Audio Engineering Society

Convention Express Paper

Presented at the 155th Convention

2023 October 25-27, New York, USA

Review and Analysis of the Dinaburg C2S™ Alignment

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ABSTRACT

The concentric coplanar stabilizer (C2S™) loudspeaker design theory based on Mikail Dinaburg's patent [1] is analyzed using COMSOL Multiphysics® modeling as well as comparison to prototypes based on optimized design based on the simulations. A brief description of the design theory is first presented. The building of the simulation model is then illustrated and described, including best practices. The results are presented and the optimization of the design are shown, including a direct comparison of those for a full audio band solution to a similar passive radiator design. The unique acoustic phase behavior in the interior of the design based on the Dinaburg design theory is then illustrated, with the direct relationship of this design's simulated performance to the measured sound quality and listening tests shown and described. The results indicate performance improvements when compared to a typical passive radiator design. Finally, possible applications of the design theory are briefly listed.

1 Introduction

The passive radiator loudspeaker enclosure was first described by Olsen in his 1935 patent, and in other work [2,3,4]. Further detailed analysis was carried out by Thiele [5], Small [6,7], Nomura and Kitamura [8], Clarke [9], and Hossach [10]. All the variants described by these authors are capable of alignments that give better performance than conventional sealed-box, vented-box, or traditional passive radiator systems, in that properly aligned passive radiator systems offer an improved trade-off between low frequency response, enclosure size, and efficiency.

Dinaburg Technology has a unique approach not only in packaging a passive radiator in a small volume, but also in taking advantage of a back wave from the loudspeaker's diaphragm in order to optimize the passive radiator's response and the off-axis performance of the active driver. There appear to be advantages which are audible in both prototypes and auralization.

2 The Need for the Application

In the home and business installation industry, in-wall and ceiling applications for loudspeakers with a wide frequency bandwidth and a smooth, monotonically decaying, acoustic power response is ideal and difficult to achieve. This is also the case in automotive cabin interiors and other similar vehicle cabins. In the home or business location, the listener is seldom on-axis, and can sometimes be in an area where the nearby boundaries are complex. In the case of passenger vehicles, the listener is never on-axis with any of the loudspeakers and is mostly receiving reflected sound from nearby surfaces. Having a smooth acoustic power response increases the quality of a diffuse and well-balanced sound field presented to the listener in a vehicle and in a home or business listening environment. In both environments, the depth of packaging and available footprint are always concerns. The ability to create a comparable or better low-frequency performance for a typical 6.5" diameter speaker package in an enclosed air volume that also provides a smooth axis response is a unique application, especially if the active loudspeaker is essentially a 3” diameter loudspeaker. This example is examined here.

3 From Theory to Model Setup

In Mikhail Dinaburg’s description of his invention [1], he refers to the loudspeaker cone as a “diffuser”. Interpreting the claims in the patent, the description of a loudspeaker cone as a diffuser invokes the purpose of a boundary, or a surface, to be used to better match the pressure of two air volumes. From our collective understanding of the poor impedance match of a loudspeaker cone and air, the cone diffuser is an inefficient one. The goal of the design theory as described strives to improve the efficiency of this poor diffuser. A passive ring radiator is added around a smaller diameter active loudspeaker, mounted in a box volume. This is shown in Figure 1 (taken from Dinaburg Technology’s white paper) which also describes the design theory. The ring radiator is considered a stabilizer for better matching the air volumes on either side of the boundary that is the active loudspeaker cone. This stabilizer is concentric with, and can be considered in the same plane of, the active part of the loudspeaker. This concentric passive ring radiator can reduce the required excursion from the active loudspeaker to produce lower frequencies, similar to the benefit that a bass reflex port design has over a sealed chamber. The coplanar concentric stabilizer (C2S™) from the design theory, that being the concentric passive ring radiator, is expected to have better coupling to the outside air volume than a bass reflex port would have, or even that of a nonconcentric passive radiator, which might have to be located on a different side of the enclosure. As will be shown, the passive ring radiator, designated as the coplanar concentric stabilizer (C2S™) in the design theory, can also be thought of as acoustically filtering out the upper range of the sound energy in the back chamber, minimizing comb filtering. As shown in Figure 1, the passive radiator (labelled as the “stabilizing part”) takes the form of a ring that is held in place by inner and outer surrounds of a compliant material.

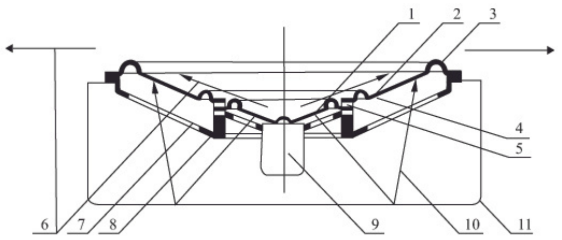

Figure 1. From US Patent. (1) Active part, (2) Stabilizing part, (3) Outer Surround, (4) Stabilizing part, (5) Phase Stabilizing Ring, (6) Direction of propagation of sound energy in the frontal plane, (7) Basket, (8) Basket structural member, (9) Magnet, (10) Direction of propagation of sound energy, inside enclosure from the reverse side of the active part of the diffuser, (11) Cabinet

In order to transform the patent claim illustration shown in Figure 1 into an entity that is realizable for prototyping and for computer-aided mathematical simulation in COMSOL Multiphysics®, a 3-D CAD model was generated (Figures 2 and 3). From the 3-D CAD model, the Simulation CAD model (Figure 4) was created for the specific Multiphysics® approach that COMSOL® [11] would provide. Figure 4 relates the elements of the Simulation CAD to the 3-D CAD and to the patent figure. The COMSOL simulation model (Figure 5) was used to integrate the mechanical, acoustical, and electrical simulations. The CAD construction was for a 90mm (3”) active loudspeaker and a 125mm (6.5”) outer diameter passive ring radiator, i.e., the coplanar concentric stabilizer (C2S™). The box volume was 2.6L (65mm x 200mm x 200mm).

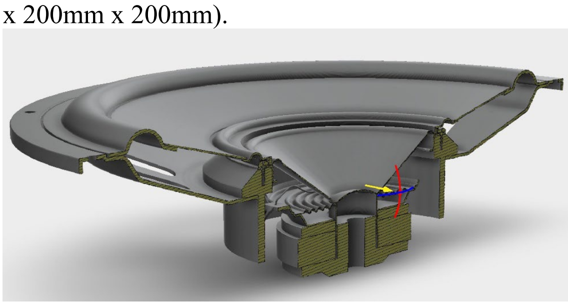

Figure 2. Speaker Design CAD

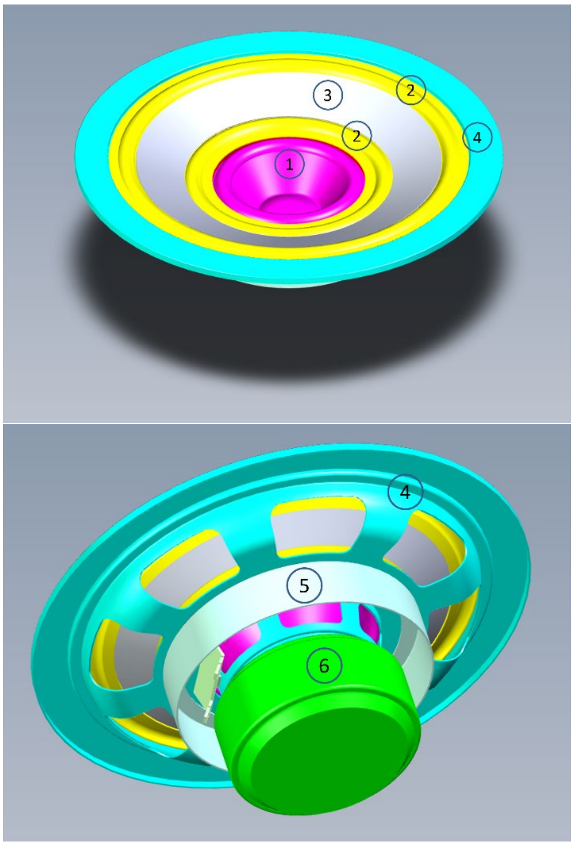

Figure 3. Speaker Design CAD: (1) Pink - Active Loudspeaker (∅90mm), (2) Yellow – Passive Suspensions, (3) Grey – Passive Membrane (Coplanar Concentric Stabilizer), (4) Cyan – Basket Frame (∅ 125mm), (5) White – Phase Stabilizing Ring, (6) Green – Motor Structure

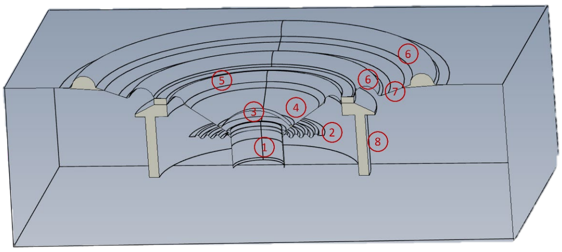

Figure 4. Speaker & Box Design CAD Section View: (1) Voice Coil, (2) Spider, (3) Dust Cap, (4) Cone, (5) Surround, (6) Inner / Outer Passive Suspension, (7) Passive Membrane (coplanar concentric stabilizer/C2S™ Stabilizer), (8) Phase Stabilizing Ring

In order to build the Multiphysics® model, the motor structure in the model is represented with the lumped electromagnetic parameters for the active 90mm (3”) loudspeaker. These parameters were applied for the driving voltage level (at 1W), force factor (Bl), coil DC resistance and inductance (L), the membrane surface area (Sd), and peak driving voltage (V0).

For the remainder of the model components, materials and thicknesses were defined for paper cone material, glues, paper cone + surround, spider, air, paper dust cap, paper dust cap + cone, copper wire, and NBR rubber surrounds. These were applied to the shell elements that defined the boundary for each of the model’s entities.

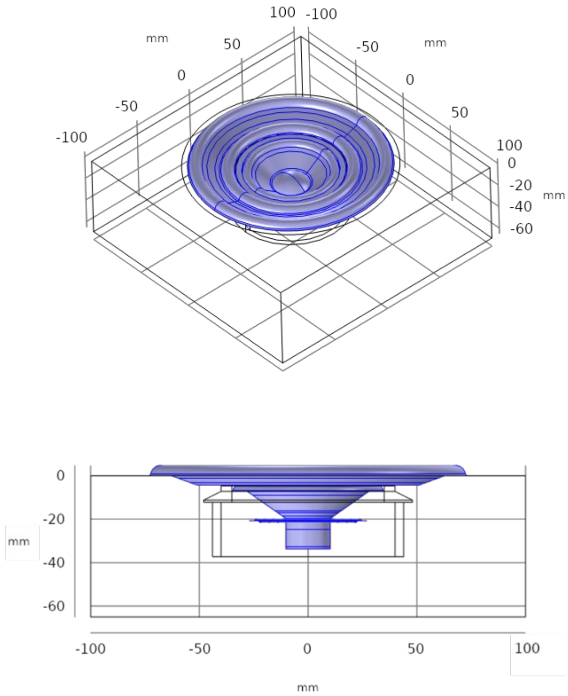

Figure 5. Simulation CAD Model. Full Box View (Top). Section View (Bottom).

The first model was run on a full speaker and box model (Figure 6) in a 3-D Acoustic Simulation (Figure 7). The purpose of the first model was to assess the validity of the base loudspeaker model when compared to the linear model theory on-axis. Also evaluated were the optimal model size and symmetry necessary to achieve the bandwidth and ultimately off-axis performance behavior. A Perfectly Matched Layer (PML) was placed at 4 meters from the center of the active speaker’s dust cap. The PML is used to create a non-reflective boundary for a free field solution.

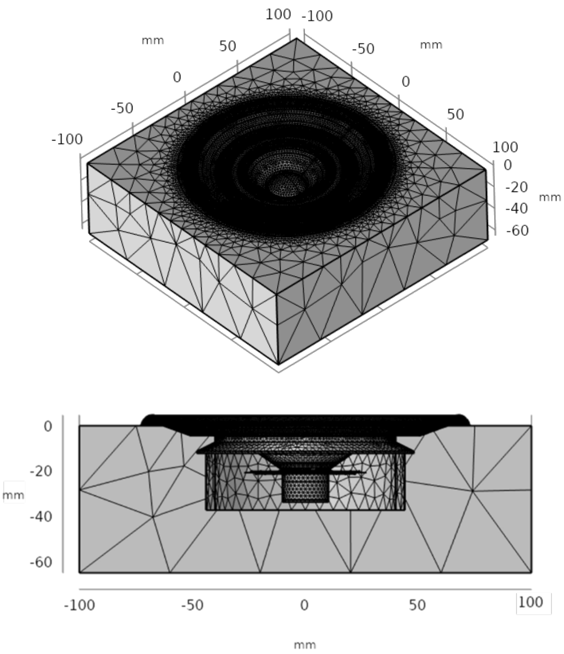

Figure 6. Simulation Speaker Box Model FEA Mesh. Full Box View (Top). Section View (Bottom).

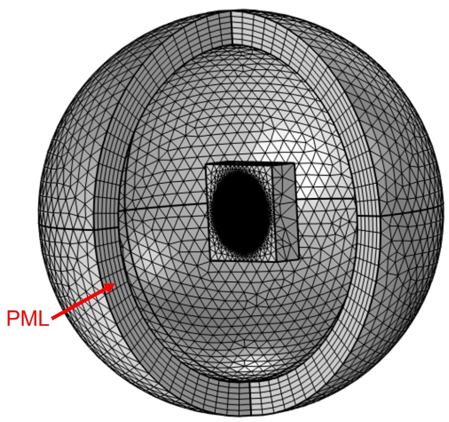

Figure 7. Full Acoustic 3D Simulation FEA Mesh. Quarter Section View. Perfectly Matched Layers (PML), non-reflective boundary for Free Field Solution. 20-2kHz, 1/12th Octave Acoustic Solution. (461,613 elements)

The 1/12th octave acoustic solution was able to give results for 20-2kHz. This provided enough low, mid and high frequency content to validate the model and assess some of the salient acoustic behavior in the design concept. Figure 8 shows the low-frequency match of the COMSOL simulation of the 90mm (3") active driver to a Linear Parameter Model (LPM) for the 2.6L box model. The basic box model was calibrated for materials below 500Hz. Above 500Hz, the effect of the box loading in the mid-range can be

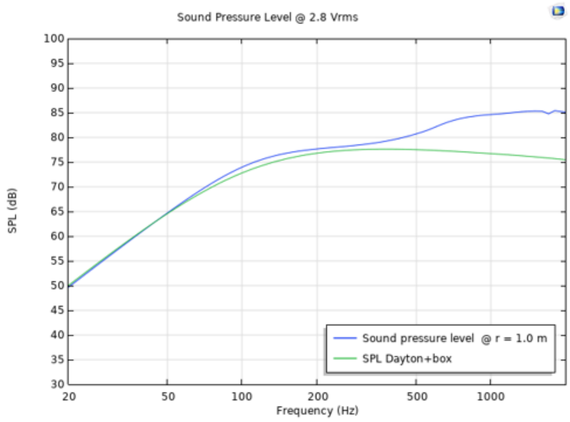

Figure 8. On-Axis SPL of 3" LPM Box (Green), 3" in Box Sim in COMSOL (Blue) 2kHz

seen. Figure 9 shows the On-Axis SPL up to 2kHz for the 3" speaker in a box simulation without the Dinaburg alignment and for the same 3" with the Dinaburg alignment, as well as an LPM estimate for a ring radiator. Here, the effect of adding the passive ring radiator to the box can be seen, and also that that the low-frequency simulation agrees well with an LPM for a simple passive radiator in a box. What is not seen in the on-axis response is the pressure behavior inside the box and how that might relate to the coherent relationship of the interior and exterior pressure, or how that could relate to improved mid-range clarity and improve off-axis behavior.

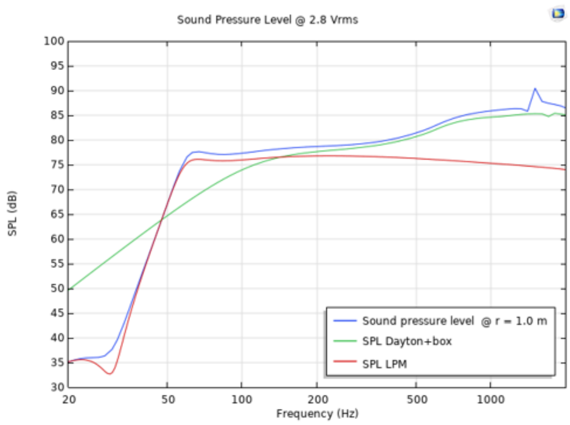

Figure 9. On-Axis SPL of 3" Box Sim (Green), 3" with Dinaburg Ring Radiator LPM (Red), 3" with Dinaburg Simulation (Blue). 2kHz.

In order to review the off-axis behavior and to see the behavior of interior and exterior pressure in more detail, a model was created that extended in high frequency up to at least the upper frequency of the active driver (approximately 12kHz).

In order to achieve the higher frequency range in the Finite Element Analysis (FEA) model, a smaller element size is needed. However, filling the full 3-D model with smaller elements would reach the limit of computer memory. To continue to use an FEA model, there are symmetries in the design that can be used to reduce the size of the model while allowing for more, and smaller, elements. Figures 10 and 11 show the quarter-symmetry model that was created. This allowed for the 20-12kHz frequency range in the model, which was solved with 1/12th octave frequency points.

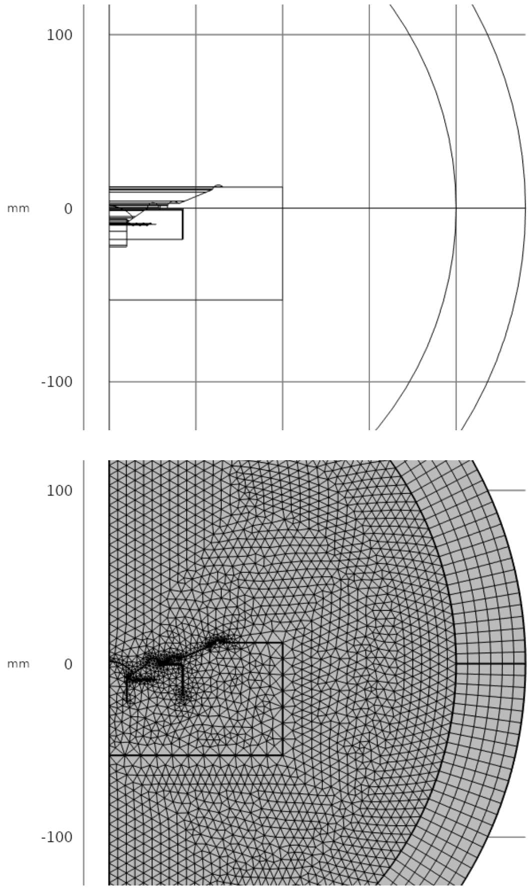

Figure 10. Quarter-Symmetry Simulation Model. 20-12kHz, 1/12th Octave Acoustic Solution. (859,864 elements)

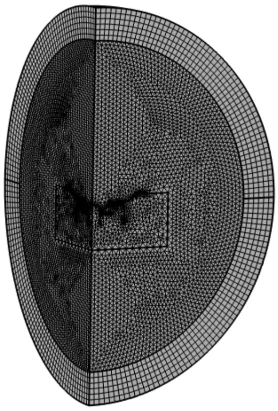

Figure 11. Quarter-Symmetry Simulation Model, Full View. 20-12kHz, 1/12th Octave Acoustic Solution. (859,864 elements)

4 Modeling & Simulation Results

4.1 Dinaburg Design

In Figures 12-14 below, the sound pressure level contours inside and outside of the box are shown. The lighter orange contour line inside the box indicates a pressure null. There is some evidence that the phase relationship between the rear radiation of the active speaker and the passive ring radiator is being controlled by the phase-stabilizing ring (shown in white). The pressure on the passive ring radiator is more coherent with the active speaker pressure radiation because of this relationship. How well the phase is managed can be assessed by following the pressure null that travels from the back of the active driver around the phase ring (in white) and up to the passive ring radiator.

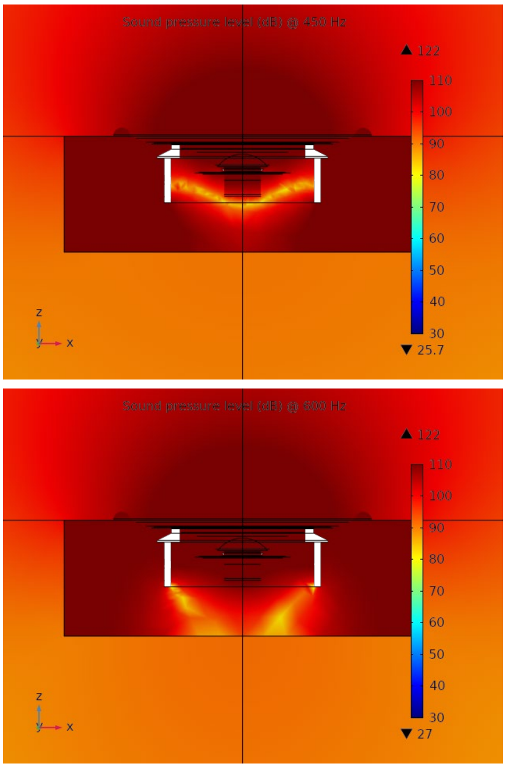

Figure 12. Full Symmetry Model. Interior and Radiated Sound Pressure. 450 Hz & 600 Hz

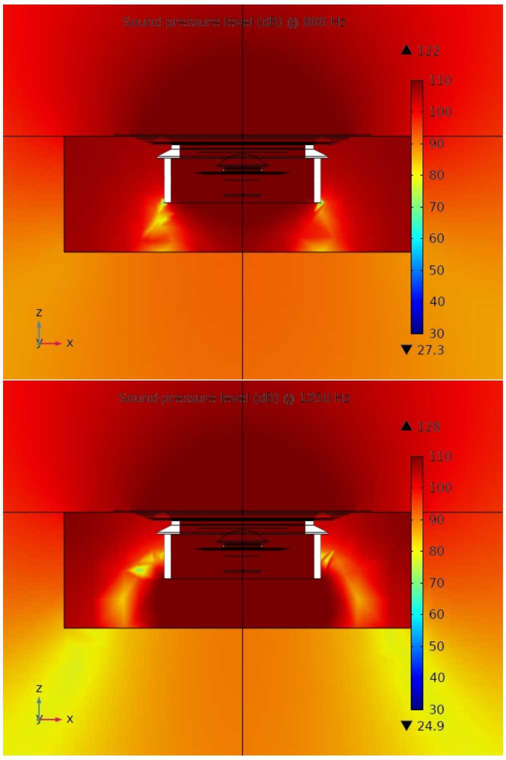

Figure 13. Full Symmetry Model. Interior and Radiated Sound Pressure. 800 Hz & 1250 Hz

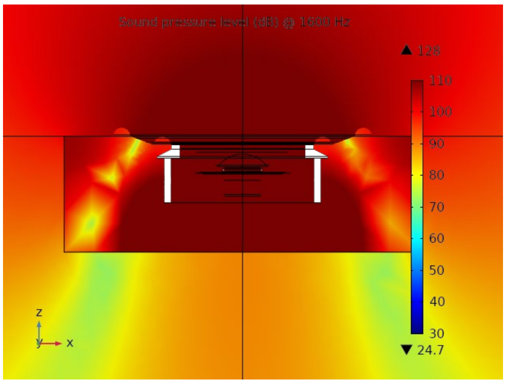

Figure 14. Full Symmetry Model. Interior and Radiated Sound Pressure. 1600Hz

The higher frequency model helps to visualize not only the lower and mid voices of 500-1600Hz behavior, but also the frequencies that define the off-axis behavior.

For the quarter-symmetry model, the frequency response (Figure 15) was extended to 12kHz, which was more than adequate for the active driver's upper bandwidth frequency, approximately 8kHz.

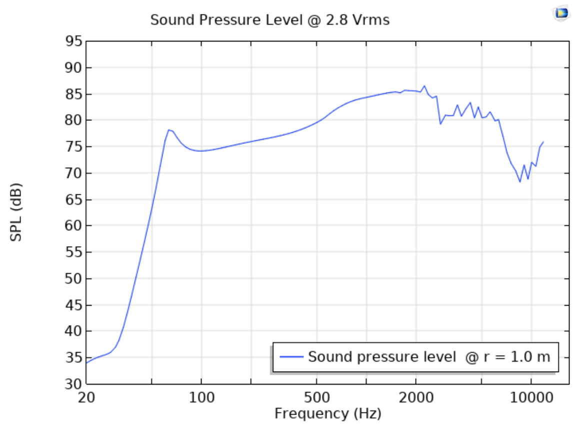

Figure 15. On-Axis SPL of 3" with Dinaburg C2S™ @1m (12kHz)

Figure 16 shows the sound pressure in the box interior only for the quarter-symmetry model in a three-quarter view. The quarter-symmetry is seen to have added a more refined display of the sound pressure contours.

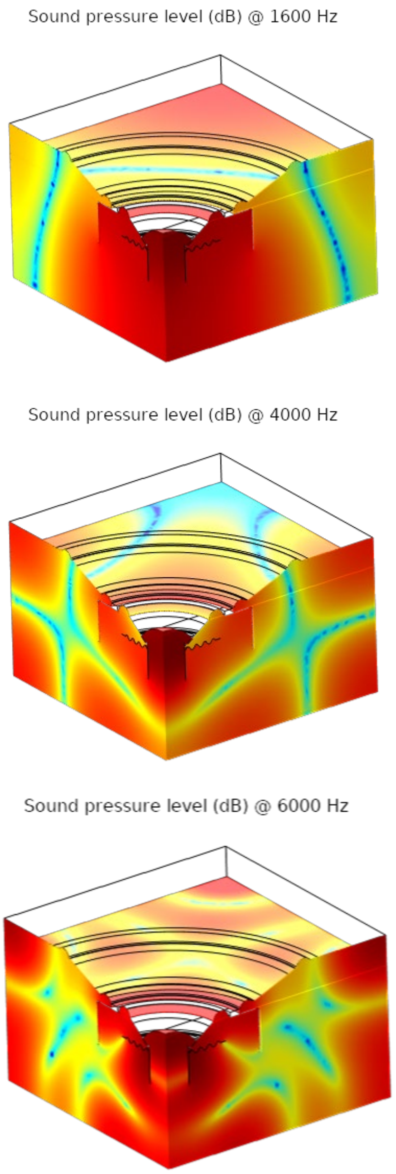

Figure 16. Quarter Symmetry Model (20-12kHz). Sound Pressure Inside the Box (1600Hz, 4000Hz, 6000Hz)

Following the now light blue pressure null line around the white phase-stabilizing ring in Figures 17-19, the control of the pressure inside the box and the coherence of phase at the passive ring radiator in the model is seen once again.

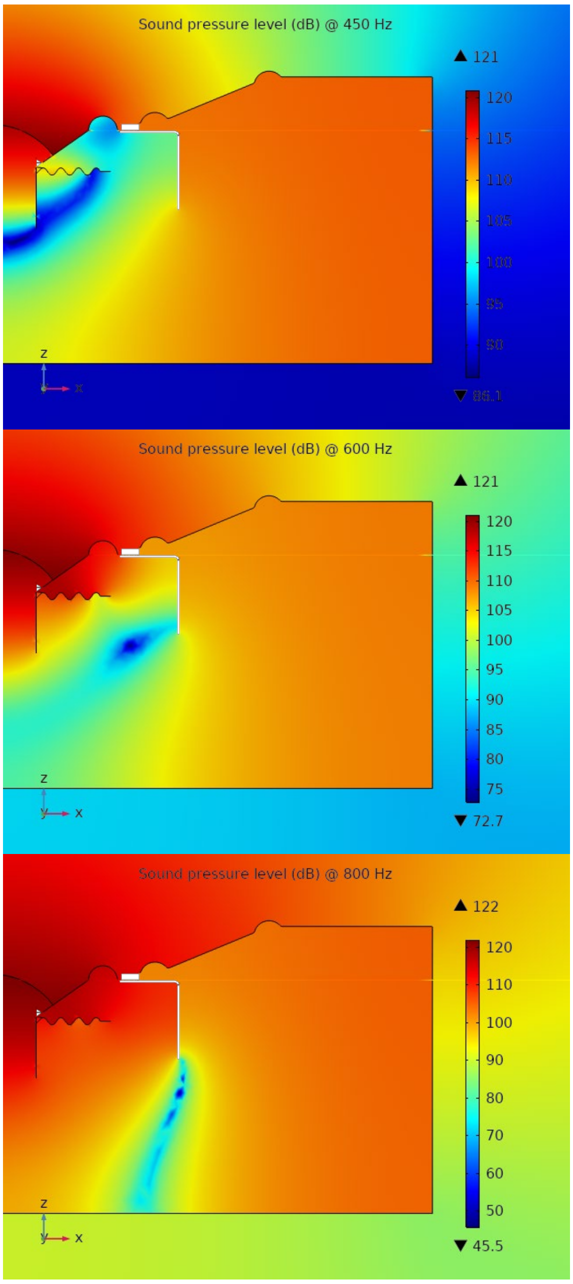

Figure 17. Quarter Symmetry Model (20-12kHz). Interior and Radiated Sound Pressure. (450Hz, 600Hz, 800Hz)

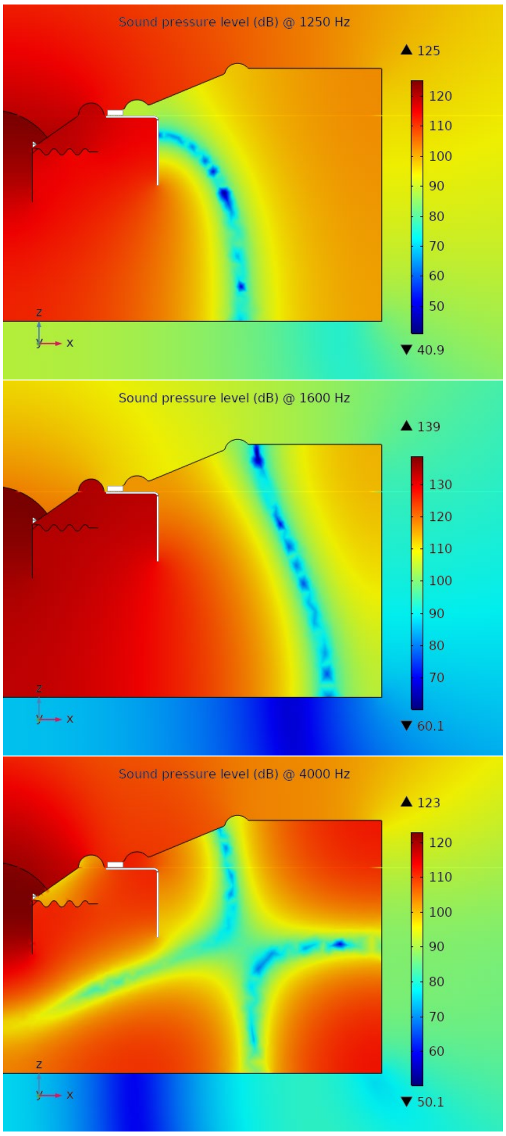

Figure 18. Quarter Symmetry Model (20-12kHz). Interior and Radiated Sound Pressure. (1250Hz, 1600Hz, 4000Hz)

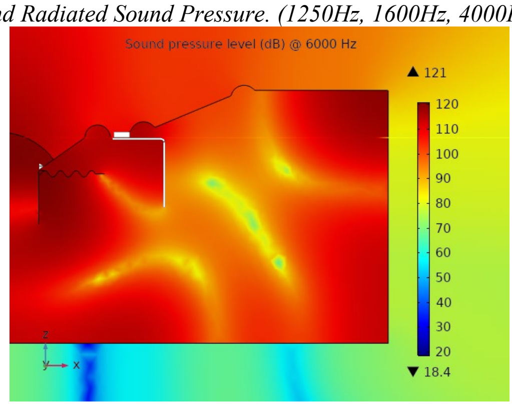

Figure 19a. Quarter Symmetry Model (20-12kHz). Interior and Radiated Sound Pressure. (6000Hz)

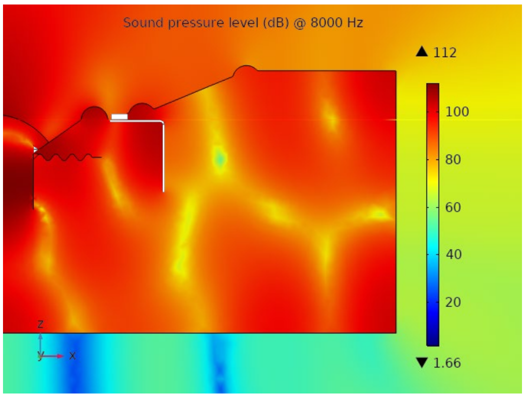

Figure 19b. Quarter Symmetry Model (20-12kHz). Interior and Radiated Sound Pressure. (8000Hz)

When considering the off-axis polar plots for higher frequencies of 6000Hz and 8000Hz (Figure 20), a broader off-axis response is seen.

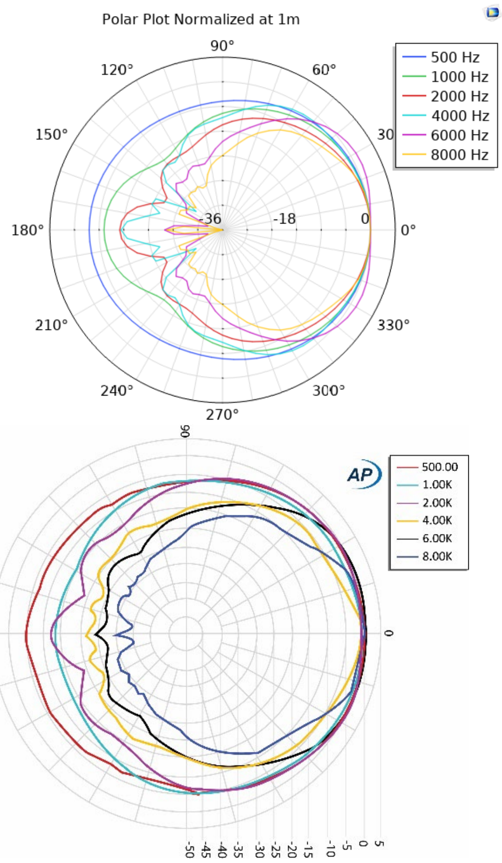

Figure 20. Simulation Polar Response (Top) & Measured Polar Response (Bottom)

The polar response measurements of the prototype's directivity compare well to the simulation results. This encourages the use of this simple COMSOL model as a method to analyze the Dinaburg design concept.

4.2 Rear Passive Radiator Design

Before looking at additional measurements of the Dinaburg design, a COMSOL model using the same 3” active speaker with a rear passive radiator, which had a surface area equivalent to the ring passive radiator, was created to compare the two design approaches (Figure 21).

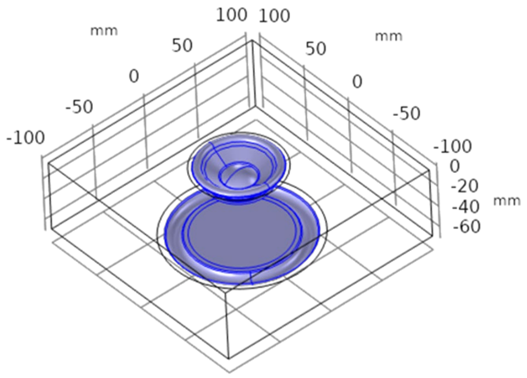

Figure 21. Rear Passive Radiator Geometry

The expectation was that a rear passive radiator design would have a similar on-axis response to the Dinaburg design. It was not clear that would be seen in the interior pressure and phase behavior or in the off-axis behavior. Any differences were expected to provide some understanding of the Dinaburg design’s influence or lack of influence from a typical passive radiator.

In Figures 22 and 23, the controlled pressure null seen in the Dinaburg design is absent. No complex phase behavior can be seen. Any phase behavior that appears in the interior pressure does not seem to have any coherence with the active speaker or its radiation.

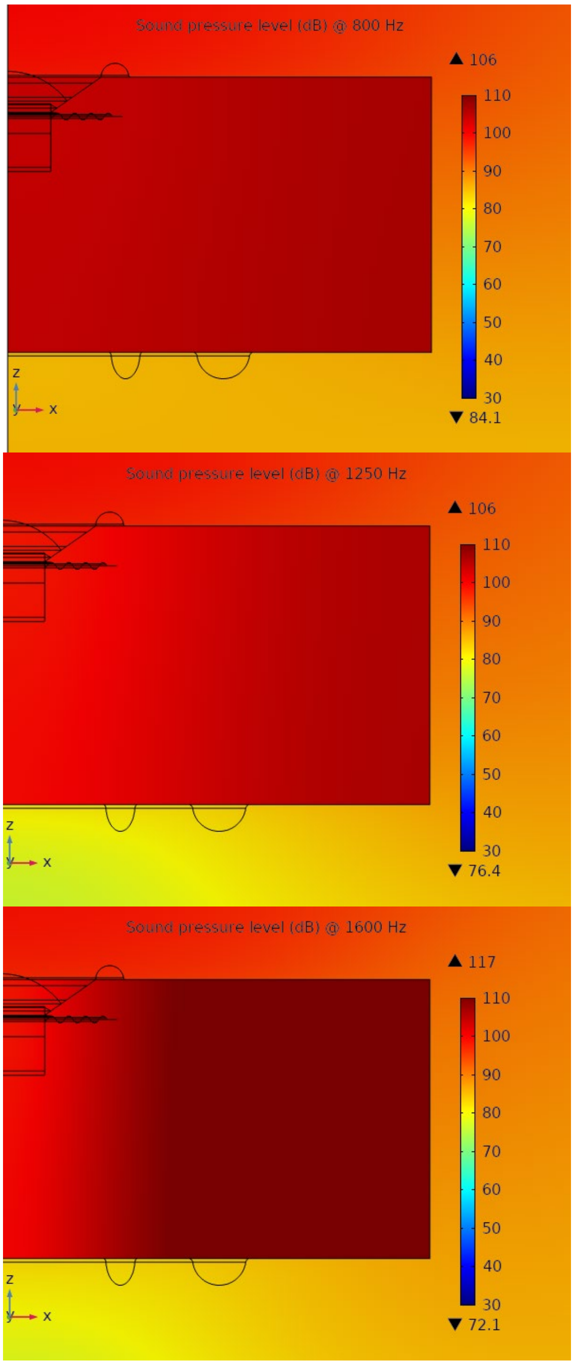

Figure 22. Passive Rear Radiator, Quarter Symmetry Model (20-12kHz). Interior and Radiated Sound Pressure. (800Hz, 1250Hz, 1600Hz)

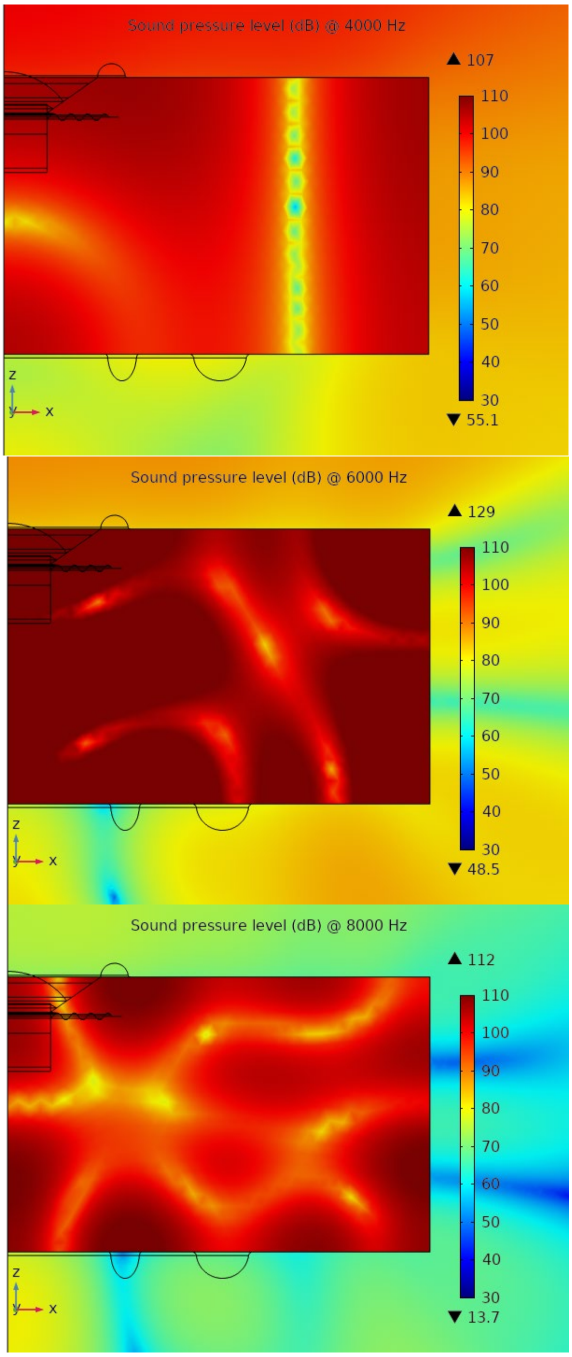

Figure 23. Passive Rear Radiator, Quarter Symmetry Model (20-12kHz). Interior and Radiated Sound Pressure. (4000Hz, 6000Hz, 8000Hz)

The on-axis frequency response from the passive rear radiator design looks similar to that of the Dinaburg design, although the Dinaburg is smoother in the upper mid-range (Figure 24).

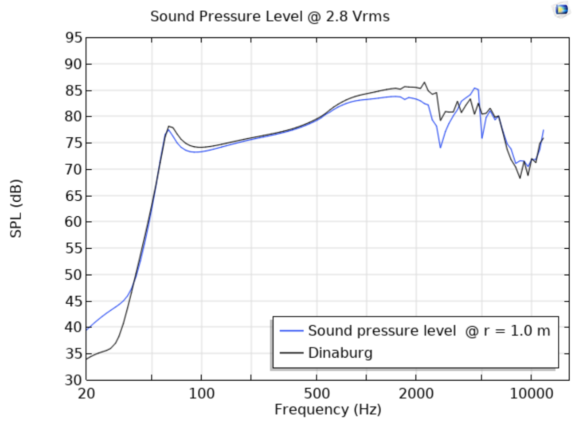

Figure 24. On-Axis SPL of 3" with Dinaburg C2S™ @1m (Black), vs. Rear Passive Radiator (Blue) (20-12kHz)

The polar response comparison (Figure 25) shows a broader off-axis response and less beaming in the Dinaburg design. With respect to the rear passive radiator design, the Dinaburg design's high frequency is much closer to its low-frequency off-axis response, even at angles up to 60 degrees off-axis.

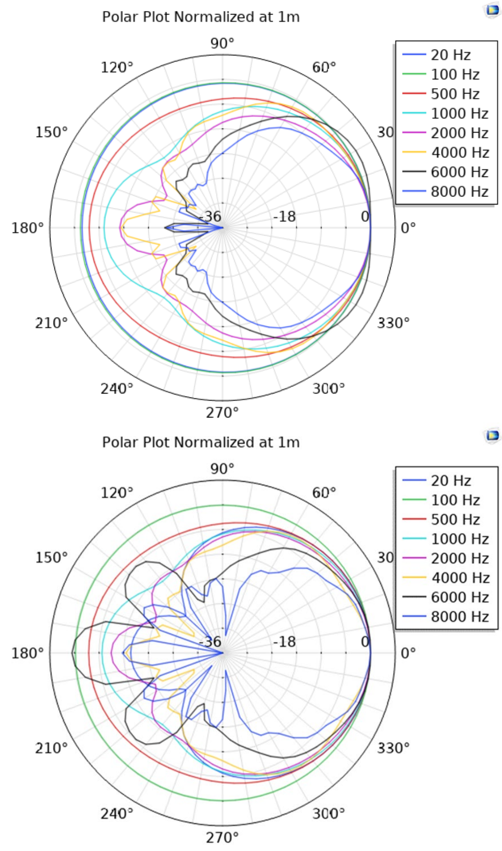

Figure 25. SPL Polar of 3" with Dinaburg C2S™ @1m (Top), vs. Rear Passive Radiator (Bottom) (20-8kHz)

With these differences between the typical passive radiator and the Dinaburg design, one could begin to correlate the differences to the improved performance of the Dinaburg design.

What follows are measurements of a prototype that can also help in understanding more about the Dinaburg design's behavior in correlation to the listening quality of the prototypes and the COMSOL model results.

5 Measurements

From measurement data of a physically realized prototype, a very low level of mid-range power compression and a drop in mid-range distortion were seen in the Dinaburg speaker. The drive level to the speaker was increased from 30mV (-30.5dBV) to 100mV (-20dBV) in approximately 3dB steps. The total change in level from start to finish was 10.5dB. From 100Hz to 20kHz there was minimal compression (Figure 26).

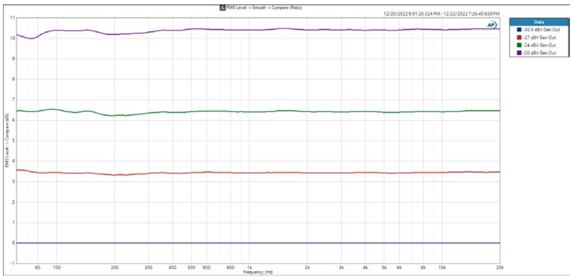

Figure 26. The Dinaburg C2S™ speaker was driven with the amp set to 20dB of gain (x10). The 60Hz – 20 kHz log-chirp drive level from the generator of the APx 515 was increased from 30mV (-30.5dBV) to 100mV (-20dBV) in approximate 3dB steps.

Despite a 10dB increase in SPL, the THD in the mid-range (500Hz – 3 kHz) decreased by as much as 10 dB with THD levels as low as -65dB (0.05%) (Figure 27).

Figure 27. THD Measurements. The absolute SPL at the 1-meter, on-axis microphone position was in this frequency range 82-83 dBSPL.

In Figure 28, phase was measured for the prototype. This graph could also help anticipate the intelligibility and clarity of the Dinaburg design. Typically, a phase measurement made across what could be called the "crossover" frequency of a passive radiator or bass reflex system will generally have a very sharp transition going from the active radiator to the passive radiator. In this case, the transition area is in the 200Hz region. Surprisingly, there is no discontinuity in the 200Hz region. This could be at least partially responsible for the Dinaburg C2S™ system's ability to play complex multi-voice harmonies which can be heard during a listening experience.

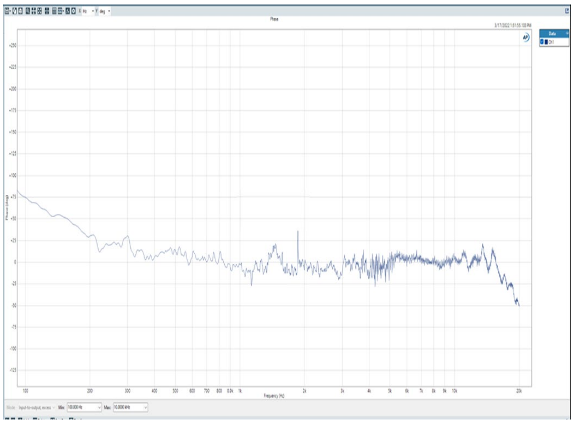

Figure 28. Phase Linearity Measurement

In several formalized listening tests, which could be the subject of a future paper, there is general agreement that reproduction of the mid-range, in particular with female vocals, sounded clearer when reproduced by a Dinaburg C2S™ driver compared to an equivalent conventional driver.

One of the aspects of a driver designed following the Dinaburg C2S™ design theory that seems unique is that it can reproduce a wide range of frequencies from one acoustic center. For a single acoustic center, the group delay would be smooth and at a constant delay over a wide frequency range. From low frequencies that are typically reproduced by a woofer to higher frequencies which are reproduced by a tweeter, the group delay would vary slightly. The measurements show that from 400Hz to 10kHz, the group delay is ±250 microseconds, which is indeed very slight and smooth (Figure 29).

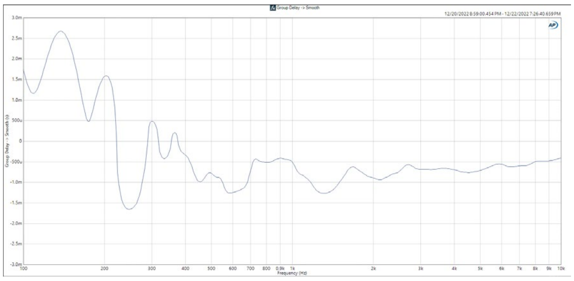

Figure 29. Group Delay.

6 Conclusions

The first prototypes that were created based on the modeling results and were used for the measurement comparison had the attributes from listening tests of intelligibility and clarity, and a depth of detail in the harmony of vocals. They maintained these attributes even when listening at a wide off-axis angle of 60 degrees. Each aspect of the Dinaburg C2S™ design was analyzed, either through physical measurements of prototypes built from designs optimized with FEA models or from a detailed look at acoustic pressure behavior on the interior of the enclosure and on the interior and exterior surfaces of the passive ring radiator; this was only practical with the FEA models, using the tools of COMSOL Multiphysics®. In doing so, the effects of the phase-stabilizing ring interacting with the concentric ring radiator (designated by Dinaburg as the coplanar concentric stabilizer) could be seen. The phase-stabilizing ring seems to enable the passive ring radiator to present a very stable phase relationship to the listener on- and off-axis. Virtual listening tests, using auralization to play back music convolved with the design's simulated impulse response, agreed with the listening experience of practical prototypes. These formalized tests can be reported on in a later paper. The purpose of the work presented here was to find some understanding of the acoustical behavior of the realized design theory, which might relate to listening experience.

When played back, the complex multi-voice harmonies were clear and cohesive, without audible distortion. At present, the COMSOL modeling and the measurements appear to justify that. There is now an understanding of the nature of the design theory and how it can be applied to a variety of applications, such as automotive speakers, in-wall and ceiling speakers, and headphone designs.

Acknowledgements

The author would like to thank Dan Foley for the measurements given in Figures 26 and 27, and also Jim Toumy for those given in Figures 28 and 29.

References

[1] Dinaburg, "Speaker With Dual Diffuser", United States Patent No. 10,812,912 B2, 2020.

[2] H. F. Olson, "Loud Speaker and Method of Propagating Sound" U.S. Patent 1,988,250 application 1934 Feb. 17; patented 1935 Jan. 15.

[3] H.F. Olson, "Drone-Cone, Phase Inverter" *J. Audio Eng. Soc.* vol. 21, no. 7, pp. 582,583. (September 1973)

[4] Harry F. Olson, John Preston and Everett G. May, "Recent Developments in Direct-Radiator High-Fidelity Loudspeakers," *J. Audio Eng. Soc.*, vol. 2, no. 4, p. 219 (October 1954)

[5] A.N. Thiele, "Loudspeakers in vented Boxes, Parts I and II", *J. Audio Eng. Soc.* vol. 19, no. 5, pp. 382, no. 6, p. 471. (May, June 1971)

[6] Richard H. Small, "Direct Radiator Loudspeaker System Analysis", *J. Acous. Soc.* vol. 20, no. 5, pp. 383, (1972)

[7] R.H. Small, "Passive-Radiator Loudspeaker Systems, Part 1, Analysis," *J. Audio Eng. Soc.,* vol. 22, pp. 592-601 (1974 Oct.).

[8] Y. Nomura and Z. Kitamura, "An Analysis of Design Conditions for a Phase-Inverter Speaker System with a Drone Cone," *IEEE Trans. Audio Electroacoust.*, vol AU-21, pp. 397-407 (1973 Oct.)

[9] T.L. Clarke, "Augmented Passive Radiator Loudspeaker," U.S. Patent 4,076,097, application 1976 Aug. 4, patented 1978 Feb. 28.

[10] E. Hossbach, "Loud Speaker System," U.S. Patent 3,772,466, application 1971 Nov. 24, patented 1973 Nov. 13.

[11] COMSOL Multiphysics 5.5., Model Library, © 1998-2021 COMSOL AB