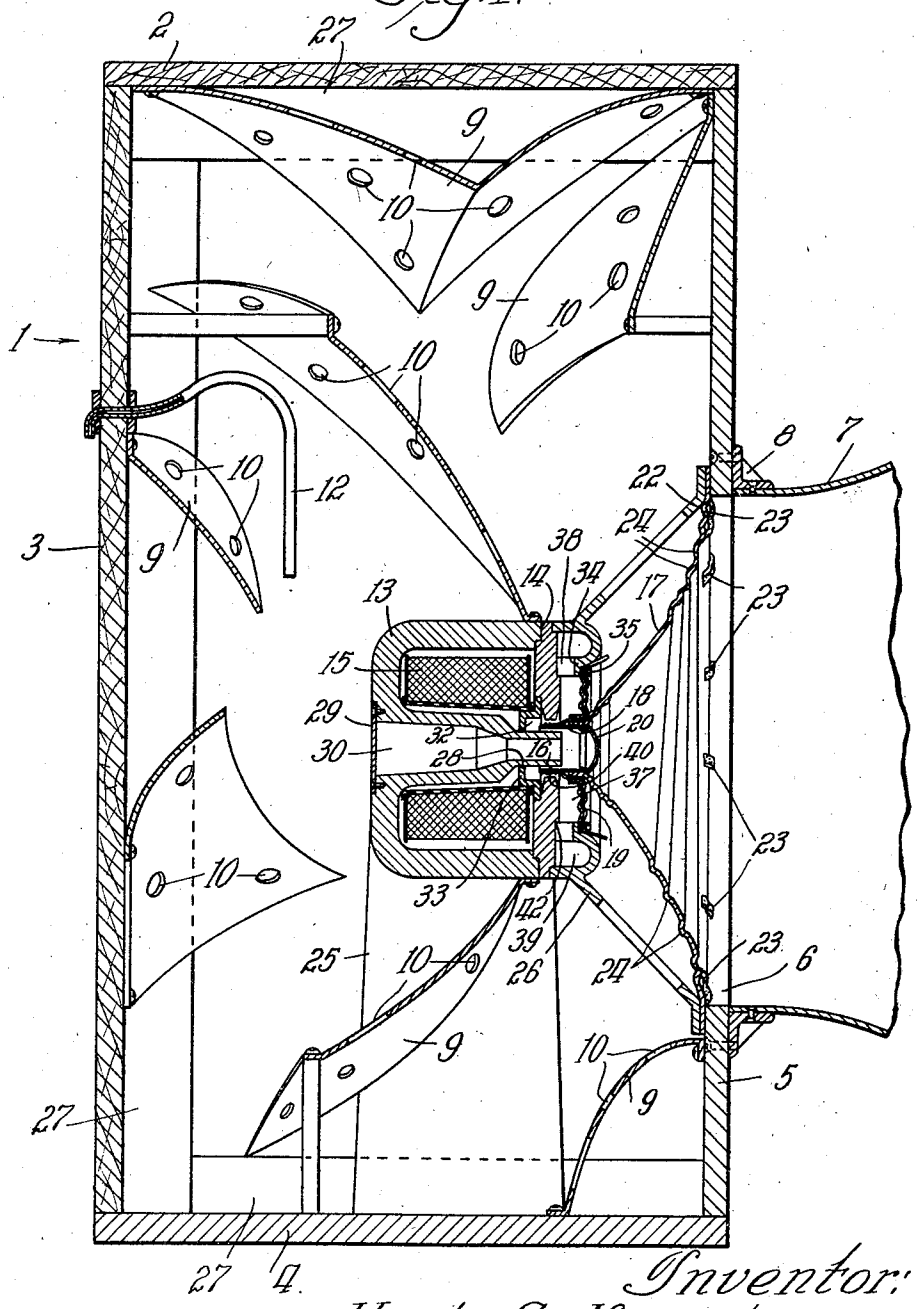
Oct. 21, 1947. H. S. KNOWLES 2,429,470

LOUD-SPEAKER WITH PRESSURE-EQUALIZED CHAMBER SYSTEM ENCLOSING FLUX GAP

Original Filed June 4, 1934 3 Sheets-Sheet 1

Fig. 1.



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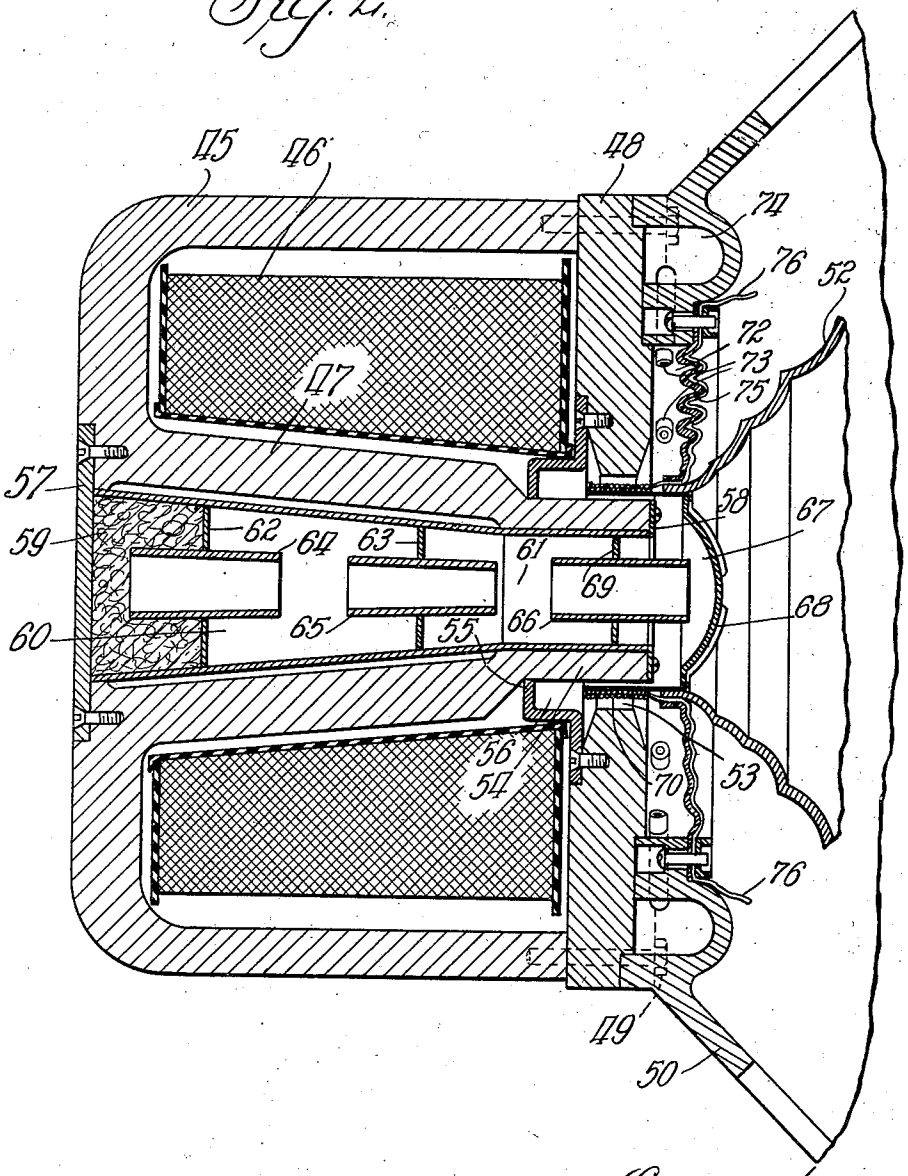
Original Filed June 4, 1934 3 Sheets-Sheet 2

Fig. 2.



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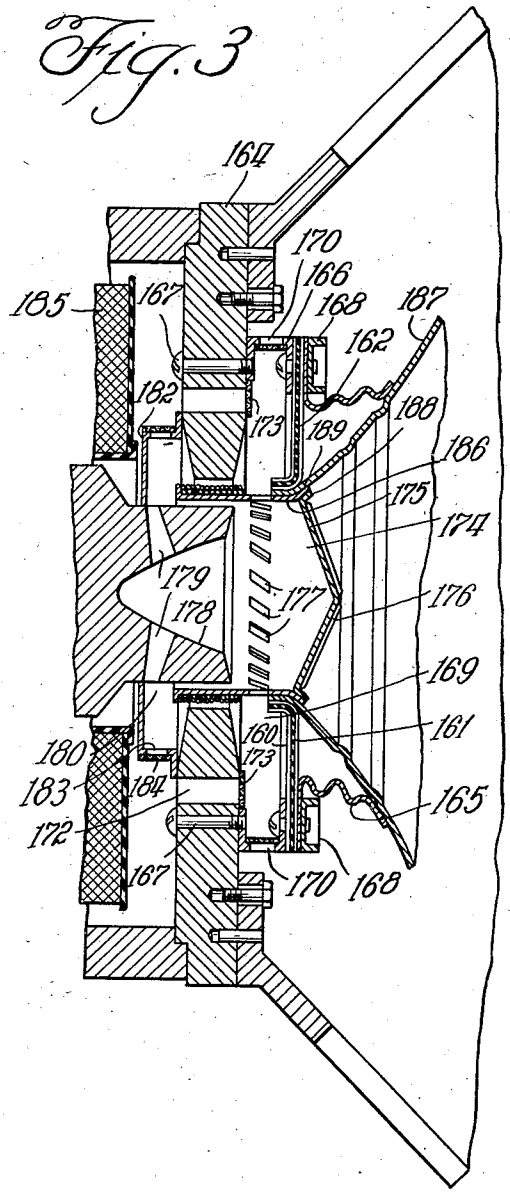
Original Filed June 4, 1934 3 Sheets-Sheet 3

Fig. 3



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Patented Oct. 21, 1947

2,429,470

UNITED STATES PATENT OFFICE

2,429,470

LOUD-SPEAKER WITH PRESSURE-EQUALIZED CHAMBER SYSTEM ENCLOSING FLUX GAP

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Original Application June 4, 1934, Serial No. 728,993. Divided and this application September 3, 1942, Serial No. 457,159

7 Claims. (Cl. 179—115.5)

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This invention is a division of my application S. N. 728,993 filed June 4, 1934, now Patent No. 2,295,483, granted Sept. 8, 1942, and relates to loud speakers, and is more particularly directed to loud speakers or telephones of the electro-dynamic or moving coil type.

A speaker of this type, when operating in open or unconfined fluid, radiates little power at low frequencies, because the compression wave from one side of the moving system is almost completely neutralized by the rarefaction wave on the other side. The use of an infinite baffle for separating the front and rear radiation of a moving diaphragm system will effectively overcome this difficulty, but such a construction is, of course, not of practical utility.

Also, there is considerable power loss or loss of effective sound radiation from a loud speaker due to the resistance caused by forcing the air in and out through the annular gap between the top plate of the coil assembly and the voice coil bobbin, and between the voice coil bobbin and the core. At low frequencies, especially below the fundamental resonance of the system, the resistive component impedes the movement of the diaphragm with a corresponding decrease in effective sound radiation, which may be termed a power loss, due to this highly resistive impedance. Also, the enclosure produces constructive and destructive interference at various frequencies, causing changes in the velocity of the moving system, or resonance. Particularly is this true when the enclosure is made large enough to provide low stiffness reactance at low frequencies in order to avoid any objectionably high fundamental resonant frequency of the system.

One object of the present invention is the provision of an acoustical network which, in itself, is acoustically coupled, and which, as an entity, is coupled to a vibrating system, the network having a stiffness reactance in most of the useful frequency range of the vibrating system. This network is designed to add but little stiffness to the moving system at low frequencies with a relatively increasing amount of stiffness as the frequency increases, so that the effective reactance of the vibrating system is a minimum and the velocity is a maximum in most of the useful frequency ranges.

This network is adapted to cooperate with the enclosure for reducing the mechanical resistance to flow through the air gap. It preferably comprises a plurality of tapered or, if desired, uniform iterated chambers, preferably having such stiffness in the first section as to make the stiffness

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reactance high at high frequencies. This may, of course, require the use of a large number of sections if all the sections are made uniform, in order to make the stiffness at low frequency sufficiently low to prevent power loss of the sound radiating system.

In carrying out the object of my invention, which is to improve the efficiency of loud speaker units by substantially eliminating the power loss due to the resistance component of the impedance to motion of the fluid within the restricted voice coil passages I make the fluid particle velocity in these passages negligibly low when the vibrating system is in motion. This is done by substantially eliminating any pressure differential across these restricted passages. I accomplish this by so proportioning the enclosures communicating with these passages that the pressure increases (or decreases) an equal amount in each enclosure when the vibrating system is displaced, or by providing low impedance paths in parallel with the high impedance paths so that substantially all the fluid displacement takes place through the low impedance and low resistance paths, giving a negligible pressure differential across the high impedance paths and therefore negligible fluid flow through them.

Another object secured by the present invention is the provision of a vibration cone or diaphragm which possesses relatively great mechanical strength to static deflection, and which is so formed as to have eccentric radial sectors for decreasing or distributing the resonance at higher frequencies. This eccentricity may be produced in any desired manner as will be pointed out hereinafter. The eccentric rings, corrugations or the like, may be formed in the cone, or may be of material such as fibrous rings, which add mass, stiffness and resistance to the diaphragm.

Other objects and advantages of the present invention, such as certain details of construction and operation which present novel features not, to my knowledge, heretofore provided, will be described in detail in connection with the following description, which, taken in connection with the accompanying drawings, will disclose to those skilled in the art a preferred embodiment of the present invention.

In the drawings:

Figure 1 is a sectional elevational view of a speaker unit embodying the teachings of the present invention.

Figure 2 is a vertical sectional view of a modified form of the invention;

Figure 3 is a vertical sectional view of a still further modified form of the invention;

Referring now in detail to the drawings, in Figure 1 I have provided an enclosure indicated generally at 1, comprising a top wall member 2 formed of wood or the like, a rear wall member 3 formed of wood, a lower wall 4 preferably formed of metal or a heat conducting material, and a front wall 5 formed of metal or a heat conducting material, the front wall 5 being provided with the opening 6 disposed below the center of the enclosure for centering the speaker unit with respect thereto. An annular outwardly flaring horn 7 is mounted about the defining edge of the opening 6 and is secured in position by means of the annular angle bracket member 8.

Within the enclosure 1, I preferably provide irregularly shaped rigid dispersion plates or vanes, which may be made of metal, wood, thin fibrous material, or any rigid dispersion surface which preferably occupies small volume so that the total effective volume of the enclosure is not appreciably reduced. These surfaces are so shaped and mounted that adjacent elements of area on the plates differ in distance from some element of area on the cone. Optionally, these vanes may be perforated or the surfaces of the vanes may be coated with material for damping their self-resonance.

To provide for such changes in barometric pressure which otherwise might produce a differential pressure between the front and back sides of the diaphragm, a high resistance vent or tube 12 may be provided, which extends through a suitable opening in the rear wall 3 of the enclosure.

The speaker unit, which, in this particular embodiment, is of the large diaphragm electro-dynamic type, has a field structure 13, comprising a substantially cup-shaped housing, which is secured to a top plate 14, and has mounted therein the field coil 15. This coil, when energized, produces the desired magnetic flux in the annular air gap 16. The vibrating assembly consists of the diaphragm 17, the voice coil and bobbin assembly 18, the flexible centering member 19, the dome-shaped cover 20, the flexible annular diaphragm support or closure member 22 and the self-damping strips 23.

The rings or corrugations 24, since they may comprise rings felted or otherwise mounted on the diaphragm, or corrugations formed directly in the diaphragm, are preferably so made that the annular ring sections of the diaphragm between them are not of constant width. The rings may be disposed to lie in the position as determined by the inter-section of the surface of the diaphragm and a plane not quite perpendicular to the axis of the speaker. The radial distance between different sections of the rings and between the rings and the annular flexible support 22 should preferably not be a constant.

The field assembly 13 is held in position by means of a pair of strip supporting members 25 which are formed of heat conducting material, and which are spaced apart to provide a through air space therebetween in order to eliminate any resonating effects from the provision of a confined chamber formed by these conducting strips. These strips serve to conduct the heat generated in the coil 15 from the housing 13 to the metal wall 4 of the enclosure, and, in combination with the metallic cone housing 26 which extends between the top plate 14 and the outer peripheral edge of the diaphragm 17, serves to conduct this heat away from the coil assembly and to the bottom and front walls 4 and 5 of the enclosure.

The wall members 2, 3 and 4 are provided with stiffening channels or ridges 27 formed therein, which, in addition, serve to prevent self-resonance of these wall surfaces.

In the conventional type of speaker, the movement of the voice coil bobbin assembly 18 into and out of the air gap 16 between the core indicated generally at 28 and the defining edge of the opening in the top plate 14 results in movement of the diaphragm 17. This produces an increase in the pressure of fluid on the back sides of the centering member 19 and the bobbin cover 20 as the diaphragm moves inwardly, which ordinarily results in some flow of fluid from the spaces back of the centering member and bobbin cover through the air gap between the top plate 14 and the voice coil assembly 18, and between the voice coil assembly and the core tip 28 of the field structure.

With such an air flow, which directionally is out of phase with voice coil assembly movement, there is a considerable power loss due to frictional resistance of the air, which results in loss of effective sound radiating capacity, especially at low frequencies. In the present invention, the resistive component of the reaction of the fluid on the moving system, due to unwanted movement of the fluid through this gap, is substantially eliminated.

The core 28 is preferably made hollow, and is closed at its outer end by means of the closure plate 29 which is substantially fluid-tight. Thus, when the voice coil assembly 18, with the dome 20, moves inwardly with respect to the field assembly, there is compression of fluid in the space 30 of the core assembly. At the same time, due to the volume of the defining end of the voice coil assembly, there is compression of fluid in the annular chamber 32 surrounding the core tip 28, and sealed from the coil assembly 15 by means of the annular shield member 33. The volumes 30 and 32 are preferably so chosen that, with the proportionate displacement of the end of the voice coil assembly 18 and the displacement of the dome 20, the fluid is compressed by an equal amount in these two chambers so that there is no differential in pressure therebetween, which prevents the flow of fluid from the chamber 32 past the outer surface of the tip 28 and within the voice coil assembly 18 into the space 30, or vice versa.

The flexible centering member 19, which is, in this embodiment of the invention, composed of an imperforate, eccentrically-corrugated flexible member, is substantially fluid-tight, being mounted upon a shoulder 34 formed on the spider 26, by means of an annular channel member 35, which allows tightening of the outer defining edge of the member 19 into sealing engagement with the shoulder 34 without producing any torsional stresses therein. As the diaphragm, therefore, moves inwardly, the flexible member 19 compresses the air in the chamber 37, which air may be allowed to escape to some extent through the ports 38 formed in the spider 26, and which lead to an annular chamber 39 therein. Preferably, the volume of the chambers 37 and 39 with the space within the ports 38 is so proportioned with respect to the chambers 30 and 32 that upon inward movement of the vibrating assembly, the compression effected in the chamber 37, or in the chambers 37, 38 and 39, is substantially equal to the compression

existing in the chambers 30 and 32, which means that the pressure at opposite ends of the gap passage 40 between the top plate 14 and the outer surface of the voice coil assembly 18 remains substantially equalized, so that no flow of fluid through this gap is caused. This provides for inward movement of the voice coil assembly without producing a substantial flow of fluid through the annular gap between the core and the top plate, which means that the resistive component or friction loss is eleminated, thus improving effective sound radiation at low frequency. The pressures existing in the chambers 30, 32 and 37 (including 38 and 39) produce a pure stiffness for the vibrating assembly, which stiffness is relatively low at low frequencies when the three chambers are relatively large so that the unit variation in pressure is small.

To further reduce the stiffness contributed by the volumes 30, 32 and 37, it may be desirable to substitute a substantially air-tight bulbous enclosure for the cover plate 29, in order to increase the total volume of the chamber 30. It is to be understood that these three volumes are not independently variable since the requirement is that the instantaneous pressure in all three be substantially the same at low frequencies. If desired, the entire volume of the enclosure may be used for one of the chambers, the other two volumes being proportioned in accordance therewith to produce the same intantaneous pressure in each of the chambers upon vibration of the system at low frequencies.

The cone housing 26 is centered on the top plate 14 by the shoulder 42, which shoulder is formed concentric with the gap and the voice coil assembly. It is important in an assembly of this type in which the voice coil is completely enclosed, to provide means for permitting access to the voice coil to permit repairs, adjustments, or the removal of foreign particles inadvertently introduced during assembly. The shielding member 33 fits snugly on the core, but may be removed from it and from the top plate 14 to permit the removal of particles which inadvertently get into the enclosure 32. This construction makes all parts of the enclosure readily accessible.

In this embodiment of the invention, the dome 20 is a relatively light rigid member which may have embossings thereon to increase its rigidity, and is connected to the voice coil bobbin 18 by means of a stiff annular ring or shoulder which is centered on the bobbin and helps to keep the voice coil round. The stiffness of the ring and the mass of the dome are normally so chosen as to give a rise in velocity of the dome at high frequencies. This frequency may be slightly above the frequencies at which the sound output of the speaker without the dome would begin to fall. This extends the frequency range of the speaker.

The use of the imperforate spider or centering member 19 prevents paramagnetic dust particles or the like which may be suspended in the fluid surrounding the magnetic circuit of the speaker from being drawn past the dome 20 around the outer periphery of the diaphragm 17 and into the annular gap about the core tip, since the introduction of such particles thereinto will destroy the operating efficiency of the speaker.

Considering now the embodiment of the invention shown in Figure 2, in which is provided a field coil assembly comprising the field housing 45, having the field coil 46 mounted therein about a centrally extending core 47, the field housing 45 being secured to the top plate 48 by bolt members 49 spaced about the periphery thereof. These bolts, at the same time, are adapted to secure the cone-supporting spider 50 to the top plate.

The top plate 48 is provided with an annular central opening 53, which is disposed concentrically about the core tip 54. A shielding member or the like, indicated at 55, is secured to the under surface of the top plate 48, and engages the outer periphery of the core 54 to define an annular chamber 56 therebetween, corresponding to the chamber 32 of Figure 1. The core 47 is provided with a tapered hollow opening, which is closed at its outer end by the closure plate 57 bolted to the housing 45, and at its inner end is provided with an annular retaining member 58, for a purpose to be hereinafter described.

Within the hollow core 47 is disposed what I term an acoustically coupled network, which, in the present embodiment, comprises three successive chambers, indicated at 59, 60 and 61, which are separated by partitions 62 and 63 and communicate by means of centrally disposed tubes 64, 65 and 66 with the space 57 behind the dome 68 of the diaphragm. If desired, the chamber 59 may be filled with sound absorbing material, although this is not necessary. This material may comprise hair felt, mineral or glass wool, or the equivalent, to provide a resistive termination at high frequency. In the particular form shown, the masses and stiffnesses of successive sections of the filter are unequal so that a tapered transmission line is produced. The member 58 holds this assembly in position within the hollow core 47. The chamber 67, between the dome 68, the retaining member 58, the partition 69 and the tube 66 provides a stiffness reactance to the diaphragm through the dome 68. This is connected by the mass of the fluid in the tube 66 to the volume or chamber 61 included between the partitions 63 and 69, which chamber adds a certain stiffness reactance, being in turn coupled through the mass of the fluid in tube 65 to the space or volume 60 between the partitions 63 and 69 and outside of the tubes 64 and 65. The latter chamber 60 is connected through the tube 64 to the chamber 59 to provide the next successive stiffness reactance to the vibrating system.

In general, the fundamental resonance frequency of the vibrating sound radiating system is made low enough to prevent introduction of objectionable resonance in the voice range. It is therefore desirable to couple the vibrating system to a network which produces very little stiffness at low frequencies and increasing stiffness at higher frequencies. The velocity of the system and hence the sound output, is increased by the addition of sound reactances, since this lowers the impedance of the vibrating system. This network may either be a mechanical or acoustical network. In this particular embodiment an acoustical network is employed.

In the particular embodiment shown, at extremely low frequencies the volumes 59, 60, 61 and 67 are all in parallel, that is, when the dome 68 moves in slowly the mass reactance of the fluid in the tubes 64, 65 and 66 may be neglected so that the fluid in the entire network is compressed. This volume is so chosen that, for a given displacement of the dome 68, the voice coil 70, the diaphragm 52 and the centering member 75, which constitute the moving system, the pressure in chamber 67 just equals the pressure in the chamber 56, which in turn equals the pressure in the chamber 72, ports 73 and annular

chamber 74, so that there is no differential in pressure through either the annular gap between the voice coil 70 and the top plate 48, or between the voice coil and the core tip 54. It is therefore apparent that a substantially pure reactance or stiffness component is added to the system at low frequencies.

At increasingly higher frequencies, the mass reactance of the fluid in the tube 66 increases so that the particle velocity of the fluid is smaller, and the compression becomes largely localized in chamber 67. This produces a stiffness which is greater than that of the low frequency stiffness and which is approximately inversely in ratio as the volume of the space 67 is to the combined volumes 59, 60, 61 and 67.

In general, since it is desirable to make the ratio of these stiffnesses large in order to make the stiffness reactance large at high frequencies where the mass reactance of the vibrating system is large, it is desirable that the volume shown at 67 be substantially smaller than the remaining volumes. This volume may be controlled by movement of the partition 69 toward the dome 68, or it may be formed as an integral part of the retaining washer 58. Thus, the volume 67 may be reduced to the minimum required by the maximum displacement of the vibrating system. The number of sections may be increased, if desired, by successively reducing the volumes 59, 60 and 61, and by the addition of additional partitions and connecting tubes. By thus increasing the number of sections and the length of the network or line, the ratio of the stiffness at low and at very high frequencies can be increased considerably.

In the embodiment shown in Figure 2 the tubes 73 perform the same coupling function between volumes 72 and 74 that the tubes 64, 65 and 66 provide between volumes 59, 60, 61 and 67.

Referring now to the embodiment shown in Figure 3, an alternative construction is provided in which a plurality of pairs of relatively thin flexible members 160 and 161 form support means to which is cemented a thin perforate screen 162, which may be made of porous cloth, felt, or similar material, or formed as a light metal screen. In situations in which no other provision is made for the by-passing of the high resistance fluid flow path between the voice coil 163 and the top plate 164, it is necessary that the screen 162 be perforated.

On the other hand, if any of the arrangements previously described are used in which no venting through the flexible member is necessary, this material should preferably consist of a flexible imperforate member, such as rubber, leather, thin sheet metal or the like, which has a slight amount of elasticity and a large amount of mechanical resistance to suppress the natural modes or vibrations of the flexible supporting arms 160 and 161. These supporting arms may either be of the conventional flat radial or non-radial type.

As an alternative, in place of the screen 162, the centering and enclosing functions may be separated by the use of a bellows-like collar 165 which preferably is corrugated eccentrically, having corrugations which vary in depth and width at different parts of its circumference to supress the natural modes of vibration. The same precautions should be exercised in its design and construction that are exercised in the case of the flexible support members. It may be perforated in a case in which the high impedance fluid paths are to be shunted through this member, or it may be imperforate in cases in which the effect of the high impedance path is eliminated by eliminating the pressure differential as described in connection with Figure 1.

The flexible centering means is supported upon a ring member 166 which is fastened to the top plate 164 by means of screws 167. These screws pass through clearance holes in the top plate so that the voice coil may be centered in the gap, after which the screws 167 are tightened. The flexible supporting members 160 and 161 are clamped by the circular channel or clamping ring 168, and the space between the screen 162 and the top plate, indicated at 169, is vented through the ports 170 formed in the supporting ring 166. This volume is also vented through the top plate by means of ports 172 formed therein, which preferably are covered by screen members 173.

The volume or chamber 174, beneath the dome 175, which dome is preferably provided with reenforcing ribs 176, similar to the ribs shown in Figure 2, is vented through the diagonal ports 177 and through the dome-shaped depression 178, the depression 178 communicating through ports 179 with the annular chamber 180 formed by the closure member 182. This chamber 180 is vented through ports 183 and screens or filter members 184 into the space occupied by the field coil 185.

By the provision of the depression 178, the volume under the dome 175 is considerably increased, and the pressure variations are therefore correspondingly reduced. As far as possible, the construction at the core tip is formed to prevent increasing the reluctance of the core tip. The diagonal vents 177 in the voice coil bobbin 186 are so formed that the intermediate supports between the ports 177 act as the stiffness members through which the voice coil drives the cone 187. By increasing the angle subtended by the strips with the axis of the coil, the stiffness can be reduced, and therefore the angularity of the openings 177 will, to a large extent, determine the selection of the stiffness produced by the voice coil assembly and thus will control the mass of the voice coil winding and the effective mass of the cone at high frequencies, so that the sound radiated at high frequencies can be increased or decreased as desired. It will be noted that the dome 175, with its reenforcing webs 176, is provided with a shoulder 188 which cooperates with a corresponding shoulder 189 of the voice coil bobbin 186 to bear directly against the diaphragm 187. The dome 175 is thus provided with enclosed reenforcing members and with a shoulder which bears directly on the voice coil bobbin shoulder and provides good thermal conduction to the voice coil bobbin 186 and diaphragm 187. The dome is preferably formed, in each of the embodiments of the invention described, of some light weight metal having high heat conductivity, such as aluminum, magnesium beryllium and their alloys.

What is claimed is:

1. In a loud speaker, field magnet structure forming an annular fluid gap, a vibrating assembly comprising a diaphragm, a bobbin closed at its outer end and carrying a voice coil, and a closure member attached to the outer surface of the diaphragm near the small end thereof, means including the inner end of said bobbin forming a chamber located within said magnet structure and communicating with said fluid gap, means including said closure member forming a cham-

ber located without said magnet structure and communicating with said first-mentioned chamber through said gap, and means including said bobbin forming a chamber located without said magnet structure and communicating with said first-mentioned chamber through said gap, each of said three chambers being of such volume and so related to the volumes of the other two chambers that the instantaneous proportionate volumetric displacement within each chamber resulting from movement of the vibrating assembly is the same in all chambers.

2. In a loud speaker, field magnet structure forming an annular fluid gap, a vibrating assembly comprising a diaphragm, a closure member attached to the outer surface of the diaphragm near the small end thereof, and a bobbin centered within said gap and dividing said gap into an inner annular passageway and an outer annular passageway, said bobbin being closed and attached at its outer end to the small end of the diaphragm and carrying a voice coil, means including the inner end of said bobbin forming an internal chamber located within said magnet structure and communicating with both the inner and outer annular pasageways, means including said closure member forming a first external chamber located without said magnet structure and communicating with said internal chamber through the outer annular passageway, and means including said bobbin forming a second external chamber located without said magnet structure and communicating with said internal chamber through the inner annular passageway, the volumes of said three chambers being such and so related that instantaneous pressures in all chambers are always equal whereby the pressure differentials at the ends of both annular passageways are substantially nil.

3. In a loud speaker, field magnet structure comprising a top plate having a central opening and a central pole piece extending through said opening to form a fluid gap, said central pole piece having a well formed therein opening at the exposed tip thereof, a vibrating assembly comprising a diaphragm, a bobbin closed at its outer end and carrying a voice coil, and a closure member attached to the outer surface of the diaphragm near the small end thereof, means including the inner end of said bobbin forming a chamber located within said magnet structure and communicating with said fluid gap, means including said closure member forming a chamber located without said magnet structure and communicating with said first-mentioned chamber through said gap, and means including said bobbin forming a chamber located without said magnet structure and communicating with said first-mentioned chamber thrcugh said gap, said last-mentioned chamber including the volume of the well within said central pole piece, the volumes of said three chambers being such and so related that instantaneous pressure variations resulting from movement of the vibrating assembly are the same in all chambers.

4. The structure of claim 1 and including a network of acoustic reactance chambers coupled with and forming a part of the volume of at least one of the two chambers without the field magnet structure.

5. The structure of claim 3 and including at least one transverse partition within the well of the central pole piece forming at least two acoustic reactance chambers and a tube segment passing through the partition to acoustically couple adjacent reactance chambers.

6. The structure of claim 3 in which communication between the volume within the bobbin and the volume within the well in said central pole pieces is restricted to a relatively long and narrow passageway.

7. In a loud speaker, field magnet structure forming an annular fluid gap, a vibrating assembly comprising a diaphragm, a bobbin closed at its outer end and carrying a voice coil, an open spider centering member attached to said diaphragm at the small end thereof, and a flexible closure member attached to the outer surface of the diaphragm at a small distance from the small end thereof, means including the inner end of said bobbin forming a chamber located within said magnet structure and communicating with said fluid gap, means including said bobbin forming a chamber located without said magnet structure and communicating with said first-mentioned chamber through said gap, and means including said flexible closure member forming a chamber located without said magnet structure and communicating with said first-mentioned chamber through said gap, said centering member being disposed within said last-mentioned chamber, each of said three chambers being of such volume and so related to the volumes of the other two chambers that the instantaneous proportionate volumetric displacement within each chamber resulting from movement of the vibrating assembly is the same in all chambers.

HUGH S. KNOWLES.

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