July 26, 1932. A. L. THURAS 1,869,178

SOUND TRANSLATING DEVICE

Filed Aug. 15, 1930 3 Sheets-Sheet 1

FIG. 1

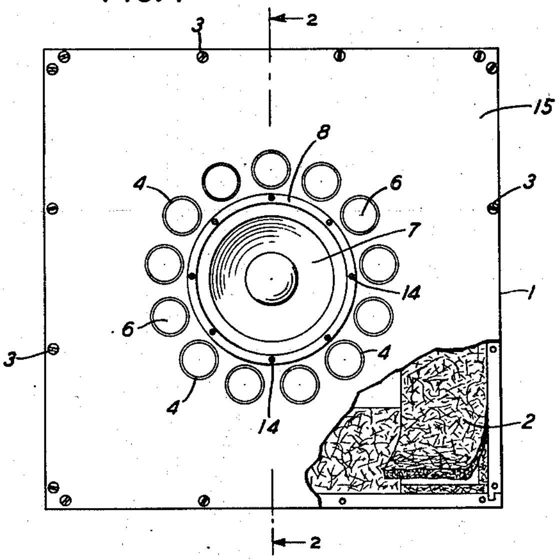


FIG. 2

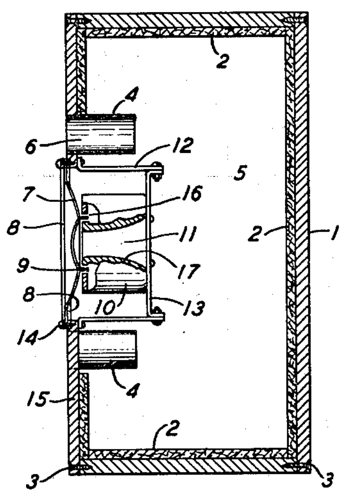


FIG. 3

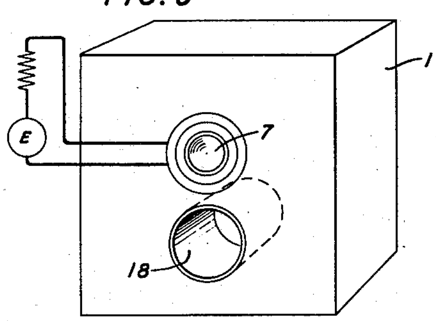


FIG. 4

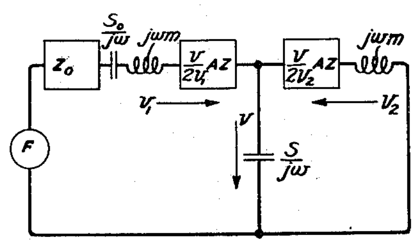
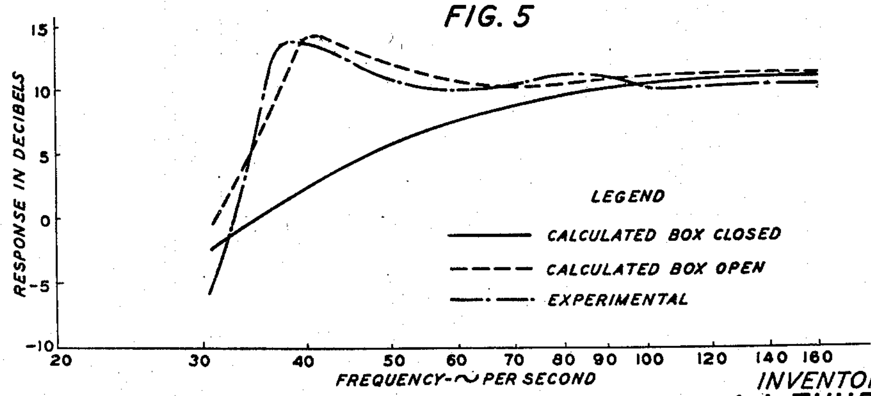


FIG. 5



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SOUND TRANSLATING DEVICE

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FIG. 6

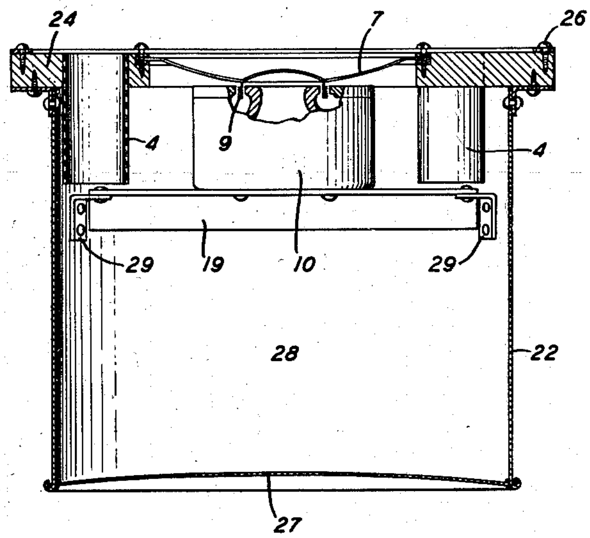


FIG. 7

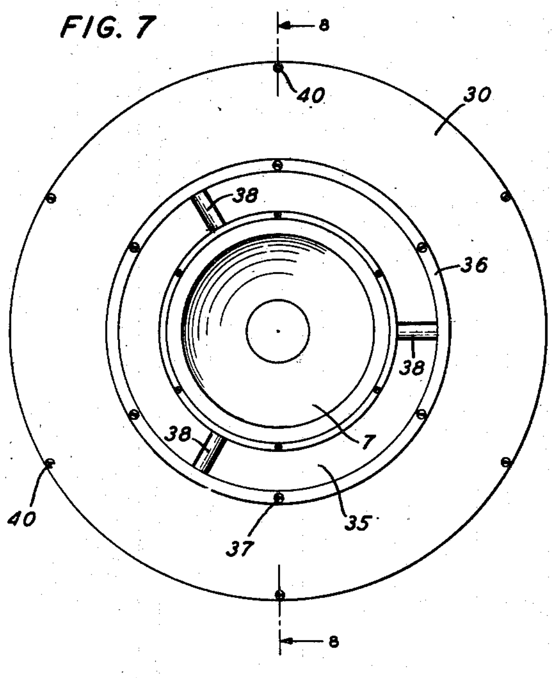
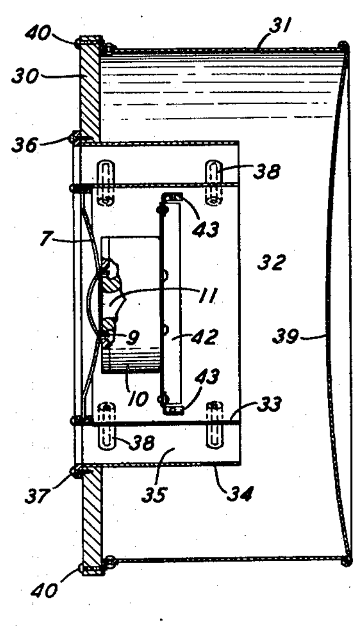


FIG. 8



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SOUND TRANSLATING DEVICE

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FIG. 9

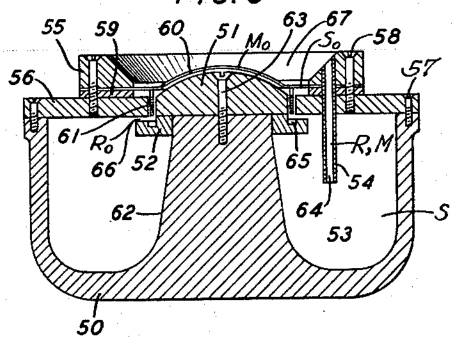


FIG. 10

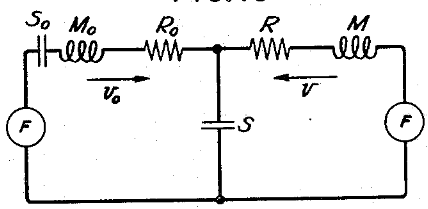


FIG. 11

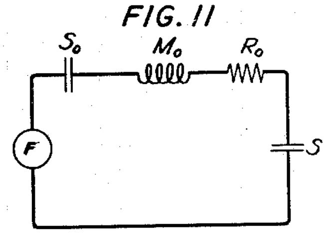
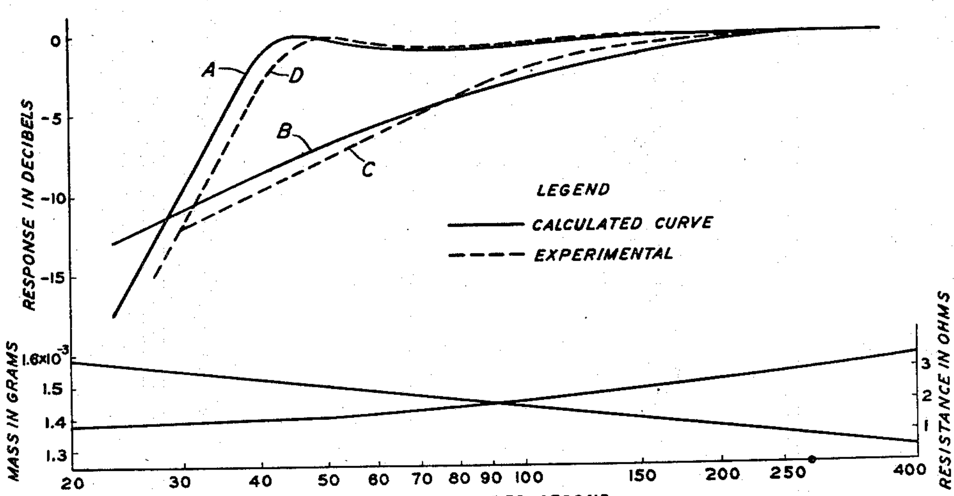


FIG. 12



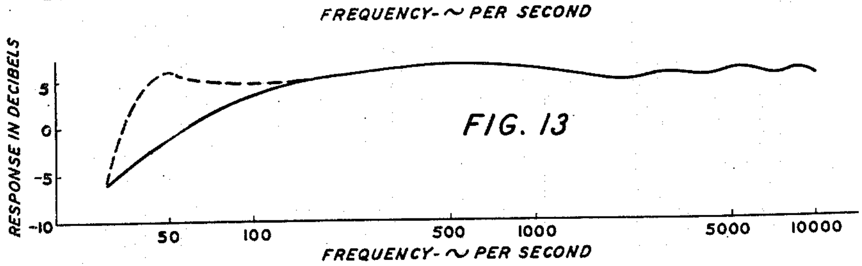


FIG. 13

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Patented July 26, 1932 1,869,178

UNITED STATES PATENT OFFICE

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SOUND TRANSLATING DEVICE

Application filed August 15, 1930. Serial No. 475,468.

This invention relates to sound translating devices and more particularly to a method and means for increasing the response of such devices at the lower frequencies.

An object of this invention is to increase the response of sound translating devices at the lower frequencies whereby the low notes of speech and music are more faithfully translated and in a more proportionate degree to the higher notes than has been possible hitherto.

One feature of this invention comprises utilizing the sound vibrations translated by the two surfaces of a diaphragm to effectively reenforce each other by causing the sounds translated by one surface to be changed in magnitude and phase with reference to those translated by the other surface.

Another feature of this invention resides in its application to a loud speaking receiver whereby the radiation resistance per unit area of the diaphragm thereof at the lower frequencies is effectively increased by providing an acoustic path from the rear surface to the front surface of said diaphragm which at its outlet, in close proximity to said diaphragm, is substantially the same area as that of the diaphragm, said acoustic path defining an acoustic filter.

Another feature of this invention is its application to a device for translating acoustic vibrations into electrical vibrations which consists in increasing the amplitude of vibration of the vibratory element of said device by causing a portion of the acoustic vibrations to be translated to be directed against the rear surface thereof after having passed through an acoustic filter so proportioned as to stiffness and mass that such acoustic vibrations act to reenforce the effect of the vibrations impressed on the front surface of said diaphragm.

In accordance with this invention the diaphragm of a sound translating device is enclosed on one surface by a fluid chamber having a passage-way leading therefrom to the atmosphere adjacent the other surface of said diaphragm, said chamber and said passage-way being so dimensioned that the fluid contained therein provides a stiffness and a mass element, respectively, of an acoustic filter, so proportioned that when the diaphragm is actuated to translate acoustic vibrations, the vibrations particularly those of the lower frequencies, translated by each surface of said diaphragm, are caused to reenforce each other to increase the response of said sound translating device.

A more complete understanding of this invention will be obtained by reference to the appended drawings wherein:

Fig. 1 is a front view of a sound translating device embodying features of this invention;

Fig. 2 is a sectional view taken along the line 2—2 of the device shown in Fig. 1;

Fig. 3 shows a simplified schematic sketch of the device shown in Figs. 1 and 2;

Fig. 4 illustrates the equivalent impedance circuit of the device shown in Figs. 1 and 2;

Fig. 5 shows graphically the operating characteristics of a sound translating device such as shown in Fig. 1;

Fig. 6 shows a view partly in section of another embodiment of this invention;

Fig. 7 shows a front view of still another embodiment of this invention;

Fig. 8 is a sectional view of the embodiment shown in Fig. 7 taken along the line 8—8;

Fig. 9 shows a sectional view of a telephone transmitter incorporating features of this invention;

Fig. 10 is an electric circuit analogy of the acoustic elements involved in the operation of the device shown in Fig. 9;

Fig. 11 is an electric circuit analogy of the acoustic elements involved in the operation of a device similar to that shown in Fig. 9 without features of this invention;

Fig. 12 shows graphically the operating characteristics in the low portion of the frequency range of the device shown in Fig. 9 and of the same device without features of this invention; and

Fig. 13 shows typical overall response characteristics of the device shown on Fig. 9 incorporating and not incorporating the features of this invention.

Referring now to the drawings, there is

shown in Figs. 1 and 2, a sound translating device of the loud speaking receiver type embodying the features of this invention consisting of enclosure member 1 which is here shown as of rectangular and box-like shape whose wall elements are held together by screws 3 and which provides a fluid chamber 5 behind a vibratory element or diaphragm 7.

The diaphragm 7 may be of a light material such as an alloy of aluminum or other suitable material. It comprises a curved central portion with a surrounding reversely curved portion terminating in a flat rim. The diaphragm is shown supported in an aperture in the front wall 15 of the enclosure member 1 and at its periphery is secured to said wall between mounting members 8 in any suitable manner, for example, by screws 14. Current coil 9 is attached to the inner or rear surface of the diaphragm and is disposed in the magnetic air gap 16 provided by the magnet 10 which may be either of the permanent magnet or of the electromagnetic type. Central pole portion 17 of the magnet is preferably hollow thereby providing a passage-way 11 whereby sound disturbances radiated by the rear surface portion of the diaphragm inside the driving coil 9 may readily pass into the chamber 5. The magnet 10 is supported on the cross piece 13 which is, in turn, attached to a plurality of vertical supports 12 secured to the inner surface of the front wall 15. The inner surfaces of the walls of the chamber 5 are lined preferably with layers of hair felt or other suitable sound absorbing material of such a thickness that sound radiations of the high frequencies given off by the rear surface of the diaphragm will be prevented from being reflected, but the low frequencies will suffer substantially no attenuation. A plurality of tubular members 4 open at each extremity, provide an outlet passage from the chamber 5 to the atmosphere adjacent the front surface of the diaphragm. These tubular members are preferably situated as closely as possible adjacent the periphery of the diaphragm. As shown, each tubular member is at one extremity substantially flush with the front wall 15 of the enclosure member and has its other extremity projecting into the chamber 5. When the diaphragm 7 is caused to vibrate by the movements of coil 9 in response to the passage therethrough of currents which produce a variable field interacting with the fixed strength field of the magnet 10, both the front and the rear surfaces of the diaphragm will cause acoustic disturbances to be propagated through the fluid thereadjacent. The sound waves generated by the rear surface of the diaphragm, particularly the low frequencies, are caused to be conducted through said chamber and outlet passage to combine with the sound waves generated by the front surface of the diaphragm and to reenforce the same at the low frequencies.

In order that this invention may be more readily understood it is believed that a discussion of the theoretical considerations involved in its operation and application to the loud speaker receiver of Figs. 1 and 2 should be outlined.

Theory and measurements show that generally speaking, the direct radiating type of loud speaker of moderate size, has a relatively small response and inadequate power output capacity at low frequencies. By the method comprising one feature of this invention and with a structure as described above for increasing the response of loud speakers at low frequencies, both sides of the diaphragm 7 are utilized and the radiating resistance per unit area of the diaphragm is thereby increased. By means of an acoustic stiffness and mass, the air displacement from the back of the diaphragm is shifted approximately 180° in phase and led out at the front of the diaphragm. The acoustic stiffness is obtained from the volume of air in the chamber 5 at the back of the diaphragm and the acoustic mass from the air in the outlet passage comprising the paths 6 in the tubular members 4 leading from the chamber to the front of the diaphragm. The phase relation of the volume velocity of the diaphragm and the air in the passage opening is somewhat similar to that in an electrical low-pass filter in which the currents in the two adjoining series arms (containing small resistances) are nearly 180° out of phase above the cutoff frequency of the filter. The acoustic system as regards power output differs considerably from the electrical filter in that the radiation resistance and air mass of the diaphragm and the corresponding radiation resistance and air mass of the passage have a mutual reaction on each other and furthermore their acoustic impedances vary with frequency. A solution of this problem is rather complicated, but by making a few simplifying assumptions a general idea of the gain in sound power output can be obtained. If the area of the passage is taken equal to the effective area of the diaphragm and a frequency such that the vibratory velocity of the diaphragm is equal to the vibratory velocity of the air in the passage, then the effective radiating area is doubled and the radiation resistance per unit area is doubled compared with that of the diaphragm acting alone. Therefore for the same amplitude of the diaphragm in the two cases the power output will be approximately 6 decibels (hereafter abbreviated db.) higher when the passages are open. On lowering the frequency the air velocity in the passage will increase relative to that of the diaphragm thus effectively imposing an increasingly larger resistance load on the diaphragm over that which would obtain at the same frequency with the passage closed. This will give an increasingly higher gain down to the cutoff of the acoustic system. Above the frequency where a 6 db. increase is obtained the velocity in the passage will decrease with increase of frequency until there is no velocity in the passage. Above this frequency the loud speaker will act substantially as if the passage were closed.

A simplified theory of the operation of this phase shifting acoustic system has been worked out and approximate equations formulated for the case in which the area of the passage is equal to the effective area of the diaphragm and the mass of the mechanical moving element (diaphragm and coil) is equal to the mass of air in the passage.

The response of a loud speaker connected to the output of a vacuum tube may be expressed in terms of the acoustic power radiated when a constant voltage is impressed in series with the electrical impedance of the driving coil and the impedance of the source. The acoustic power is obtained by (1) deriving an expression for the velocity of the diaphragm and of the air in the passage in terms of the acoustic impedance and constant impressed voltage in the electrical circuit; (2) deriving an expression for the acoustic impedance of the air and the mutual impedance caused by the velocity of the diaphragm and velocity of the air in the opening. The power output is then the sum of the products of the square of these velocities and corresponding resistances.

Refer now to Figures 3 and 4 which show a simplified schematic sketch of the loud speaker, and its equivalent impedance circuit. Fig. 3 shows a single opening 18 only leading from the chamber behind the diaphragm but the theoretical considerations are the same regardless of whether one or more openings are employed if the area relations here considered are not departed from.

To simplify the calculations the following assumptions have been made—(1) the area of the outlet passage from the chamber is equal to the effective area of the diaphragm, (2) the mass of air in the opening is equal to the effective mass of the moving element, and (3) the wavelengths of the frequencies considered are long compared with the dimensions of the acoustical system.

Letting,

E = constant voltage in the electrical circuit.

F = mechanical force $=\frac{HlE}{10R}$.

Z_o = impedance in the mechanical circuit caused by the electrical circuit.

which is equal to

$Z_o=\frac{H^2l^2 10^{-9}}{R}$ — If the impedance in the electrical circuit is assumed to be a pure resistance equal to R.

H = field intensity

l = length of wire in the moving coil

$\frac{S_o}{j\omega}$ = edge stiffness reactance of the diaphragm

$\frac{S}{j\omega}$ = stiffness reactance of volume of air in the enclosure.

$j\omega m$ = mass reactance of the diaphragm = mass reactance of the air in the opening.

V, V_1, V_2 = velocities in the various parts of the acoustical-mechanical system.

$\frac{V}{2V_1}AZ$ and $\frac{V}{2V_2}AZ$ = air impedances imposed on the diaphragm and on opening respectively.

A = effective area of the diaphragm = area of the outlet passage.

Z = air impedance per unit area of an area twice the area of the diaphragm.

In the impedances

$$\frac{V}{2V_1}AZ \text{ and } \frac{V}{2V_2}AZ$$

it is assumed that mutual air mass effect varies with the velocity in the same way as the radiation resistance. These expressions for impedance are therefore only approximately correct.

Applying Kirchhoff's laws to the circuit in Fig. 4:

$$F=Z_oV_1+\frac{S_o}{j\omega}V_1+j\omega mV_1+\frac{AZV}{2}+\frac{S}{j\omega}V$$

$$O=j\omega mV_2+\frac{AZV}{2}+\frac{S}{j\omega}V$$

$$V=V_1+V_2$$

If $Z=r+jx$

Then the acoustic power output is

$$W=\underset{\text{part}}{\text{real}}\left(\frac{V}{2V_1}AZ\right)\left|V_1\right|^2+\underset{\text{part}}{\text{real}}\left(\frac{V}{2V_2}AZ\right)\left|V_2\right|^2=\frac{Ar}{2}\left|V\right|^2 \quad (1)$$

The value of V is obtained from Kirchhoff's equations given above.

$$V=\frac{F}{Z_o+\frac{S_o}{j\omega}+AZ+\frac{2S}{j\omega}+j\omega m+\frac{Z_oAZ}{2j\omega m}-\frac{Z_oS}{\omega^2 m}-\frac{AZS_o}{2\omega^2 m}-\frac{SS_o}{j\omega^3 m}}$$

Substituting in equation (1), expressing F in terms of E and dividing by 10^7, gives the acoustic power output in watts.

$$W=\frac{5ArB^2l^2 10^{-8}E^2}{R^2\left|Z_o+\frac{S_o}{j\omega}+AZ+\frac{2S}{j\omega}+j\omega m+\frac{Z_oAZ}{2j\omega m}-\frac{Z_oS}{\omega^2 m}-\frac{AZS_o}{2\omega^2 m}-\frac{SS_o}{j\omega^3 m}\right|^2}$$

The following electrical, mechanical and acoustical constants were used in an experimental loud speaker incorporating the features of this invention:

$A = 558$ sq. cm $\quad S_0 = 2 \times 10^6$ dynes/cm
$B = 15000$ lines/sq. cm $\quad S = 1 \times 10^6$ dynes/cm
$l = 1330$ cm $\quad m = 10$ grams
$R = 36$ ohms
$Z = \rho CS(X + iY)$
where
ρ = density of fluid
C = velocity of sound
S = area of diaphragm considered as piston
X = resistance factor of diaphragm considered as piston
Y = reactance factor of diaphragm considered as a piston.

This experimental loud speaker was similar in structure to that described with reference to Figs. 1 and 2. The diaphragm had an effective diameter of 10.5″ (area=558 sq. cms) and was mounted in the aperture of the front wall of a box which was 3¼ ft. x 3¼ ft. x 1½ ft. Around the diaphragm and closely adjacent thereto thirteen equally spaced 3 in. holes were provided in which were fitted tubular members of phenol fibre 6 in. in length. These tubes were used because they were found easier to construct than the single opening for the loud speaker box. In this particular embodiment of the invention, the volume of the air in the chamber 5 and in the tubular members 4 gave an acoustic stiffness and mass respectively which had a cutoff frequency of 40 cycles.

The full line and the dotted line curves in Fig. 5 picture the sound output to be expected when a loud speaking device, such as described above, is operated with passageways connecting front and rear surfaces of the diaphragm closed and opened respectively, the source of impedance being equal to twice the impedance of the coil attached to the diaphragm of the speaker. These curves were plotted from power output calculations based on Formula (2) above. The broken line curve is drawn through values of response at particular frequencies obtained by taking the difference between measured values of response for the loud speaker with the passage-ways opened and closed and using the calculated response for the loud speaker with the chamber outlet passage-way closed as a base line. It will be apparent from these curves that the actual response of a loud speaker embodying the features of this invention agrees closely with the theoretical response to be expected. If it is desired to avoid any pronounced peak in the response near the cutoff acoustic damping material may be placed in the outlet passage.

It is apparent that this invention not only increases the relative response, but also increases the sound power output capacity of direct acting types of loud speakers in the low frequencies. The air displacement from a loud speaker with this acoustic system is greater than the diaphragm displacement and the ratio of the air displacement to the diaphragm displacement increases as the frequency decreases thus compensating to a large extent for the decrease in radiation resistance. Since direct acting loud speakers are limited in their power output capacity by the amplitude of motion of the diaphragm at low frequencies, the importance of this acoustic system is evident when the large acoustic powers developed by the long pipes of the organ and the low frequency instruments of the orchestra are considered. This invention will permit the reproduction of the low frequencies of speech and music in more proportionate degree to the high frequencies than has been hitherto possible.

It is to be understood that the description of the experimental loud speaking device built in accordance with this invention is of an illustrative nature only and is not intended as a limitation on the scope of this invention; nor is it intended that the recitation of what has been found to be a desirable relation between the diaphragm area and that of an outlet passage connecting the fluid adjacent each surface of the diaphragm and that between the mass of the fluid in said passage and that of the diaphragm and coil should be construed as a limitation. It will be apparent to those skilled in the art that variations in structure and proportions may be made without departing from the essence of the invention.

Fig. 6 shows a side view partly in section of another embodiment of this invention. Instead of a rectangular enclosure behind the rear surface of the diaphragm, a cylindrical member 22, which may be of metal, is attached to an annular member 24 which supports a diaphragm 7 similar to that of Fig. 2, and a plurality of tubular members 4 providing an outlet passage from within the chamber 28, provided by said member 22 and its curved base 27, in a manner similar to that described with reference to Figs. 1 and 2. Magnet 10 is supported by a cross piece 19 which, at its extremities, is attached to angle pieces 29 in turn riveted or otherwise secured to the inner wall of the member 22. The base 27 of the member 22 is preferably slightly curved to avoid the possibility of a drum head effect when the loud speaker is in operation and the member 22 is preferably cylindrical in order to substantially eliminate the effect of the natural frequency of the wall thereof.

This invention may be structurally embodied in still another form as shown in Figs. 7 and 8. A cylindrical drum 31 having a slightly curved base 39 and an annular front wall 30 to which it is connected by bolts 40, provides an air chamber 32 behind a diaphragm 7 similar to that of Fig. 2, to which is attached a current coil 9 disposed in the magnetic air gap provided by the magnet

10 which is provided also with a hollow central pole as shown in Fig. 2. Cylindrical tubes 33 and 34 held in spaced relation by the separating members 38 provide an annular passage 35 connecting the chamber 32 with the atmosphere adjacent the front surface of the diaphragm 7. The magnet 10 is supported by the cross piece 42 which at its extremities is attached to angle pieces 43, which are in turn secured to the inner surface of the tube 33. The diaphragm, its actuating mechanism and the spaced tubes 33 and 34 may all be supported by the front wall 30 of the chamber 32, as shown, being secured thereto by screws 37. The air in the chamber 32 and that enclosed between the tubes 33 and 34 have such stiffness and mass respectively that they form elements of an acoustic filter whereby the sound vibrations translated by each surface of the diaphragm at the low frequencies act to reenforce each other, thereby increasing the relative response and power output of the device in the low frequency region.

This invention is not limited in its application to sound translating devices for reproducing sound, but may be applied to sound translating devices for changing acoustic vibrations into electrical vibrations. In Fig. 9 there is shown a transmitter of the moving coil type comprising a magnet structure 50 which is preferably of the permanent magnet type having a central pole portion 62 to which a curved pole piece 51 is secured by means of the screw 63. The other pole piece consists of an annular plate member 56 secured to the magnet by screws 57 and having a central aperture, the bounding wall of which is in spaced relation to the pole piece 51 thereby providing a magnetic air gap in which a current coil 61 attached to the diaphragm 60 is disposed. The diaphragm 60 has a curved central portion surrounded by a flat portion and is preferably of a light metal, such as alloy of aluminum, although any other suitable material may be used therefore. Surrounding the upper portion of the central pole and the magnet immediately under the pole piece 51 is an annular member 52 which provides a very shallow recess 65 under the moving coil to insure sufficient clearance for the coil when vibrating and a narrow passage-way 66 therefrom leading into the hollowed portion or chamber 53 of the magnet. The diaphragm 60 is supported at its periphery and clamped between ring members 55 and 59 by screws 58 which thread into plate member 56. The ring 55 is provided with a tapered inner surface 67 to substantially eliminate the increase in pressure on the diaphragm caused by the resonance of the chamber above the diaphragm. Extending through an opening provided in the ring members 55 and 59, the diaphragm 60 and the plate member 56, is a tube 54 which projects into the chamber 53 of the magnet thereby providing a passageway 64 connecting the interior of said chamber with the atmosphere adjacent the front surface of the diaphragm.

The operation of this device as a sound translating instrument for changing acoustic vibrations to electrical vibrations is as follows:

The acoustic vibrations are impressed upon the front surface of the diaphragm such that a portion thereof acts thereagainst and another portion passes through the tube 54 into the chamber 53 and acts upon the rear surface of the diaphragm. Those vibrations, however, which act upon the rear surface of the diaphragm are so changed in phase and magnitude that they act to reenforce the effect of the vibrations impressed on the front surface of the diaphragm whereby the amplitude of vibration of the latter is increased. This reenforcing action is particularly prominent at low frequencies, a great increase in the response of the device over its response when not incorporating this feature of the invention being obtained. It will be understood, of course, that when acoustic vibrations are impressed upon the diaphragm currents varying in accordance with said acoustic vibrations will be produced in the coil 61 because of its movement in the field provided by the magnet 50.

It will be apparent that the method outlined in the previous paragraph for increasing the response of the transmitter at the low frequencies is similar to that for increasing the response of a loud speaking receiver such as that described with reference to Figs. 1 and 2. It is believed, however, that a clearer understanding of this invention as applied to a transmitter of the moving coil type will be obtained from the consideration which follows of the factors involved in its operation.

The voltage generated by a moving coil transmitter is proportional to the velocity of the diaphragm. This fact makes the problem of getting a uniform response down to low frequencies difficult in a transmitter of practical sensitivity. It means that either the diaphragm must have a very low stiffness or some way must be provided to amplify the action of the sound waves on the diaphragm relative to that at higher frequencies. The method here described increases the force on the diaphragm at low frequencies sufficiently to compensate for the reactance of the edge stiffness down to relatively low frequencies. It is possible by this method to maintain a uniform response two octaves below the frequency at which the edge stiffness of the diaphragm begins to show a decrease in the response characteristic of the transmitter.

The force on the diaphragm at low frequencies is increased by means of the connecting tube 54 between the front of the diaphragm 60 and the chamber 53 back of the diaphragm whereby the pressure at the front of the diaphragm after being changed both in magnitude and phase is impressed on the back of the diaphragm. The magnitude and phase of the pressure on the back of the diaphragm are controlled by the acoustic constants of the air in the tube and chamber. Fig. 9 shows the transmitter with the open end of the connecting tube close to the diaphragm so that the phase of the pressure is the same over the diaphragm and tube opening. Fig. 10 is a circuit diagram with pressure applied to the mechanical and acoustic constants of the transmitter. Fig. 11 is a circuit diagram of the transmitter shown in Fig. 9 without the tube 54. A comparison of these two figures readily shows the change wrought therein by the insertion of the tube. The small air chamber between the diaphragm and acoustic resistance, R_o, has been omitted in the diagrams of Figs. 10 and 11 because of its negligible effect at low frequencies. For convenience the pressure and the constants of the transmitter have been referred to the effective area of the diaphragm; for example, the force F is equal to the open air pressure at the diaphragm multiplied by the effective area of the diaphragm.

The response or voltage generated by the moving coil of the transmitter is proportional to the velocity of the diaphragm divided by the force on the diaphragm. Expressing this ratio in terms of the mechanical and acoustic constants of the transmitter there is obtained:

$$\frac{v_o}{F}=\frac{R+j\omega m}{S_o m+Sm_o-\omega^2 m_o m+Sm-\frac{S_o S}{\omega^2}+R_o R+j\left(R_o\omega m-\frac{R_o S}{\omega}-\frac{S_o R}{\omega}+\omega m_o R-\frac{SR}{\omega}\right)} \quad (3)$$

in which

m_o = effective mass of the diaphragm, mass of the coil and the mass of air in the resistance gap referred to the diaphragm.
S_o = edge stiffness of the diaphragm.
R_o = resistance of the air gap referred to the diaphragm.
S = stiffness of the air in the transmitter chamber referred to the diaphragm.
R and m = impedance of the air in the compensating tube referred to the diaphragm.

In calculating the impedance of the air in the tube it was found that the radius (r_o) of the tube gave a value of the discriminant

$$kr_o=r_o\sqrt{-\frac{i\rho\omega}{\mu}}$$

between 1 and 10 in which neither Posseuille's coefficient

$$\left(R=8\frac{\mu}{r^2}\right)$$

for narrow tube nor the simplified expression

$$Z=\frac{1}{r_o}\sqrt{2\mu\rho\omega}+i\left(\rho\omega+\frac{1}{r_o}\sqrt{2\mu\rho\omega}\right)$$

for large tubes can be used. The tube impedance coefficient was therefore calculated from the general expression

$$Z=-\mu k^2\left[\frac{1}{1+\frac{2J_1(Kr_o)}{Kr_oJ_o(Kr_o)}}\right]$$

in which $-\mu K^2=i\rho\omega$ and

$$Kr_o=r_o\sqrt{-\frac{i\rho\omega}{\mu}}.$$

The calculated coefficients of mass and resistance for a transmitter tube of .112 cm radius are shown plotted in the lower portion of Fig. 12. For a tube 3 cm long the mass and resistance referred to the diaphragm were found from these curves to be 6.4 grams and 600 ohms at about 50 cycles. It will be sufficiently accurate to use these average values of impedance in the response Equation (3).

The measured and calculated constants of a transmitter constructed in accordance with this invention were:

$S_o=2\times10^6\ \frac{\text{dynes}}{\text{cm}}$ $m=6.4$ grams
$m_o=.22$ gram $R=600$ ohms
$R_o=4000$ ohms $\omega=2\pi f$
$S=.5\times10^6\ \frac{\text{dynes}}{\text{cm}}$

Substituting these values in Equation (3) and solving for absolute values gives the upper full line curve A, shown in Fig. 12, plotted in decibels.

If the tube 54 is closed Equation (3) reduces to

$$\frac{v'_o}{F}=\frac{1}{R_o+j\left(\omega m_o-\frac{S_o}{\omega}-\frac{S}{\omega}\right)} \quad (4)$$

If the above values are substituted now in Equation (4) the lower full line curve B, shown in Fig. 12, is obtained. These calculated response curves are indications of the greater response at the lower frequency to be expected of a given device when the method and means comprising this invention are embodied therein.

The dotted curves C and D show the experimentally measured response of the transmitter in decibels when the tube is closed and opened respectively. These measurements it will be noted agree closely with the theoretical calculations; the variation in the two sets of curves below 50 cycles can be accounted for by a probable error of 10% in the measurement of the edge stiffness of the diaphragm S_o.

Fig. 13 shows the overall frequency response of a moving coil transmitter and associated transformer between 30 and 10,000 with the tube 54 opened and closed. It will be noted that above 200 cycles the response of the particular transmitter considered above appears to be unaffected by the presence of the passage-way between the front and rear of the diaphragm but that below that frequency the increase in response is very marked.

It will be understood, of course, that although specific dimensions and proportions have been given in describing the application of this invention to sound translation devices, the embodiments described are illustrative only of this invention which is to be considered as limited only by the scope of the appended claims.

What is claimed is:

1. A sound translating device comprising a diaphragm, means defining an acoustic stiffness adjacent one surface of said diaphragm, the other surface of said diaphragm being open to the atmosphere, and means defining an acoustic mass providing an acoustic path between the two surfaces of said diaphragm, said acoustic mass and stiffness proportioned so that over a portion of the frequency range the sound vibrations translated by the opposite surfaces of said diaphragm have their magnitude and phase so related that they act to effectively reenforce each other whereby the amplitude of the translated vibrations is increased.

2. A sound translating device comprising a diaphragm, one surface of which is open to the atmosphere, means defining a fluid chamber enclosing the other surface of said diaphragm, and means closely adjacent the periphery of said diaphragm and defining a fluid passage-way leading from said chamber to the atmosphere and through which a movement of fluid may occur when said diaphragm is actuated whereby over a portion of the frequency range the vibrations translated by each surface thereof reenforce each other thereby increasing the amplitude of the translated vibration.

3. A sound translating device comprising a diaphragm one surface of which is open to the atmosphere, means defining a fluid chamber enclosing the other surface of said diaphragm, and means defining a fluid passage-way leading from said chamber to the atmosphere and through which a movement of fluid into and out of said chamber may take place, the fluid in said chamber and said passage-way having such stiffness and mass, respectively, that when the diaphragm is actuated the low frequency vibrations translated by each surface are caused to have such magnitude and phase relationship that they effectively reenforce each other to increase the amplitude of the translated sound.

4. The method of increasing the response of a loudspeaking device at the low frequencies which comprises utilizing the radiation from each surface of the diaphragm whereby the radiation resistance per unit area of the diaphragm is effectively increased and caus'ng the sound waves from one surface of the diaphragm to act in phase with those emanating from the other surface by providing an acoustic stiffness and mass through which the sound emanations from the one surface must act before combining with those from the other surface.

5. A loudspeaking device comprising a d:aphragm, one surface of which is open to the atmosphere, means defining a fluid chamber enclosing the other surface of said diaphragm, and means defining a fluid passage-way leading from said chamber to the atmosphere closely adjacent the surface of said diaphragm open to the atmosphere, sa:d passage-way having an area substantially equal to that of the diaphragm and when said diaphragm is actuated enabling fluid to be pumped into and out of said chamber whereby over a portion of the frequency range the acoustic disturbances emanating from the two surfaces of said diaphragm comb:ne to reenforce each other.

6. A loudspeaking receiver comprising a diaphragm, means for driving said diaphragm, and an enclosure for said driving means and the rear surface of said diaphragm, said enclosure hav:ng an aperture therein of substantially the same area as the diaphragm and adjacent thereto, the chamber behind said diaphragm and the volume enclosed by said aperture providing the stiffness and mass elements respectively of an acoustic filter through which sound disturbances over a portion of the frequency range emanating from the rear surface of sa:d diaphragm pass and are shifted through approximately 180° before combining with the sound disturbances emanating from the front of the diaphragm.

7. A sound translating device comprising a diaphragm, means for utilizing the front and rear surfaces of sa:d diaphragm as effective sound translating surfaces, said means comprising a fluid enclosure for the rear surface of said diaphragm defining an acoustic stiffness, and a tubular member leading into said fluid enclosure connecting the same with the outs:de atmosphere adjacent the front surface of the diaphragm and defining an acoustic mass, said acoustic mass and stiffness acting as elements in an acoustic filter to change the magnitude and phase of the acoustic disturbances over a portion of the frequency range which are transmitted to the rear surface of the diaphragm whereby said d:sturbances act to reenforce the effect of the sound disturbances impressed on the front surface of said diaphragm to increase the amplitude of vibration thereof.

8. A sound translating device comprising a hollow magnet structure defining a magnetic air-gap, a diaphragm, means for supporting said diaphragm, driving means at-

tached to said diaphragm and disposed in said air-gap, and a tube open at each end having one extremity adjacent said diaphragm and the other extremity projecting into the hollowed portion of said magnet structure and providing an acoustic path between the atmosphere and said hollowed portion, the fluid in the latter and that enclosed by said tube having such stiffness and mass, respectively, that the front surface is subjected to substantially all of the impressed acoustic disturbances and the rear surface of said diaphragm is subjected to a portion only of the impressed acoustic disturbances, said mass and stiffness acting to change the magnitude and phase of a portion of said sound disturbances before the latter act upon the rear surface of said diaphragm whereby the disturbances impressed on opposite sides of said diaphragm reenforce one another to increase the amplitude of vibration of the diaphragm.

9. A sound translating device comprising a sound translating diaphragm having a driving means secured thereto and an enclosure for one surface of said diaphragm, the other surface being open to the atmosphere, said enclosure providing a shunt stiffness into which said one surface of said diaphragm works, and means providing an acoustic passage from said enclosure to the atmosphere adjacent the other surface of said diaphragm, the area of said acoustic passage being substantially equal to the effective area of the diaphragm and the mass of the fluid therein being substantially equal to the effective mass of the diaphragm and said driving means.

10. A sound translating device of the loud-speaking receiver type comprising a sound translating diaphragm having a driving means secured thereto, an enclosure for one surface of said diaphragm defining a body of fluid there adjacent, said fluid providing an acoustic stiffness into which said one surface of said diaphragm works, and means providing an acoustic passage between the enclosed surface and the other surface of said diaphragm, the fluid in said passage having a mass substantially equal to the effective mass of said diaphragm and said driving means and the fluid in said enclosure an acoustic stiffness such that the low frequency sounds translated by the enclosed surface of said diaphragm act through said stiffness and mass to reenforce the sounds translated by the other surface of said diaphragm.

11. A sound translating device comprising a diaphragm and means defining an acoustic filter of the low pass type between the two surfaces of said diaphragm, the stiffness and mass element of said filter proportioned with reference to said diaphragm so that sound vibrations translated by the two surfaces thereof are effectively utilized to increase the response of said device at the low frequencies over that of a device without said means.

12. A sound translating device comprising a diaphragm and means defining an acoustic filter of the low pass type providing an acoustic path between the two surfaces of said diaphragm, said filter so proportioned that the low frequency sounds translated by said surface of each diaphragm are so related in phase and magnitude as to effectively reenforce each other.

13. A sound translating device comprising a diaphragm and means defining an acoustic filter of the low pass type providing an acoustic path between the two surfaces of said diaphragm, the mass and stiffness elements of said filter proportioned so that the phase of the low frequency sounds translated by the surface of said diaphragm is substantially reversed with reference to that of the sounds translated by the other surface of the diaphragm whereby the response of said device is increased over that of a device without said means.

14. A sound translating device comprising a diaphragm and means defining an acoustic filter providing an acoustic path between the two surfaces of said diaphragm whereby the sounds translated by one surface of said diaphragm are caused to so act with reference to those translated by the other surface of said diaphragm so that the response of the device is increased at the lower frequencies over that of a device not having said means, said filter acting to substantially reverse the sound vibrations propagated therethrough and translated by said one surface.

15. A sound translating device comprising a diaphragm and means defining an acoustic filter providing an acoustic path between the opposite surfaces of said diaphragm, the stiffness and mass of said filter proportioned so that the cutoff frequency is in the region of the lowest frequency to be translated.

16. A sound translating device comprising a diaphragm and means defining an acoustic filter providing an acoustic path between the opposite surfaces thereof, the stiffness and mass elements of said filter proportioned so that the acoustic vibrations translated by each surface of said diaphragm are caused to reenforce each other at low frequency.

17. In an acoustic device, a diaphragm, means substantially closing one surface of said diaphragm from the atmosphere and defining an air chamber there-adjacent, and means for acoustically coupling the opposite surfaces of said diaphragm, said means comprising a tubular member having one end open to the atmosphere and the other end within and opening into said air chamber.

18. In an acoustic device, a diaphragm, means substantially closing one surface of said diaphragm from the atmosphere and defining an air chamber there-adjacent, and

means for coupling the opposite surfaces of said diaphragm through said air chamber so that sound waves originating on the exposed surface of the diaphragm act on opposite surfaces of the diaphragm to effectively increase the response thereof over the response with sound waves acting on one surface only, said means comprising a tubular member having an open end in the vicinity of the exposed surface of said diaphragm and another open end within the air chamber.

19. An acoustic device comprising a diaphragm, driving means attached thereto, an enclosure for one surface of said diaphragm, the other surface being exposed to the atmosphere, said enclosure providing an air chamber into which said one surface of the diaphragm works, and means providing an acoustic passage from said enclosure to the atmosphere, the area of said passage being substantially equal to the effective area of the diaphragm and the mass of the fluid therein being substantially equal to the effective mass of the diaphragm and driving means, said means comprising a plurality of tubular members.

20. An acoustic device comprising a diaphragm, driving means attached thereto, an enclosure for one surface of said diaphragm, the other surface being exposed to the atmosphere, said enclosure providing an air chamber into which said one surface of the diaphragm works, and means providing an acoustic passage from said enclosure to the atmosphere, the area of said passage being substantially equal to the effective area of the diaphragm and the mass of the fluid therein being substantially equal to the effective mass of the diaphragm and driving means, said means comprising a plurality of concentric spaced annuli.

21. An acoustic device comprising a diaphragm, driving means attached thereto, an enclosure for one surface of said diaphragm, the other surface being exposed to the atmosphere, said enclosure providing an air chamber into which said one surface of the diaphragm works, and means providing an acoustic passage from said enclosure to the atmosphere, the area of said passage being substantially equal to the effective area of the diaphragm and the mass of the fluid therein being substantially equal to the effective mass of the diaphragm and driving means, said means comprising a plurality of individual tubes each defining a portion of the acoustic passage.

22. An acoustic device comprising a diaphragm, an air chamber on the back side of the diaphragm, a second and larger air chamber on the back side of the diaphragm, said chambers being connected by a narrow passageway, and hollow means providing a passage for sound waves of a portion of the audio frequency range between the front side of the diaphragm and said larger air chamber.

23. An acoustic device comprising a casing, said casing comprising a plurality of wall members defining an air chamber, one of said wall members having an opening therein, a diaphragm, said diaphragm mounted in said opening, and means providing an air passage connecting the air chamber with the atmosphere outside of said casing adjacent the periphery of the diaphragm, said means comprising a tubular member open at each end thereof.

24. An acoustic device comprising a diaphragm, an air chamber on the back side of the diaphragm, a second and larger air chamber on the back side of the diaphragm, said chambers being connected by a narrow passageway, and means providing a passage for sound waves from the front side of the diaphragm to said larger air chamber, said passage having an impedance characteristic such that substantially no waves having a frequency greater than approximately two hundred cycles per second pass therethrough.

25. An acoustic device comprising a diaphragm, an enclosure providing an air chamber on the back side of said diaphragm, and means providing a passage from the front side of said diaphragm to said air chamber, said means comprising a hollow member open at its ends, said passage offering such a high impedance to waves of a frequency greater than approximately two hundred cycles per second that substantially no waves above that frequency pass therethrough.

26. An acoustic device comprising a diaphragm, a casing, said casing providing a substantially closed air chamber on one side of said diaphragm, said casing having an opening therein adjacent said diaphragm, and a tubular member open at each end adjacent said casing and providing a continuation of said opening, the casing chamber and said tubular member being proportioned so that sound waves in the region below approximately two hundred cycles per second are translated by each side of the diaphragm, and sound waves above approximately two hundred cycles per second are translated by one side of the diaphragm only.

27. An acoustic device comprising a diaphragm, one surface of which is freely exposed to the atmosphere, an enclosure forming an air chamber on the other surface of the diaphragm, and means for fixing the lower cut-off of the device, said means comprising a hollow air enclosing member open at each end, extending into said chamber, and connecting the latter with the atmosphere adjacent the exposed surface of the diaphragm.

In witness whereof I hereunto subscribe my name this 13th day of August, 1930.

ALBERT L. THURAS.