Acoustic Patents

By James Croft (Croft Acoustical)

Editor's Note: The patent review for this month is a combination of a reprint of the Dinaburg patent from the May 2021 issue of Voice Coil*, combined with an addendum of additional exploration of the Dinaburg concept, exposing an additional set of advantages not discussed in the patent.*

The following loudspeaker-related patent was filed primarily under the Office of Patent and Trademarks classification 181 for acoustical devices and 381 for electrical-signal processing systems and HO4R for international patents. This also includes new patent applications that are published in the *Patent Application Journal*.

Title: Speaker with Dual Diffuser
Patent/Publication Number: US 10,812,912
Inventor: Mikhail Dinaburg (Plano, TX)
Assignee: Dinaburg Technology Corp. (East Gwillimbury, ON, Canada)
Filed: April 24, 2018
Current International Class: H04R 9/06 (20060101)
Granted: October 20, 2020
Number of Claims: 16
Number of Drawings: 8

Abstract from Patent

An improved loudspeaker is disclosed. The speaker includes at least one permanent magnet, an electromagnet and a diaphragm. The diaphragm has an inner portion (active portion) and an outer portion (stabilizing portion) that are both typically ring-shaped. The interaction between the magnets causes the inner portion to move back and forth according to the electrical signal inputted. As the inner portion moves forward, the outer portion tends to move backward relative to the inner portion. The movement of the active portion tends to produce corresponding forces on the stabilizing portion that cause the stabilizing portion to move and create sound in a symbiotic fashion. In certain embodiments, the portions move relative to each other as sound is produced so that a relatively constant volume of air is displaced on either side of the diaphragm thus minimizing acoustic distortion. The inner portion may be connected to the outer portion via a hinge and/or flexible material which allows the portions to move relative to each other.

Independent Claims

1. An acoustic speaker for converting an electrical signal into sound, the speaker comprising: a speaker enclosure, a cradle in the speaker enclosure, at least one permanent magnet and at least one electromagnet to receive an electrical signal; a diaphragm configured to move back and forth according to the interaction of the magnets, the diaphragm comprising an inner component and an outer component, the inner component being positioned proximal to electromagnet and the outer component being positioned distal to the electromagnet, the outer edge of the inner component flexibly attached to the cradle via a first hinge, and the inner edge of the outer component flexibly attached to the cradle via a second hinge, such that the inner component and the outer components may move relative to each other in opposite directions; in which the inner and outer components move off-phase relative to each other such that the volume of air displaced is substantially equal on both sides of the diaphragm.

10. An acoustic speaker for converting an electrical signal into sound, the speaker comprising: at least one driver for producing sound, the driver comprising an electromagnet; a circular diaphragm attached to the at least one driver having a circular flange, the flange fixed in place relative to the driver, the diaphragm comprising a flexible inner component and a flexible outer component, the inner component being positioned proximal to the driver and the outer component being positioned distal to the driver, the outer edge of the inner component flexibly attached to the flange via a first hinge, and the inner edge of the outer component flexibly attached to the flange via a second hinge, such that the outer component may move relative and opposite to the direction the driver causes the inner component to move; in which the inner and outer components move back and forth off-phase relative to each other in the longitudinal direction of the speaker driver, and in which the volume of air displaced at any one time remains relatively constant on either side of the diaphragm such that acoustic distortion is reduced.

11. An acoustic speaker for converting an electrical signal into its corresponding sound, the speaker comprising: at least one electromagnet and at least one permanent magnet; a diaphragm configured to move back and forth to create sound depending on the interaction between the electromagnet and the permanent magnet, the interaction controlled by an electrical input signal; the diaphragm comprises an active component proximal to the electromagnet and a stabilizing component distal from the electromagnet, the active component being separated from the stabilizing component via a hinge mechanism comprising a fixed ring, a first hinge and a second hinge, wherein the active component is attached to the fixed ring via the first hinge and the stabilizing component is attached to the fixed ring via the second hinge; wherein the movement of the active component to create sound creates corresponding forces on the stabilizing component such that the two components move relative to each other and in the opposite directions.

Reviewer Comments

While bass reflex based low-frequency systems have certain benefits, such as reduced enclosure size or extension of low-frequency bandwidth or greater efficiency, there is a few different trade-offs for this gain in performance. One of those trade-offs is that of having to provide a passive acoustic mass in at least one of the enclosure walls, communicating from the interior enclosure volume to the world outside the enclosure.

This requires additional cost for the acoustic mass element itself, which in its simplest forms tend to vary anywhere from a simple vent opening to an elongated port, or a passive diaphragm radiator, which is essentially a diaphragm mounted on a surround suspension and a secondary, stabilizing suspension, most often provided as a spider assembly displaced forward or back from the surround suspension.

Besides the financial cost, there is also a cost in enclosure real estate relative to mounting the passive acoustic radiator, be it a vent, port, or passive diaphragm. This real estate impact can be that of internal volume and/or enclosure external surface area. As an enclosure volume is reduced, to maintain the same tuning frequency, a port will have to have its acoustic mass increased by either 1) a reduction in cross-sectional area (which increases port losses and causes more distortion and exit noise or "chuffing" as port air velocity increases beyond a certain threshold); or 2) port length increased, which causes the recursive problem of further reducing internal volume that requires more acoustic mass, and so forth to the point where for a given total enclosure volume and tuning frequency, a port is no longer a practical means of providing the acoustic mass required.

In this type of situation, the passive diaphragm radiator becomes the go-to port replacement, due to its low impact on internal enclosure volume, which comes with a price to be paid in terms of some reduction in low-frequency performance (a steeper immediate high-pass slope characteristic due to the addition of the parasitic suspension stiffness) and in terms of increased area requirements on the surface of the enclosure. This increased required surface area to mount the passive radiator is magnified by the fact that to maintain suspension linearity, the area of the passive diaphragm should be at least twice that of the active woofer if the passive radiator is to remain within the same excursion limits as the active driver.

This tends to be a bit awkward since the ideal, double area diaphragm tends not to fall within the standard transducer sizes, such that an 8" driver would require a passive radiator of at least 11.2", requiring one to move up to a 12" passive radiator, or develop a more sophisticated suspension, if maintaining linearity was a significant goal. So, this raises the issue of how to meet the target increase in passive diaphragm area, while achieving practical and efficient utilization of enclosure surface area, when the primary reason for switching to a passive radiator in the first place was the reduction in enclosure size and internal volume.

One of the most straightforward methods to deal with this issue was presented in US 7,158,648, "Loudspeaker System with Extended Bass Response" by Aaron L Butters and Sargam Patel, assigned to Harman International Industries, Inc. In most embodiments of the patent the passive radiator is mounted coaxially around the circumference of the active driver, utilizing the remaining frontal surface area of the enclosure face. In the most thorough space utilization form, the outer surround of the passive radiator is placed around the periphery of the enclosure front panel.

Taking the basic idea a step further, in US 9,674,594, titled "Speaker," inventor Shengbo Li, also of Harman International, extends the passive radiator to include the whole enclosure, with the passive radiator suspension dividing the enclosure in half, allowing the totality of the front and rear halves of the enclosure to act as the passive radiator for the active transducer mounted on the front panel of the enclosure.

The patent under review takes a somewhat different approach to integration of a passive radiator with an active driver in a bass reflex system. The inventor's disclosure of the invention is interesting and entertaining, with a view of acoustical theory that may be even more novel than the invention itself. I'll let his words provide an introduction.

Background

"Heavy and expensive enclosure cabinets may be incorporated into speaker design in order to mitigate the phenomenon of acoustic short circuit and other issues. Acoustic short circuit refers to sound distortion and cancellation that occurs when sounds waves collide and/or are absorbed by other speaker components such as the enclosure, which results in wasteful vibrations. Unfortunately, speaker enclosures that attempt to minimize sound distortions are often heavy and expensive, and results in very low efficiency of often under 5%, as a substantial portion of the sound energy is cancelled and/or converted to vibration. The low level of efficiency requires a much greater amount of energy in proportion to the actual sound produced which is wasteful and adds cost to the operation and maintenance of the speaker. There is therefore a need for improved speaker technology that solves or mitigates at least one problem in the prior art."

Brief Summary

"By way of introduction, the invention includes various embodiments of an acoustic loudspeaker that are improvements over speakers of the prior art. Some embodiments of the claimed invention improve sound quality over prior art speakers, other embodiments improve energy efficiency over prior art speakers, and yet other embodiments improve both sound quality and energy efficiency compared to prior art speakers. Still other embodiments allow for a larger frequency range of sound to be outputted, thus reducing the need for additional components such as amplifiers, frequency splitters, and so forth."

"In one aspect, the invention provides an acoustic speaker for converting an electrical signal into sound. The speaker includes at least one electromagnet and at least one permanent magnet. A diaphragm/cone is attached to the electromagnet, which is typically contained in a housing. The terms diaphragm, cone, and diffuser are used interchangeably herein. The diaphragm has an inner (active) portion/component and an outer (stabilizing) portion/component. The inner component may be attached to the outer component via a hinge mechanism and the outer component may be attached to a cradle (basket) via a hinge mechanism. The hinges allow the inner and outer components to travel independent of each other in the longitudinal direction that the components move (i.e., back/forth, front/back)."

"In typical usage, the interaction between the magnets causes the inner component to oscillate back and forth according to the electrical signal provided, which represents the desired sound. The outer component moves off-phase relative to the inner component. The term off-phase in this specification means that the components move relative to each other in opposing directions. For example, when the inner component moves forward, the outer component moves backward relative to the inner component."

"In some aspects, the volume of air displaced by the inner and outer portions at the front and back of the diaphragm remains substantially constant during movement. The effect is to substantially reduce acoustic short circuit and other distortions produced by speakers of the prior art. In some embodiments, the movement of the active portion causes air pressure changes within an enclosure and/or surrounding environment which in turn causes the stabilizing portion to move and thus create sound."

"Referring first to **Figure 1**…As sound is produced, the inner and outer portions are configured to move back and forth substantially along the axis defined by arrow 180. The portions move off-phase relative to each other, meaning that, if one portion is positioned in the forward direction (i.e., in the direction of arrow 180), the other portion is positioned in the rear direction (i.e., opposite of arrow 180). The forces created by the active part of the diffuser tend to move the stabilizing portion in the opposite direction that the active portion is driven. This allows the stabilizing portion to create sound by capturing and utilizing sound energy created by the active portion. In some embodiments, the volume of air displaced on either side of the diffuser during movement is relatively consistent. By leveraging the forces created by one portion of the diffuser to move the other portion in the opposite direction, sound distortion is substantially reduced, which allows accurate sound to be produced without the need for expensive enclosures and/or other sound equipment."

"In some embodiments that incorporate a speaker enclosure (such as in **Figure 2**), the movement of either component in the direction of the back of the enclosure creates a corresponding force in the opposite direction against the other portion. For example, when the active portion is driven toward the rear of the speaker enclosure, the application of Boyle's Law (PV=constant) ensures that

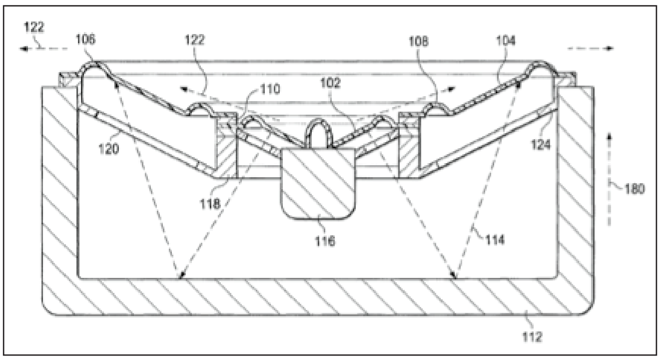

Figure 1: A cross-sectional side view of the invention is shown.

the volume of air remains relatively constant. Because movement of the active portion will tend to increase the pressure momentarily, the stabilizing portion will tend to move toward the front of the speaker ensuring that the volume of air within the speaker is relatively constant (and the pressure is relatively constant as well). A person skilled in the art will recognize that the relationship defined by Boyle's Law, and leveraged by embodiments of the invention, is an approximation given that the enclosure may not be completely airtight."

Inventor's Summary

"Embodiments of the invention are disclosed that incorporate a diaphragm having an active part and a stabilizing part. The active part is driven back and forth by the interaction of magnets according to an electrical input signal. The stabilizing part moves as a result of forces that are created by the active part in motion. The active part creates forces that cause the stabilizing part to move in the opposite direction of the active part. These forces in turn allow the stabilizing part to create usable sound instead of wasting much of the energy produced by the active part though acoustic wave collision and acoustic collisions with speaker enclosures as found with prior art speakers. The movement of the active and stabilizing parts thus operates in a symbiotic fashion, which allows high-quality sound to be created in an efficient manner across a wide range of frequencies."

The inventor's description of the invention appears to be a fascinating treatise on acoustics, if all acoustical events were to take place at DC, or zero Hz. The underlying principle of the invention as stated appears to be that when the active diaphragm portion moves inward, the "stabilizing part or portion" (inventor's name for the passive radiator) moves outward, and this supposedly facilitates the avoidance of an "acoustical short circuit" and associated distortions. When in actuality the textbook definition of an acoustical short circuit is to have the phase polarity of the front wave of a transducer be met with the opposite polarity wave of the rear wave of the transducer, which is what happens at DC with a bass reflex system incorporating a port or passive radiator, such as in the invention. Push an active driver cone inward with your finger, and the passive radiator will move outward. The invocation of Boyle's Static Law of gases, while inappropriate for audio frequency loudspeakers, is actually

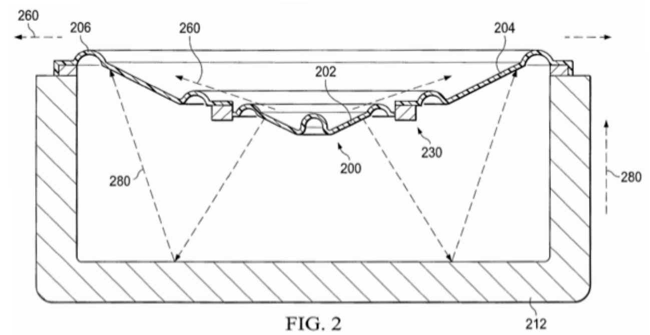

Figure 2: A cross-sectional side view of the invention and forces relative to the active and passive diaphragms are depicted.

quite apropos if one were operating a loudspeaker only at DC.

With all of that said, the curious theoretical notions along with the questionable associated benefits belie that fact that the invention, if realized with the correct parameters, is a useful device that should provide high performance in a practical package. The basic concept, as shown in a frontal view in **Figure 3**, of a single woofer transducer chassis with an active driver in the center, combined with a passive radiator mounted coaxially around the periphery of that active driver may well be beneficial in several applications.

There are a few prior art examples that appear to disclose devices that function in essentially the same manner, such as US 9,042,582, "Coaxial Passive Radiation Monomer" by Mathew Chan, et al., assigned to Plastoform Industries; and US 2014/0029782, "Weatherproof Loudspeaker and Speaker Assembly" by Gary Rayner, assigned to TreeFrog Developments, along with some embodiments of the previously mentioned Aaron Butters/Harman International patent. Additionally, an interesting bandpass form of the concept can be found in US 4,387,275 by Yasuomi Shimada, "Speaker and Speaker System" assigned to Matsushita Electric. In any case, the USPTO has granted Mr. Dinaburg his patent and a 20-year monopoly to put it to good use.

Addendum to the Original Patent Review Dinaburg: A Second Look

When reviewing patents, my main focus is on reviewing the aspects of the technology that is disclosed in the specification and written up in the claims, which actually defines what aspect of the invention is being claimed as novel and protected. The Dinaburg patent itself discloses the form and structure of the invention, but it limits its characterization of the invention to that of a new means for producing bass.

After writing my original patent review of the Dinaburg invention, with my evaluation focused on the invention as claimed, I felt that I had not done service to the full scope of what the Dinaburg structure had to offer.

It is noted in the original review, that in this reviewer's opinion, there does not seem to be a basis for improved low-frequency behavior when compared to a conventional passive radiator-based system wherein the passive radiator has the same surface area, mass, and compliance, and is placed on the front of an enclosure of the same internal volume.

But, low-frequency response is not the only attribute of the Dinaburg configuration. What appears to be a more compelling feature of the device is that of the concentric passive radiator functioning as a dual-purpose structure. Besides its bass reflex based, passive radiator duties, it can also, when properly optimized, operate as a "virtual" directivity controlling waveguide for the central active transducer.

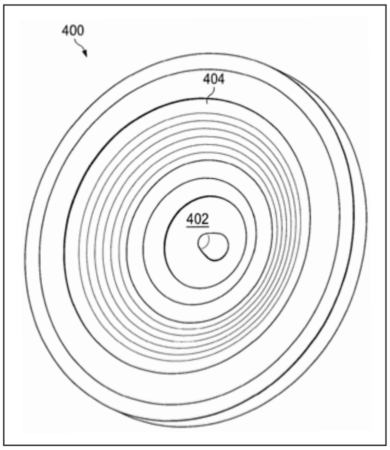

Figure 3: This is a frontal view of the invention.

The basic concentric passive radiator (CPR) itself has a number of prior art examples, a few of which were disclosed in the original review, plus others with significant relevance, such as US 9,426,548, "Loudspeaker Having a Passive Radiator" and US 9,094,747, "Weatherproof Loudspeaker and Speaker Assembly," both invented by Gary Rayner and assigned to TreeFrog Developments, as shown in **Figure A**. The Rayner device would be expected to have comparable low-frequency performance to the Dinaburg loudspeaker if both devices had an identical active driver with equivalent Thiele-Small parameters, identical enclosure volume, and CPRs with equivalent mass and compliance.

The significant difference is that the Rayner device is shown with the concentric passive radiator utilizing a flat/planar diaphragm that is substantially parallel to the plane of the front of the enclosure, while the Dinaburg illustrations show the concentric passive radiator expressed as a suspended "conical" diaphragm.

The conical diaphragm of the Dinaburg system opens the possibility of utilizing that cone-shaped diaphragm as a waveguide extension for the active inner driver. By doing so, one cannot only receive the benefits of the passive radiator extending the bass and reducing diaphragm excursion throughout the bottom octave of the passband, but also to maintain a more confined and constant directivity of the active driver along with increasing baffle support and pattern control to a much lower frequency, which in many embodiments, can minimize the need for baffle step correction (BSC) in the crossover network, and by doing so, providing another +3 to 6dB of system headroom and efficiency, as compared to having to apply passive BSC.

While the Dinaburg patent doesn't address the issue, the central active driver would seem best served by applying a coaxial, or concentric, driver with a center-mounted high-frequency tweeter. This can allow the shape of the small active driver diaphragm to provide the throat and early portion of the overall waveguide, while the concentric passive radiator continues the waveguide with the optimal profile.

If one were not going to use a coaxial/concentric active driver, with a centrally mounted tweeter, the required

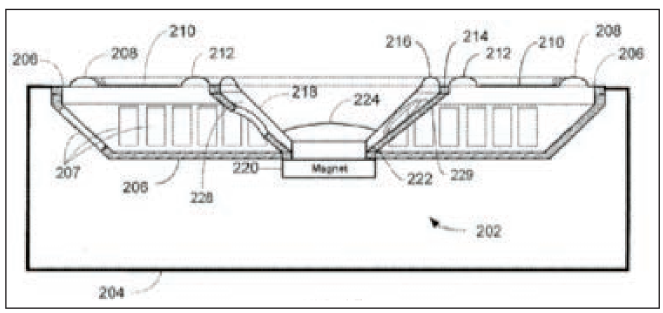

Figure A: A cross-sectional view of a prior art concentric passive radiator loudspeaker system.

placement of the tweeter would tend to have a center-to-center spacing from the active driver that is significant distance compared to a wavelength at the crossover frequency (due to being positioned beyond the outer edge of the passive radiator) and therefore would be sub-optimal relative to interactive comb-filtering at off-axis positions. This strongly suggests the preference of a concentric or some form of full-range transducer in the active driver position.

Besides the passive radiator/waveguide having an effective profile, additional concerns that would need to be addressed is that of the convex surround forms of the driver and passive radiator, and the "bridge" between the driver and the passive radiator, to provide a smooth transition from the center of the active driver to the outer rim of the passive radiator, minimizing any discontinuity that would cause diffraction effects with resultant frequency response anomalies and non-ideal pattern control of directivity. This might be partially accomplished by using concave surrounds on the driver and passive radiator combined with a transition bridge between the active and passive diaphragms that is formed for minimal disruption. One can even use partial covers over approximately half of the concave surrounds to further maintain a smooth surface.

There are many significant details of construction for further optimization for the waveguide aspect of the passive radiator that were not disclosed or suggested in the Dinaburg patent, but that would be very useful in maximizing the performance of this system for a much wider range of benefits than what is covered in the patent disclosure or claims.

Besides optimization of various elements of the structure for best performance, one can imagine that the passive radiator would not necessarily need to be limited to a circular form, wherein an elliptical or racetrack shape could be used for a more narrow and tall or short and wide structure while still providing the same surface area and bass bandwidth, while re-optimizing directivity control to a wide variety of desired vertical and horizontal radiation patterns.

One could realize a system of substantially equivalent performance to what is described here by merely providing a fixed waveguide around a small active driver and place the passive radiator separately at a different location on the surface of the enclosure, such as on the front baffle, below the driver/fixed waveguide, but that would require nearly twice the front baffle surface area to accommodate that arrangement. Alternately, one could place the passive radiator on the rear of the enclosure, or two passive radiators on the sides of the enclosure, or even replace the passive radiator with an elongated port, exiting the front and requiring very little additional surface area. All these alternatives may be able to equal the overall performance in terms of low-frequency capability and directivity control, and they would use conventional components as opposed to requiring a uniquely tooled compound active driver/passive radiator structure. But the Dinaburg system does have a certain elegance to its multi-purpose capability of providing a means for bass reflex bass extension combined with inherent optimization of directivity control and unique packaging, that provides utility and value beyond what is suggested in the patent. It does deserve a second look. ***VC***