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ACOUSTIC SYSTEM FOR LOUD-SPEAKERS

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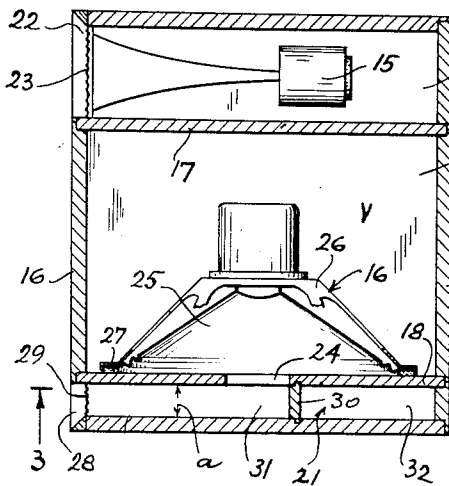


FIG. 2.

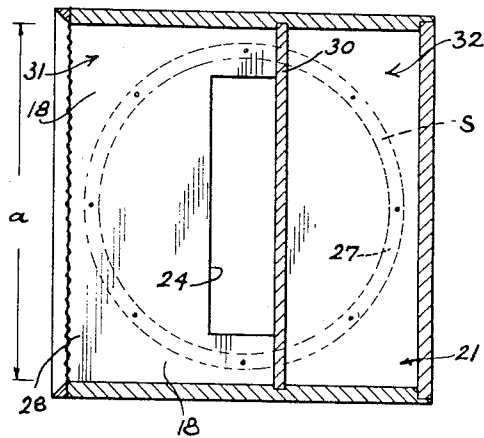


FIG. 3.

FIG. 1.

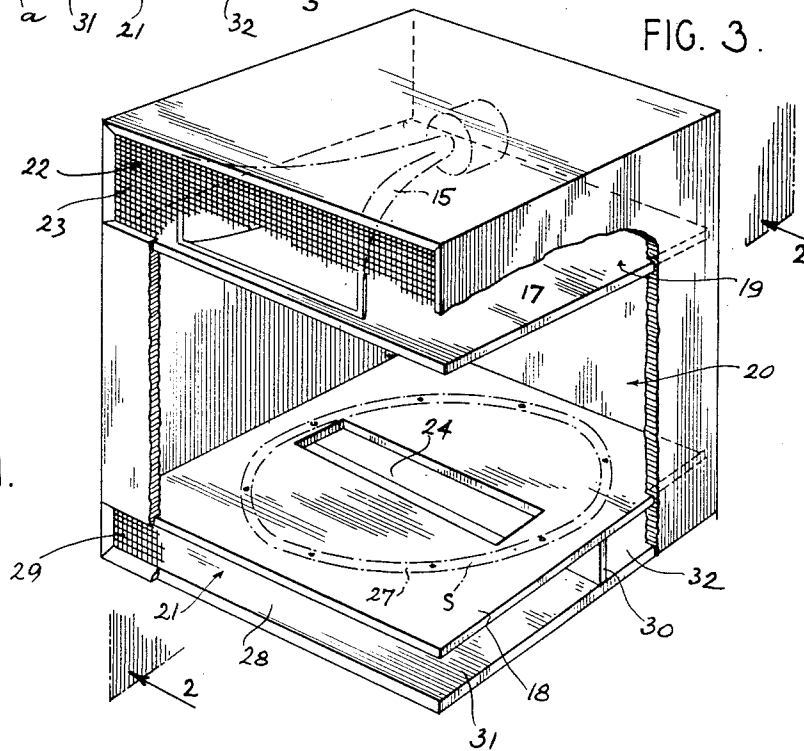
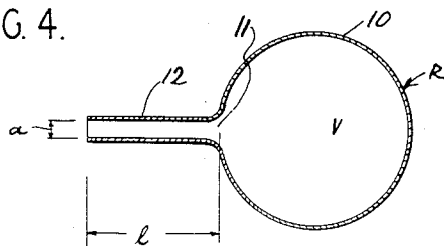


FIG. 4.



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ACOUSTIC SYSTEM FOR LOUD-SPEAKERS

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3 Claims. (Cl. 181—31)

This invention relates to sound-reproducing apparatus and more particularly to acoustical enclosures for loud-speaker systems.

The art reveals evidence of many attempts to produce sound with maximum fidelity throughout the audible frequency range and especially at the low audio frequencies. Several of such attempts have been eminently successful, but have necessitated the utilization of enclosures, baffles, cabinets, horns and the like which are extremely large relative to the size of the speaker employed. The widespread use of such arrangements has therefore been limited since rooms in average homes are too small to house such large cabinets or baffles in addition to a radio, television, or phonograph set, and other furniture.

The main problem in the field, therefore, has been to provide a speaker enclosure or system which will produce a satisfactory response in the low frequencies while at the same time being small enough to be built or mounted in a normal console-type television or radio set.

One attempt at solving this problem has been the provision of the so-called "bass reflex" type of cabinet which has resulted in cabinets of fairly moderate size, but which is subject to several disadvantages, including the necessity of coordinating the enclosure exactly with the characteristics of the loudspeaker unit used if optimum results are to be obtained, and compromising the fidelity of sound in the low frequencies where space restrictions govern. Even the general type of "bass reflex" enclosure, however, is too large for general use.

The present invention contemplates the mounting of a speaker within a compartment which is entirely enclosed except for an opening which connects the internal speaker cone with an outside duct opening into the atmosphere.

It is the principal object of this invention to provide a speaker enclosure of the character described in which the compartment is only slightly larger in size than the speaker housed within.

Another object of the invention is the provision of a speaker enclosure of the character described, in which the size limitation of the enclosure is attained while at the same time providing smooth response frequency characteristic, over a wide range and especially in the low audible frequency range.

Still another object of the invention is the provision of a speaker enclosure of the character described which can be easily imparted with a selected natural resonant frequency in the low audible frequency range, which frequency will remain substantially constant regardless of the type or size of speaker mounted within the enclosure.

Other objects and advantages of our invention are set forth in the following description and drawings which illustrate a preferred embodiment thereof, it being understood that the above statement of the objects of the invention is intended to explain the same without limiting it in any manner.

Fig. 1 is a perspective view of a speaker enclosure constructed according to the invention, with the major portion of the front and side wall broken away to reveal the internal construction thereof.

Fig. 2 is a section taken along the plane 2—2 of Fig. 1.

Fig. 3 is a section taken along line 3—3 of Fig. 2.

Fig. 4 is a vertical section through the center of a classical Helmholtz resonator.

In its broad aspect, the invention comprises the mounting of a loudspeaker within an enclosed compart-

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ment having a duct, the dimensions of said duct and compartment being generally determined by the formulae developed in the construction of Helmholtz resonators.

Fig. 4 shows a classical type of Helmholtz resonator R which comprises an enclosed spherical cavity 10 which has an orifice 11 communicating with a cylindrical duct 12. The resonator R also generally was provided with a protuberance opposite the duct 12, which protuberance was sized to fit within the ear. When in this position, the air in resonator R would vibrate when an external sound, having the same frequency as the natural resonant frequency of the resonator, was directed toward the open end of duct 12. The resonator was, therefore, used in the acoustic analysis of complex sounds, especially musical sounds.

It was early discovered that by varying the ratio of the internal volume of the cavity 10 to the internal volume of the duct 12, the natural resonant frequency of the resonator R would vary to such an extent that any selected resonant frequency within the audible range could be produced. The formula developed for controlling the resonant frequency of such a Helmholtz resonator is as follows:

$$f = \frac{C}{2\pi} \sqrt{\frac{S}{lV}}$$

where

C=velocity of sound

S=cross-sectional area of the duct

V=volume of the cavity

l=length of duct

The Helmholtz resonator and the formulae applying thereto are amply discussed in the literature on acoustics.

As was previously mentioned, the Helmholtz resonators have heretofore been used only in conjunction with measurement of external sounds. We have discovered that by mounting a loud speaker within a closed compartment, a duct may be added thereto and the entire arrangement may be constructed in accordance with the Helmholtz resonator principle to selectively provide any desired resonant frequency to the system.

One of the long-standing problems in acoustical engineering has been to produce low fundamental cabinet resonance and low basic cone resonance for smooth reproduction down to the lowest audible frequencies. These low resonances are required to raise the volume of the response in the low frequency range since, as is well known the response curve tends to drop sharply in this range. A further problem has been the elimination of resonant peaks throughout the frequency range in the vicinity of 100 cycles, and below since distortion is generally emphasized in this range. Heretofore, it has required very large speaker enclosures or enormous baffles to overcome this difficulty. In an attempt to reduce the size of the enclosure, intricate systems of labyrinthine passages have been devised, but the total size of the system has remained too large for widespread popular use. Eight to ten cubic foot enclosures are quite common, and many larger ones are commercially marketed for bass speakers having cone resonances of sixty cycles or less. Such enclosures have sides of large area which in themselves tend to vibrate to produce false resonances unless properly braced or fortified to prevent such vibration. The art reveals numerous arrangements for reducing undesirable resonances in the speaker cabinet by the use of thick oak walls, brick, concrete, sand-filled panels, and the like.

By contrast, we are able to achieve the same ends in a very simple and economical manner by the use of relatively diminutive speaker enclosures. The small proportions of the enclosure in itself eliminates many of the aforementioned problems, as will be later set forth.

Figs. 1 to 3 illustrate a preferred embodiment of the invention. The cabinet shown therein employs separate compartments or enclosures for a high frequency speaker or "tweeter" 15 and a bass speaker or "woofer" 16, which arrangement is optional. The "tweeter" and "woofer" types of speakers are conventional and well-known, and are therefore neither shown nor described in detail.

The speaker 15 and 16 are adapted to be connected to the usual amplifier-fed dividing network which feeds low frequencies only to the "woofer" 16 and high frequencies only to the "tweeter" 15. Such arrangements are also common in the art, and are therefore not shown.

The cabinet contains two spaced, parallel partitions 17 and 18 which divide the interior of said cabinet into an upper compartment 19, central or intermediate compartment 20, and a lower compartment 21.

The upper compartment 19 is completely enclosed except for an open front end 22 which may be covered by the usual grill or speaker cloth 23. The high frequency speaker or "tweeter" 15 is mounted in the conventional manner within the compartment 19, namely, with its mouth directed toward the open front end 22. The arrangement of the "tweeter" 15 forms no part of the present invention except insofar as it completes the acoustical arrangement of the system shown. Optionally, the "tweeter" 15, if it is of the type shown in Figs. 1 and 2, with an enclosed horn, may be mounted within the interior of the central compartment 20, with the mouth of said horn extending through and closing off an opening provided in said compartment 20. As an alternative, the "tweeter" 15 and its enclosure 19 may be entirely eliminated, and the cabinet designed for a single speaker which covers the entire audible frequency range, as will be presently described in greater detail.

The central or intermediate compartment 20 is completely enclosed on all sides by the cabinet walls and the partitions 17 and 18. The partition 18 is however provided with a through-and-through central aperture 24 which is preferably elongated and rectangular. The aperture 24 opens into the lower compartment 21.

The bass speaker or "woofer" 16 is of the usual construction and includes a speaker cone 25, a frame 26, and a mounting ring 27 affixed to the frame 26. The mounting ring 27 contains the usual spaced holes through which screws or bolts may be inserted for clamping said ring 27 tightly against the mounting surface. In the present instance, the ring 27 is mounted centrally on the upper surface of the partition 18 in the position indicated by the broken line circle S in Figs. 1 and 3. In this position, the center of the speaker cone 25 is located above, and in registry with the center of the aperture 24. The mounting ring 27 is preferably clamped tightly against the upper surface of partition 18 so that no air or sound waves can pass beneath the speaker mouth from the back of the cone 25 to the interior thereof, or vice versa.

It is to be noted that the area of the aperture 24 is appreciably smaller than the mouth area of the cone 25.

The lower compartment 21 has an open front end 28 which may be covered by a grill or speaker cloth 29. The compartment 21 contains a transverse vertical partition 30 which extends the entire width and height of said compartment 21 and divides it into a forward duct 31 and a rear chamber 32 which is entirely enclosed. As shown in Figs. 2 and 3, the partition 30 is flush with the rear longitudinal edge of the aperture 24, so that the duct 31 extends from said rear edge to the front open end 28 of lower compartment 21.

It is apparent that sound waves emitted by the mounted bass speaker 16 will pass from the interior of the speaker cone 25 through the aperture 24, into the duct 31 and thence through the open front end 28.

This construction of the lower compartment 21 is optional, it being emphasized that the shapes and arrangements in which the duct 31 may be made are too numerous to mention. For example, the duct may extend the length or width of the cabinet and be open at both its front and rear ends, thus eliminating the closed chamber 32, or, alternatively, all four sides of the duct may be open. Again, the duct 31 may be located above the compartment 20 with the speaker 16 inverted and facing upwardly.

It will be noted that the compartment 20 and the duct 31 roughly correspond to the Helmholtz resonator R shown in Fig. 4. Thus the compartment 20 corresponds to the cavity 10, the aperture 24 to the orifice 11, and the duct 31 to the duct 12. This being the case, it is then apparent that the Helmholtz principle of resonant frequency will apply to the speaker enclosure, and tests have proved this to be so. Certain modifica-

tions have, however, been developed in the Helmholtz formula due to the configuration and shape of the duct employed. For example, the duct 31 is folded so that it is contiguous with and parallel to the partition 18 instead of extending perpendicularly therefrom as in the conventional Helmholtz resonator R. This folded arrangement of the duct 31 is made to provide a compact cabinet of smaller overall dimensions and does not in any way lessen the efficiency of the enclosure.

It will be further noted that the internal dimensions of the entire compartment 20 are not much greater than the external dimensions of the speaker. This desirable arrangement is achieved without sacrificing low frequency response, by the utilization of the Helmholtz principle.

Since according to the Helmholtz resonator formula, the resonant frequency of the cavity 10 in Fig. 4 depends not upon its size but upon the ratio between the internal volume of the cavity 10 and the internal volume or mass of air within the duct 12, the cavity 10, however small, may be given any selected resonant frequency provided that the duct 12 is dimensioned accordingly. The same is true with the speaker enclosure shown in Figs. 1-3, although practical minimum limits on the size, shape and selected resonant frequency of the enclosure are set by the size and acoustical characteristics of the speaker 16.

As was previously indicated, the Helmholtz formula as applied to the classical Helmholtz resonator shown in Fig. 4, has been modified to conform to the peculiarities of the loudspeaker system of the present invention. The modified formula is as follows:

$$f = \frac{C}{2\pi} \sqrt{\frac{S^2}{V(Sl + E)}}$$

where

C is the velocity of sound,

S is the cross-sectional area of aperture 24,

l is the length of duct 31,

V is the volume of compartment 20, and

E is the end correction at both ends of duct 31.

The quantity S which corresponds to the cross-sectional area of aperture 24 may also correspond to the cross-sectional area of the duct 31 which is represented by the reference letter *a* in Fig. 2. This is the case in the preferred embodiment shown in the drawings in which we prefer to make the area of the aperture 24 of approximately the same cross-section as the duct 31 for the convenience of formulation and computation. For purposes of explaining the above formula, it will be assumed that these cross-sections are equal, or substantially equal. The formula to be applied if these cross-sections are unequal will be presently described.

The symbol V corresponds to the volume of enclosed air within the compartment 20, and is measured by the total internal volume of said compartment, from which is deducted the volume of the speaker frame 26 and its magnet housing.

The symbol C represents the velocity of sound which, at an average room temperature of 68° F., is 1122 feet per second.

The length l of the duct 31 is its actual length measured axially from its front open end 28 to the partition 30.

As presented in the formula, the quantity Sl in the denominator expresses the mass of air in the duct 31 which reciprocates or swings back and forth when the speaker cone 25 vibrates. To this air mass is added the quantity E which represents the end correction or masses of air extending from both ends of the duct 31 which also swing when the cone 25 vibrates.

End correction as developed by Rayleigh in his book "The Theory of Sound," Dover Publications, N. Y., 1945, vol. II, sec. 307, is approximately equal to the volume of a hemisphere of air extending from the end of an open tube of circular cross-section. The volume of such a hemisphere would be $.67\pi r^3$, where *r* is the radius of the tube, whereas Rayleigh's work develops approximately $.8\pi r^3$ as end correction for a tube of circular cross section. In the case of a rectangular duct, such as the duct 31, the end correction would thus correspond to a hemi-cylindrical mass of air arising upon, or extending from both ends of said duct 31. The end correction E at the outer open end 28 of the

duct 31 may be found according to the following equation:

$$E = \frac{\pi h^2 w}{2}$$

where h is the height of the duct 31 and w is the width of said duct.

The same equation is used to find end correction at the inner end of the duct 31, substituting the dimensions of aperture 24 for the values h and w .

For very accurate computations, the stiffness of the speaker cone mounting should be included, but we have found that this is generally a negligible factor in the result because the relatively small cavity contributes the greater stiffness.

With the aforementioned values for the symbols, the modified Helmholtz formula can be applied to the speaker enclosure in order to determine the resonant frequency of the enclosure or to determine the compartment volume-duct area ratio for the achievement of a selected resonant frequency.

Without materially increasing the size of the bass speaker compartment 20, we are thus able to select a natural resonant frequency of the enclosure which will exactly or substantially match the resonant frequency of the speaker cone 25. For example, the enclosure may be afforded a resonant frequency in the neighborhood of 50 cycles per second, and the responsive curve may therefore be flattened out thus eliminating the sharp drop in the response curve usually experienced at these frequencies, and producing a relatively smooth and wide response curve through the low frequency range.

By the way of specific illustration, in the arrangement shown in the drawings, the bass speaker 16 may have a diameter of fifteen inches. The cabinet shown, which houses a speaker of this size, has over-all dimensions of 19½ inches in height, 18 inches in length, and 18 inches in width, although it may be made smaller if the "tweeter" compartment 19 is eliminated. The interior of the bass speaker compartment 20 measures 11¼ inches in height, by 16½ inches in width, by 16½ inches in depth. The internal volume of the resonant cavity is thus 3062 cubic inches. From this is subtracted the volume of the speaker magnet housing and frame which is approximately 190 cubic inches, leaving a total effective volume of 2872 cubic inches. The aperture 24 is 10 inches by 2½ inches, thus having an area of 25 square inches. The height and width of the duct 21 measured at a is 1¾ inches by 16½ inches, so that its cross-sectional area is 22.7 square inches, an amount which is approximately equal to the area of aperture 24. The length of duct 21 is 10¼ inches.

The duct 21 has an internal volume of 232 cubic inches which represents the mass of air in said duct. To find the mass of air in the end correction at the outer mouth of duct 21, the duct cross-sectional measurements of 1¾ inches by 16½ inches are applied to the equation

$$E = \frac{\pi h^2 w}{2}$$

resulting in an end correction of 12 cubic inches. Using the same equation and applying the dimensions of aperture 24, the mass of air in the end correction at the inner end of the duct 21 is revealed to be 25 cubic inches. The total end correction, or the value E , is thus 37 cubic inches.

The speed of sound C is taken at its value of 1122 feet per second at 68° F.

Applying these values to the modified Helmholtz formula, it will be found that the resonant frequency of the compartment 20 is 55 cycles per second.

The observed resonant frequency of the aforementioned arrangement has been measured to be 55 C. P. S. The audio frequency sound output response curve on tests using a sine wave variable frequency signal generator has been observed to be essentially uniform down to the frequency of 55 C. P. S. and decreasing about 12 decibels per octave below this frequency.

As was previously indicated, we also prefer to make the area of aperture 24 equal or substantially equal to

the transverse cross-sectional area of the duct 31 for the sake of simplicity. We have found, however, that by decreasing the area of either the aperture 24 or the duct 31 relative to the other and keeping all other values constant, the frequency of the combination will be reduced accordingly. Where, for convenience in a particular installation, the area of the aperture 24 appreciably varies from the cross-sectional area duct 31, such variance must be taken into account in the computation of the enclosure resonance. For this purpose the following equation may be utilized:

$$\tan\left(\frac{\pi f}{2\pi f_t}\right) = \frac{2\pi A_d f}{C \frac{A_a}{l_a}} \left[1 - \left(\frac{f}{f_n}\right)^2\right]$$

where

f is the frequency of the combination,

f_t is the frequency of the duct alone (treated as isolated from the compartment),

f_n is the normal frequency of the compartment 20 and its aperture (treated as isolated from the duct),

A_d is the cross-sectional area of the duct,

C is the velocity of sound,

l_a is the length of the aperture (determined by the thickness of the partition wall 18 and the end corrections upon the aperture), and

A_a is the area of the aperture.

This equation is suggested in "Acoustics" by Stewart and Lindsay (1930) at page 59, for application with a Helmholtz resonator which has an aperture of small diameter connecting the cavity to a duct of larger area.

The aperture 24 is shown as being optionally rectangular and transversely elongated, rather than square, so as to enable the sound to emit from a linear source of large over-all size. Good results have, however, been obtained from apertures or openings which were square or round in configuration.

The mounting of the bass speaker 16 within a totally enclosed chamber of small size has the desired effect of improving the loading and damping characteristics of said speaker. The relatively small volume of enclosed air behind the speaker cone 25 will result in good loading while the restricted size of the aperture in front of the speaker will also contribute to this effect. This arrangement therefore makes available to the speaker the excellent damping characteristics of horn loading, and tests have disclosed desirable transient response characteristics which heretofore have required long or large and bulky folded horns.

The small enclosure afforded by the construction previously described, in addition to its adaptability to mounting within a radio or television console-type cabinet, has other advantages which become apparent. In conventional enclosures having walls of large dimensions, the mere size of these walls produces sustained vibration thereof which results in false cabinet resonances. To eliminate these, many systems of bracing, ballasting, and the like have been devised to fortify the enclosure walls. Since all the sides of the compartment 10 are of relatively short dimensions, (i. e. a very low size to thickness ratio), the presence of spurious cabinet resonances is easily eliminated merely with the use of ordinary materials such as wood or other cabinet material. Thus, no elaborate bracings or stays are required to eliminate these false or spurious resonances as is the case in the larger conventional enclosures.

Further since the compartment 20 is relatively vibrationless because of the small dimensions of its walls, it can be readily incorporated within radio-phonograph consoles without producing the undesirable acoustic feedback effects on the sensitive vacuum tube elements or other electronic components, or upon the needle and arm system of the phonograph.

Still further, the lowest standing wave which is set up within the enclosure 20 is determined by the longest inside dimension (diagonally corner-to-corner). Since this is a relatively small distance, the frequency is much higher as compared to large enclosures and is much more easily absorbed, and thus eliminating the undesirable interaction of this standing wave on the speaker cone, and further improving the fidelity of the system.

In the preferred arrangement of the invention illustrated in the drawings, the speaker 16 is shown with its

mounting ring 27 clamped tightly against the partition wall 18 so that an effective air-tight seal is provided around the mouth of the speaker cone 25. Such an arrangement is preferred because the peak usually arising at basic cone resonance becomes wholly submerged in the resonant frequency of the unit as a whole, thus promoting smooth response.

We have found, however, that satisfactory results can be achieved by providing edge relief between the speaker mouth and the partition wall 18. This edge relief is achieved by spacing the mouth of the speaker 16 a slight distance from the partition wall 18, so that a leakage space is provided through which air (and sound waves carried by this air) can escape from the interior of compartment 20 behind the speaker 16, to the front of said speaker and through aperture 24.

As edge relief is introduced, the basic loaded-cone resonance, if different from the enclosure resonance, becomes more and more prominent and distinct from the basic resonance of the compartment 20, so that two distinct resonant peaks may be produced. The resonant peak of the speaker cone, if lower in frequency, may be utilized to extend the response curve into the extremely low frequency range. In other words, the speaker enclosure may be designed according to the formulae previously presented, to operate in conjunction with a speaker of low basic cone resonance to extend the low range another octave by producing a peak in the response curve at the basic cone resonance. With such an arrangement, a response curve down to 32 C. P. S. was obtained using a small 12 inch speaker with an unloaded cone resonance of 65 C. P. S. and about 1/8 inch edge relief.

While a preferred embodiment of the invention has been shown and described herein, it is obvious that numerous additions, changes, and omissions may be made without departing from the spirit and scope thereof. For instance, the speaker need not be facing in a downward direction, but may be inverted and directed toward a duct located at the top of the cabinet instead of at the bottom thereof. Also, in the claims where a "speaker" is referred to, it is intended to cover broadly any type of acoustic drive means.

We claim:

1. A loud-speaker enclosure comprising a closed chamber having a wall containing a through-and-through aperture, a hollow duct outside of said chamber communicating with said aperture and directly with the outside atmosphere, said duct having a longitudinal axis which is parallel to said wall and being contiguous with said wall and having a constant cross-sectional area along its length, said wall being of sufficient size to permit the mounting of the loud-speaker thereupon with the loud-speaker mouth in registry with said aperture and communicating with the duct through said aperture, said aperture being of smaller area than the area of the speaker mouth, said chamber being of a size only slightly larger than the size of the contained speaker, the internal volume of said duct and said chamber and the area of said aperture being regulated to produce a selected resonant frequency of said enclosure according to the formula:

$$f = \frac{c}{2\pi} \sqrt{\frac{S^2}{V(Sl+E)}}$$

2. A loud-speaker enclosure comprising a closed chamber having a wall containing a through-and-through aperture, a loud-speaker mounted in said chamber, said speaker having a cone-shaped diaphragm communicating with the mouth thereof, said speaker mouth facing said chamber wall and in registry with said aperture, a hollow duct of constant cross-sectional area outside said chamber in communication with said aperture and having an open end communicating directly with the outside atmosphere, the longitudinal axis of said duct being parallel to said chamber wall, said speaker diaphragm communicating with said duct through said aperture, said aperture being of smaller area than the area of said speaker mouth said chamber being of a size only slightly larger than the size of said speaker, the ratio between the internal volume of said duct and said chamber, and the area of said aperture being regulated to produce a selected resonant frequency of said enclosure in the low audible frequency range.

3. A loud-speaker enclosure comprising a closed chamber having a wall containing a through-and-through aperture, a loud-speaker mounted in said chamber, said speaker having a cone-shaped diaphragm communicating with the mouth thereof, said speaker mouth being rigidly mounted against said chamber wall with the diaphragm in registry with said aperture and closing off said aperture to the passage of air, a hollow duct of constant cross-sectional area along its length outside said chamber in communication with said aperture and having an open end communicating directly with the outside atmosphere, the longitudinal axis of said duct being parallel to said chamber wall, said speaker diaphragm communicating with said duct through said aperture, said aperture being of smaller area than the area of said speaker mouth, said chamber being of a size only slightly larger than the size of said speaker, the ratio between the internal volume of said duct and said chamber, and the area of said aperture being regulated to produce a selected resonant frequency of said enclosure according to the formula:

$$f = \frac{c}{2\pi} \sqrt{\frac{S^2}{V(Sl+E)}}$$

where the quantity E represents the end correction at both ends of said duct.

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