March 27, 1962 L. GLADSTONE 3,026,957

LOUDSPEAKER SYSTEM

Filed June 2, 1959

FIG. 1.

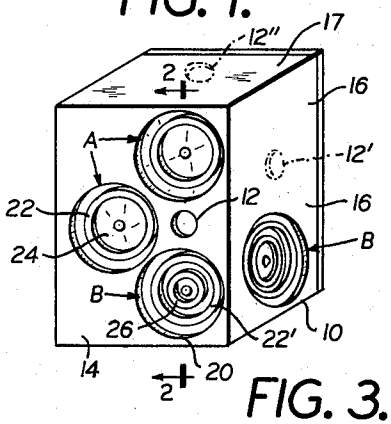


FIG. 2.

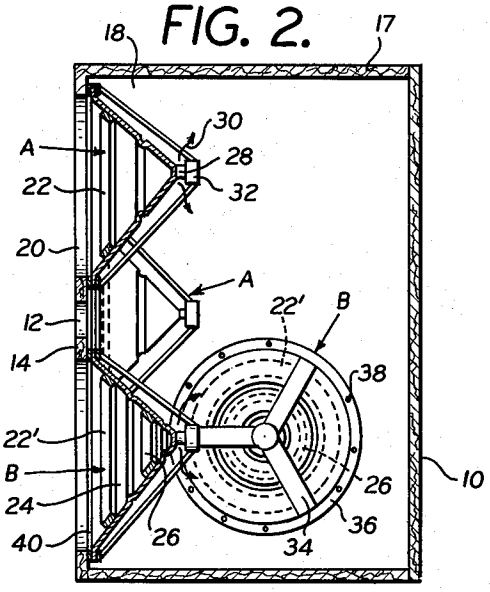


FIG. 3.

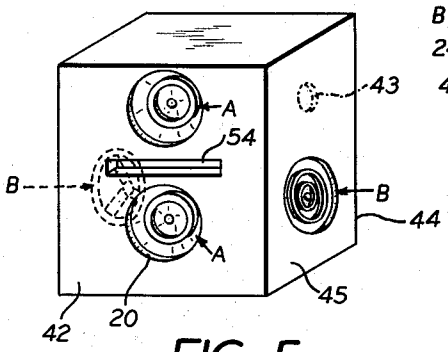


FIG. 4.

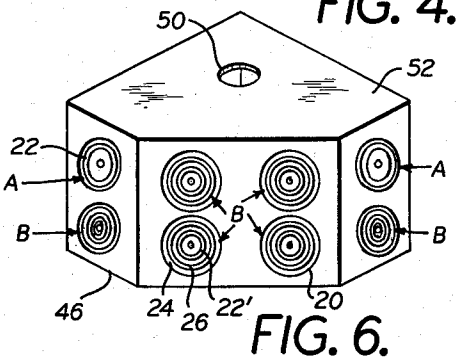


FIG. 5.

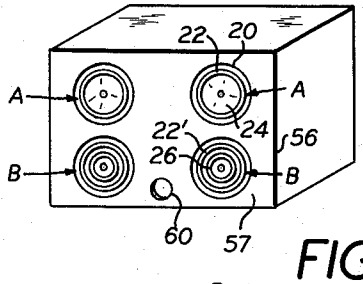


FIG. 6.

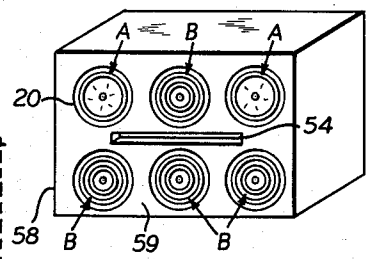
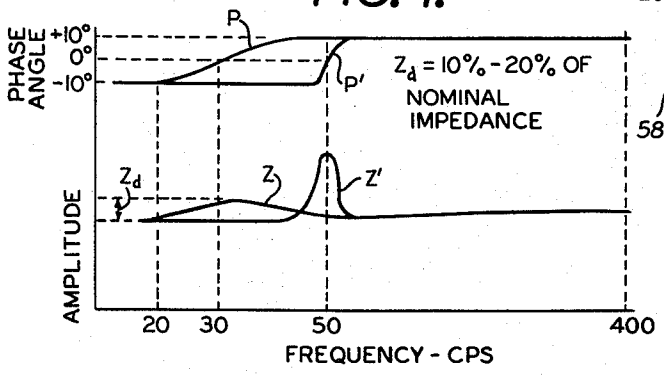


FIG. 7.



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LOUDSPEAKER SYSTEM

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This invention relates to the art of acoustics and particularly concerns a novel loudspeaker system.

A principal object of the invention is to overcome difficulties and disadvantages experienced with conventional loudspeakers and loudspeaker systems. These problems and difficulties involve:

A. Non-linear air loading with respect to frequency. This phenomenon directly limits the bass and sub-bass regions of the audible frequency spectrum of the loudspeaker system and is a source of many other difficulties.

B. Non-linear distortion. This condition results in harmonic and intermodulation distortion products in the acoustic output. It is most prevalent in large cone excursions in the bass and sub-bass regions of the spectrum.

C. Non-linearity of cone transmission velocity with changes in frequency. This condition manifests itself as peaks in the acoustic output, in frequency response changes with amplitude, and causes distortion due to non-linearity of the cone in flexure.

D. Mechanical damping of the fundamental self-resonance of the cone. This condition can be a source of distortion, of instability upon aging, and can cause a loss of efficiency in the piston region of the cone.

E. Impedance and phase shift effects. These effects cause instability of driving amplifiers, and tend to make the loudspeaker system performance depend on electrical characteristics of the driving amplifiers.

F. Adverse effects on bass range performance due to internal air pressures developed in closed radiators. This condition has heretofore required unduly large cabinets in association with the loud speakers in order that reasonable efficiency coupled with low fundamental mechanical resonance is maintained.

G. Difficulties caused by use of horns. These devices, by virtue of their high radiation resistances, tend to minimize some adverse effects produced by use of cone radiators, but they introduce other difficulties, particularly when reasonably small-sized cabinets are employed for production of very low, audible frequencies. Horns have limited frequency ranges, so that additional drivers are required to produce a complete audible frequency spectrum. Small sizes of horns raise the bass cut-off frequency of the associated acoustic system and lower the efficiency of sound transmission to that of a direct radiator at very low frequencies or cut off entirely the very low frequencies.

A further object of the invention is to provide a loudspeaker employing a plurality of properly loaded, cone-type loudspeakers whereby the difficulties and problems encountered with prior known loudspeakers systems are avoided and substantial linearity of response over the effective range of the system is maintained.

The invention will be best understood from the following detailed description taken together with the drawing wherein:

FIG. 1 is a perspective view of a loudspeaker cabinet employing a loudspeaker system embodying the invention.

FIG. 2 is a sectional view taken on an enlarged scale on line 2—2 of FIG. 1.

FIGS. 3–6 are perspective views of other loudspeaker systems according to the invention.

FIG. 7 is a graphical diagram useful in explaining the invention.

Referring to FIGS. 1 and 2, there is shown a substantially closed rectangular cabinet 10 having a port 12 in any side such as the front side 14. The port may be located in any other side such as indicated at 12′ and 12″ in walls 16 and 17 respectively. In the front and side walls 14, 16 and 18 are openings 20 in which are secured conical loudspeakers of either of two types, designated A and B in the drawing. The loudspeakers of type A carry a single annular loading ring 22 on their conical bodies 24 located close to the open ends thereof. The loudspeakers of type B have a similar loading ring 22′ and in addition a further smaller loading ring 26 is secured to the bodies 24 and located closer to the apical ends of the bodies. The loudspeakers have conventional voice coils 28 energized via wire leads 30 and operated in conjunction with permanent magnets 32. Spider frames 34 support the magnets and voice coils at the apical ends of the conical bodies and are secured to frame rings 36. The loudspeakers are secured to the walls of the cabinet by screws 38. Rings 40 are gaskets which seal the loudspeakers at the cabinet walls.

It will be noted that the basic structures of the loudspeakers are substantially conventional. The structures are modified by the addition of the novel loading rings 22, 22′ and 26 to accomplish the new and unusual acoustic results, in conjunction with the remainder of the system, as will be described.

Each of the rings 22, 22′ and 26 is formed of a non-hardening flexible substance such as mastic or a latex. This substance can be applied in plastic or viscous form to the fibrous body of each loudspeaker and will adhere thereto to accomplish the desired mechanical loading of the cone. The system employs five loudspeakers of which two loudspeakers have the single loading ring while the remainder of the loudspeakers have two loading rings.

In FIGS. 3 to 6 are shown various other arrangements for the loudspeaker system. In FIG. 3, four loudspeakers are employed, two of type A on the front wall 42 of cabinet 44 and one each of type B on the side walls 45. Cabinet 46 shown in FIG. 4 is a corner type loudspeaker having four loudspeakers of type B on the front wall 47 and two loudspeakers on each of the angularly disposed end walls 48 and 49. One loudspeaker on each of the end walls is of type A and one is of type B. A port 50 is provided in the top 52 of the cabinet. An elongated rectangular port 54 is provided in cabinet 44 but if desired a differently shaped port may be located in any side such as port 43 indicated by dotted lines in side wall 45.

FIGS. 5 and 6 show rectangular cabinets 56 and 58 having four and six loudspeakers in their front walls 57 and 59 respectively. Two of the loudspeakers of each system are of type A and the others are of type B. A port 60 is shown provided in wall 57. A port may be provided in any wall of cabinet 58 as shown at 54 in FIG. 6. It is possible to fabricate each of the cabinets without a bottom if the cabinet is to be set down flat on a floor. The floor will then serve as the bottom of the cabinet. At least two of each of the loudspeakers in the cabinet should be of type A and the others should be of type B.

In order that a better understanding may be had of the advantages obtained by the present invention, reference is made to FIG. 7. Curves Z and P are representations of electrical impedance and phase angle characteristics of a loudspeaker system such as shown in FIGS. 1 and 2 in which six loudspeakers are employed, two of type A and four of type B. Curves Z′ and P′ are representations of impedance and phase angle characteristics of a loudspeaker system with conventional loudspeakers arranged as shown in FIGS. 1 and 2 but without the loading rings 22, 22′ and 26 which characterize the loudspeakers of types A and B.

The impedance curves are plotted as amplitude against

frequency of the several systems. It will be noted that the impedance of the system with the types A and B loudspeakers having loading rings, has an impedance variation Z_d which does not exceed more than 10% to 20% of the nominal impedance of the system. In the system using conventional loudspeakers by contrast, a sharp peak occurs at the mechanical resonant frequency of the system. The phase angle of the system employing types A and B loudspeakers changes sign slowly between —90° and +90° at the fundamental resonance frequency.

The present invention depends on its effectiveness on the use of a multiplicity of loudspeakers having different low resonant frequencies, with different mechanical loading of the loudspeakers. The loudspeakers employed in the present system preferably all have cones 24 which vibrate in parts and which decouple at approximately one kilocycle per second. Their fundamental resonant frequencies occur in the low bass region below sixty cycles per second. The cones of type A loudspeakers decouple smoothly at eighty cycles per second due to the presence of the single loading rings 22, and these loudspeakers attain full output in the range of 200 to 600 cycles per second. Each of the rings 22 and 22' in the loudspeakers of types A and B are thick and heavy and provide radial rigidity near the front of the loudspeaker. These rings lower the resonance frequencies of the loudspeakers. By employing a slightly different mass of material in each of the rings 22 and 22' it is possible to insure that each loudspeaker has a different low resonant frequency. Rings 26 in the loudspeakers of type B are moderately heavy and operate to suppress or control interference effects which would otherwise occur in the mid-range of approximately 300 to 600 cycles per second.

Each of the six loudspeakers in the system of FIG. 6 covers the same general region of the audible frequency spectrum but all different in mechanical resonant frequency and loading. Their size is large and distributed over an area which is somewhat large compared to the wavelengths of the frequencies radiated. As a result, the sound has a more diffused quality, free of beaming and the well known "hole in the wall" effect. Interference effects which normally occur at half wavelength spacing points in a conventional loudspeaker system are minimized and controlled by the judicious use of rings 26. Where conventional systems experience a sharp rise of about three times the nominal impedance and often more, the present system experiences a change in impedance of no more than 20% of nominal impedance. The attendant phase shifts are reduced accordingly and the in-phase or real currents are representative of the actual useful cone velocities. As a result, the amplifier which is normally used to drive the voice coils is more uniformly loaded and its internal feedback stability is increased. The damping imposed by the amplifier has no significant effect since the damping characteristics are now produced by, and are self-contained in the loudspeaker system per se without regard to the driving amplifier.

Since the cones in the present system interact with each other, each of the cones tends to relieve air pressure experience by the others in the same degree as the reactive components are cancelled. The phase shifting which occurs between cones reduces air pressures. This occurs regardless of the manner of connection of the voice coils, i.e., parallel, series-parallel, parallel or other arrangement. In the present system, the combined effects of improved air loading and coupling and novel selective damping result in a bass radiating efficiency increase of approximately ten to twelve db as compared with the highest quality prior known loudspeaker systems.

Non-linear distortions in the present system are kept to negligibly small values. For example, at twenty cycles per second and thirty-five watts input, such distortions range well below 3%. This low distortion characteristic is due to the reduction in cone excursions by a factor of thirty-six times or more, a reduction in velocities of each cone by more than thirty-six times in the bass regions, and by at least a factor of six in the higher frequency region; and prevention of undesired flexures of the cones because of the novel damping means employed.

In operation of the system of FIG. 6, six driving cones of equal size provide thirty-six times as much effective piston or sound radiating area as a single cone of that size. Below the point of ultimate air resistance the air load that each cone encounters falls off as the inverse square of the frequency, or about twelve db per octave. This point of ultimate air resistance is a function of the effective piston or radiating area. By increasing the effective radiating area, the ultimate air load is shifted downward with resulting improvement in bass radiation efficiency. Since the increase is, in general, proportional to the square of the increased vibrating area, the six loudspeakers employed provide an improvement in radiating efficiency by a factor of thirty-six. This applies to air coupling. Since the cone air loading is increased thirty-six times, the axial excursion of each cone for a given bass power radiating level is decreased proportionately by thirty-six times. As a matter of fact due to the proximity of the cones to each other and to the adjacent floor, walls and ceiling where the system may be installed, the apparent radiating area is even further increased. This is due to air trapped between the driven loudspeaker cones and between external boundaries such as floor, walls and ceiling, so that the six cone array provides somewhat more than thirty-six times better radiation efficiency than a single cone.

Because of the much lower cone velocities and the damping means employed in the system, cone "breakup," i.e., vibrations in undesired directions and in random parts, is substantially eliminated. The attainment of this desirable objective is evidenced by the uniformity of response characteristics manifested by the system when operated anywhere, at from very low to very high power levels, the smoothness of response, and freedom from distortion in the effective radiation range of the system.

Because of the different fundamental resonant frequencies of the loudspeakers due to their different masses and compliances, the individual cone phase shifts tend to be conjugate or complementary, i.e., positive and negative shifts of each cone are equal in magnitude and opposite in sign to phase shifts of adjacent cones. Thus each voice coil is loaded by conjugate loads imposed by the other voice coils. Acoustically, each cone tends to circulate the equivalently reactive air into the others. This serves to lower the radiation impedance to reactive components and cancels the effect of the larger mass as far as the damping currents are concerned. The voice coil resistances are more prominent than in conventional systems. No significant damping with its mechanical loading of the cones occurs at frequencies above resonance. This contributes to radiation efficiency and freedom from breakup.

Unsuccessful attempts have been made heretofore to employ damping methods in which a very strong magnetic field is imposed upon the voice coils. Such methods require negative resistance types of outputs from the amplifiers to realize maximum damping. Such amplifiers are somewhat critical in adjustment, increase the complexity and expense of the amplifiers, and increase the cost and complexity of the loudspeakers.

The loudspeakers of type B are loaded so that substantial flatness of response within three db in the range of 200 to 600 c.p.s. is maintained. Above this region the sound wavelengths are too short to cause mutual coupling and interference between the adjacent cones, so that the cones are then quite independent of each other, each reacting with its own air load. The non-uniformity in mechanical resonant frequencies results in high internal damping and smoothness of the impedance characteristics. Because of the controllably different dynamics of

the individual cones there is obtained a composite or blending quality of exceptional smoothness.

The systems which employ less than six loudspeakers may be expected to provide less advantageous results as compared with systems employing six or more loudspeakers. In any case, the use of loudspeakers of types A and B in any system will provide readily audible improvements over any systems not so treated, and will represent an inexpensive and precise control.

The present systems accomplish their superior results without use of special amplifiers, bass compensation or equalization circuits. The cabinets may be of very simple construction and generally employ less material since they may be of smaller size than conventional cabinets of conventional systems employing the same numbers of loudspeakers. The systems described rely wholly on the unique mechanical features to achieve the superior acoustic results obtained. These results are obtained at less cost and with less complexity than has hitherto been considered possible.

It will be helpful at this point to summarize the acoustic and related advantages produced by the present systems.

A system embodying the invention described has the following characteristics:

(1) Improved air coupling.
(2) Improved power handling capacity.
(3) Very low cone velocities to avoid breakup.
(4) Very low cone amplitudes to avoid breakup.
(5) Very low distortion.
(6) Well integrated damping due to diversity of mechanical resonant frequencies.
(7) Low bass resonance.
(8) Reduced phase shift amplitude.
(9) Economical construction.
(10) Stability of damping and driving piston efficiency.
(11) Long life of damping material which resists aging effects.
(12) Broad sound source effects.
(13) Smoothness of response in the acoustic range employed.
(14) Economical reproducibility of dynamic characteristics.

While only a limited number of embodiments of the invention have been disclosed, it will be understood that many variations are possible without departing from the invention as defined by the appended claims.

What is claimed and sought to be protected by Letters Patent is:

1. A loudspeaker system, comprising a substantially closed cabinet having a plurality of joined walls defining a compartment containing air, certain of said walls having openings therein, a plurality of loudspeakers respectively mounted at said openings in the walls, each of said loudspeakers having a cone disposed with a base end at one of the openings and an apical end extending into the compartment, the cones of the loudspeakers having convex sides exposed to a common air mass in the compartment, said cones having concave sides exposed to the exterior of the cabinet for radiating acoustic waves simultaneously into another common air mass, all of the loudspeakers being of substantially the same size and having substantially the same acoustic range of frequency response, all of the cones being mechanically loaded by flexible rings of different sizes, one of said rings being disposed on the concave side of each cone near the base end thereof so that the several loudspeakers have different lowered bass resonant frequencies, certain of the cones being additionally loaded by other flexible rings located close to the apices of the cones on the concave sides thereof to suppress acoustic interference between the loudspeakers in a predetermined acoustic frequency range inside and outside the cabinet in the respective common air masses thereat.

2. A loudspeaker system according to claim 1, wherein each of said rings consists of a non-hardening highly viscous mass of material adhering to the cone.

3. A loudspeaker system according to claim 1, wherein each of said rings consists of non-hardening mastic material.

4. A loudspeaker system, comprising a substantially closed cabinet having a plurality of joined walls defining a compartment containing air, certain of said walls having openings therein, a plurality of loudspeakers respectively mounted at said openings in the walls, each of said loudspeakers having a cone disposed with a base end at one of the openings and an apical end extending into the compartment, the cones of the loudspeakers having convex sides exposed to the common air mass in the compartment, said cones having concave sides exposed to the interior of the cabinet for radiating acoustic waves simultaneously into another common air mass, all of the loudspeakers being of substantially the same size and having substantially the same acoustic range of frequency response, all of the cones being mechanically loaded by flexible rings of different sizes, one of the rings being disposed on the concave side of each cone near the base end thereof so that the several loudspeakers have different lowered bass resonant frequencies, said loudspeakers exceeding two in number, all of the loudspeakers except two thereof being additionally loaded by other rings located close to the apices of the cones on the concave sides thereof to suppress acoustic interference between the loudspeakers inside and outside the cabinet.

5. A loudspeaker system, comprising a substantially closed cabinet having a plurality of joined walls defining a compartment containing an air mass, certain of said walls having openings therein, a plurality of loudspeakers respectively mounted at said openings in the walls, each of said loudspeakers having a cone disposed with a base end at one of the openings and an apical end extending into the compartment, the cones of the loudspeakers having convex sides exposed to the common air mass in the compartment, said cones having concave sides exposed to the exterior of the cabinet for radiating acoustic waves simultaneously into another common air mass, all of the loudspeakers being of substantially the same size and having substantially the same acoustic range of frequency response, all of the cones being mechanically loaded by flexible rings of different sizes, one of said rings being disposed on the concave side of each cone near the base end thereof so that the several loudspeakers have different lowered bass resonant frequencies, the cone of at least one of the loudspeakers being additionally loaded by another flexible ring located close to the apex of the cone of said one loudspeaker on the concave side thereof to suppress acoustic interference between the loudspeakers, inside and outside the cabinet in a predetermined acoustic frequency range.

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