the phase angle ϕ equals

$$\frac{\omega d'}{C_s}$$

and is a maximum (Fig. 2). If sound approaches the microphone from a direction at right angles to arrow A, θ is ninety degrees and $\cos \theta$ is equal to zero. Consequently ϕ is equal to zero. This is equivalent to saying that the sound contacts screen 28 and diaphragm 11 at the same time and is shown in Fig. 4 where E and E' lie along the same direction. For sound of rear incidence (180°), $\cos 180^\circ$ is equal to -1 . Hence

$$\phi = -\frac{\omega d'}{C_s}$$

This is evident in Fig. 3 since E is rotated clockwise from E' which is the reverse of Fig. 1. By constructing a series of force diagrams, as indicated for Figs. 2, 3 and 4, with E' having different angularities relative to E determined by the expression

$$\frac{\omega d'}{C_s} \cos \theta$$

the complete microphone response may be determined which will show that for directions of sound incidence intermediate front and rear, the response of the microphone will be between maximum and zero and will have the shape of a cardioid.

The presence of screen 28 having acoustical inductance and resistance and cavity 29 having acoustical compliance are not necessary for unidirectional operation of the device and may be omitted in some embodiments if appropriate adjustment of the phase shifting network constants are made. Fig. 5 illustrates one example of such a microphone, and Fig. 6 is the force diaphragm for sound of a given incidence. (In Fig. 5 screen 39, 41 produces the effect produced by member 23 of Fig. 1.) Thus, when screen 28 is omitted from Fig. 1 sound approaching from the front contacts diaphragm 10 directly and E becomes coincident with or the same thing as E_1 (angle $\alpha = 0$). Then the phase angle between E and E' is equal to

$$\phi = \frac{\omega d'}{C_s} \cos \theta$$

and the phase angle between $-E'$ and E_1' determined by the phase shift network is ϕ and is made equal to

$$\frac{\omega d'}{C_s}$$

The vector diagram of Fig. 6 illustrates this situation where E is the force of sound incident on diaphragm 10, E' is the force of the sound wave incident on diaphragm 11 and is shifted with respect to E by an angle

$$\phi = \frac{\omega d'}{C_s} \cos \theta$$

determined by the effective distance d' between the diaphragms. E_1' is force $-E'$ shifted in phase by an angle equal to

$$\frac{\omega d'}{C_v}$$

by the phase shifting network and decreased in magnitude due to stiffness of diaphragm 11. As previously indicated, the phase angle between E and E' is equal to

$$\frac{\omega d'}{C_v}$$

for front incidence, is equal to

$$-\frac{\omega d'}{C_v}$$

for rear incidence, and is zero for right angle incidence. Since the phase angle between $-E'$ and E_1' is now

$$\frac{\omega d'}{C_v}$$

instead of

$$\left(\frac{\omega d'}{C_v} + \alpha\right)$$

it is seen that removing screen 28 necessitates that the phase shifting network components of mass, dissipation and compliance must have their values adjusted to produce the smaller phase shift required.

Since the distance between diaphragms may be fixed in any microphone and the velocity of sound is a constant, it is evident from the expression for phase angle

$$\phi = \frac{\omega d'}{C_v} \cos \theta$$

between two points in a sound wave that for any direction of sound incidence the phase angle ϕ is dependent on the frequency of the sound wave. The force diagrams of Figs. 2, 3, 4 and 6 are drawn for a given frequency and it is clear that the angular relationship of the forces depends on the frequency. Over a substantial range of frequencies the internal phase angle

$$\left(\frac{\omega d'}{C_v} + \alpha\right)$$

when screen 28 is present or

$$\left(\frac{\omega d'}{C_v}\right)$$

where screen 28 is lacking will be shown subsequently in this specification to vary with frequency in the same proportion as the external phase angle, and that over this range of frequencies the directivity is independent of the frequency. In one structure where screen 28 is missing, and for frequencies up to approximately 3000 cycles per second, directional action is obtained where the effective area of diaphragm 11 is 10 square centimeters, the mechanical compliance (inverse of stiffness) of the mounting of this diaphragm is 10^{-7} centimeters per dyne, the volume of cavity 16 is 10 cubic centimeters, the air in cavity 16 is at atmospheric pressure, the mass of diaphragm 11 and the drive unit 19 is .12 gram, the mechanical compliance (inverse of stiffness) of link 22 is 4.2×10^{-8} centimeters per dyne, and the resistance of damping element 23 is 3,460 mechanical ohms. In this instance d' is 2.5 centimeters. The effective area of the front diaphragm 10 is 5 square centimeters. The mass of diaphragm 10 and drive unit 17 and the com-

pliance of cavity 15 may in general be the same as for the rear diaphragm and cavity but for the analysis used above were assumed combined with the mass and compliance of the crystal.

The operation of my invention may be explained in greater detail and the value of the constants determined by considering the various elements of the microphone as analogous to certain circuit elements of an electrical circuit. In presenting these analogues it is customary to treat acoustical mass (inertance) and mechanical mass as if they were electrical inductances; acoustical and mechanical compliances as if they were electrical capacitances; and acoustical and mechanical resistances (fluid friction) as if they were electrical resistors. In the conventional analogues the equivalent electrical circuit may be in either the mechanical or acoustical constants of the network. When various acoustic elements are associated with a single diaphragm, the mechanical constants of all elements are obtained from acoustical constants by multiplying the acoustic impedance of all acoustic elements by the square of the area of the diaphragm. In all the following circuit constants, acoustical units for mass are grams cm^{-4} ; for resistance, $\text{cm}^5 \text{ sec}^{-1} \text{ dyne}^{-1}$; for compliance, $\text{cm}^5 \text{ dyne}^{-1}$. Mechanical units for mass are grams; for resistance, $\text{cm}^1 \text{ sec}^{-1} \text{ dyne}^{-1}$; for compliance, $\text{cm}^1 \text{ dyne}^{-1}$. Corresponding electrical circuit elements are in henrys, ohms, and farads. In Fig. 7 the equivalent electrical circuit for the microphone of Fig. 1 is shown in terms of mechanical circuit elements. The acoustic resistance and inertance of screen 28, R and L in series multiplied by the square of the diaphragm area, correspond to electrical resistance and inductance in ohms and henrys respectively. The mechanical compliance reflected upon the diaphragm 10 by the cavity 29 in centimeters per dyne is analogous to an electrical shunt capacity C, in farads. The mechanical mass of diaphragm 10, drive unit 17, and crystal 24 in grams are lumped together and correspond to the electrical inductance L_3 in henrys. The mechanical compliance of the mounting edge of diaphragm 10, crystal 24, and the compliance reflected by the air within cavity 15 upon the diaphragm 10, are lumped together and correspond to the electrical capacity C_3 in farads. The mechanical mass of diaphragm 11, drive unit 19, and any effective mass of the dissipative element 23 in grams are lumped together and correspond to the electrical inductance L' in henrys. The mechanical compliance of the mounting edge of diaphragm 11, the effective or equivalent compliance of dissipative element 23 and the air within cavity 16 (reflected upon the diaphragm) in centimeters per dyne are lumped together and correspond to the electrical capacity C_1 in farads. The mechanical resistance or damping in dynes per centimeter per second of element 23 corresponds to the electrical resistance R' in ohms. For this to be true the damping of element 23 must be of a viscous character, which is to say that the force developed across it is dependent upon the velocity of the force. The mechanical compliance of link 22 in centimeters per dyne corresponds to the electrical shunt capacity C_2 in farads. E, as already defined, is equal to PA and E' is equal to $P'A'$ where P and P' are the sound pressures on diaphragms 10 and 11, and A and A' are the areas thereof. The atmosphere is known to load the diaphragms. This gives rise to an additional impedance term which is generally small compared with other elements

in the circuit, and it may be neglected. When such is not the case, however, this additional term should be taken into account in the calculations.

Referring to the Patent No. 2,305,596, filed April 7, 1941, issued on December 22, 1942, under the name of Benjamin B. Bauer and assigned to the same assignee as the present invention, the electrical circuit illustrated in Fig. 8 thereof corresponds in form to the electrical circuit of Fig. 7 of this specification, and following the analysis there given cardioid directivity is obtained, that is, the voltage e across C_3 and L_3 in series is zero, or the force tending to deform crystal 24 is zero for rear sound incidence when

$$1 + \frac{Z_1'}{Z_2'} / 1 + \frac{Z_1}{Z_2} = \frac{E'_{180}}{E_{180}} \quad (I)$$

where

$$Z_1 = R + j\omega L$$

$$Z_2 = \frac{1}{j\omega C}$$

$$Z_1' = R' + j\omega L' + \frac{1}{j\omega C_1}$$

$$Z_2' = \frac{1}{j\omega C_2}$$

E'_{180} is the voltage or force at diaphragm 11 due to sound incident from the rear.

E_{180} is the voltage or force at screen 28 due to sound incident from the rear.

The voltages or forces E' and E , irrespective of the direction of sound incidence, are equal to the product of the sound pressure and diaphragm areas and in general are not equal.

ω is as already defined.

j is the mathematical symbol for the expression $\sqrt{-1}$

Substituting the foregoing into Equation I there results

$$\frac{1 + j\omega R'C_2 - \omega^2 L'C_2 + \frac{C_2}{C_1}}{1 + j\omega CR - \omega^2 LC} = \frac{E'_{180}}{E_{180}} = \frac{P'_{180}A'}{P_{180}A} \quad (II)$$

If it is defined that

$$C' = \frac{C_1 C_2}{C_1 + C_2}$$

which is the expression for the total capacitance of C_1 and C_2 in series circuit and recalling that P'_{180} and P_{180} are equal in magnitude but differ in phase by the angle $\omega d' / C_v$, then

$$\left(1 + \frac{C_2}{C_1}\right) \left(\frac{1 + j\omega R'C' - \omega^2 L'C'}{1 + j\omega CR - \omega^2 LC} \right) = \frac{A'}{A} \angle \omega d' / C_v \quad (III)$$

where

$$\angle \omega d' / C_v$$

represents the phase angle between P'_{180} and P_{180} , the symbol $\angle$ is the vectorial notation for phase angle and all other quantities are as already defined. The factor

$$\left(\frac{1 + j\omega R'C' - \omega^2 L'C'}{1 + j\omega CR - \omega^2 LC} \right)$$

represents a quotient of two vectors, each of which may be made very nearly a unit vector operating at an angle proportional to frequency, if the relationship between resistance, inductance and capacitance is such that:

$$L = \frac{CR^2}{2} \quad \text{and} \quad L' = \frac{C'R'^2}{2} \quad (IV)$$

The factors

$$\frac{A'}{A} \quad \text{and} \quad \left(1 + \frac{C_2}{C_1}\right)$$

being pure numbers, Equation III is true only if

$$\frac{1 + j\omega R'C' - \omega^2 L'C'}{1 + j\omega CR - \omega^2 LC} = \angle \omega d' / C_v \quad (V)$$

and

$$\left(1 + \frac{C_2}{C_1}\right) = \frac{A'}{A} \quad (VI)$$

Suppose for purposes of analysis that the compliance C_1 were equal to infinity, that is to say that the stiffness of the mounting of diaphragm 11 and the air trapped in cavity 16 is reduced to zero, or so small as to be negligible. Then the factor

$$\left(1 + \frac{C_2}{C_1}\right)$$

reduces to unity for finite values of C_2 and the areas of the diaphragms would be equal in this limiting case. Practically this condition is obtained if the compliance of the link 22 is much less than the combined compliance of the mounting of diaphragm 11 and cavity 16. Also under this assumption

$$\frac{1 + j\omega R'C' - \omega^2 L'C'}{1 + j\omega CR - \omega^2 LC}$$

$$\frac{1 + j\omega R'C_2 - \omega^2 L'C_2}{1 + j\omega CR - \omega^2 LC}$$

where $1 + j\omega R'C_2 - \omega^2 L'C_2$ is a unit vector operating at an angle very nearly proportional to frequency but with C_2 only present, and Equation III becomes

$$\frac{1 + j\omega R'C_2 - \omega^2 L'C_2}{1 + j\omega CR - \omega^2 LC} = \angle \omega d' / C_v \quad (VII)$$

The vector diagram of Fig. 3 corresponds to Equations II and III, both being for rear sound incidence. Thus, E' is force on diaphragm 11, is equal to $P'A'$, and corresponds to E'_{180} ; E is the force available at screen 28, is equal to PA , and corresponds to E_{180} , E being less than E' due to the difference in the areas of the diaphragms and lagging behind E' by an angle ϕ equal to $\omega d' / C_v$ as previously pointed out; E_1 is the force on the front of diaphragm 10 and lags behind E by an angle α represented by the factor $1 + j\omega CR - \omega^2 LC$, and E_2' is the force shifted from the force $(-E')$ by an angle $(\phi + \alpha)$ represented by the factor $1 + j\omega R'C' - \omega^2 L'C'$. In this case the force E_2' is across C_1 and C_2 in series and it is only the force across C_2 or E_1' that opposes E_1 . Since a portion of the force applied is used to overcome C_1 (to deflect diaphragm 11 and compress the air in cavity 16), it is necessary that the force E_2' be greater than the force E or E_1 in order that the component of force E_2' across C_2 , namely E_1' , be equal to E_1 . E_1' is the force transmitted to drive unit 17 from diaphragm 11 and is combined with E_1 , the force transmitted to drive unit 17 from diaphragm 10, to give the resultant force applied to crystal 24, which for 180 degree sound incident must be zero.

Thus, due to the compliance of the mounting of diaphragm 11 and the air in cavity 16, in order to have E_1' and E_1 equal in magnitude, the force

originating at diaphragm 11 must be greater than the force at diaphragm 10 by the factor

$$\left(1 + \frac{C_2}{C_1}\right)$$

If the compliance C_1 is infinite, the areas of diaphragms 10 and 11 would be equal, and if the force diagrams of Figs. 2, 3, 4 and 5 were plotted, these would differ from those of the present figures in that the forces E , E_1 , E' , $-E'$, and E_1' would all be of equal magnitude. The angular relations would remain the same. By constructing diaphragms 11 and 10 such that their areas have the ratio defined by Equation VI, the compliance of the mounting of diaphragm 11 need not be neglected but may be taken account of to produce directivity over the complete frequency range. This result is attained by virtue of the fact that the pressure on diaphragm 11 is transmitted as a force and not as a pressure. Hence, increasing the area increases the force.

Also following the analysis given in the patent and from Equation III of this specification where $\omega R'C'$ and ωRC individually are considerably less than one

$$\frac{\omega d'}{C_v} = (R'C' - RC)\omega \quad (\text{VIII})$$

from which it follows that ω , the frequency term may be eliminated and

$$\frac{d'}{C_v} = R'C' - RC \quad (\text{IX})$$

The expression

$$\frac{\omega d'}{C_v}$$

represents the external phase angle and the expression $\omega(R'C' - RC)$ represents the internal phase angle, the factors $\omega R'C'$ and ωRC being due to the phase shifting network and the screen 28 respectively.

From the foregoing equations the various constants given hereinafter for unidirectional response of the microphone may be calculated, Equation III being valid throughout the range of frequencies wherein d' is not larger than one quarter of the sound wave. Thus, if d' is equal approximately to two and one-half centimeters, cardioid directivity is obtained for all frequencies up to approximately 3,000 cycles per second. Since C_v , the velocity of sound, is a known constant for given conditions of temperature and pressure, the expression d'/C_v is known for any value of d' which may be chosen. Then the values of $R'C'$ and RC may be determined in accordance with Equation IX and L and L' may be determined from Equation IV.

It should not be assumed, however, that above 3000 cycles per second directional action ceases, because above the frequency where the transverse dimension of the microphone is a quarter wave length or greater, the instrument tends to become highly unidirectional in favor of sounds arriving from the front because of diffraction and the so-called "baffle effect." With a transverse dimension of three centimeters, this effect begins at about 2500 cycles per second and directional action may therefore be obtained essentially throughout all of the important frequency range.

When the choice of microphone constants is made in accordance with the foregoing equations, the microphone will be insensitive to sound waves arising from the rear, that is, impinging perpen-

dicularly upon diaphragm 11 (direction of arrow B) and will have its greatest sensitivity to sound falling directly on diaphragm 10 (direction of arrow A). The sensitivity pattern will be heart shaped, i. e., the cardioid pattern shown in Fig. 8, $k=1$.

The presence of screen 28 has some effect upon the directional properties of the microphone, it being responsible for the factor RC of Equation IX. It has been found, however, that by making the cavity 29 small, the principal effect of the screen is to dampen mechanical resonance of diaphragm 10. If screen 28 is completely eliminated, a slightly different choice of dimensions of dissipative element 23 and compliant link 22 is sufficient to restore the desired directional properties. In this instance Equation IX reduces to

$$\frac{d'}{C_v} = R'C'$$

Such a construction is advantageous in many instances since the cardioid directivity may be obtained for greater values of d' . The constants may be so chosen that the viscosity of element 23 is sufficient to dampen the motions of diaphragm 10 and crystal 24 because of the coupling which attains through link 22.

In Fig. 5 another method of obtaining the dissipative component is shown. In this embodiment a screen 39 with fabric 41 attached thereto is placed behind diaphragm 11, the screen and fabric being placed very close to the diaphragm so that the volume of the cavity therebetween is very small. Hence the fluid motion of the air through the screen is, for all practical purposes, identical with the motion or displacement of the diaphragm. The screen 39 and fabric 41 have acoustical resistance which is the resistance to the flow of air therethrough and may be determined by measuring the pressure, in dynes per square centimeter, necessary to force a steady stream of air at the rate of one cubic centimeter per second through the screen. The acoustical resistance is then numerically equal to this pressure and will provide the mechanical damping or dissipation which may be calculated by multiplying the acoustical resistance by the square of area of diaphragm 11.

Correspondingly, screen 39 and fabric 41 have acoustical mass or inertance and to obtain the mechanical mass the acoustical mass is also multiplied by the square of the diaphragm area.

The embodiment of Fig. 5 has a number of important advantages. It is known, for example, that compliance and inertance of air cavities and passages vary with the atmospheric pressure. For instance, compliance varies inversely with variations in the atmospheric pressure and inertance varies directly with variations in the atmospheric pressure. On the other hand, the viscosity of air remains constant with atmospheric pressure through an unusually wide range of pressures. Likewise, viscosity remains practically constant with varying temperature. The embodiment of Fig. 5 employs the mass of diaphragm 11 and drive unit 19 and the mechanical compliance of link 22 for obtaining the reactive components of the phase shifting network at the same time it uses the acoustical resistance of screen 39 and fabric 41 for obtaining the dissipative element. In this manner a structure is obtained producing the desired unidirectional effect which is sub-

stantially independent of the air pressure and temperature and the microphone has unvarying unidirectional properties when used in high altitude flying, for example.

Fig. 9 shows another manner of obtaining the dissipative effect producing damping of diaphragm 11 in order to obtain the necessary phase shift. In Fig. 9 the casing 13 is shown in fragmentary form together with drive unit 19, the drive unit being attached on each side of casing 13 to metallic diaphragms 31 and 32 by soldering or welding, for example. Diaphragms 31 and 32 are spaced from casing 13 by annular members 33 and 34 and cooperate therewith to define a chamber 35 filled with a suitable viscous substance such as a light oil or liquid silicone. The casing 13 between diaphragms 31 and 32 is provided with a number of small openings through which oil may flow. When the drive pin moves back and forth diaphragms 31 and 32 move therewith forcing the oil in chamber 35 to move back and forth through the openings in casing 13, thereby causing a dissipative action which provides the necessary damping component. The compliance of diaphragms 31 and 32 becomes a part of the total compliance indicated as C' in Fig. 2 and the same analysis is applicable.

In Fig. 10 another method of obtaining the requisite dissipative component is shown. The casing 13 is provided with a cylindrical portion 36 which is adapted to be closed by a cover 37 and flexible seals 40 and 21, chamber 36 being filled with petroleum or silicone jelly or a similar semi-solid substance. A disc 38 is attached to the drive unit 19 so that to-and-fro motions thereof produces to-and-fro motions of the disc in the jelly-like substance and provides a satisfactory amount of dissipation for operation of the structure.

As already pointed out in Equation VIII the left-hand side, $\omega d'/C_v$, represents the external phase difference, i. e., the phase difference between E and E' which results from the time required for the sound wave to travel to the effective distance d' . The right-hand side, $\omega(C'R - CR)$, represents the internal phase difference, i. e., the difference between the phase shift the force E' experiences in passing through the rear phase shifting network and the phase shift the force E experiences in passing through the acoustical screen 28 and cavity 29 to diaphragm 10. If the quantity k is defined such that

$$k = (C'R - CR) C_v / d' \quad (X)$$

that is, as equal to the ratio of the internal phase difference to the external phase difference, then the resulting response of the microphone r , in polar coordinates, in terms of the angle of sound incidence, θ , is given by

$$r = p(k + \cos \theta)$$

where p is proportional to the maximum pressure of the sound wave. As indicated in the patent referred to, this is the equation of the limaçon. By substituting different values of R' or different values of C' in the expression for k and using this value of k in the equation of the limaçon, the variation in directional response with the choice of the mechanical constants may be determined. When k equals one, that is, when Equation IX holds, a cardioid directional pattern results (Fig. 8). This is the directional characteristic frequently desired and

the one to which detailed consideration has been given. The microphone is capable of giving other responses. When k equals infinity the response is non-directional, i. e., it is a pressure responsive microphone. As k is made less than one, the microphone maintains its unidirectional property, or preferential response to sound of front incidence, but it has a definite, although a diminished, response to sound of rear incidence with zero response along two axes at an angle to the line of rear incidence. In the limiting case when k equals zero, that is, when $R'C'$ equals CR , the microphone becomes a cosine bidirectional type (maximum response from front and rear and zero response from the sides).

Since d' depends on the external shape of the microphone, and R and C are determined by the screen 28 and the volume of the cavity 29 respectively, the value of k is most conveniently changed by altering the product $R'C'$. All unidirectional characteristics of the microphone between the non-directional and the cosine bidirectional which are given by the equation of the limaçon are obtained by varying k between zero and infinity. The value of infinity is obtained by eliminating the link 22; the value of zero is obtained by making the link 22 a rigid connection. By varying the value of the dissipation of element 23 or the resilience of link 22, the varying types of unidirectional response are obtained including the cardioid case. The spacing d and consequently d' may be varied by eliminating spacers 14 and casing 20 and movably mounting one of casings 12 and 13 relative to the other, such as by a rack and pinion. Varying this spacing will vary the directional pattern as already indicated.

One manner of obtaining variations in the compliance of link 22 connecting diaphragms 10 and 11 and in the amount of dissipation or damping associated with diaphragm 11 is shown in Fig. 11. In this embodiment the general constructional features of the microphone are similar to those illustrated in Fig. 1 and the same reference numerals are used for corresponding parts. The structure of Fig. 11 differs from that of Fig. 1 in two respects, the first of these being that the fixed compliant link 22 of Fig. 1 has been replaced with a variable compliant link 56 and the second of these being that the block of dissipative material 23 of Fig. 1 has been replaced with an electromagnetic damping unit 67.

Compliant link 56 comprises a stirrup 68 connected to drive unit 19 and a resilient member or spring 69 connected to drive unit 17. Stirrup 68 includes a pair of spaced apart members 71 and 72, the member 71 being relatively rigid and the member 72 being relatively flexible. The resilient member 69 is rigidly attached to the end of arm 71, is slidably arranged in the corresponding end of arm 72, and is rigidly attached to the drive unit 17. Adjacent resilient member 69 an adjusting screw 73 is provided and is threadably received in cooperating threads in arm 71 and through a hole in arm 72.

In the position shown, arms 71 and 72 are symmetrically disposed with respect to drive unit 17. This is the normal position of arm 72 relative to arm 71. Since the member 69 is resilient or flexible, it is evident that the link 56 has a certain value of compliance depending upon the relative lengths of the portions

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of member 69 on each side of the drive unit 17. With the arms 71 and 72 symmetrically disposed about drive unit 17, the compliance of resilient member 69 may be so chosen that Equation IX is satisfied, that is to say, $k=1$ and the microphone has a cardioid response (for definite values of dissipation). By rotating adjusting screw 73, the position of arm 72 may be changed from the position shown to any position up to those shown in broken lines. As arm 72 moves toward drive unit 17, it is evident that the length of the resilient member 69 between drive unit 17 and arm 72 is decreasing. Accordingly, the stiffness of resilient member 69 is increasing or the compliance thereof is decreasing. At the point where arm 72 is in contact with drive unit 17, the compliance of link 68 has been reduced to zero. In other words, it is now a direct or rigid mechanical connection. As pointed out previously in this specification, when the link is rigid, $k=0$ and the microphone becomes a bidirectional or cosine law response microphone. Thus the type of microphone response may be changed from cardioid to cosine law merely by changing the position of the adjusting screw 73. Similarly, the adjusting screw may be varied to move arm 72 outward from its initial position to thereby decrease the stiffness of the link with a consequent reduction of the factor k and an approach of the response pattern toward the pressure response. After a definite value of R' has been chosen, such as for cardioid response, changing the position of adjusting screw 73 will change the compliance of the link and thus change the value of C' in equation X to give a certain value of k and consequently a different directional pattern of the microphone.

The dissipative unit 67 comprises a magnet 74 having a central pole 75 which may be circular in cross-section and an outer pole 76 which may be annular in cross-section, the outer pole and the central pole defining an air gap between them within which a coil 77 is adapted to move. The magnet is arranged to be held rigidly relative to casing 13. The ends of coil 77 are brought out of the casing along the diaphragm, one end thereof being connected to a resistor 78 and the other end being connected to a movable contact 79 for contacting resistor 78 at different points along its extent. By shifting contact 79, varying amounts of resistance may be placed in circuit with coil 77. The coil 77 is mounted on a support which is rigidly connected to the drive unit 19 and thus the coil moves in its magnetic air gap whenever diaphragm 11 moves or vibrates. As coil 77 moves in the magnetic air gap a voltage is generated therein which causes a current to flow through resistor 78, the amount of resistance in the circuit determining the magnitude of the current. The current flowing in coil 77 sets up a magnetic field which interacts with the magnetic field of magnet 74, tending to oppose movement of diaphragm 11 or to dissipate the energy of its motion to produce damping of the vibrations. Hence, by providing a variable resistor 78 the amount of damping or dissipation provided by the unit 67 may be varied. The coupling between the magnet and the coil may be varied by other similar means, such as by partially withdrawing the magnet from engagement with the coil.

In order to satisfy the relationship defined by Equation IX, it is evident that the values of C' and R' must be varied in a definite relationship.

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Thus, whenever the value of C_2 supplied by link 66 is varied, the amount of damping R' supplied by unit 67 may be varied in order to satisfy the necessary relations. Moreover, the value of R' may be varied to satisfy Equation X to produce a directivity pattern other than the cardioid.

In one specific instance which has been found extremely desirable, k is made equal to the ratio 37/63. For this choice of k , the microphone has a unidirectional index of 14, that is, sounds coming at random from the solid angle encompassed by the front hemisphere will produce a response 14 times as great as sounds coming at random from the solid angle encompassed by the rear hemisphere. Whatever value one chooses for k , however, the proper choice of circuit constants is given by Equations IV and X.

It is not necessary that the coupling means between the two diaphragms be merely compliant. It may include mass or inertance and resistance as well, that is, it may be a general impedance. In Fig. 15 one form of such a coupling connects the drive units 17 and 19 of the structure of Fig. 1, for example. Connected to drive unit 19 is a cylinder 70, surrounding which is a ring 71a of T shape in cross section. The ring 71a is connected by means of a stirrup 72a to drive unit 17.

The cylinder 70 is held in position by a pair of flexible diaphragms 73a and 74a which are attached to the outer diameter of ring 71a to form a chamber on each side of the central portion of the ring. The chambers are filled with liquid, such as a light oil, which is forced to move from one chamber to the other through the annular slit between the outside diameter of cylinder 70 and the inside diameter of the ring. The movement of the liquid through the narrow passage causes the presence of both resistance and inertance or mass. The compliance of the diaphragms 73a and 74a is the principal compliance of the system and serves to transmit the force from drive unit 19 to drive unit 17.

Following an analysis similar to that outlined for the structure of Fig. 1, cardioid directivity is obtained by the structure of Fig. 15 when the relationship of the constants is given by the expression

$$\frac{C_2}{C_1+C_2}(C_1R_1-C_2R_2)=\frac{d'}{C_1}$$

up to a frequency where d' is not greater than one quarter wave length. In this expression C_1 is the compliance of the mounting of diaphragm 11, R_1 is resistance of the damping unit 23 (Fig. 1), C_2 is the compliance of the diaphragms 73 and 74, and R_2 is the resistance of the fluid flowing in the annular slit. The mass of diaphragm 11 is given by the expression

$$L_1=\frac{C_1R_1^2}{2}$$

and the inertance or mass of the fluid flowing in the slit is given by the expression

$$L_2=\frac{C_2R_2^2}{2}$$

In order that directivity may be had at all frequencies, including the low frequencies, the ratio of areas of diaphragms 11 and 10 is given by the expression

$$\frac{A_1}{A}=1+\frac{C_2}{C_1}$$

where these terms are as already defined. If the mounting compliance of diaphragm 11 is negligible then the areas A_1 and A may be equal.

Another embodiment of my invention is illustrated in Fig. 12. In this embodiment the microphone comprises a casing 44 of sound-impermeable material having two portions thereof of different diameters, the smaller portion being closed by a diaphragm 45 and the larger portion being closed by a diaphragm 46 thereby to define a closed cylindrical chamber 51. Extending inwardly from the apex of diaphragm 45 and attached thereto is a drive unit 47, and extending inwardly from the apex of diaphragm 46 and attached thereto is a drive unit 48, the drive units being connected together by means of a compliant link 49 which may be made of a spring, rubber, or elastomer similar to compliant link 22. Supported within the casing 44 is a crystal 52 relatively rigidly connected to drive unit 47 by a collar 50 whereby movements of diaphragm 45 are communicated thereto. Extending inwardly from casing 44 is a relatively rigid member 53 adapted to hold a dissipative element 54 (an elastomer for example) which is connected to the drive unit 48 to dampen the movements of diaphragm 46.

It will be seen that the microphone illustrated in Fig. 12 is similar to that of Fig. 1 in that two diaphragms are coupled by means of a compliant link, and the modification of Fig. 12 differs from that of Fig. 1 in that diaphragms 45 and 46 in addition to link 49 are coupled by the compliance of the air within chamber 51, whereas in Fig. 1 diaphragms 10 and 11 are not coupled by an air cavity. Compliant link 49 may be omitted, leaving only the coupling effected by the air cavity, without changing the unidirectional character of the microphone if compensatory changes are made in the remaining microphone structure, as will be subsequently explained.

The microphone of Fig. 12, while different in construction from, operates similarly to that of Fig. 1 in that the force arising from sound waves falling upon diaphragm 45 produces one force acting upon crystal 52 through drive unit 47, and the force arising from sound waves falling upon diaphragm 46 produces a second force transmitted to the crystal 52 through drive pin 48, the deformation of the crystal, and hence its output, being proportional to the resultant of the difference of these forces since the diaphragms oppose each other. The second force is made up of two parts, one of which is a force transmitted through link 49 and the other of which is a force resulting from the pressure transmitted through the air in cavity 51 and converted into a force at the underside of diaphragm 45. The mass of diaphragm 46 and the compliance of its mounting, the compliance of the air in cavity 51, and the compliance of link 49, together with the damping of dissipative element 54, produce a phase shifting network by means of which the second force acting upon the crystal 52 is so shifted relative to the force arising from sound waves falling externally upon diaphragm 46 that the microphone has maximum response for normal front incidence of sound (indicated by the arrow A) and minimum response for rear incidence of sound (indicated by the arrow B). Other directional patterns may be obtained by proper selection of the network constants.

Since the output of this microphone also is due to the deformation of the crystal 52, when there is no deformation of crystal 52 there is no voltage output, and when the deformation of crystal 52 is at a maximum there is maximum voltage

output. Accordingly, for this microphone to have a cardioid directional response, the elements thereof are arranged so that the deformation of crystal 52 is zero when sound is directly incident on the rear diaphragm.

In order to have the deformation of crystal 52 equal to zero, it is evident that the resultant force acting on the crystal must be zero. Since sound pressures P and P' of equal magnitude act on diaphragms 45 and 46 respectively producing forces E and E', these forces arising from the same sound wave, it is evident that the final combination of forces resulting from the forces E and E' must be zero for sound of rear incidence.

This may be visualized by the vector diagram of Fig. 13 which shows the relationship of forces for sound of rear incidence. Thus the vector E' is the force due to sound falling on diaphragm 46, the sound coming in the direction of the arrow B, the length of the vector E' being equal to P'A' where P' is the pressure of the sound wave and A' is the area of diaphragm 46. The sound wave continuing to travel also falls upon diaphragm 45 and exerts a force E equal to PA where P is the pressure of the sound wave and A is the area of diaphragm 45. Due to the time necessary for the sound wave to travel the effective distance d' between diaphragms 45 and 46, the force E lags behind the force E' by phase angle ϕ which is equal to

$$\frac{\omega d'}{C}$$

Hence, on the vector diagram, E is shown clockwise from E' by an angle ϕ . Whereas the force on diaphragm 46 is opposed to the force on diaphragm 45, as for the microphone of Fig. 1, the force E' is reversed and is shown as a force -E' on the diagram. The force E', even when reversed to -E', does not combine directly with the force E, but due to the inherent characteristics of diaphragm 46, that is, its mass and the compliance of its mounting, and due to the characteristics of the means for transmitting the force from diaphragm 46 to diaphragm 45, that is, the compliance of link 49, the compliance of the cavity 51 and the damping of the element 54, the force E' finally transmitted through the link and through the cavity 51 to rear of diaphragm 45 and to the driving unit 47 has a phase angle relative to the force -E', this phase angle being designated as the internal phase angle of the microphone. On the vector diagram the shifted force -E' is shown as E2'. Due to the compliance of diaphragm 46 a certain proportion of the force -E' is consumed in deforming this element and thus is not available for transmission to drive unit 47 either through the air cavity 51 or the link 49. However, of the force E2' a component E1' is transmitted to drive unit 47, and consequently combines with the force E to act on crystal 52. When the microphone is designed in accordance with the invention, the internal phase angle may be made equal to

$$\frac{\omega d'}{C}$$

which is equal to the angle ϕ for sound of rear incidence, and the magnitude of E1' made equal to the magnitude of E. Accordingly E1' and E may be made to directly oppose each other and their resultant in zero. Since the resultant force is zero, there is no deformation of crystal 52 and the output of the microphone is zero.

For sound of front incidence (direction of arrow A) the force diagram is of the same form as in Fig. 6. The force acting on diaphragm 45 may be illustrated as a vector E having the same magnitude as the vector E in Fig. 13. Then, due to the time necessary for sound to travel the effective distance d' , the force E' , due to the sound falling on diaphragm 46, may be illustrated as a vector E' at a clockwise angle

$$\phi = \frac{\omega d'}{C_2}$$

relative to the vector E since $\cos \theta = 1$ for front incidence. In this case also, since the forces produced by the diaphragms are opposed to each other, the force E' is acting reversely from the direction shown and accordingly is reversed to $-E'$. As indicated for the case of rear incidence of sound, due to the diaphragm plus the network coupling diaphragms 45 and 46, the force E_2' lags behind the force $-E'$ by an internal phase angle which, in this case, is equal to the internal phase angle of Fig. 13 since the internal network has not been changed. In this case also a certain proportion of the force $-E'$ or E_2' is consumed in deforming diaphragm 46 and thus is not available for transmission to drive unit 47. However, there is a component of this force E_1' equal in magnitude to the force E when the microphone is designed in accordance with the invention, which is transmitted to drive unit 47. The resultant E_r of forces E_1' and E deforms crystal 52 and produces the microphone output. Accordingly, it is evident that for sound of front incidence a force of definite value is available to deform crystal 52 and produce microphone output.

A microphone with cardioid directional properties up to 3000 cycles per second due to the network may be constructed in accordance with the invention having the following constants: The volume of cavity 51 equal to 10 cubic centimeters; the area A' of the rear diaphragm equal to 10 sq. centimeters; the acoustical compliance C_4 of the air cavity equal to 7.1×10^{-6} cubic centimeters per dyne per square centimeter; the mechanical compliance C_2 of the link equal to 1×10^{-7} centimeters per dyne; the mechanical compliance of the mounting of the rear diaphragm C_1 equal to 1×10^{-7} centimeters per dyne; the mass of rear diaphragm and driving unit 48 equal to .090 gram; the resistance of dissipative element 54 equal to 2470 ohms. The compliance of the mounting and mass of front diaphragm and drive unit 47 may be equal to those of the corresponding rear elements; the area of the front diaphragm being equal to 5 square centimeters. It should not be assumed that unidirectivity stops at 3000 cycles per second since above this frequency the microphone becomes highly unidirectional from the front due to the baffle effect of the casing (A' being 10 square centimeters, the transverse dimension will approximate 3 centimeters).

For a more complete understanding of the invention and for a knowledge of the manner of computation of the microphone constants, an analysis of the equivalent electrical circuit (Fig. 14) of the microphone of Fig. 12 may be made. Referring to Fig. 14, E is analogous to the force produced by the pressure P of sound waves falling on diaphragm 45 and is equal to PA where A is the area of the diaphragm. E' is analogous to the force produced by the pressure P' of sound waves falling on diaphragm 46 and is equal to

$P'A'$ where A' is the area of this diaphragm. The mechanical mass of diaphragm 45, drive unit 47 and crystal 52 in grams lumped together, are analogous to the inductance L_3 , and the mechanical compliance of the mounting of diaphragm 45 is analogous to the electrical capacity C_3 . The mass of the diaphragm 46, of the drive unit 48, and the equivalent mass of dissipative unit 54 in grams may be lumped together and are analogous to the electrical inductance L_1 . The mechanical resistance of the dissipative element 54 is analogous to the electrical resistance R' . The mechanical compliance of the mounting of diaphragm 46, and the equivalent compliance of the dissipative element 54 may be lumped together and are analogous to the electrical capacity C_1 . The compliance of link 49 is analogous to the electrical capacity C_2 , and the compliance of the air within the cavity 51 is analogous to an electrical capacity C_4 .

The two compliant elements, link 49 and the air in cavity 51, are factors in coupling the vibrations of diaphragms 45 and 46, and may be considered to be acting separately, and are shown coupled by idealized transformers 55, 55a, 56 and 56a, including respectively windings 57 and 58, 59 and 61, 62 and 63, and 64 and 65. The turn ratios of windings 57 to 58 and 62 to 63 are as one to one, the turn ratio of winding 59 to winding 61 is as A to one, and the turn ratio of winding 64 to winding 65 is as one to A' , A and A' being the areas of diaphragms 45 and 46 respectively. Thus the mechanical compliance of the link 49 (C_2) is directly coupled to the diaphragms and the acoustical compliance of the air in cavity 51 (C_4) is coupled thereto through transformers having a ratio of one to A and one to A' respectively.

The treatment of the air coupling of cavity 51 (C_4) and the link 49 (C_2) coupling the diaphragms through transformers having transformation ratios corresponding to the areas of the diaphragms and having transformation ratios of unity is a consequence of the fact that the link 49 transmits a force and the air in cavity 51 transmits a pressure. When pressure is exerted on the exterior of diaphragm 46, there is a total force produced equal to product of the pressure and area. This force decreased by the amount needed to overcome the compliance of the mounting of diaphragm 46 is transmitted in proportionate amounts as a pressure through the air in cavity 51 and as a force through link 49 to diaphragm 45 and drive unit 47, depending on the relative compliance of these elements.

Since link 49 transmits its proportionate amount of force directly without any change in its value, it is represented as coupling the diaphragms through one to one ratio transformers. However, the proportion of force transmitted by the air appears as a pressure inside of the casing, and while this proportionate part of the force at diaphragm 46 is equal to pressure inside of the casing multiplied by the area of the diaphragm, only the inside pressure is transmitted to diaphragm 45 where the force is this pressure multiplied by the area of diaphragm 45. Due to link 49 the force transmitted from one diaphragm to the other depends on the diaphragm areas, and since the pressure in cavity 51 has an average value, the air is shown coupling the diaphragms through transformers having the areas as ratios of transformation.

For cardioid directivity the resultant force for sound of rear incidence tending to deform crystal

52 must equal zero, as pointed out previously, or the voltage e across L_3C_3 must be equal to zero. Analyzing the circuit of Fig. 14 and imposing the condition that the response (voltage e) be zero for rear or 180° sound incidence, the following relation is obtained

$$\frac{C''}{C'}[1 - \omega^2 L' C' + j\omega R' C'] = \frac{E'_{180}}{E_{180}} \quad (\text{XI})$$

where

$$\frac{1}{C'} = \frac{1}{C_1} + \frac{1}{C_3} + \frac{(A')^2}{C_4} \quad (\text{XII})$$

and

$$\frac{1}{C''} = \frac{1}{C_2} + \frac{AA'}{C_4} \quad (\text{XIII})$$

E'_{180} is the voltage or force arising from sound pressure on diaphragm 46, it being equal to $P'A'$ and E_{180} is the force of sound pressure on diaphragm 45 and is equal to PA . It should be noted that C'' and C_2 are units of mechanical compliance, centimeters per dyne, while C_4 is given in units of acoustic compliance, cubic centimeters per dyne per square centimeter. Since diaphragms 45 and 46 are spaced apart, there is a phase difference between the external sound pressures exerted thereon, as has already been pointed out, equal to

$$\phi = \frac{\omega d'}{C_v} \cos \theta$$

where d' is the effective distance between the two diaphragms. For a small distance d' , the magnitude of the pressure of the sound wave at the two diaphragms is equal and Equation XI may be rewritten as follows:

$$\frac{C''}{C'}[1 - \omega^2 L' C' + j\omega R' C'] = \frac{A'}{A} \frac{\omega d'}{C_v} \quad \text{XIV}$$

For values of C' , L' , and R' chosen in accordance with Equations IV and IX where R and C are set=0, the expression $(1 - \omega^2 L' C' + j\omega R' C')$ is a phase angle and must equal

$$\frac{\omega d'}{C_v}$$

and during this range of values

$$\frac{A'}{A} = \frac{C''}{C'} \quad (\text{XV})$$

or substituting the values of C'' and C' there is obtained

$$\frac{A'}{A} = 1 + \frac{C_2}{C_1} \quad (\text{XVI})$$

From the expression

$$\frac{A'}{A} = 1 + \frac{C_2}{C_1}$$

it is evident that the ratio of the diaphragm areas depends upon the ratio of the compliance of the mounting of diaphragm 46 and the compliance of link 49.

Where the mounting compliance of diaphragm 46, C_1 , is very large compared to the compliance C_2 of link 49 (compliance C_1 equal to infinity or the stiffness of link C_2 is great compared to the stiffness of diaphragm 46) the ratio of areas

$$\frac{A'}{A}$$

becomes equal to unity. In other words, to have equal diaphragm areas, the compliance of diaphragm 46 must be equal to infinity or unidirectionality at low frequencies will not occur. Where

the stiffness of diaphragm 46 may not be ignored in obtaining unidirectionality at all frequencies, the area of this diaphragm may be increased as determined by the relation given to compensate therefor. As explained in connection with the microphone of Fig. 1, link 49 transmits a force. When the area of diaphragm 46 is increased, the total force available is increased and the proper portion of the increase is transmitted to diaphragm 45 to compensate for the force consumed in deforming diaphragm 46. The links C_2 may be omitted in some instances leaving only the air in cavity 51 coupling diaphragms 45 and 46. When this occurs there is only the pressure of the air in cavity 51 to transmit force from diaphragm 46 to diaphragm 45. Increasing the area of diaphragm 46, then, has no effect and there could be unidirectionality at all frequencies only if the stiffness of diaphragm 46 can be neglected. The actual evaluation of microphone constants to compensate for the assumption that the compliance of diaphragm 46 is infinite, or that the compliance of link 49 is infinite may be understood by a reference to Equations XV and XVI.

From Equation XIII for unidirectional operation and for the instance where the expression $\omega R' C'$ is considerably less than 1, one may write the expression

$$\frac{\omega d'}{C_v} = \omega R' C'$$

where

$$\frac{\omega d'}{C_v}$$

is the external phase angle due to the sound traveling the effective distance d' and $\omega R' C'$ is the internal phase angle due to the network interconnecting the diaphragms 45 and 46. From this relationship the factor ω may be eliminated giving

$$\frac{d'}{C_v} = R' C'$$

Since this expression must be true for cardioid directional operation, if R' has been chosen, the factor C' must remain the same since

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

is a constant for any microphone. Accordingly, if the values of any of C_1 , C_2 and C_4 are changed, the remaining values must be made to conform to this relationship.

The compliance C_1 of the rear diaphragm is a factor in the equations and is taken account of by the link 49 and the increased area of diaphragm 46 to produce directivity at all frequencies up to those for which the effective distance d' is not greater than one-quarter of the sound frequency. In instances where the compliance of the rear diaphragm is high enough to be neglected, which is true only above the lower frequencies, the microphone may have directional operation without the link 49 and with the areas of the two diaphragms equal providing R' and C_4 are properly chosen as outlined above.

While the description relating to Fig. 12 has been with reference to cardioid directivity, it will be understood that this is exemplary only. The various factors of R' , C_2 , d' may be made in accordance as outlined in connection with Figs. 1, 5 and 11 to obtain bidirectional response, pressure response or variations therefrom. Moreover, as outlined, the directional pattern may be made

adjustable by providing means to adjust the constants.

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 comprising first and second diaphragms adapted to vibrate relative to each other and defining an enclosed chamber containing a gaseous medium, said diaphragms being spaced from each other thereby to effect a phase difference between the force of sound waves striking one of said diaphragms and the force of said sound waves striking the other of said diaphragms, means for transforming vibrations into electrical variations, a stiff link for transmitting the force arising at said one diaphragm to said transforming means, compliant means including said gaseous medium for transmitting the force arising at said second diaphragm to said transforming means, and means for damping vibrations of said second diaphragm.

2. A microphone translating preferentially sounds received from one direction comprising first and second diaphragms adapted to vibrate relative to each other, said diaphragms being spaced apart from each other thereby to effect a phase difference between the force of sound waves striking one of said diaphragms and the force of said sound waves striking the second one of said diaphragms, means for transforming vibrations into electrical variations, a stiff link for transmitting the force arising at said one diaphragm to said transforming means, compliant mechanical link means for transmitting a function of the force arising at said second diaphragm to said transforming means, and means for damping vibrations of said second diaphragm, said compliant mechanical link means, said damping means, and said diaphragm producing a phase shift of the force arising at said second diaphragm having a certain phase relationship to the force arising at said one diaphragm.

3. A directional sound translating device comprising first and second diaphragms adapted to vibrate relative to each other, said diaphragms being spaced apart from each other thereby to effect a phase difference between the force of sound waves striking one of said diaphragms and the force of said sound waves striking the other of said diaphragms, means for transforming vibrations into electrical variations, phase shifting means including said second diaphragm for producing a phase shift between the forces acting on the two sides of said first diaphragm, and means for transmitting the resultant of said forces acting on the two sides of said first diaphragm to said transforming means.

4. A directional sound translating device comprising a first diaphragm having a certain surface area and compliance and adapted to vibrate in response to the forces exerted on its two sides, one of said two sides being substantially exposed whereby sound waves incident thereon exert a force, casing means, a second diaphragm having a certain surface area and compliance spaced from said first diaphragm vibratable relative thereto and having one side substantially

exposed whereby sound waves incident thereon exert a force, said casing means and said diaphragms defining an enclosed chamber containing an elastic medium, a transducing element relatively rigidly connected with only said first diaphragm, a compliant link interconnecting said diaphragms, and means for damping vibrations of said second diaphragm, said medium and said link transmitting a force from said second diaphragm to the other side of said first diaphragm, the surface area of said second diaphragm being greater than the surface area of said first diaphragm to compensate for the stiffness of said second diaphragm, said second diaphragm being greater in area in proportion to the ratio of the compliance of said link and said second diaphragm.

5. A directional sound translating device comprising a first diaphragm having a certain surface area and compliance and adapted to vibrate in response to the forces exerted on its two sides, one of said two sides being substantially exposed whereby sound waves incident thereon exert a force, casing means, a second diaphragm having a certain surface area and compliance spaced from said first diaphragm vibratable relative thereto and having one side substantially exposed whereby sound waves incident thereon exert a force, said casing means and said diaphragms defining an enclosed chamber containing an elastic medium, a transducing element relatively rigidly connected with only said first diaphragm, a compliant link interconnecting said diaphragms, and means for damping vibrations of said second diaphragm, said medium and said link transmitting a force from said second diaphragm to the other side of said first diaphragm, the surface area of said second diaphragm being greater than the surface area of said first diaphragm to compensate for the stiffness of said second diaphragm, the ratio of the area of said second diaphragm to said first diaphragm being substantially equal to unity plus the ratio of link compliance to the compliance of said second diaphragm.

6. A directional sound translating device comprising a pair of spaced apart diaphragms adapted to vibrate relative to each other and defining a closed chamber containing an elastic medium, means for transforming vibrations into electrical variations relatively rigidly connected to one of said diaphragms, means for damping vibrations of the other one of said diaphragms, means including a compliant link and the elastic medium in said chamber for coupling said diaphragms.

7. A directional sound translating device comprising a first diaphragm adapted to vibrate in response to the forces exerted on its two sides, one of said two sides being substantially exposed whereby sound waves incident thereon exert a force, means including a second diaphragm spaced from said first diaphragm vibratable relative thereto and having one side substantially exposed whereby sound waves incident thereon exert a force, said means and said diaphragms defining an enclosed chamber containing an elastic medium, a transducing element relatively rigidly connected with only said first diaphragm, a compliant link interconnecting said diaphragms, and means for damping vibrations of said second diaphragm, said medium and said link transmitting a force to the other side of said first diaphragm.

8. A directional sound translating device comprising a first diaphragm adapted to vibrate in

response to the forces exerted on its two sides, one of said two sides being substantially exposed whereby sound waves incident thereon exert a force, means including a second diaphragm spaced a fixed distance from said first diaphragm vibratable relative thereto and having one side substantially exposed whereby sound waves incident thereon exert a force, said means and said diaphragms defining an enclosed chamber containing an elastic medium, a transducing element relatively rigidly associated with only said first diaphragm, a resilient link interconnecting said diaphragms, and means for damping vibrations of said second diaphragm, said medium and said link transmitting a force from said second diaphragm to the other side of said first diaphragm, said link, said medium, said damping means and said second diaphragm constituting a phase shift network for shifting the phase of the force on said other side of said first diaphragm relative to the force on said second diaphragm by a value equal to the phase difference between sound pressures of a sound wave traveling said distance.

9. A directional sound translating device comprising a first diaphragm adapted to vibrate and defining at least a portion of one side of a closed chamber containing an elastic medium, a transducing element relatively rigidly connected to said first diaphragm, a second diaphragm adapted to vibrate relative to said first diaphragm and defining at least a portion of one side of another closed chamber containing an elastic medium, each of said diaphragms being adapted to have sound waves fall thereon, and a compliant link interconnecting said first and second diaphragms.

10. A directional sound translating device comprising a first diaphragm adapted to vibrate and defining at least a portion of one side of a closed chamber containing an elastic medium, a transducing element relatively rigidly connected to said first diaphragm, a second diaphragm adapted to vibrate relative to said first diaphragm and defining at least a portion of one side of another closed chamber containing an elastic medium, each of said diaphragms being adapted to have sound waves fall on one side thereof, a compliant link transmitting a force from said second diaphragm to the other side of said first diaphragm, and means for damping vibrations of said second diaphragm, said damping means, said compliant link, said second chamber and said second diaphragm constituting phase shifting means for shifting the phase of the force exerted on said other side of said first diaphragm relative to the force exerted on said one side of said second diaphragm.

11. A directional sound translating device comprising a first diaphragm having a certain surface area and compliance adapted to vibrate and defining at least a portion of one side of a closed chamber containing an elastic medium, a transducing element relatively rigidly connected to said first diaphragm, a second diaphragm having a certain surface area and compliance adapted to vibrate relative to said first diaphragm and defining at least a portion of one side of another closed chamber containing an elastic medium, said first and second diaphragms being spaced apart from each other a fixed distance and being adapted to have sound waves fall on the outside thereof, and a compliant link coupling said first and second diaphragms, the surface area of said second diaphragm being greater than the surface area of said first diaphragm to compensate for the stiffness of said second diaphragm, said sec-

ond diaphragm being greater in area in proportion to the ratio of the compliance of said link and said second diaphragm.

12. A directional sound translating device comprising a first diaphragm having a certain surface area and compliance adapted to vibrate and defining at least a portion of one side of a closed chamber containing an elastic medium, a transducing element relatively rigidly connected to said first diaphragm, a second diaphragm having a certain surface area and compliance adapted to vibrate relative to said first diaphragm and defining at least a portion of one side of another closed chamber containing an elastic medium, said first and second diaphragms being spaced apart from each other a fixed distance and being adapted to have sound waves fall on the outside thereof, elastic means coupling said diaphragms thereby to transmit a force from said second diaphragm to the other side of said first diaphragm, and means for damping the vibrations of said second diaphragm, the surface area of said second diaphragm being greater than the surface area of said first diaphragm to compensate for the stiffness of said second diaphragm, the ratio of the area of said second diaphragm to said first diaphragm being substantially equal to unity plus the ratio of the compliance of said elastic means to the compliance of said second diaphragm, said damping means, said second diaphragm, and said other chamber constituting phase shifting means for shifting the phase of the force transmitted to said other side of said first diaphragm relative to the force exerted on the outside of said second diaphragm by a value substantially equal to the phase angle between pressures in a sound wave traveling said distance.

13. A directional sound translating device comprising a first diaphragm having a certain surface area and compliance, a second diaphragm having a certain surface area and compliance, said first and second diaphragms being spaced apart from each other a fixed distance, and a link having compliance coupling said diaphragms, the surface area of said second diaphragm being greater than the surface area of said first diaphragm to compensate for the stiffness of said second diaphragm, said second diaphragm being greater in area in proportion to the ratio of the compliance of said link and said second diaphragm.

14. A directional sound translating device comprising a first diaphragm having a certain surface area and compliance, a second diaphragm having a certain surface area and compliance, said first and second diaphragms being spaced apart from each other a fixed distance, and a link having compliance coupling said diaphragms, the surface area of said second diaphragm being greater than the surface area of said first diaphragm to compensate for the stiffness of said second diaphragm, the ratio of the area of said second diaphragm to said first diaphragm being substantially equal to unity plus the ratio of link compliance to the compliance of said second diaphragm.

15. A directional sound translating device having a pair of spaced apart diaphragms, a transducing device connected to one of said diaphragms for converting vibrations thereof into electrical variations, and means including a compliant link between said one and the other of said diaphragms for transmitting forces therebetween, the other of said diaphragms being greater in surface area than said one diaphragm, the

ratio of the surface area of said other diaphragm to said one diaphragm being greater than unity and sufficient to compensate for the stiffness of said other diaphragm over a substantial range of sound frequencies.

16. A directional sound translating device having a pair of spaced apart diaphragms, a transducing device connected to one of said diaphragms for converting vibrations thereof into electrical variations, and means including a compliant link between said one and the other of said diaphragms for transmitting forces therebetween, the other of said diaphragms being greater in surface area than said one diaphragm, the ratio of the surface area of said other diaphragm to said one diaphragm being substantially equal to one plus the ratio of the stiffness of said compliant link and the stiffness of said other diaphragm.

17. A directional sound translating device comprising a first diaphragm having a certain surface area and compliance and producing a force from sound waves thereon, a second diaphragm spaced from said first diaphragm vibratable relative thereto and producing a force from sound waves falling thereon, said second diaphragm having a certain surface area and compliance, transducing means relatively rigidly connected to said first diaphragm, means including compliant means coupled to said second diaphragm for subtractively transmitting said forces to said transducing means, the surface area of said second diaphragm being greater than the surface area of said first diaphragm to compensate for the stiffness of said second diaphragm, the ratio of the area of said second diaphragm to said first diaphragm being substantially equal to unity plus the ratio of the compliance of said compliant means to the compliance of said second diaphragm.

18. A directional sound translating device comprising a first diaphragm having a certain surface area and compliance and producing a force from sound waves thereon, a second diaphragm having a certain surface area and compliance spaced from said first diaphragm vibratable relative thereto and producing a force from sound waves falling thereon, transducing means relatively rigidly connected to said first diaphragm, compliant means coupling said diaphragms, and means for varying the compliance of said compliant means, the surface area of said second diaphragm being greater than the surface area of said first diaphragm to compensate for the stiffness of said second diaphragm, the ratio of the area of said second diaphragm to said first diaphragm being substantially equal to unity plus the ratio of the compliance of the compliant

means to the compliance of said second diaphragm.

19. The invention according to claim 3 characterized in that the phase shifting means for producing a phase shift between the forces acting on the two sides of the first diaphragm, in addition to the second diaphragm, comprises a link having mechanical impedance including compliance between the first and second diaphragms.

20. The invention according to claim 3 characterized in that the phase shifting means for producing a phase shift between the forces acting on the two sides of the first diaphragm, in addition to the second diaphragm, comprises a link having mechanical impedance including inductance, compliance, and non-gaseous fluid friction.

21. The invention according to claim 2 characterized in that the means for damping vibrations of the second diaphragm comprises fluid friction means.

22. The invention according to claim 2 characterized in that the means for damping vibrations of the second diaphragm comprises a relatively movable vane and viscous medium.

23. The invention according to claim 2 characterized in that the means for damping vibrations of the second diaphragm comprises semi-fluid solid medium means.

24. The invention according to claim 2 characterized in that the means for damping vibrations of the second diaphragm comprises electromagnetic means.

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