Review and Analysis of the Dinaburg C2S™ Alignment

May 3, 2023. Roger Shively.
About 2700 words.

INTRODUCTION

In the nearly 100 years of speaker innovation, every once in a while, we see something that makes our heads turn. And it makes us want to look closer. Dinaburg Technology has a unique approach not only to packaging a passive radiator in a small volume but also to taking advantage of a back wave from the loudspeaker's diaphragm to optimize the passive radiator's response and the off-axis performance of the active driver. The advantages are clearly audible, and it makes us want to take a closer look.

WHY IT IS NEEDED

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 complicated. 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 defuse 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. To be able 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 unique, especially if the active loudspeaker is essentially a 3" diameter loudspeaker. This example is what we come to look at.

HOW IT IS ACCOMPLISHED (THEORY)

In Mikhail Dinaburg's description of his invention (US Patent: US10812912B2), he refers to the loudspeaker cone as a diffuser. 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. In the case of a loudspeaker, the cone diffuser is an inefficient one. Mikhail, in his design theory, 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, which is from Dinaburg Technology's white paper "Theory of C2S™: The coplanar concentric stabilizer for cohesive sound reproduction." 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 a bass reflex port design has over a sealed chamber. The coplanar concentric stabilizer from the design theory, which is the concentric passive ring radiator, has a better coupling to the outside air volume than a bass reflex port would have or even a nonconcentric passive radiator, which might have to be located on a different side of the enclosure. The passive ring radiator, designated as the coplanar concentric (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 again in Figure 1, the passive radiator (titled the stabilizing part) takes the form of a ring that is held in place by inner and outer surrounds of a compliant material.

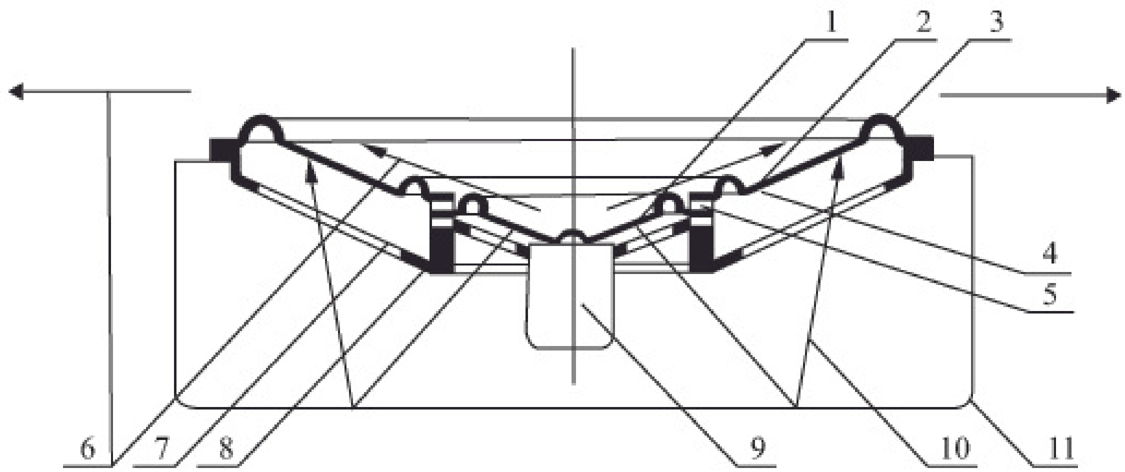

Figure 1. (1) Active part, (2) Stabilizing part, (3) Outer Surround, (4) Stabilizing part, (5) Phase Stabilizing Ring, (6) Direction of propagation of sound energy in the frontal plane, (7) Basket, (8) Basket structural member, (9) Magnet, (10) Direction of propagation of sound energy, inside enclosure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

To realize the design for prototyping and for computer aided mathematical simulation in COMSOL Multiphysics®, 3-D CAD was generated. The Simulation CAD (Figure 4.) was created for the specific multiphysics approach that COMSOL® would provide, integrating the mechanical, acoustical, and electrical simulations. Figures 2-4 below show the CAD construction for a 90mm (3") active loudspeaker and a 125mm (6.5") outer diameter passive ring radiator, i.e., the coplanar concentric stabilizer. The box volume: 2.6L (65mmx200mmx200mm

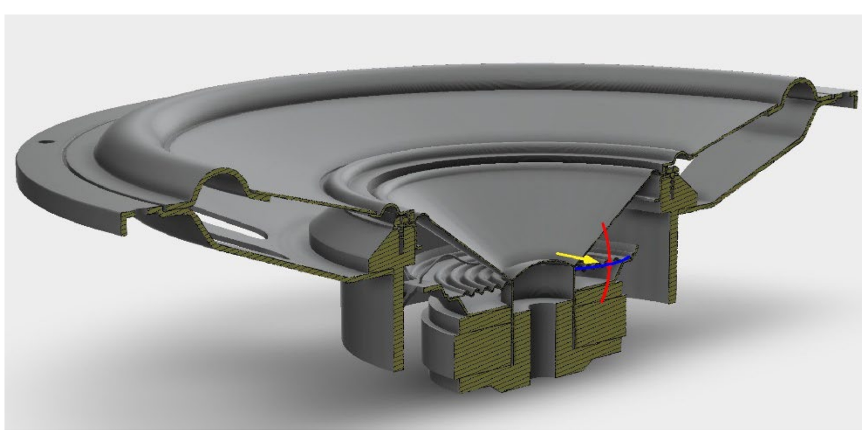

Figure 2. Speaker Design CAD

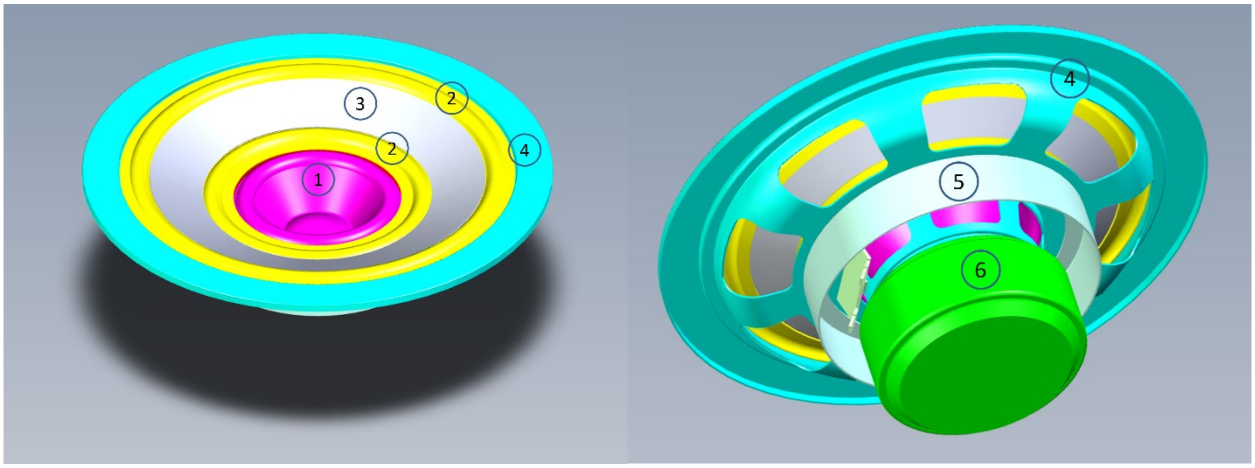

Figure 3. Speaker Design CAD: (1) Pink - Active Loudspeaker (∅ 90mm), (2) Yellow – Passive Suspensions, (3) Grey – Passive Membrane (Coplanar Concentric Stabilizer), (4) Cyan – Basket Frame (∅125mm), (5) White – Phase Stabilizing Ring, (6) Green – Motor Structure

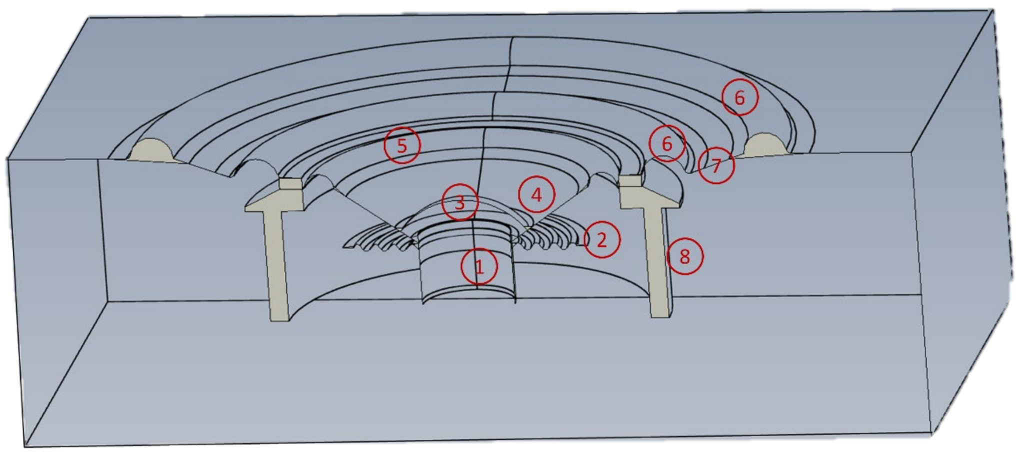

Figure 4. Speaker & Box Design CAD Section View: (1) Voice Coil, (2) Spider, (3) Dust Cap, (4) Cone, (5) Surround, (6) Inner / Outer Passive Suspension, (7) Passive Membrane (coplanar concentric stabilizer/C2S™ Stabilizer), (8) Phase Stabilizing Ring

To build the Multiphysics® model, the motor structure in the model is represented with the lumped electromagnetic parameters for the active 90mm (3”) loudspeaker 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, NBR rubber surrounds; and, these were applied to the shell elements that defined the boundary for each of the model’s entities.

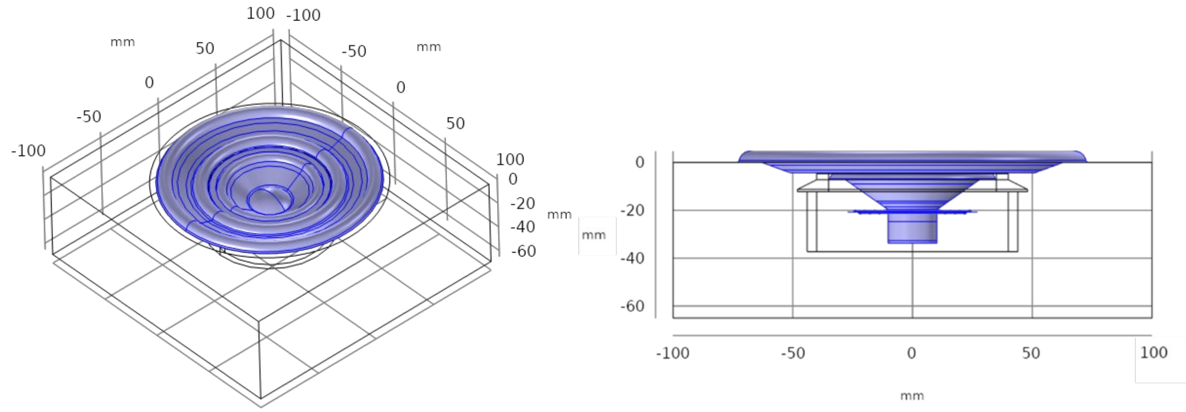

Figure 5. Simulation CAD Model. Full Box View. Section View.

The first model was run on a full speaker and box model (Figure 6) in a 3D Acoustic Simulation. (Figure 7). Perfectly Matched Layers (PML) were placed at 4 meters from the center of the active speaker's dust cap. The PML is used to create non-reflective boundary for a Free Field Solution.

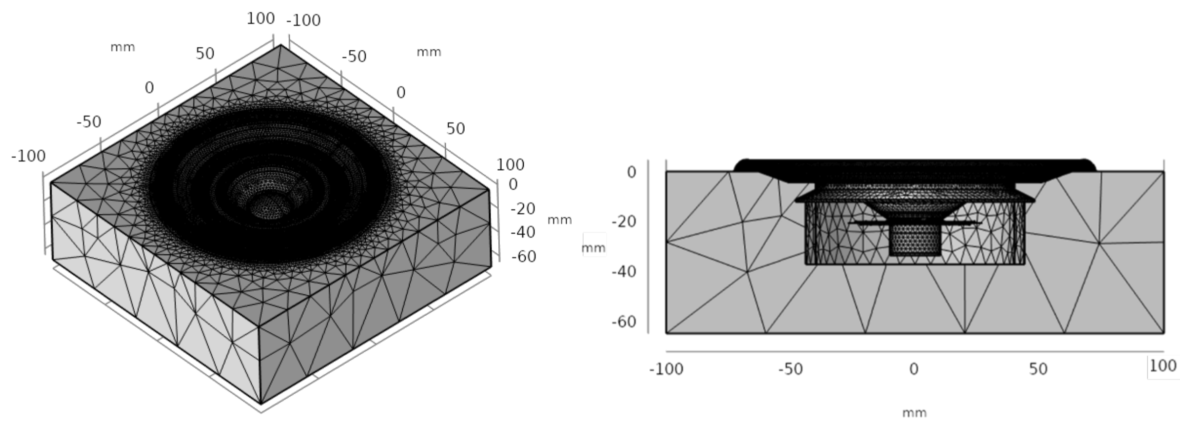

Figure 6. Simulation Speaker Box Model FEA Mesh. Full Box View. Section View.

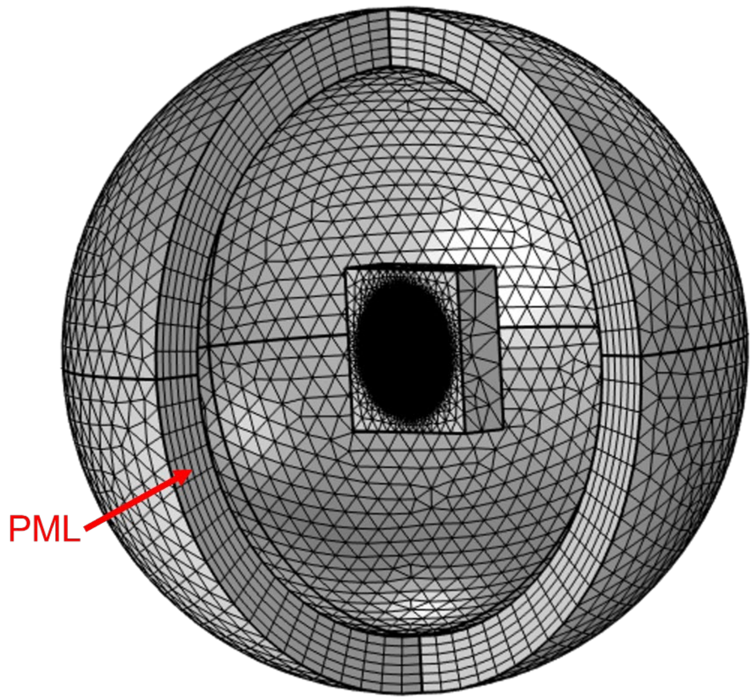

Figure 7. Full Acoustic 3D Simulation FEA Mesh. Quarter Section View. Perfectly Matched Layers (PML), non-reflective boundary for Free Field Solution. 20-2kHz, 1/12th Octave Acoustic Solution. (461,613 elements)

The 1/12th octave acoustic solution was able to give results for 20-2kHz. This provided enough low-frequency, mid and high-frequency to validate the model and assess some of the salient acoustic behavior in the design concept. Figure 7 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 500 Hz. Above 500 Hz, the effect of the box loading in the midrange can be seen. In Figure 8, we see 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 we can see the effect of adding the passive ring radiator to the box. We can also see that the low frequency simulation agrees well with an LPM for a simple passive radiator in a box. What we don't see 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 and how that could relate to improved midrange clarity and improve off-axis behavior.

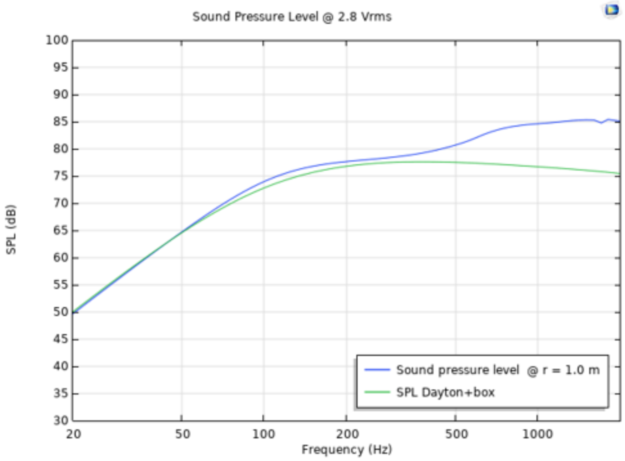

Figure 8. On-Axis SPL of 3" LPM Box (green), 3" Box Sim (Blue) 2kHz.

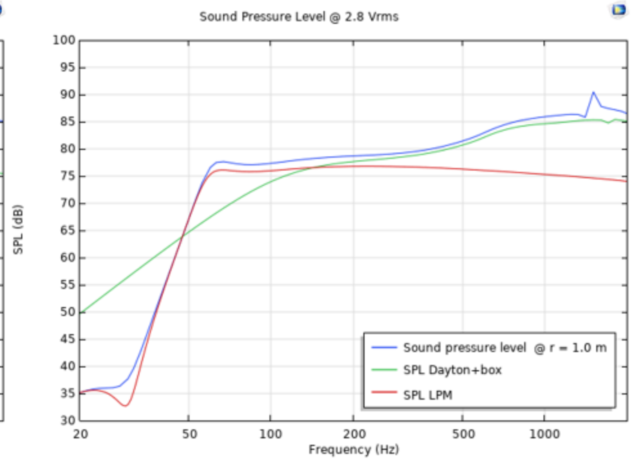

Figure 9. On-Axis SPL of 3" Box Sim (Green), 3" w/Dinaburg Ring Radiator LPM (Red), 3" w/Dinaburg Sim (Blue). 2kHz.

To review the off-axis behavior and to see a more detailed behavior of interior and exterior pressure, a model that extended in high-frequency up to at least the upper frequency of the active driver, which is approximately 12kHz.

To achieve the higher frequency range in the FEA model, a smaller element size is needed. Filling the full 3D 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, but allow for more, and smaller, elements. Figures 10 & 11 show the quarter-symmetry model that was created. This gave us the 20-12kHz frequency range in the model, which was solved 1/12th octave frequency points.

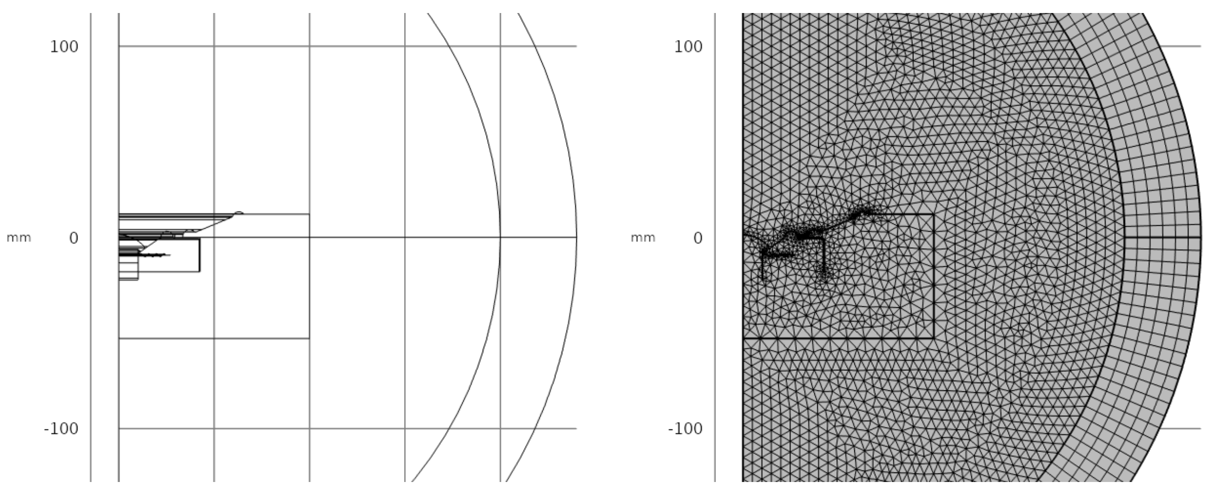

Figure 10. Quarter-Symmetry Simulation Model. 20-12kHz, 1/12th Octave Acoustic Solution. (859,864 elements)

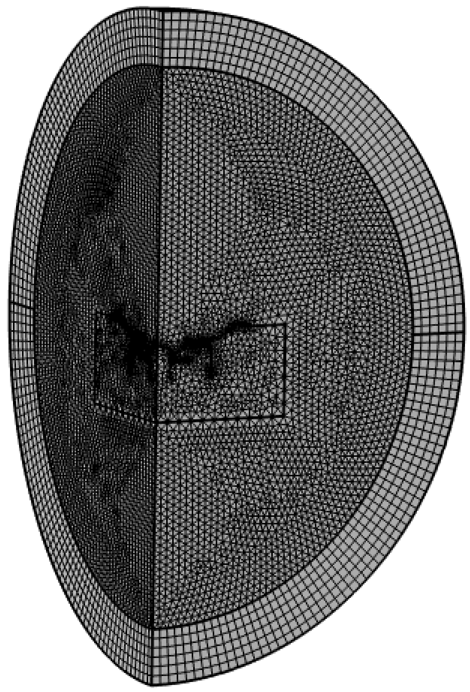

Figure 11. Quarter-Symmetry Simulation Model, Full View. 20-12kHz, 1/12th Octave Acoustic Solution. (859,864 elements)

MODELING & SIMULATION (EVIDENTIAL PROOF)

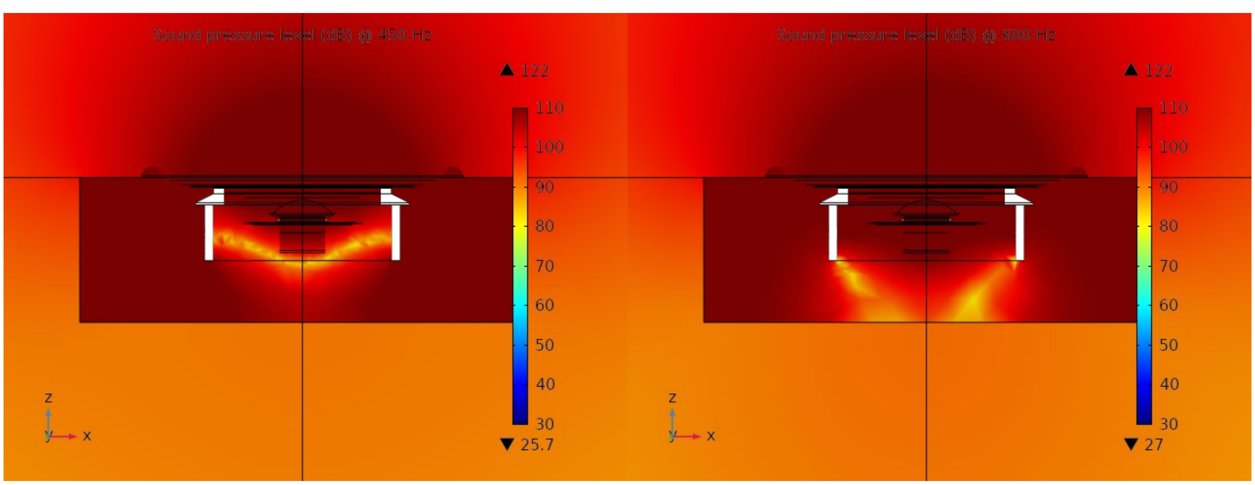

Figure 12. Full Symmetry Model. Interior and Radiated Sound Pressure. 450 Hz & 600 Hz

In Figures 12 – 14, 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. The pressure on the passive ring radiator is more coherent with the active speaker radiation. We can follow how well the phase is managed by following the pressure null (the lighter color pressure center line) that travels from the back of the active driver around the phase ring (shown here in white) and up to the passive ring radiator, which is characterized by Dinaburg as the C2S™ stabilizer (i.e., Coplanar Concentric Stabilizer).

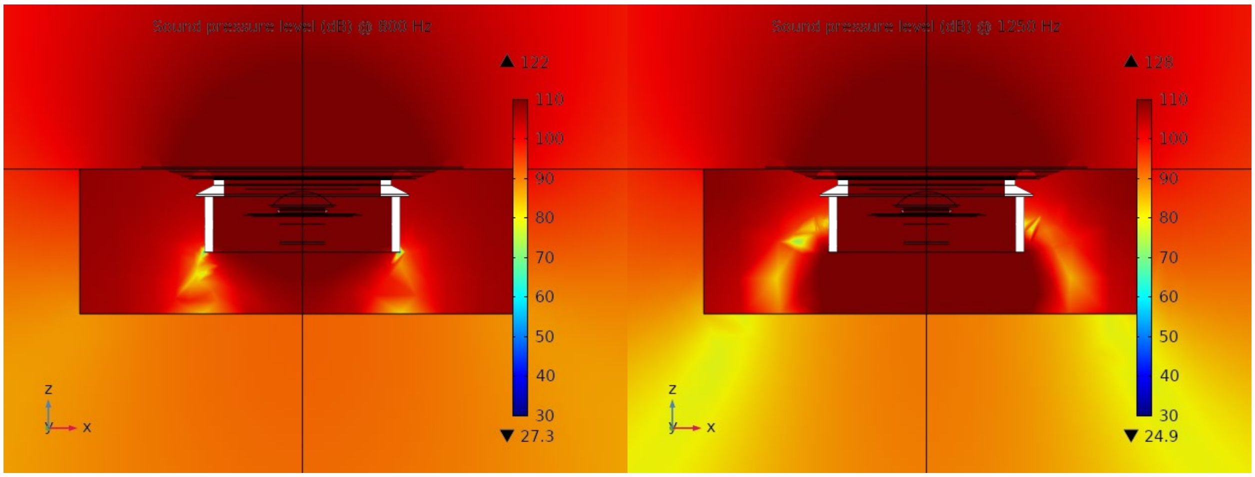

Figure 13. Full Symmetry Model. Interior and Radiated Sound Pressure. 800 Hz & 1250 Hz

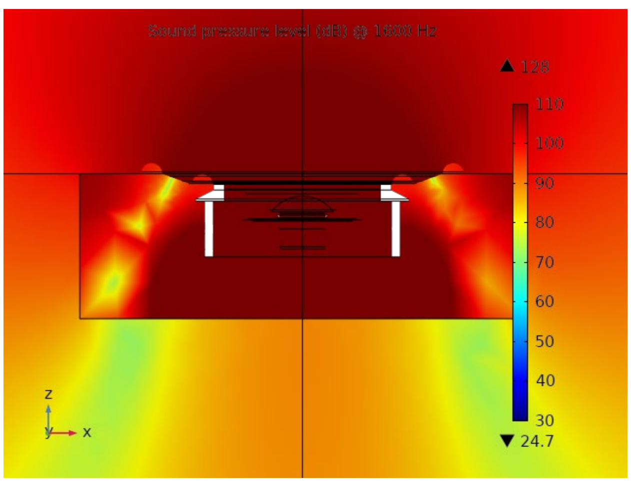

Figure 14. Full Symmetry Model. Interior and Radiated Sound Pressure. 1600Hz

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

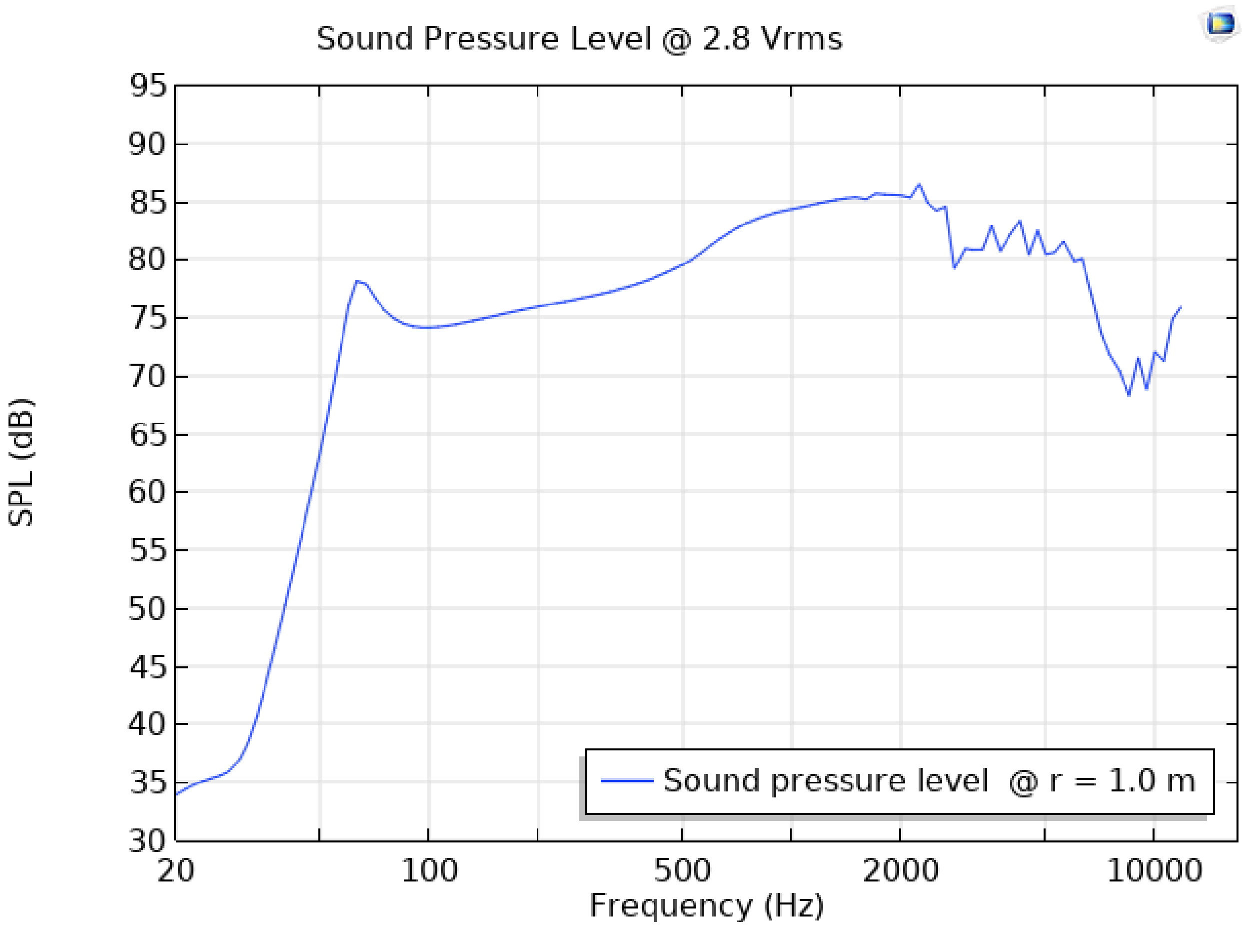

Figure 15. On-Axis SPL of 3” w/ Dinaburg C2S™ @1m (12kHz)

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

Below, in Figure 16, there is a look at the sound pressure in the box interior only for the quarter-symmetry model in a three-quarter view. We can see that the quarter-symmetry has added a more refined display of the sound pressure contours.

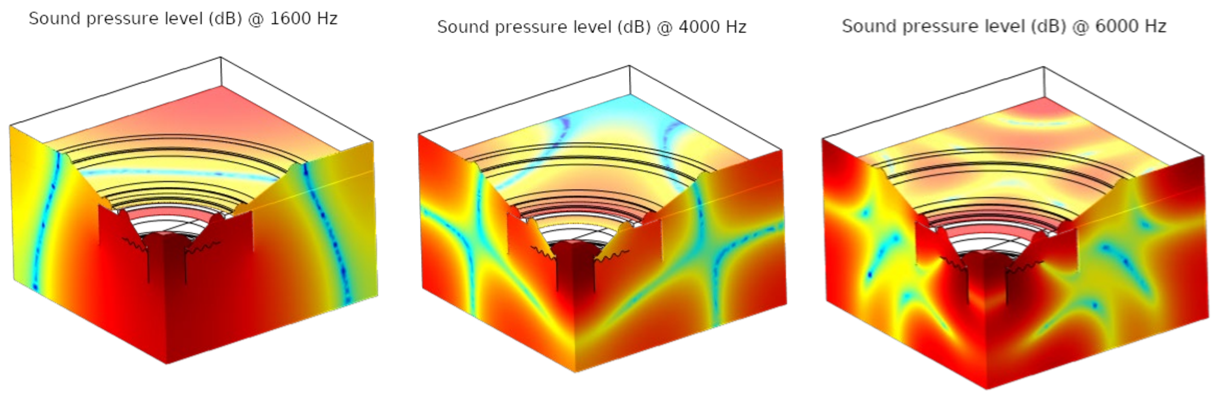

Figure 16. Quarter Symmetry Model (20-12kHz). Sound Pressure Inside the Box (1600Hz, 4000Hz, 6000Hz)

We can again see 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, which again is characterized by Dinaburg as the C2S™ stabilizer.

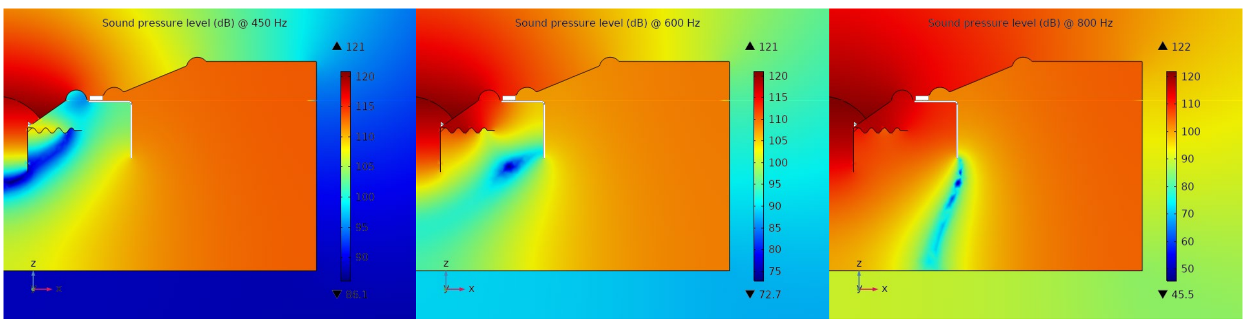

Figure 17. Quarter Symmetry Model (20-12kHz). Interior and Radiated Sound Pressure. (450Hz, 600Hz, 800Hz)

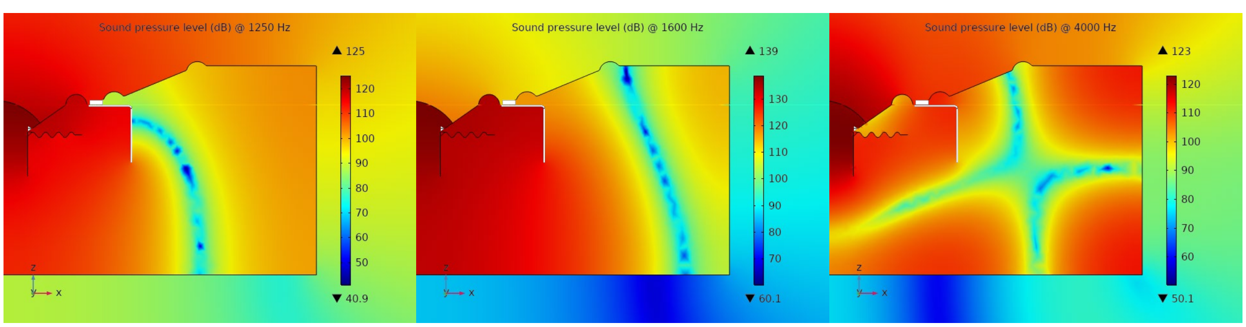

Figure 18. Quarter Symmetry Model (20-12kHz). Interior and Radiated Sound Pressure. (1250Hz, 1600Hz, 4000Hz)

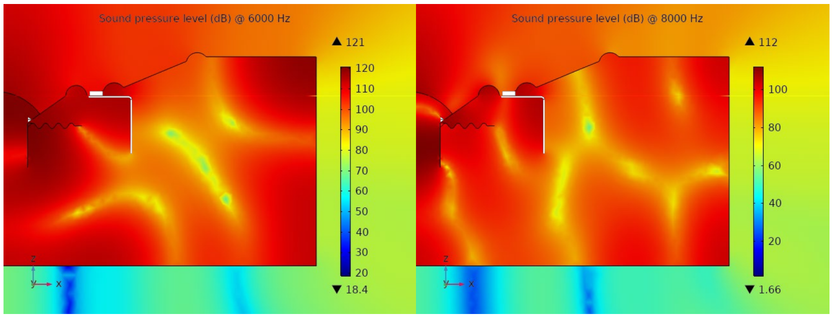

Figure 19. Quarter Symmetry Model (20-12kHz). Interior and Radiated Sound Pressure. (6000Hz & 8000Hz)

When we look at the off-axis polar plots, for higher frequencies of 6000 and 8000 Hz, we see a broader off-axis response – less beaming. It is much closer to the low frequency off-axis response, even at angles up to 60 degrees off-axis.

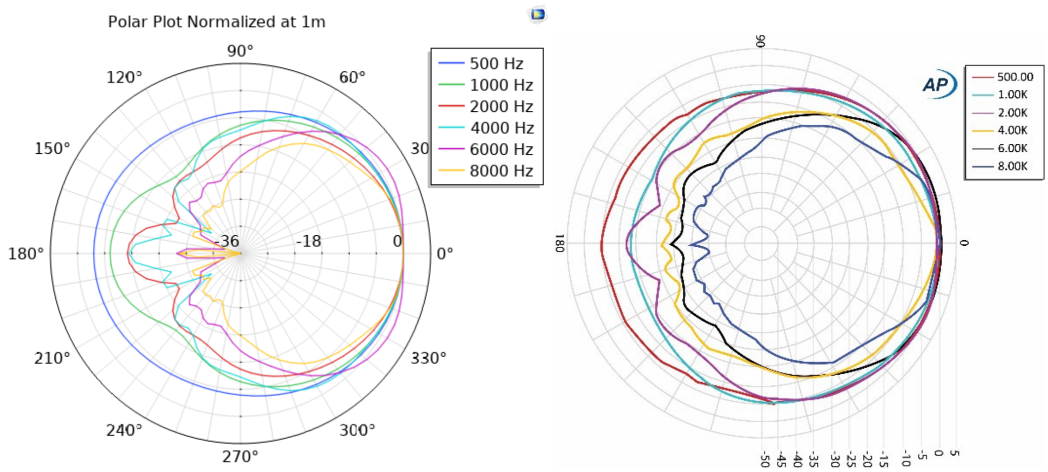

Figure 20. Simulation Polar Response (Left) & Measured Polar Response (Right)

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

The measurements of a prototype can also help understand more about the Dinaburg design's behavior to correlate to the listening quality of the prototypes and the COMSOL model results.

MEASUREMENTS

From measurement data of a physically realized prototype[1], a very low level of midrange power compression and a drop in midrange distortion was seen in the Dinaburg speaker. The drive level to the

[1] Performed by Dan Foley from Do No Harm Music (dan.foley@donoharmmusic.com)

speaker was increased from 30 mV (-30.5 dBV) to 100 mV (-20 dBV) in approximate 3 dB steps. The total change in level from start to finish was 10.5 dB. From 100 Hz to 20 kHz, there was minimal compression. (Figure 21.)

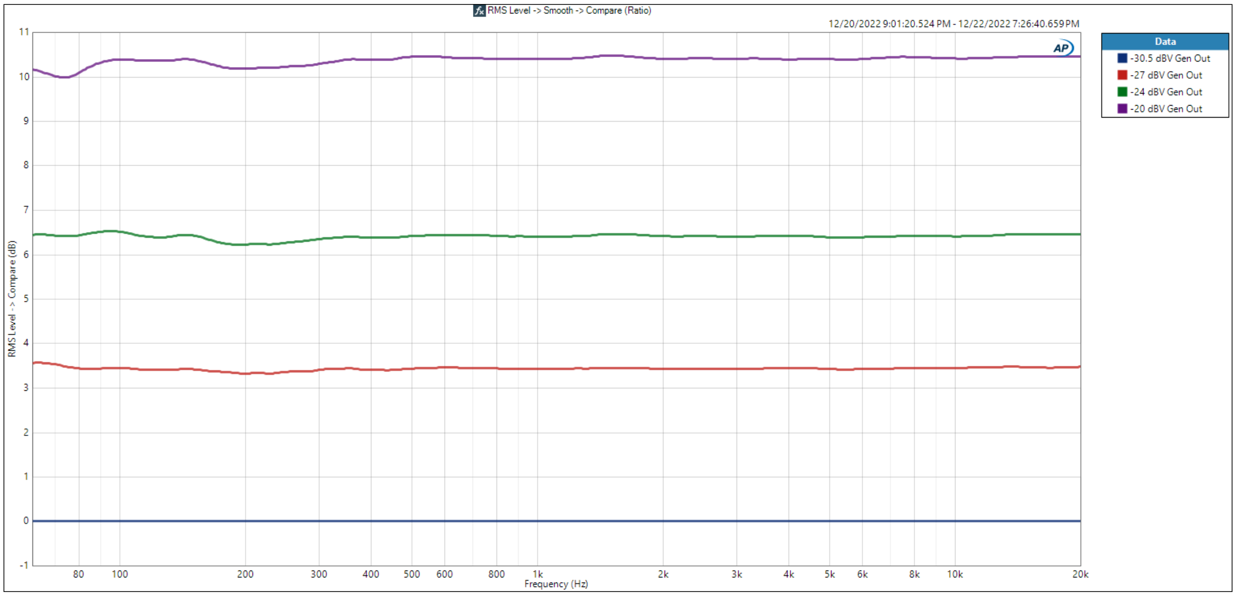

Figure 21. The Dinaburg C2S™ speaker was driven with the amp set to 20 dB of gain (x10). The 60 Hz – 20 kHz log-chirp drive level from the generator of the APx 515 was increased from 30 mV (-30.5 dBV) to 100 mV (-20 dBV) in approximate 3 dB steps.

Despite a 10 dB increase in SPL, the THD in the midrange (500 Hz – 3 kHz) went down by as much as 10 dB with THD levels as low as -65 dB (0.05%). (Figure 22.)

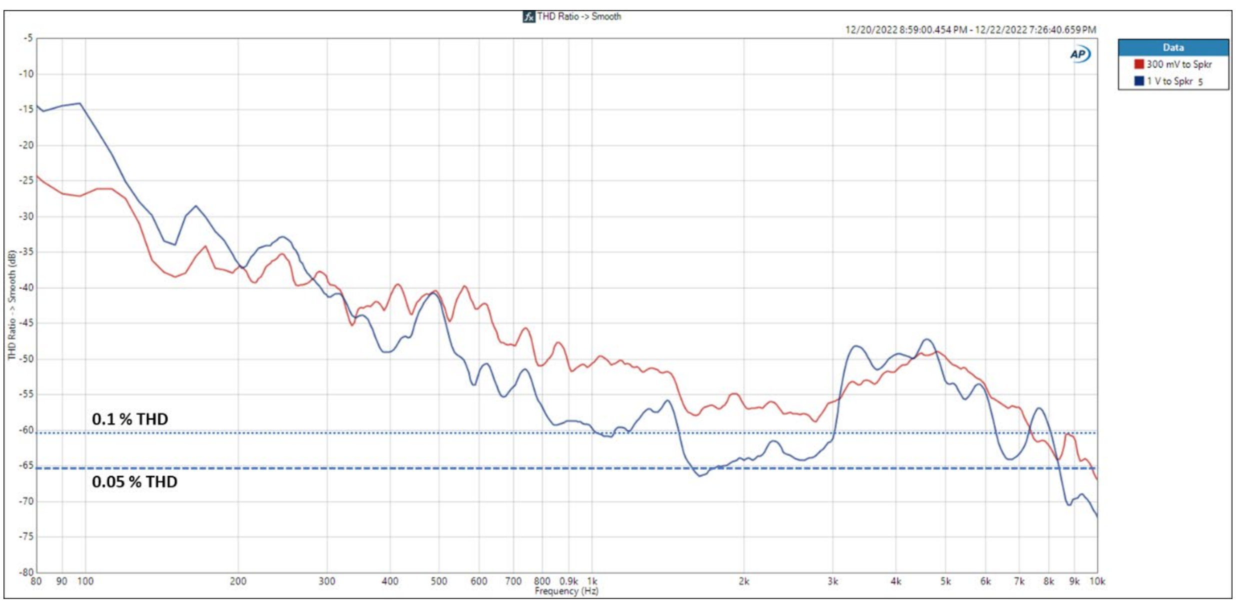

Figure 22. THD Measurements. The absolute SPL at the 1-meter, on-axis microphone position was in this frequency range 82-83 dBSPL.

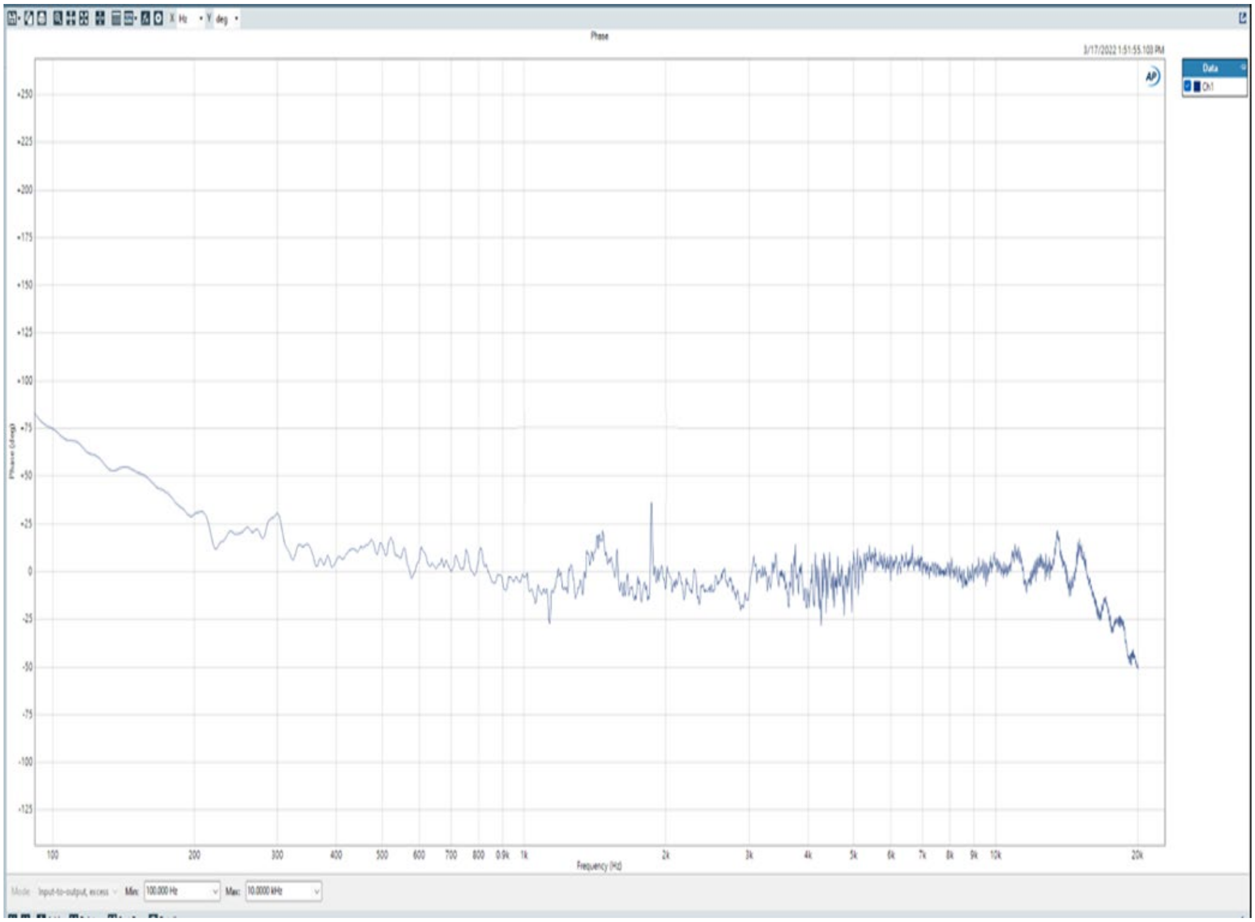

Figure 23. Phase Linearity Measurement

In Figure 23, phase was measured for the prototype.[2] This graph could also help anticipate the intelligibility and clarity of the Dinaburg design. 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 200 Hz region. There is a lack of discontinuity in the 200Hz region, which is surprising. This could be at least partially responsible for the Dinaburg C2S™ system’s good performance when playing complex multi-voice harmony.

In several listening tests, there is general agreement that reproduction of the midrange, in particular with female vocals, sounded clearer when reproduced by a Dinaburg C2S™ driver compared to an equivalent conventional driver.

One of the unique aspects of a driver designed following the Dinaburg C2S™ design theory is that it can reproduce a wide range of frequencies from one acoustic center. As such, the group delay would be very smooth and at a constant delay over a wide frequency range. From low frequencies that are typically reproduced by a woofer to frequencies reproduced by a tweeter, the group delay would vary

[2] Measured by Jim Tuomy (jimtuomy@gmail.com)

slightly. The measurements show that from 400 Hz to 10 kHz, the group delay is ±250 microseconds, which is indeed very slight and smooth. (Figure 24.)

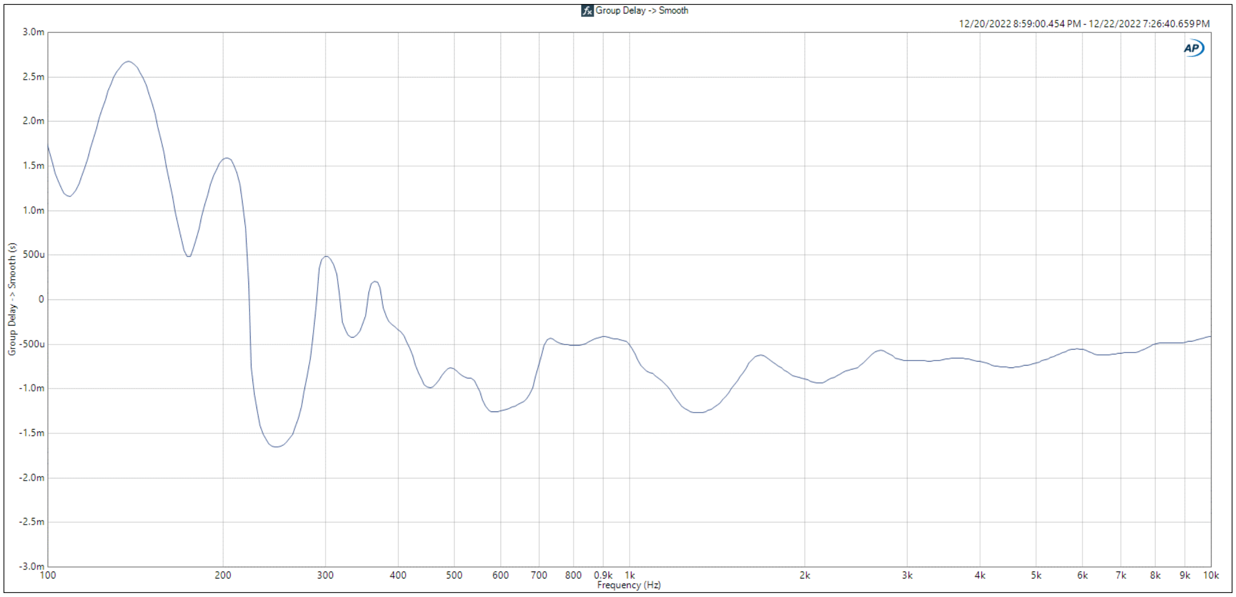

Figure 24. Group Delay.

CONCLUSION

In the early empirical days of designing and tuning automotive audio systems, hours and days were spent finding the right combination of tuning parameters for a specific speaker placement in the cabin interior to create not only a good tonal balance, but sense of staging and spaciousness. At first, it wasn't clear why one simple architecture would sound more coherent and spatial than another, until time was spent analyzing each one of the aspects of the car's interior, speaker design, and speaker location to understand the timing relationship within the car's interior modal behavior and reflective surfaces near a speaker and a listener. Then, the understanding of why a solution worked could be applied to a variety of applications for automotive interiors. This analogy applies to the Dinaburg Technology's design theory to understand how it can be applied consistently across many product designs and applications.

The early prototypes that were created 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 the detailed look at acoustic pressure behavior on the interior of the enclosure and on the interior and exterior surfaces of the passive ring radiator, which was only practical with the FEA models, using the tools of COMSOL Multiphysics. We could see the effects of the phase stabilizing ring interacting with the concentric ring radiator (i.e., designated by Dinaburg as the coplanar concentric stabilizer as mentioned before). 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.

Indeed, complex multi-voice harmonies were clear and cohesive, without audible distortion. The COMSOL modeling and the measurements so far justify that. It makes sense that Dinaburg calls this design concept "C2S™, The Concentric Coplanar Stabilizer". There is now understanding of the nature of the solution and how it can be applied to a variety of applications: From automotive speakers, in-wall and ceiling speakers, and headphone designs.