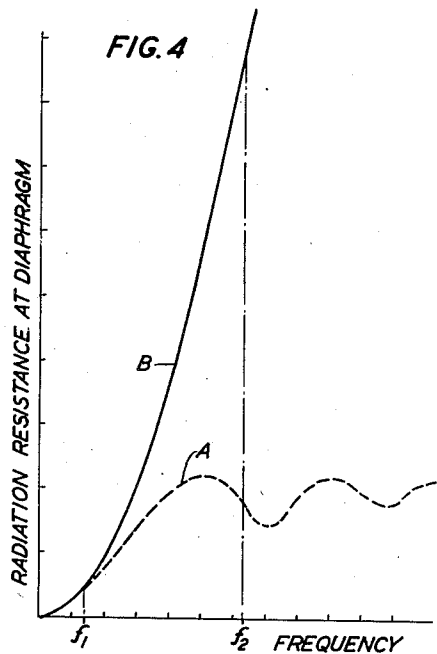
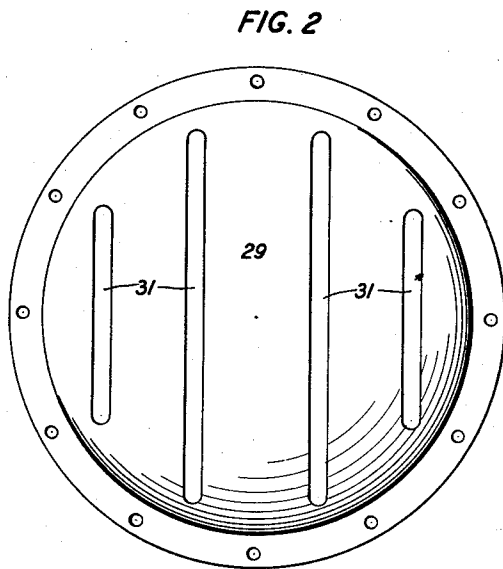
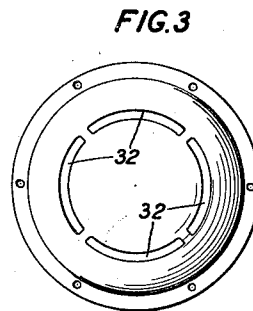
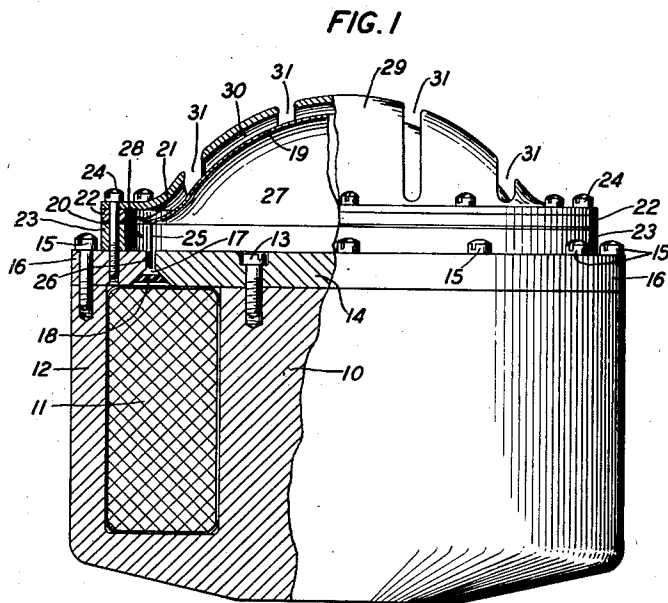


June 29, 1937.

L. G. BOSTWICK
SOUND TRANSLATING DEVICE
Filed Feb. 21, 1935

2,085,073



INVENTOR
L. G. BOSTWICK

BY
Walter C. Kiesel
ATTORNEY

UNITED STATES PATENT OFFICE

2,085,073

SOUND TRANSLATING DEVICE

Lee G. Bestwick, Chatham, N. J., assignor to Bell
Telephone Laboratories, Incorporated, New
York, N. Y., a corporation of New York

Application February 21, 1935, Serial No. 7,484

13 Claims. (Cl. 181—31)

This invention relates to sound translating devices and more particularly to loud-speakers of the moving coil type including a diaphragm of sufficient area to propagate sound waves of substantial intensity without the aid of a horn.

In loud-speakers including relatively large direct acting piston diaphragms of the mass controlled type, that is loud-speakers wherein the mass reactance of the vibrating system is made the predominating vibratory impedance, substantially constant electro-acoustic conversion efficiency may be obtained throughout the lower portion of the audio-frequency range. Throughout this range the vibrational velocity of the diaphragm varies inversely as the frequency and the radiation resistance varies directly as the square of the frequency. The range of frequencies in which these relations obtain is dependent upon the radius of the diaphragm, and in general, the larger the diaphragm, the smaller is the frequency range wherein the acoustic power is substantially uniform. If it were desired to attain a uniform output from a device of this type throughout a frequency range of several thousand cycles, the diaphragm necessarily would be so small that an unduly large vibrational amplitude would be required for even moderate acoustic outputs. If a larger diaphragm were used to avoid these difficulties, the acoustic output at the higher frequencies would be deficient and an undesirable concentration of the sound field at high frequencies would result.

Furthermore, loud-speakers having mass-controlled diaphragms, in general, inherently have a relatively low electro-acoustic efficiency as compared, for example, with horn type loud-speakers. This is occasioned by the fact that inasmuch as the mass reactance of the vibrating system in such loud-speakers is the predominating impedance, a large portion of the actuating force for the vibrating system is expended in accelerating the vibrating mass so that but a relatively small portion thereof is available for producing sound radiations.

One general object of this invention is to reproduce sound uniformly, efficiently and with substantial intensity throughout a relatively wide band of frequencies. More specifically, objects of this invention are:

To obtain with loud-speakers having diaphragms sufficiently large to propagate sound waves of substantial intensity without the aid of a horn, the relatively wide frequency range of uniform reproduction, and the wide sound field obtainable with smaller diaphragms;

To obtain, with hornless loud-speakers, a high electro-acoustic efficiency throughout a wide band of frequencies;

To prevent, in loud-speakers having chambers adjacent the non-radiating surface of the diaphragm, undesirable resonance in such chambers.

In one embodiment illustrative of this invention, a loud-speaker comprises a magnet having pole-pieces spaced to form an air-gap, the gap being sealed at one end by a gasket. A diaphragm is mounted upon the magnet and includes a peripheral portion secured upon the outer pole-piece, a central dished or dome-shaped portion, and an annular troughed intermediate portion connecting the peripheral and the dished or dome-shaped portions. The diaphragm is actuated by a coil disposed in the air-gap and preferably is of such construction that the central portion vibrates as a whole, analogous to a piston, throughout the band of frequencies to be reproduced.

In accordance with a feature of this invention, a dished or dome-shaped member is provided adjacent the outer or radiating surface of the dished or dome-shaped portion of the diaphragm, this member being provided with sound openings. The openings are made of such area that the radiation resistance at the diaphragm varies as the square of the frequency up to substantially the highest frequency it is desired to reproduce.

In accordance with another feature of this invention, the openings and the chamber between the dished or dome-shaped portion of the diaphragm and the dome-shaped member are so designed that the mass reactance of the air at the openings and the stiffness reactance of the chamber are substantially equal at or near the highest frequency in the band it is desired to reproduce. This accentuates the radiation resistance at the diaphragm at the higher frequencies of the band reproduced, thereby increasing the acoustic output. This increase may correspond to a similar increase at the lower frequencies in the band reproduced, attained in other ways, such for example, as described in my patents 1,895,441, granted January 31, 1932 and 1,967,223, granted July 24, 1934, whereby the efficiency of the device is effectively increased.

In accordance with a further feature of this invention, the chambers behind the dished or dome-shaped and troughed portions of the diaphragm are designed so that the pressure changes in these chambers are equal and in phase. Air flow through the air-gap from one chamber to the

other, therefore, does not occur and undesirable resonance effects are avoided.

The openings in the dished or dome-shaped member may be of various forms and may be disposed in various ways, the form and disposition being so chosen that the sound field distribution is particularly suitable to meet the exigencies of the specific installation in which the loud-speaker is utilized. It is usually desirable, however, that the openings be so disposed that substantially uniform sound paths are obtained for waves originating at spaced points on the diaphragm whereby interference effects are reduced.

The invention and the several features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

Fig. 1 is a side elevational view, partly in cross-section of a loud-speaker constructed in accordance with, and illustrative of, one embodiment of this invention;

Fig. 2 is a top view of the dished or dome-shaped member overlying the diaphragm in the loud-speaker shown in Fig. 1;

Fig. 3 is a top view, to a reduced scale, of another dished or dome-shaped member which may be incorporated in a loud-speaker of the general construction shown in Fig. 1; and

Fig. 4 illustrates typical radiation resistance characteristics of a loud-speaker of usual design including a relatively large diaphragm radiating directly into the atmosphere and of a loud-speaker, such as shown in Fig. 1, constructed in accordance with this invention.

Referring now to the drawing, the loud-speaker in Fig. 1 comprises a magnet having a central pole 10 encompassed by a field or excitation coil 11, and an outer pole 12. The central pole has secured thereto, as by screws 13, only one of which is shown, a circular pole-piece 14, and the outer pole 12 has secured thereto, as by screws 15, an annular pole-piece 16. The pole-pieces 14 and 16 are coaxially arranged and spaced to form an annular air-gap 17, the inner end of the gap being acoustically sealed by an annulus 18, which, for example, may be of rubber and suitably secured to the pole-pieces 14 and 16.

A diaphragm, which may be of a suitable lightweight metal such as duralumin, is mounted upon the outer pole-piece 16 and includes a dished or dome-shaped portion 19, a peripheral portion 20, and an intermediate annular flexible troughed portion 21. The diaphragm may be fabricated in one piece or the several portions may be formed separately of the same or different materials. The peripheral portion 20 is clamped between two rings 22 and 23 which are held together and secured to the outer pole-piece 16 by screws 24. A cylindrical form or support 25, which may be of impregnated paper, is suitably secured to the diaphragm, as by cementing, adjacent the base of the dished portion 19 and carries an annular driving coil 26 which is disposed in the air-gap 17. As will be seen from Fig. 1, the dished portion 19 of the diaphragm, the form or support 25 and the pole-piece 14 form a relatively large chamber 27, having a volume V_1 and stiffness S_1 , and the annular troughed portion 21, the form or support 25, ring 23, and pole-piece 16 form a relatively small chamber 28 having a volume V_2 and stiffness S_2 , the two chambers 27 and 28 being serially connected by the air-gap 17. The troughed portion 21 is preferably made sufficiently flexible and the dished portion 19 is preferably made sufficiently rigid so that the dished

portion 19 may vibrate bodily analogous to a piston through the range of frequencies desired to be reproduced.

As is known in the art, the radiation resistance of a diaphragm vibrating as a piston in open air varies approximately as the square of the frequency up to some frequency such as f_1 as shown in Fig. 4. Above this frequency the radiation resistance increases less rapidly and finally approaches a substantially constant value after going through a series of oscillations as shown by curve A in Fig. 4. If the vibrational velocity of the diaphragm is inversely proportional to the frequency, as is the case for mass controlled diaphragms, the sound radiated will be uniform up to the frequency f_1 (Fig. 4) but above this frequency the sound radiated will decrease in correspondence with the less rapid increase in the radiation resistance.

The frequency range throughout which the radiation resistance is proportional to the square of the frequency is dependent upon the size of the diaphragm. In order that the radiation resistance will vary approximately as the square of frequency up to a certain desired frequency, the radius of the diaphragm must not be appreciably greater than that given by the relation

$$r_d = \frac{25 \times 10^3}{2\pi f_0} \text{ c. g. s. units} \quad (1)$$

where r_d is the radius of the diaphragm, and f_0 is the desired frequency.

From Equation (1), it will be apparent that in order to obtain uniform acoustic output throughout a range of several thousand cycles from a loud-speaker having a mass controlled diaphragm, the diaphragm would have to be small. Inasmuch as the radiation resistance is dependent upon the size of the diaphragm, the acoustic output from a diaphragm of the small size necessitated by the above relation would be of small magnitude unless, as has been noted hereinbefore, the amplitude of vibration of the diaphragm were relatively great. For example, if it were desired that the acoustic output be uniform up to 3000 cycles, the radius of the diaphragm would have to be not materially greater than $\frac{1}{2}$ inch; and in order to obtain an acoustic output of approximately two watts at 400 cycles it would be necessary that a diaphragm of this size have a double vibration amplitude of about two inches. A loud-speaker having a diaphragm of this size and vibrating with this amplitude would be impractical, for the diaphragm suspension means permitting such an amplitude would be extremely difficult to obtain and the cost of the magnet would be relatively high.

From the foregoing, it would follow, then, that a diaphragm larger than that permitted by Equation (1) must be used if a substantial acoustic output of the order of the magnitude indicated above is desired and the resulting nonuniformity of response permitted. For example, in order to obtain a substantial output without unduly large vibrational amplitudes of the diaphragm and to obviate the use of a relatively costly magnet, a diaphragm having a diameter of four inches has been used. For a diaphragm of this size, as determined from Equation (1), f_1 would be about 780 cycles.

In accordance with this invention, the limitations set forth hereinabove are circumvented, so that a relatively greater acoustic output is obtained and the range of frequencies throughout which the output will be uniform is materially

increased. In one illustrative embodiment of this invention shown on Fig. 1, a diaphragm of a size larger than that dictated by Equation (1) is used, so that greater acoustic output is obtained, and a rigid dished member or cover 29 is placed over the outer or radiating surface of the diaphragm. This dished member or cover conforms in shape to the central portion 19 of the diaphragm and forms therewith a chamber 30 having a volume V_3 and stiffness S_3 . The cover is secured upon the ring 22 by the screws 24 and is provided with a plurality of elongated parallel openings or apertures 31. The aggregate area of the elongated apertures 31 is made equal to that of a circle with a radius sufficiently small to approximately satisfy Equation (1) at the highest frequency it is desired to reproduce. For example, if it is desired that the acoustic output be substantially uniform up to 3,000 cycles (f_2 in Fig. 4) the aggregate area of the openings could be of the order of five square centimeters.

The radiation resistance, R'_R , at the openings 31 may be expressed by the equation

$$R'_R = \frac{\omega^2 r_0^4}{18 \times 10^6} \text{ c. g. s. units} \quad (2)$$

where r_0 is the radius of a circle having the same area as the aggregate area of the openings, and ω is $2\pi f$. At the diaphragm this resistance is increased by the fourth power of the ratio of the diaphragm radius, r_d , to the equivalent radius, r_0 , so that the apertures 31 have a radiation resistance, R_R , at the diaphragm of

$$R_R = R'_R \left(\frac{r_d}{r_0} \right)^4 = \frac{\omega^2 r_d^4}{18 \times 10^6} \quad (3)$$

From Equations 1, 2 and 3, it will be seen that the air load on the diaphragm of a loud-speaker constructed in accordance with this invention is the same as the air load on the diaphragm of a loud-speaker without the cover, up to the limiting frequency (f_1 in Fig. 4) for the diaphragm of radius r_d as dictated by Equation (1). However, in a loud-speaker constructed in accordance with this invention, the air load increases as the square of frequency up to a frequency (f_2 in Fig. 3) determined by the radius r_0 , so that a substantial increase in the frequency range throughout which uniform output obtains is achieved. Inasmuch as the air load on the diaphragm is the same for frequencies up to f_1 for loud-speakers with or without a cover, such as the cover 29, the efficiency and sound power capacity of a loud-speaker constructed in accordance with this invention is as great as that of loud-speakers without a cover, with which a uniform output is obtainable up to the frequency f_1 , and is greater than that of loud-speakers without a cover, with which a uniform output is obtainable up to the frequency f_2 .

In order to obtain a relatively high electro-acoustic conversion efficiency in devices of the type contemplated by this invention, the resonance frequency of the vibrating system should be within the band of frequencies it is desired to translate, as described in detail in my aforesaid Patents Nos. 1,895,441 and 1,967,223. In the embodiment of my invention illustrated in Fig. 1, the resonance frequency of the vibrating system is dependent upon, among other factors, the parameters of the diaphragm and of the chambers 27 and 28. If, for example, it is desired that the range of frequencies to be reproduced be 400 to 3,000 cycles, the diaphragm and chambers 27 and 28 may be so designed that the resonance fre-

quency of the vibrating system is approximately 500 cycles.

This increases the acoustic output at the lower frequencies and necessitates some further accentuation of the higher frequencies in order that the acoustic output be substantially uniform throughout the desired band of frequencies. This accentuation may be accomplished by so designing the member 29 that the stiffness reactance of the chamber 30 is equal to the air mass reactance, ωM_R , of the openings 31, at or near the frequency f_2 . This produces an anti-resonance effective at the diaphragm, which results in an increase in both the radiation resistance and the velocity of the vibrating system at the higher frequencies, that is, the frequencies in the vicinity of f_2 .

The air mass reactance, ωM_R , of the openings 31 may be ascertained from the relation

$$M_R = \frac{4\pi\rho r_d^4}{r_0} \frac{K_1(y)}{y^3} \quad (4)$$

where ρ is the air density

$$y = \frac{2\omega r_0}{c}$$

c being the velocity of sound, $K_1(y)$ is a Bessel function represented by the series

$$\frac{2}{\pi} \left(\frac{y^3}{3} - \frac{y^5}{3^2 \cdot 5} + \frac{y^7}{3^2 \cdot 5^2 \cdot 7} - \dots \right)$$

and r_0 and r_d are as noted hereinabove.

The stiffness of the chamber 30 may be ascertained from the relation

$$S_3 = \frac{\rho c^2 A_d^2}{V_3} \quad (5)$$

where A_d is the effective area of the diaphragm and the remaining characters have the same significance as hereinbefore.

As noted previously, the openings in the dished or cover member 29 may be of various forms and disposed in various ways. As shown in Fig. 3, for example, the cover may be provided with arcuate openings 32 disposed in circular formation about the center of the cover. A single straight slit or opening, or opening of other form may be used and advantage taken of the sound field distribution characteristics of the particular form of opening. The specific forms and arrangements of the openings shown in Figs. 2 and 3 have the particular advantages of equalizing the sound paths between various parts of the dished portion 19 of the diaphragm and the openings whereby interference effects are substantially eliminated, and of insuring a substantially uniform distribution of all frequencies in the band radiated throughout a relatively large solid angle.

In order to prevent local resonance effects to the rear of the diaphragm, the chambers 27 and 28 are so designed that the pressure changes in these chambers, occasioned by vibration of the diaphragm, are equal and in phase so that air flow through the air-gap 17 from one chamber to the other does not occur. The pressure changes in the chambers 27 and 28 are equal when the chambers are so proportioned that

$$\frac{\partial V_1}{V_1} = \frac{\partial V_2}{V_2} \quad (6)$$

where V_1 and V_2 are the volumes of the chambers 27 and 28, respectively, when the diaphragm is at rest, and ∂V_1 and ∂V_2 are the changes in volumes in the chambers 27 and 28, respective-

ly, occasioned by vibrational displacement of the diaphragm.

Although specific embodiments of the invention have been shown and described, it is to be understood, of course, that modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. A sound translating device comprising a diaphragm having a portion vibratile as a whole throughout a band of audio frequencies, said portion being of sufficient area to propagate sound waves of substantial intensity without the aid of a horn, means for actuating said diaphragm, and means adjacent the radiating surface of the diaphragm for increasing the range of frequencies in which the radiation resistance at said diaphragm varies as the square of frequency, by several thousand cycles.

2. A sound translating device comprising a direct acting diaphragm having a portion of the order of four inches in diameter vibratile as a whole throughout a band of audio frequencies, means for actuating said diaphragm, and means adjacent the radiating surface of said diaphragm for increasing the range in which the radiation resistance at said diaphragm varies as the square of frequency up to substantially 3000 cycles.

3. A sound translating device comprising a direct acting diaphragm having a portion vibratile as a whole throughout a band of audio frequencies, said portion having a radiating surface in communication with the atmosphere and the opposite surface acoustically sealed from the atmosphere, and a member adjacent said radiating surface and forming a chamber therewith, said member having a restricted sound opening of such area that the radiation resistance at said diaphragm varies as the square of frequency up to substantially the highest frequency said device is intended to translate.

4. A loud-speaker comprising a diaphragm having a portion vibratile as a whole throughout a band of audio frequencies, said diaphragm being of sufficient area to propagate sound waves of substantial intensity without the aid of a horn, means for actuating said diaphragm, and a member overlying said portion and forming a chamber therewith, said member having a restricted sound opening of an area commensurate with the area of a mass-controlled piston type diaphragm for which the radiation resistance varies substantially as the square of frequency up to the highest frequency said first diaphragm is intended to radiate.

5. A sound translating device comprising a diaphragm having a dome-shaped portion, means for supporting said portion so that it is vibratile as a whole, means for actuating said diaphragm, and means for increasing the range in which the radiation resistance of said diaphragm varies substantially as the square of frequency, said third means including a dome-shaped member overlying said dome-shaped portion and having a restricted opening therein.

6. A loud-speaker comprising a diaphragm of sufficient area to propagate sound waves of substantial intensity without the aid of a horn, said diaphragm including a dished portion and a supporting portion sufficiently flexible to allow said dished portion to vibrate as a whole, means for actuating said diaphragm, and means for increasing the range in which the radiation resistance at said diaphragm varies substantially as the square of frequency, including a dome-shaped

member substantially conforming to said dished portion, said member having a plurality of restricted openings.

7. A loud-speaker comprising a direct acting diaphragm having a dished portion of sufficient area to propagate sound waves of substantial intensity without the aid of a horn, said portion having a radiating surface in direct communication with the atmosphere, means sealing the opposite surface of said portion from the atmosphere, means supporting said dished portion so that it is vibratile as a whole, means for actuating said diaphragm, and a dished member overlying the radiating surface of said dished portion and having a plurality of elongated parallel openings.

8. A loud-speaker comprising a direct acting diaphragm having a dished portion vibratile as a whole and of sufficient area to propagate sound waves of substantial intensity without the aid of a horn, said portion having its radiating surface in direct communication with the atmosphere, means for actuating said diaphragm, and a dished member overlying the radiating surface of said dished portion and having a plurality of arcuate openings arranged in circular formation about the center of said dished member.

9. A sound translating device comprising a diaphragm having a dome-shaped portion, and a dome-shaped member overlying said portion and forming a chamber therewith, said member having sound openings therein of an area such that the air mass reactance at said openings and the stiffness reactance of said chamber are substantially equal at the highest frequency said device is intended to translate.

10. A loud-speaker comprising a diaphragm of sufficient area to propagate sound waves of substantial intensity without the aid of a horn, said diaphragm having a dished radiating portion, means for actuating said diaphragm, and a dome-shaped member adjacent and conforming to said dished portion and forming a chamber therewith, said member having a plurality of elongated openings of such area that the air mass reactance at said openings is substantially equal to the stiffness reactance of said chamber at the highest frequency said loud-speaker is intended to reproduce.

11. A loud-speaker comprising a direct acting diaphragm having a portion of the order of four inches in diameter and vibratile as a whole, means for actuating said diaphragm, and a member adjacent the radiating surface of said portion having one or more sound openings therein of such aggregate area that the radiation resistance at said diaphragm varies as the square of frequency up to substantially 3000 cycles.

12. A loud-speaker comprising a direct acting diaphragm having a dished portion of the order of four inches in diameter and vibratile as a whole, means for actuating said diaphragm, and a dished member overlying the radiating surface of said dished portion and substantially conforming thereto, said dished member having one or more openings therein of an aggregate area commensurate with the area of a mass-controlled piston type diaphragm for which the radiation resistance varies as the square of frequency up to substantially 3000 cycles.

13. A loud-speaker comprising a diaphragm having a dome-shaped portion of the order of four inches in diameter and vibratile as a whole, means for actuating said diaphragm, and a dome-shaped

member overlying said dome-shaped portion and forming a chamber therewith, said member having sound openings of an aggregate area commensurate with the area of a mass-controlled piston type diaphragm for which the radiation resistance varies as the square of frequency up to

substantially 3000 cycles, said openings and said chamber being so constructed that the mass reactance of the air at said openings and the stiffness reactance of said chamber are substantially equal at 3000 cycles.

LEE G. BOSTWICK.