July 4, 1967 H. B. SHAPER 3,329,235

LOUDSPEAKER SYSTEM

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FIG. 1.

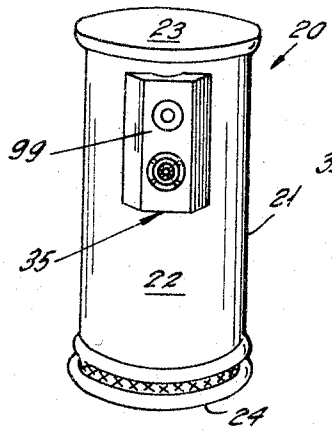


FIG. 2.

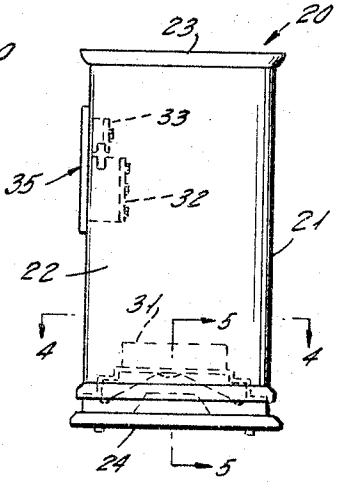


FIG. 3A.

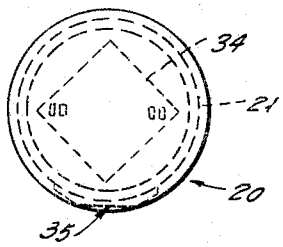
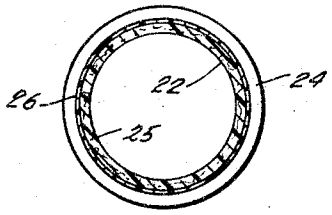


FIG. 4.



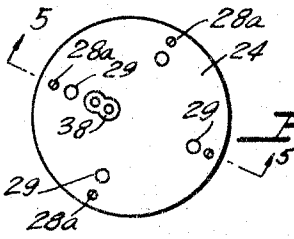


FIG. 3B.

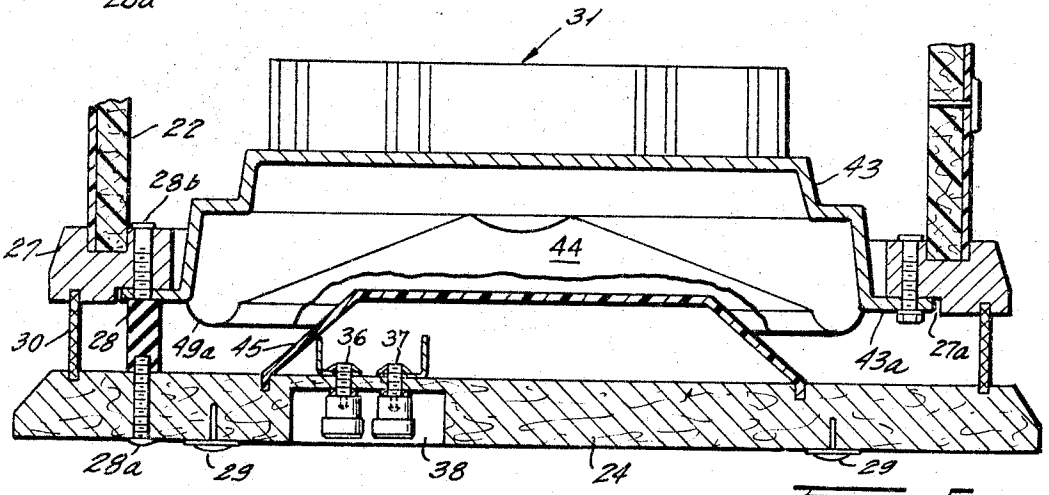
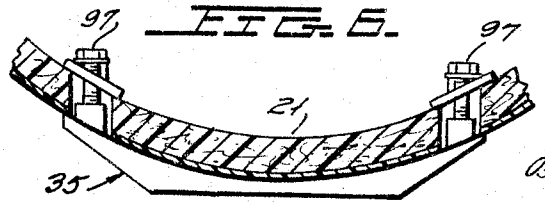


FIG. 5.

FIG. 6.



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FIG. 7

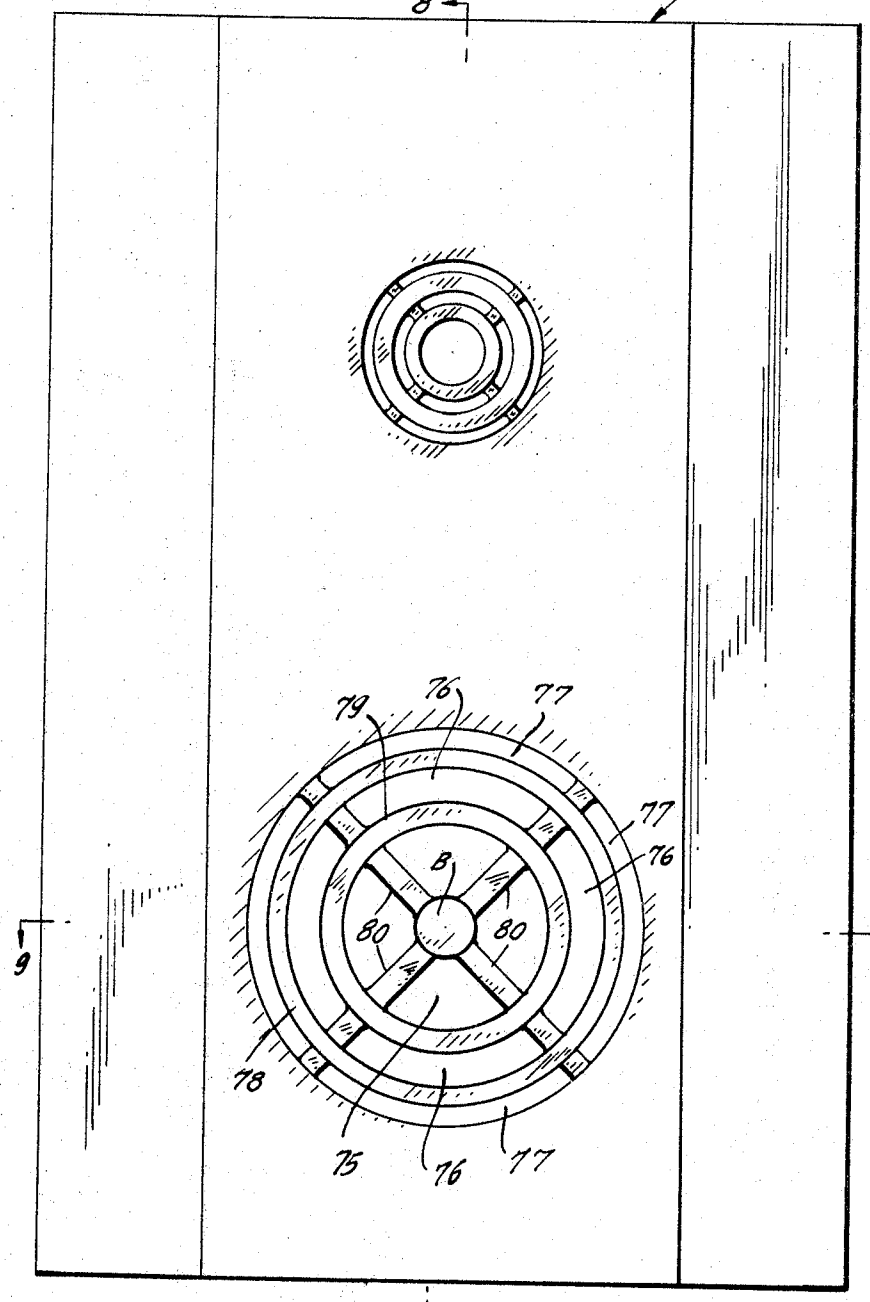


FIG. 8

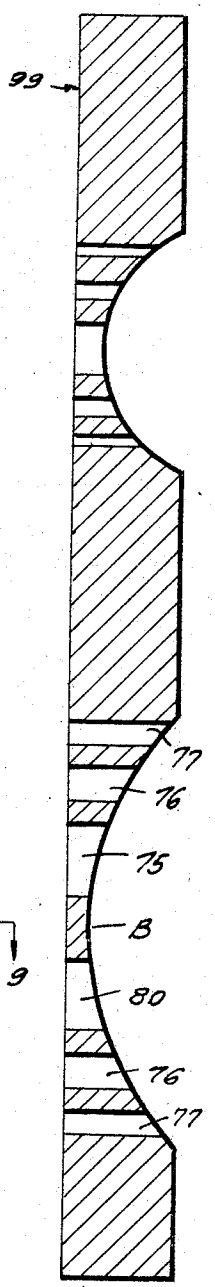
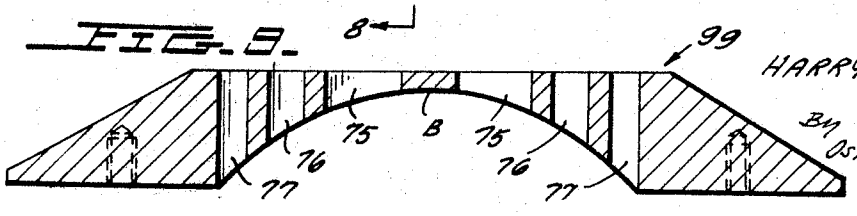


FIG. 9



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FIG. 10

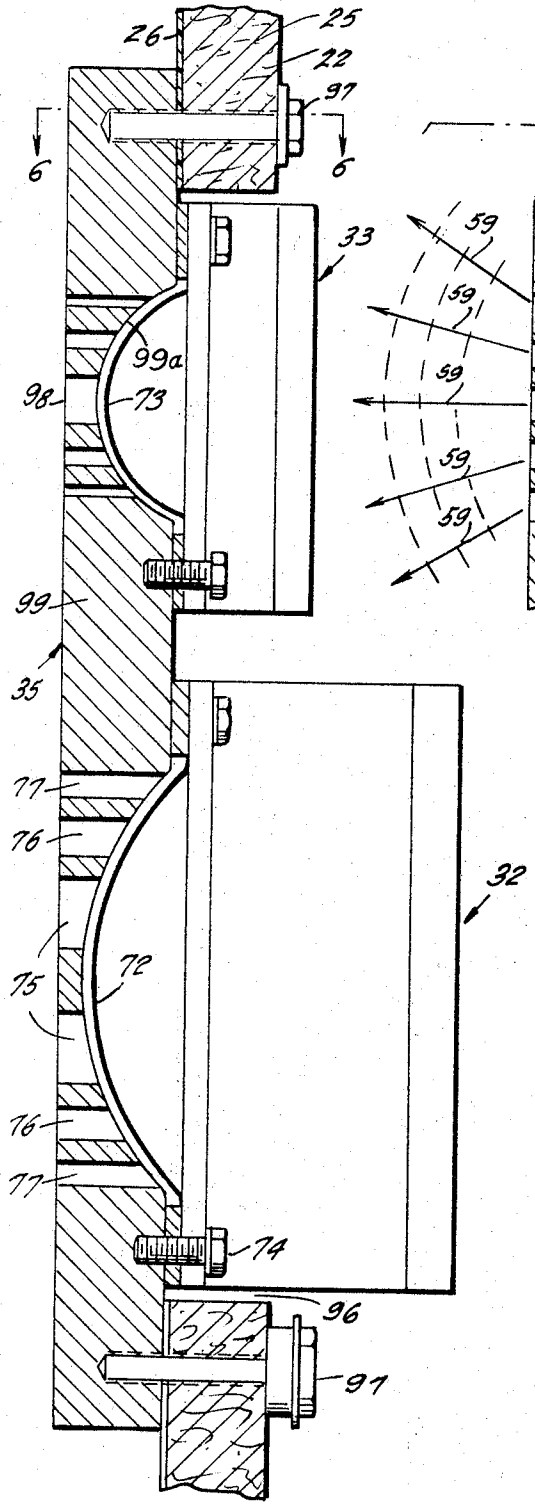


FIG. 12

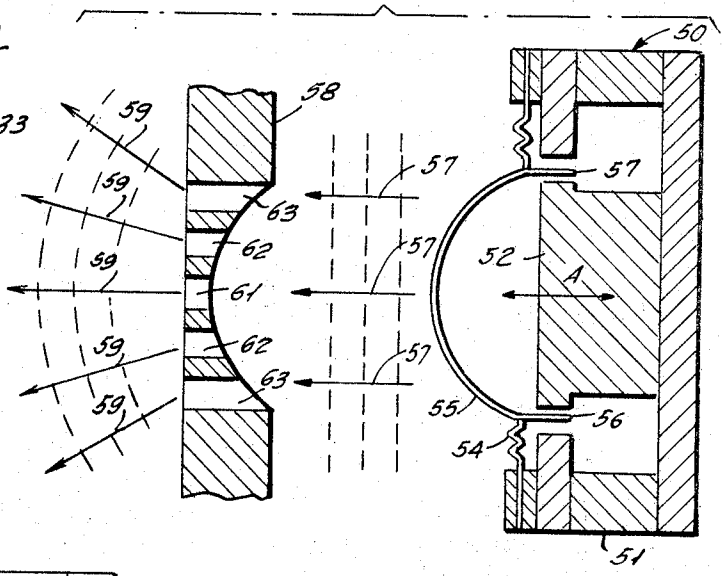
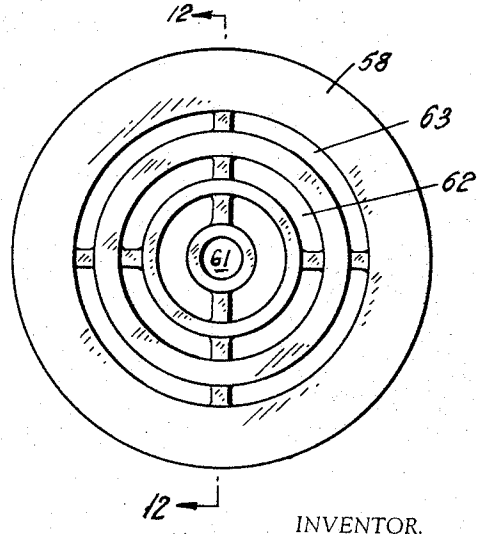


FIG. 11



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FIG. 13.

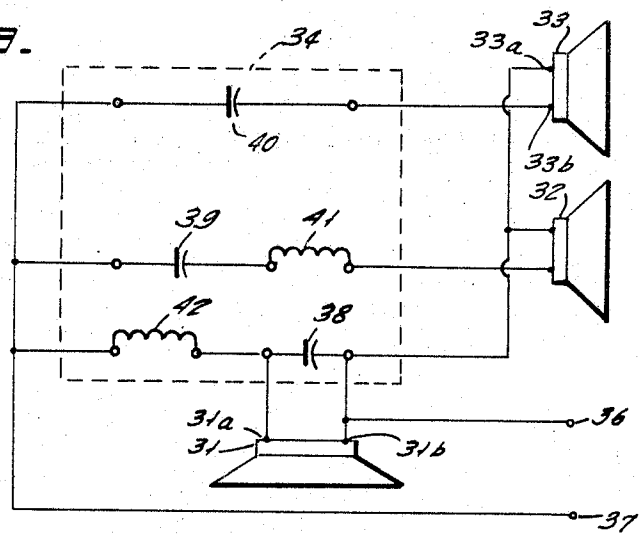
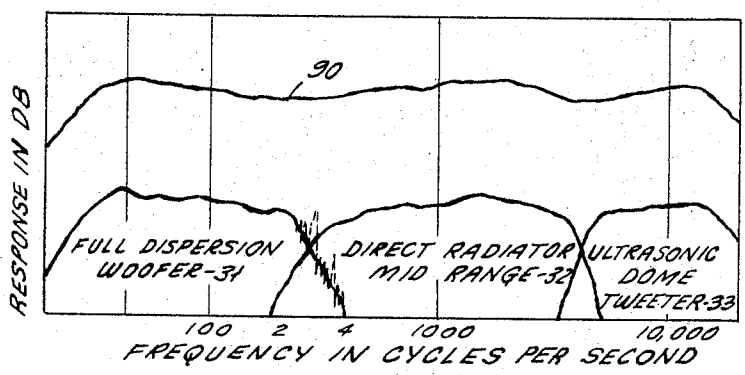


FIG. 14.



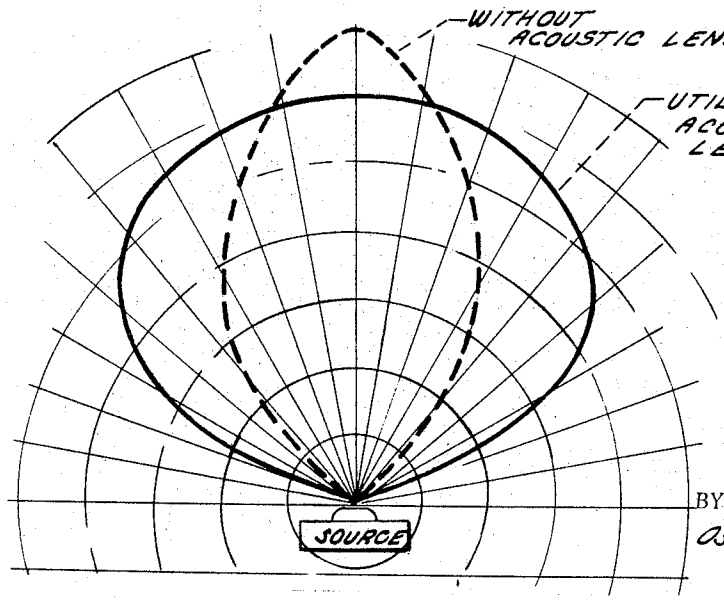


FIG. 15.

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United States Patent Office 3,329,235 Patented July 4, 1967

3,329,235

LOUDSPEAKER SYSTEM

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Filed Dec. 24, 1964, Ser. No. 421,008
15 Claims. (Cl. 181—31)

This invention relates to sound reproducing apparatus in general and more particularly to a loudspeaker system including an acoustical enclosure and acoustic lens means operating in conjunction with a plurality of loudspeakers each operating over a predetermined portion of the audio band.

For the most part, prior art high fidelity speaker systems have of necessity been too large in size to be utilized effectively in the average home. Prior art attempts at constructing relatively compact loudspeaker systems have resulted in a moderate amount of success but retain notable shortcomings. More particularly, one such relatively compact construction is the so-called bass reflex. In this construction the fidelity of sound at low frequencies must be compromised because of space restrictions.

Further, the sound dispersion characteristic of the bass reflex construction is such that sound is emitted in one or more narrow bands. The latter is particularly objectionable in the case of stereophonic reproduction in that placement of the speaker systems in a room is critical and the listener must be positioned within a very small area in order to obtain satisfactory listening.

The instant invention provides a high fidelity loudspeaker system which is relatively compact and disperses sound waves over a relatively wide area. This is accomplished by utilizing an elongated tubular enclosure positioned with its longitudinal axis extending vertically. The woofer is placed at the bottom of the enclosure with the front of the woofer facing downward and feeding through a front loaded horn with a 360° aperture throat. This provides for full dispersion of sound and prevents standing waves from developing in the room. The tweeter and mid-range speakers are mounted to an acoustic lens assembly secured to the side of the enclosure at a position above the woofer. The acoustic lens is so constructed that sound waves generated by the tweeter and mid-range speakers are caused to disperse over relatively wide angles without sacrificing fidelity.

Accordingly, a primary object of the instant invention is to provide a novel construction for a high fidelity speaker system.

Another object is to provide a novel construction for a speaker system in which there is a downwardly facing woofer feeding a horn with a 360° aperture throat and an acoustic lens means for dispersing the sound waves emitted by the tweeter and mid-range speakers.

Still another object is to provide a novel construction for a speaker system in which the enclosure is an elongated tube standing on end.

A further object is to provide a novel construction for a speaker system in which there is a hollow cylindrical housing constructed of rigid acoustic material.

A still further object is to provide a novel speaker system having a combination of electrical and acoustic crossovers and cutoffs which prevent woofer cone breakup and mid-range response dips.

Yet another object is to provide a novel speaker system so constructed that placement of the units is not critical even to obtain full frequency and separation for stereo reproduction.

These as well as other objects of this invention will become readily apparent after reading the following description of the accompanying drawings in which.

FIGURE 1 is a perspective of a loudspeaker system constructed in accordance with the teachings of the instant invention.

FIGURE 2 is a side elevation of the speaker system illustrated in FIGURE 1.

FIGURES 3A and 3B are top and bottom views, respectively, of the speaker system of FIGURE 1.

FIGURE 4 is a cross section taken through line **4**—**4** of FIGURE 2 looking in the directions of arrows **4**—**4** but showing only elements of the enclosure.

FIGURE 5 is an enlarged fragmentary cross section taken through line **5**—**5** of FIGURE 3B looking in the direction of arrows **5**—**5**.

FIGURE 6 is a fragmentary plan view taken through line **6**—**6** of FIGURE 10 showing the manner in which the acoustic lens assembly is mounted to the side of the enclosure.

FIGURE 7 is a front elevation of the acoustic lens assembly.

FIGURES 8 and 9 are cross sections of the acoustic lens assembly taken through lines **8**—**8** and **9**—**9**, respectively, of FIGURE 7 looking in the direction of the respective arrows.

FIGURE 10 is a view similar to FIGURE 8 showing the mounting of the acoustic lens assembly to the enclosure and the mounting of the tweeter and midrange speakers to the acoustic lens.

FIGURE 11 is a front elevation of an acoustic lens included for purposes of illustration.

FIGURE 12 is a cross section taken through line **12**—**12** of FIGURE 11 looking in the direction of arrows **12**—**12**. In addition FIGURE 12 shows a mid-range speaker and the manner in which sound waves emitted by this speaker are caused to diverge.

FIGURE 13 is an electrical schematic showing the interconnections between the tweeter, mid-range and woofer.

FIGURE 14 is a frequency response curve showing the outputs of the individual speakers and the combined output of the speaker system of the instant invention.

FIGURE 15 is a polar plot of equal loudness for a six kilocycle tone with and without the utilization of the acoustic lens of the instant invention with the solid line showing increased polar spread when sound waves are dispersed by the lens.

Now referring to the figures. Speaker assembly **20** includes enclosure **21** in the form of elongated tube **22** mounted with its axis positioned vertically and provided with a top cover **23** and a base **24**. As best seen in FIGURE 4 tube **22** is of cylindrical cross-section and includes the rigid inner tube portion **25** typically constructed of formed plywood or a synthetic material containing wood pulp. Portion **25** is covered by an outer layer **26** of decorative and mar resistant material such as formica. Of all columnar shapes, from an acoustical viewpoint a cylinder provides the greatest stiffness.

As best seen in FIGURES 3B and 5, the lower end of tube **22** is tightly fitted into an angular groove in the upper surface of ring **27** with the latter positioned in spaced relationship above base **24** by means of four standoffs **28** secured to base **24** by screws **28***a* and to ring **27** by screws **28***b*. Bumpers **29**, mounted to the lower surface of base **24**, prevent damage to the surface upon which speaker assembly **20** is placed. The space between ring **27** and base **24** forms a 360° aperture covered by annular grill **30** constructed of a suitable mesh material, known to the art, which will not impede the propagation of sound waves. As seen in FIGURE 2, low frequency speaker or woofer **31** is mounted at the bottom of tube **22** while mid-range speaker **32** and low range speaker or tweeter **33** are mounted above woofer **31** behind decorative lens plate **99**.

Crossover network 34 (FIGURE 3A) is mounted to the underside of top plate 23 and is a conventional construction having electrical elements as shown in FIGURE 13. Terminal connector 36, 37 mounted to base 34 extend into recess 38 in the bottom surface of base to be accessible for the making of external connections to speaker assembly 10.

In particular, crossover network 34 consists of three capacitors 38, 39, 40 and two inductances 41, 42. Inductance 42 and capacitor 38 are connected in series between external terminal 37 and terminal 32*a* of mid-range speaker 32, the latter terminal being connected directly to terminal 33*a* of tweeter 33. Capacitor 38 is also connected between terminals 31*a*, 31*b* of woofer 31 with the latter terminal being connected directly to external terminal 36 and inductance 42 being interposed between capacitor 38 and external terminal 37. Capacitor 39 and inductor 41 are connected in series with the former being connected directly to external terminal 37 and the latter being connected directly to terminal 32*b* of mid-range speaker 32. Capacitor 40 is connected directly from external terminal 37 to terminal 33*b* of tweeter 33.

Circular cup shaped shell 43 of woofer 31 is provided with an outwardly extending peripheral flange 43*a* disposed in circular recess 27*a* in the bottom surface of ring 27 extending to the inner edge thereof. Standoffs 28 support shell 43 above base 24 while screws 28*b* fix the angular position thereof. As best seen in FIGURE 5, conical diaphragm 44 of woofer 41 faces downward and is confronted by acoustic impedance element 45 in the form of a truncated cone mounted to the upper surface of base 24. It has been found that the presence of impedance element 45 results in improved response at the low end of the audio spectrum. That is, the response curve of a high fidelity woofer is relatively flat in the low woofer range and tapers off as frequency increases. However, in the range where woofer response tapers off there is usually found a series of resonant peaks (see dotted curve portion of FIGURE 14) resulting in non-uniform response throughout the effective range of the speaker system. The presence of conical element 45 serves to suppress these objectionable resonant peaks so that sound passing through the 360° aperture between ring 27 and base 24 falls off gradually at the high end of the woofer spectrum.

As in many conventional speaker constructions shell 43 of woofer 31 is provided with a series of slits (not shown). Although not shown, the portion of enclosure 21 behind shell 43 may contain sound absorbent foam material. It is noted that there is a good seal between the compliant edge 49*a* of speaker cone 44 and shell 43 and that the latter is well sealed to ring 27 which in turn is well sealed to tube 22. Top cover 23 and lens plate 99 are all sealed to cylinder 22 and speakers 32, 33 are well sealed to plate 99. Thus, it is seen that the region of enclosure 21 behind speaker cone 44 is essentially sealed thereby providing improved frequency response in the woofer range.

It is recognized that high frequency sound waves have directional properties when emanated directly from a speaker diaphragm surface into the atmosphere and as a result are projected mainly as a narrow beam. Thus, only those listeners seated directly on the axis of the speaker may receive the full upper range of tones while listeners located at substantial distances away from the axis will not hear the upper registers in the normal proportions. It is the function of acoustic lens assembly 35, consisting of speakers 32, 33 and plate 99, to diverge the sound waves generated by speakers 32, 33 thereby broadening the listening field of high frequency response. Acoustic lens plate 99 will transform a plane wave into a curved or spherical wave, thereby creating a diverging beam of sound whereby the listening area is broadened.

A sharply beamed sound will have a plane wavefront. That is, all points of uniform phase will form a flat plane perpendicular to the axis of propagation. On the other hand a broadly angled sound, one which is widely dispersed, will have a curved wavefront, propagating radially. To achieve true spherical radiation, a speaker diaphragm would have to vibrate radially as a pulsating sphere or balloon. Such a speaker construction is not feasible in high fidelity equipment for home use. For such use, economical loud speaker constructions are provided with diaphragms which are cone shaped or formed as a dome. It is often erroneously thought that such shaped diaphragms produce a diverging beam. However, even these shapes produce a plane wave since all portions of such diaphragms move linearly or parallel to the center axis of the diaphragm.

Reference is now made to the schematic of FIGURE 12 for an explanation of the manner in which the diverging lens construction of the instant invention is effective in converting a plane wave to a diverging wave. In FIGURE 12 speaker 50 is provided with shell 51 having an open front. Permanent magnet 52 is disposed within shell 51 and extends forward from the back wall thereof. Dome-shaped diaphragm 55, whose compliant edge portion 54 is secured to shell 51 at the front thereof, covers the front opening of shell 51 with the dome 55 positioned in front of shell 51. Voice coil 56 is connected to diaphragm 55 by band 57 and is positioned so as to be positioned in the flux field generated by permanent magnet 52.

In a manner well known to the art, flux produced by current flow in coil 56 coacts the flux field generated by magnet 52 to cause movement of diaphragm 55 thereby producing sound waves when vibrations of dome 55 are within the audible range. These vibrations of diaphragm 55 are back and forth parallel to the central axis A of diaphragm 55, producing a plane wave indicated by arrows 57 which is propagated generally perpendicular to axis A. Plane wave 57 when passing through acoustic lens 58 positioned in front of diaphragm 55 is caused to diverge from central axis A to produce a spherical wave as indicated by arrows 59. This conversion from plane wave 57 to a spherical wave 59 is brought about by providing lens 58 with ducts 61, 62, 63 formed as a series of concentric circles about axis A and the lengths thereof being measured parallel to axis A. The more distant the ducts from axis A the greater would be the length thereof. Thus intermediate duct 62 is longer than inner duct 61 and shorter than outer duct 63. These ducts 61–63 constitute inertia or mass control acoustic paths which delay sound waves with this delay becoming progressively greater as the distance from axis A increases. This appears to be analogous to a plane-concave optical lens where bending of light to a broad beam results from increased thickness of the lens at its edge.

In the case of acoustic lens 58 each aperture 61–63 is in the form of a duct containing a mass of air. These masses of air have the effect of reducing the sound propagations velocity resulting in a delay or phase lag in each duct. Since the amount of phase lag is a direct function of the inertia of the duct and adjacent ducts increase in length toward the edge of the lens there is increasing delay toward the edge. Thus, the emerging wave 59 is time delayed and bent to some degree depending on the differences in duct length and area. The points of equal phase form an arc and the wave is bent away from the central axis.

As best seen in FIGURE 10, mid-range and high range speakers 32 and 33 are provided with dome-shaped diaphragms 72, 73, respectively, and are generally of the same construction as speaker 50. A plurality of bolts 74 secure speaker 32 to the rear of acoustic lens plate 99 with diaphragm 72 being positioned behind the lens section consisting of ducts 75, 76, 77. For improved efficiency at the upper frequencies of speaker capability the throats of ducts 75–77 (areas thereof as seen in FIGURE 7) are of substantially equal areas.

As best seen in FIGURE 7, ducts 75–77 are concentric circles formed about central axis B of dome-shaped diaphragm 72. Four radial arms 80, which divide each of the

ducts 75 through 77 into four sections, are required to support circular dividing walls 78 and 79.

As best seen in FIGURE 10, the lower lens portion of the inner surface of plate 99 is provided with a spherical cavity 99*a* formed about a center coinciding with the center about which the dome-shaped portion of diaphragm 72 is formed. Diaphragm 72 extends into this concavity into closely spaced relationship with respect to the concave surface.

Since the construction of the acoustic lens section 98 for tweeter 33 and the mounting of tweeter 33 to plate 99 follow the same principles as the mounting of lens speaker 32 and the construction of its acoustic lens section, a detailed description of the former will be omitted and reference to FIGURES 7 through 10 should be made.

Acoustic lens plate 99 is mounted to the exterior surface of enclosure 21 by bolts 97 and covers aperture 96 in tubular enclosure section 22. Plate 99 together with diaphragms 72, 73 completely seal aperture 96, top plae 23 seals the upper end of tube 22 and compliant edge 49*a* is sealed to shell flange 43*a* with the latter sealed to ring 27 so that the portion of enclosure 21 to the rear of the cone shaped woofer diaphragm 44 is sealed.

In the diagram of FIGURE 15 the dashed line represents the polar plot of equal loudness for a six kilocycle tone in the absence of an acoustic lens constructed in accordance with the instant invention. The solid line plot shows the increased area of coverage when acoustic lens is used. Thus, it is seen that the utilization of the acoustic lens of the instant invention essentially doubles the area of coverage.

FIGURE 14 shows the frequency response curve 90 of speaker system 20 previously described while the three curves at the bottom portion of FIGURE 14 are plots of the individual contributions of the speakers 31–33 with each contribution measured exterior to enclosure 21. The dotted line portion at the upper end of the woofer response curve shows the objectionable resonant peaks which are suppressed by utilizing impedance element 45 in front of woofer cone 44.

Thus, it is seen that the instant invention provides a high fidelity loud speaker system of compact and economical construction with the resultant system possessing exceptional response characteristics especially when considered in light of the economies of construction.

Although there has been described a preferred embodiment of this novel invention, many variations and modifications will now be apparent to those skilled in the art. Therefore, this invention is to be limited, not by the specific disclosure herein, but only by the appending claims.

The embodiments of the invention in which an exclusive privilege or property is claimed are defined as follows.

I claim:

1. A loudspeaker system comprising an elongated tubular housing essentially closed on all sides thereof, means mounting said housing with its longitudinal axis positioned vertically, a first speaker means positioned at the lower end of said housing and having a downwardly facing sound generating diaphragm, said first speaker means positioned to function as a closure for said housing at said lower end, an acoustic impedance element positioned below said diaphragm and spaced therefrom to form a horn with an annular throat positioned concentric with said axis and having a width measured parallel to said axis, a second speaker means disposed within said housing and positioned above said first speaker means, and an acoustic lens means secured to said housing in front of said second speaker means to increase dispersion of sound waves generated by said second speaker means and directed through a side opening in said housing.

2. A loudspeaker system as set forth in claim 1 in which the diaphragm is conical and the acoustic impedance element is a truncated cone positioned with its bases generally horizontal with the minor base above the major base.

3. A loudspeaker system as set forth in claim 2 in which the impedance element extends into the diaphragm and the throat extends for 360°.

4. A loudspeaker system as set forth in claim 1 in which the acoustic lens includes a series of narrow annular passages concentric about a generally horizontal axis with the axial length of each of said passages being greater than the axial length of any other of said passages positioned closer to sid horizontal axis said passages bounded by spaced walls concentric about said horizontal axis; each of said walls being contoured so that all points thereof are equally spaced from said horizontal axis.

5. A loudspeaker system as set forth in claim 4 in which the second speaker means includes a dome-shaped diaphragm having its axis axially aligned with said horizontal axis.

6. A loudspeaker system as set forth in claim 5 in which the passages extend outwardly from a curved surface formed by a concavity into which said dome-shaped diaphragm extends.

7. A loudspeaker system as set forth in claim 6 in which the passages are each provided with a throat, said throats being substantially equal in area to each other.

8. A loudspeaker system as set forth in claim 1 in which the housing is of generally circular cross section and of uniform diameter throughout the length of the housing.

9. A loudspeaker system as set forth in claim 8 in which the housing includes a side wall constructed of multi-layered material with the outermost layer being a decorative veneer.

10. A loudspeaker system as set forth in claim 1 in which the first speaker means includes a woofer device and the second speaker means includes a tweeter device and a mid-range device, said acoustic lens means having a first section positioned in front of said tweeter device and a second section positioned in front of said mid-range device, said first section including a first series of narrow annular passages concentric about a first generally horizontal axis, said second section including a second series of narrow annular passages concentric about a second generally horizontal axis, within each of said series the axial length of each of said passages being greater than the axial lengths of all other of said passages, in this same series, which are positioned closer to the horizontal axis of this same series.

11. A loudspeaker system as set forth in claim 10 in which the horizontal axes are positioned one above the other in a single generally vertical plane.

12. A loud speaker system as set forth in claim 11 in which the tweeter device includes a first dome-shaped diaphragm having its axis axially aligned with said first horizontal axis and the mid-range device includes a second dome-shaped diaphragm having its axis axially aligned with said second horizontal axis.

13. A loud speaker system as set forth in claim 12 in which there is a plate-like member, a side aperture in said housing covered by said member, said first and second series of passages extending through said member, means mounting said tweeter device and said mid-range device directly to said member, said member having a first and a second concave internal surface portion from which said passages are outwardly extending, said first portion being generally concentric with said first diaphragm and closely spaced with respect thereto, said second portion being generally concentric with said second diaphragm and closely spaced with respect thereto.

14. A loudspeaker apparatus including acoustic lens means and a speaker means, said speaker means including a first and a second device each constructed to function efficiently over different adjacent portions of the audio spectrum, said lens means including a mounting member having a first series of narrow annular passages concentric

about a first axis and a second series of narrow annular passages concentric about a second axis, said axes being substantially parallel to each other and extending generally at right angles to the plane of said member, said first device positioned behind said first series of passages and said second device positioned behind said second series of passages, within each of said series the axial length of each of said passages being greater than the axial lengths of all other of said passages, in this same series, which are positioned closer to the horizontal axis of this same series said first device including a first dome-shaped diaphragm having its axis generally aligned with said first axis, said second device including a second dome-shaped diaphragm including its axis generally aligned with said second axis, said member having an inner surface facing said devices, said surface having a first and a second concave portion from which said passages extend outwardly, said first portion being generally concentric with said first diaphragm and closely spaced with respect thereto, said second portion being generally concentric with said second diaphragm and closely spaced with respect thereto.

15. A loudspeaker system as set forth in claim **14** in which the devices are mounted directly to the member.

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