

Dec. 22, 1931.

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1,837,385

SOUND RADIATOR

Filed Aug. 14, 1929

2 Sheets-Sheet 1

FIG. 1

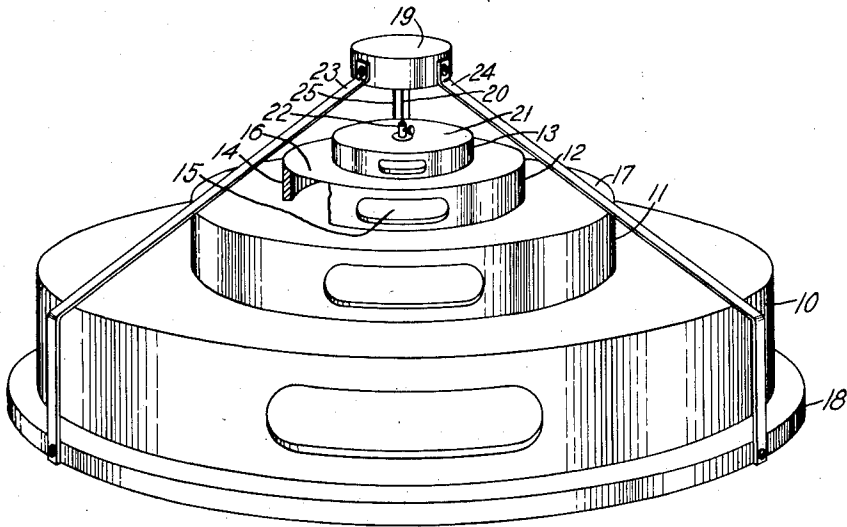
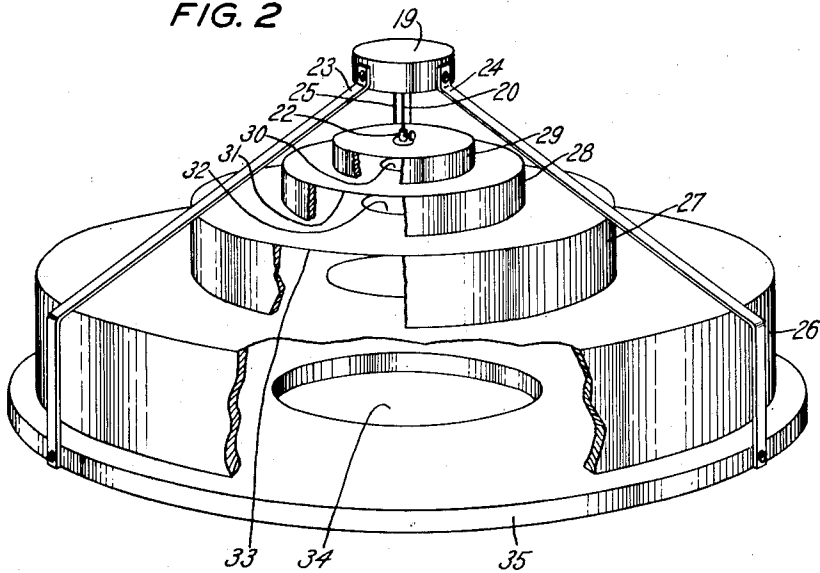


FIG. 2



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FIG. 3

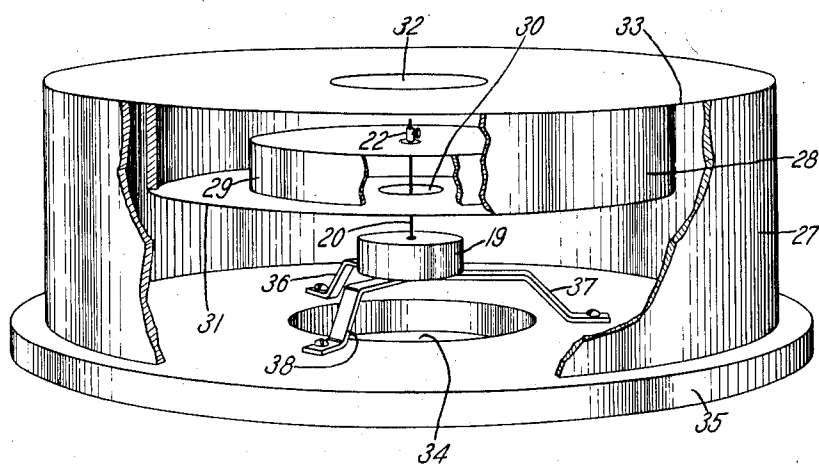
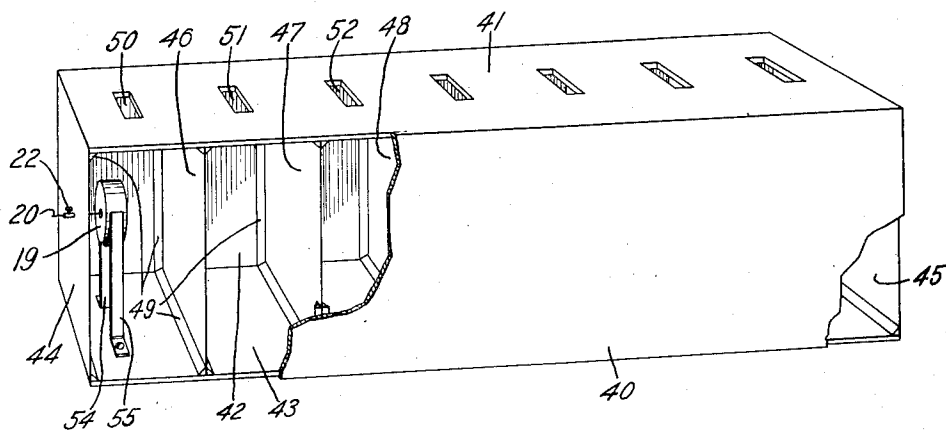


FIG. 4



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## UNITED STATES PATENT OFFICE

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## SOUND RADIATOR

Application filed August 14, 1929. Serial No. 385,914.

This invention relates to sound radiating devices and has for its object to enable the response characteristics of sound radiators to be adjusted within a wide range of variation. Another object is to secure a uniform response throughout a wide range of frequencies.

These objects are accomplished by the use of a plurality of radiating members, or stages, each of which comprises an air chamber having resilient walls and provided with an orifice from which radiation to the atmosphere takes place. Each of the radiating members is in effect a Helmholtz resonator, the walls of which as well as the contained air take part in the resonance vibration. The resonant frequencies are determined by the volume of the chamber and the area of the orifice and also by the character of the walls. The stages are coupled in tandem through the resilient walls, but in some embodiments this coupling is supplemented by openings between the chambers. The resilient walls of the chambers preferably take the form of elastic diaphragms.

The driving force which sets the system into operation is applied to one of the diaphragms by means of a sound reproducer unit. Due to the coupling, the vibrations are communicated to all parts of the system, and sound radiation takes place from the orifices. In certain embodiments the diaphragms also act as sound radiators.

In its preferred form the invention comprises a tapered system, in which the radiating stages are built progressively smaller in size. This construction permits the resonance frequencies of the system to be made more or less coincident with the resonant frequencies of the individual stages, and so enables the response of the system to be controlled, since the sizes of the members of the tapered system may be regulated to emphasize predetermined frequencies.

In the tapered construction one of the resonating stages may be attached to a base, the other stages being superposed thereon forming a pyramid. The driving force is preferably applied to the diaphragm of the smallest stage.

A further adjustment of the response

characteristics lies in the proportioning of the orifices leading to the atmosphere. The volume of sound radiated is dependent on the size of the orifices; consequently the emphasis given to a particular group of frequencies is controlled by assigning the proper size of the orifices of the particular resonators which emphasize those frequencies.

Fig. 1 illustrates an embodiment of the invention in which the resonating stages are tapered in size and are coupled by diaphragms;

Fig. 2 shows a tapered radiating system in which the coupling means include orifices as well as diaphragms;

Fig. 3 shows an alternative construction of the type of radiator shown in Fig. 2;

Fig. 4 illustrates a radiator in which the stages are uniform in size and the diaphragms are all fixed to a base.

The radiator shown in Fig. 1 comprises a plurality of resonating stages 10, 11, 12 and 13 built one upon another. All the stages are similarly constructed, so a detailed description of one of them will suffice to describe all. Consider then, stage 12, which is shown partly in section to better illustrate the construction. It comprises a rigid cylindrical wall 14, provided with an aperture 15. An elastic membrane, or diaphragm, 16 is stretched across the upper circular rim of the cylinder and fastened thereto by glue or other suitable means. The membrane may be made of a light resilient material, such as a thin foil of aluminum, while the cylindrical wall is constructed of a solid, non-yielding, material such as wood. The lower rim of the cylinder is attached to the diaphragm 17 of the next lower resonating stage 11; and likewise, the circular rim of the next smaller stage 13, is fastened to the membrane 16. In this manner, all the resonating stages are built one upon the next, in co-axial alignment, the membrane of one acting as a base for the next. Each succeeding cylinder is smaller in diameter than the one preceding, so that an outer annulus of every diaphragm is exposed to the atmosphere, with the exception of the uppermost, which is entirely exposed. The lower rim of

the cylindrical wall in the largest stage 10 is fastened to a solid base-piece 18. The radiator is driven by a reproducer unit 19 whose driving rod 20 is fastened to the center of the uppermost diaphragm 21 by a thumb-screw fastening 22. The reproducer unit is rigidly held in its position above the radiator by brackets 23, 24 and 25 fastened to the base-piece.

10 The radiator is a multiple resonant system of stages, or resonators, coupled in tandem by the diaphragms. Each stage comprises an air chamber formed by the cylindrical wall and by the diaphragms above and below, the air chamber being in communication with the atmosphere through the aperture in the cylindrical wall. This is essentially a Helmholtz resonator with vibratory walls, sound being radiated from the diaphragm and from the opening from the air chamber. The different sized stages will, in general, be responsive to different portions of the frequency range because they are resonant at different frequencies; the maximum response of a resonating stage occurs in the frequency region around the resonance point. Each stage has two resonating parts, the diaphragm, and the combination of the air chamber and orifice. It is found desirable to make these two parts resonant at about the same frequency, to secure more effective coupling between the successive stages. If the resonant frequency of the diaphragm should be much higher than that of the air chamber and orifice, the air chamber would not be set into appreciable vibration and there would be practically no radiation from the orifice. The first, or fundamental, resonant frequency,  $f_d$  of a diaphragm is expressed by:

$$f_d = \frac{1}{2\pi} \sqrt{\frac{s}{m}} \text{ c. p. s. } (1)$$

45 where  $s$  represents the elastance constant;  $m$  represents the mass constant; and c. p. s. denotes cycles per second.

For a circular stretched diaphragm, the elastance constant is approximately

$$50 \quad s = 2\pi T \text{ c. g. s. } (2)$$

where  $T$  is the tension in dynes per centimeter of length. The abbreviation c. g. s. is used throughout to indicate that the values are expressed in absolute units of the centimeter gram second system. For the same type of diaphragm, the mass constant is given approximately by

$$60 \quad m = \frac{1}{3} \pi \rho \alpha^2 \text{ c. g. s. } (3)$$

where  $\rho$  is the surface density, i. e. the weight of a square centimeter of the diaphragm material; and  $\alpha$  is the radius of the diaphragm.

From Equations (1), (2) and (3) it follows that the resonant frequency is

$$f_d = \frac{1}{2\pi} \sqrt{\frac{6T}{\rho \alpha^2}} \text{ c. p. s. } (4) \quad 70$$

The resonant frequency  $f_h$  of a Helmholtz resonator is given by the equation

$$f_h = \frac{1}{2\pi} \sqrt{\frac{e}{b}} \text{ c. p. s. } (5) \quad 75$$

where  $b$  represents a mass constant;  $e$  represents an elastance constant, these constants being determined by the geometry of the resonance chamber. For a circular aperture, the mass constant is expressed approximately by

$$b = \frac{4}{3} \pi \alpha_1^3 \rho_1 \text{ c. g. s. } (6) \quad 80 \quad 85$$

where  $\alpha_1$  is the radius of the aperture; and  $\rho_1$  is the specific density of air.

The elastic constant is given by the expression

$$e = \frac{\rho_1 c^2 S^2}{V} \text{ c. g. s. } (7) \quad 90$$

where  $c$  is the velocity of sound;  $S$  is the cross sectional area of the orifice;  $V$  is the volume of the air chamber.

From Equations (5), (6) and (7), the resonant frequency of the resonator can be expressed

$$f_h = \frac{1}{2\pi} \sqrt{\frac{3c^2 S^2}{4\pi \alpha_1^3 V}} \text{ c. p. s. } (8) \quad 100$$

Where the apertures are other than circular in cross section, the mass constant is somewhat different, and must be found by experiment.

From Equations (1) to (8) it can be seen that the smaller stages are adapted to resonate and radiate the higher frequency waves, while the larger stages operate at the lower frequencies. This follows naturally from the fact that the elasticity of the air in small air chambers is relatively large, and the masses of small diaphragms and of the air in small orifices are relatively small while the converse is true of large diaphragms and resonators.

Vibrations from the reproducer are applied to the first stage and from there are transmitted to the other stages. Radiation of the higher frequency vibrations takes place almost entirely from the smaller radiators, practically no high frequency energy passing to the larger stages because of the high impedance presented by the masses of the larger diaphragms. On the other hand, the lower frequency vibrations do not set the smaller stages into vibration because of the impedance due to their great stiffness, but they are simply caused to move en masse and the vibrations are transmitted directly to the

larger stages which are more nearly naturally resonant at these frequencies and are therefore set into vibration.

The impedance of each stage considered alone is complex, there being a reactive component due to the masses and elastances, and a resistive component due to the dissipation of energy by radiation. The effect of joining several such stages, tapered in size, in tandem, is to cause the system to be resonant at a considerable number of frequencies covering any prescribed range. These resonances, due to the dissipation of energy by radiation, are not particularly pronounced and the result is that the impedance as measured at one end of the tandem connected system is nearly purely resistive. This permits good matching of the load impedance and the impedance of the unit, which is essential for efficient energy transfer.

From the fact that the various stages of a resonator respond to different frequency ranges, it follows that it is possible to regulate the response characteristic by adjusting the sizes and numbers of the stages used. There are many variables which can be adjusted to furnish the desired characteristic. These include the material, thickness, size and amount of stretch of the diaphragms, and the volume of the air chambers and sizes of the orifices.

If it be desired to construct a radiator to accentuate the upper frequencies of, say, 3000 to 5000 c. p. s., the sections resonant within this range should be constructed to radiate with greater power than the other sections. This can be done by increasing the size of the diaphragms and of the orifices in these stages or by diminishing the sizes of these elements in the other stages, the resonance frequencies being, of course, maintained constant. On the other hand, if it be desired to accentuate the range from 50 to 1000 c. p. s., the larger resonators should be made relatively higher in their radiating power by increasing the dimensions of the diaphragms and the air chamber orifices.

Fig. 2 shows an alternative form of a radiator in which sound is radiated from both sides of the base, the radiation being from diaphragms on one side, and from an aperture in the base piece on the other side. The radiator comprises four stages 26, 27, 28 and 29 tapered in size and built one upon another in the same manner as the structure of Fig. 1. The stages are similarly constructed except that there are no openings in the cylindrical walls; but instead, an aperture is provided in each diaphragm, except the uppermost, for the purpose of forming an outlet from the air chamber of the stage built upon it. Thus, the opening from the air chamber of stage 29 is the circular hole 30 through the center of the diaphragm 31 of stage 28. Again the outlet from the air

chamber of stage 28 is the hole 32 in the diaphragm 33 of stage 27. This construction is followed throughout the entire radiator, so that each chamber opens into the next larger. The last, or largest, chamber communicates to the atmosphere through the circular aperture 34 in the base-piece 35. The diaphragm of the smallest stage 29 has no opening in it since there is no stage built upon it.

The radiation from the diaphragms takes place in the same manner as in the case of the radiator in Fig. 1, but the radiation from the air chambers takes place in a somewhat different manner. Each chamber, instead of radiating direct to the atmosphere through its own separate orifice, radiates into the next largest chamber, the entire radiation from the chambers of the system finally occurring through the opening in the base-piece. In this type of radiator, some care must be exercised in establishing the size of the base-piece; it should be so proportioned with respect to the rest of the system that waves from the diaphragms do not pass around it to the back of the radiator and feed directly into the air chamber, and vice versa.

Fig. 3 illustrates a radiator having a different arrangement of the stages and of the reproducer unit. It comprises three stages 27, 28 and 29, which have the same construction as the same numbered stages in Fig. 2. A feature of this embodiment is that each stage is built inside of the air chamber of the next largest stage; this construction provides economy of space. The circular rim of the cylindrical wall of the smallest stage 29 is fastened to the diaphragm 31 of stage 28. Stage 28 is inverted, the circular rim of its cylindrical wall being fastened to the under side of diaphragm 33 of stage 27. This construction can be followed for any number of stages, the last, and largest, stage being attached to a base 35 which is constructed the same as the same numbered base in Fig. 2. The reproducer unit 18 is located in the air chamber of the largest stage, and is attached to the base-piece by brackets 36, 37 and 38. Each diaphragm, except that of the innermost, or smallest, stage has its aperture concentrically centered so that the driving rod 20 of the reproducer unit may be passed directly through to the thumbscrew fastening in the smallest diaphragm, which, of course, has no aperture.

The operation of this radiator is very similar to the operation of the radiator of Fig. 2, except that radiation from the air chambers occurs from both sides of the base, instead of from one side only. The radiation from the back takes place through the opening 34 in the base-piece, while the radiation from the front occurs through the orifice 32 in diaphragm 33.

In Fig. 4 the system has the shape of a

rectangular prism, whose four sides 40, 41, 42 and 43 are made of solid material, such as an unyielding wood. The ends of the prism are elastic diaphragms 44 and 45. The prism is divided into a plurality of equal compartments, or air chambers, by elastic diaphragms 46, 47, 48, etc., these diaphragms being similar to those at the ends. For the purpose of holding the diaphragms in position, narrow strips 49 of molding are glued to the diaphragms and to the four solid sides of the prism. An outlet to the atmosphere from each chamber is provided in one of the solid walls. These outlets are in the form of rectangular openings 50, 51, 52, etc. in wall 41. The system is driven by the reproducer unit 19 whose driving rod 20 is fastened to the end diaphragm 44. The unit is fastened to one of the walls 43, as a base, by brackets 54 and 55.

This system operates in a manner very similar to those hereinbefore described. The stages are all uniform in construction so that they are individually resonant at the same frequencies. Due to the fact, however, that there are many stages coupled in tandem, the system as a whole is characterized by many resonances which occur within a definite frequency range. The radiator is responsive only over its range of resonances, so it is generally desirable to produce a wide resonance range extending upward from a low frequency of about 100 c. p. s. This requires that the masses and elastances of the diaphragms be relatively small in comparison to the masses of the air in the orifices and the stiffness of the air in the chambers. To provide a proper load impedance of a constant resistance value for the reproducer unit, the initial diaphragm 44 should be proportioned to have about half the mass and half the stiffness of the other diaphragms.

In any of the foregoing types of radiators, the directive response can be largely controlled by the shape and position of the openings from the air chambers. For example, a rectangular opening radiates better in a plane perpendicular to the long axis of the rectangle than it does in other directions. Consequently, for radiating to a widely spread audience at a uniform altitude, the radiator should be placed so that the long sides of the rectangles are in a vertical position. Control can be exercised over the directivity by situating the several apertures in different relative positions around the radiator. The invention is not limited to the specific forms disclosed herein, but only in accordance with the appended claims.

What is claimed is:

1. A sound radiator comprising a plurality of resonators, each resonator comprising an air chamber the walls of which include a plurality of diaphragms and a rigid portion having an orifice communicating directly with

the outer atmosphere, the mechanical resonant frequency of each resonator being the same as its acoustical resonant frequency and said resonators being coupled in tandem by means of the diaphragms, whereby vibrations imparted to one chamber are transmitted to all the chambers and sound due to said vibrations is radiated from said orifices.

2. A sound radiator according to claim 1 in which the diaphragms which couple the resonators constitute walls common to adjacent resonators.

3. A sound radiator comprising a plurality of air chambers in tandem, each chamber being coupled to the next by a diaphragm which acts as a common wall between the adjacent chambers, there being an orifice in each chamber communicating with the atmosphere, said chambers being progressively diminished in size to expose a portion of each coupling diaphragm to the atmosphere, whereby sound waves are radiated simultaneously from the exposed portions of said diaphragms and from the apertures of said chambers.

4. A sound radiator according to claim 3 in which the sizes of the chambers are so proportioned that the resonances due to the elasticities of the air in the chambers and the masses of the air in the openings occur throughout a predetermined frequency range whereby more sound is radiated in said frequency range than in other frequency ranges.

5. A sound radiator in accordance with claim 1 in which the air chambers and the coupling diaphragms are of uniform dimensions.

In witness whereof, I hereunto subscribe my name this 12th day of August, 1929.

RAYMOND L. WEGEL.