Bosi 225

by a4eAudio

My Bosi 225 design was created as an entry to the 2023 InDIYana theme competition. Surprisingly it won 1st place. Below is a ~~long-winded~~ detailed write-up of how the speaker came about and some of the decisions that I made in building and designing it.

Tweeter: Satori TW29RN-B (8)
Woofer: Dayton Audio RS225-8 (*x2 Isobaric*)
Passive Radiator: Dayton Audio DSA215-PR
Dimensions: 10.5(W) x 17.0(H) x 12.125(D)
Volume: Gross volume 0.89cf (25L). Net volume seen by woofers approx. 0.67cf (20L)
Tuning: F_b = 33hz. F3=35hz per WinISD (38/39hz per my microphone and nearfield merging)

1. Background and Design Goals

This speaker was designed for the theme competition at the 2023 Annual InDIYana speaker event. There were two aspects of my design goals: (1) the constraints put in place for the event, and (2) the self-imposed constraints I set for myself.

The theme was "Tweeter Yoga" and primarily the challenge was to use an 8" or larger woofer, a tweeter with a faceplate 4 1/8" diameter or smaller, in a 1.5cf or less two-way speaker, i.e., to take the difficult task of crossing over a large diameter woofer in a two-way design and eliminate the "easy ways" out with large tweeters and waveguides. Further details are <<HERE>>. Unlike most theme-competition rules in the past, there was no price limitation on drivers, as it was encouraged to utilize parts on hand.

My self-imposed restrictions were (1) I had to use drivers on hand, and (2) I could not design a simple 8" two-way. I went through all the drivers I had that were 10" or larger and could not come up with a driver combination that would work, so that left me with 8" drivers. I have six Dayton RS225-8s and found an old design (2005) by MarkK that was widely lauded, so at least I knew that in theory they could sound good in a two-way. (MarkK's were paired with the old Dayton Audio RS28A and used a Cauer/Elliptic filter crossed over at 1.4khz. He modified the xo for Paul Kittinger's *RS Duets* which won 1st place at Midwest Audio Fest in 2012.) Knowing I had to cross over low, I needed a robust tweeter. I had a pair of Satori TW29RN-B-8 tweeters on hand that I had acquired on eBay for a low price a few years ago.

But self-imposed constraint (2) excludes a simple 8" two-way, so what was I to do? **ISOBARIC!** When I searched the forums for isobaric configuration, I found that in almost every thread someone would quickly explain how this was a thing of the past and with MODERN drivers it doesn't make sense. Within the next few posts someone would question "*but what if you already have the drivers on hand*?", which was immediately and forever ignored. Doing a little more research, it seems an isobaric configuration is normally restricted to woofers/subwoofers with very few two-way designs. However, I found the *Totem Mani 2*, a 6½" two-way commercial speaker using Dynaudio drivers, which was widely heralded as a very good speaker and someone on Tech Talk even claimed it was a *great* speaker. So, at least in theory, a two-way isobaric can be done well.

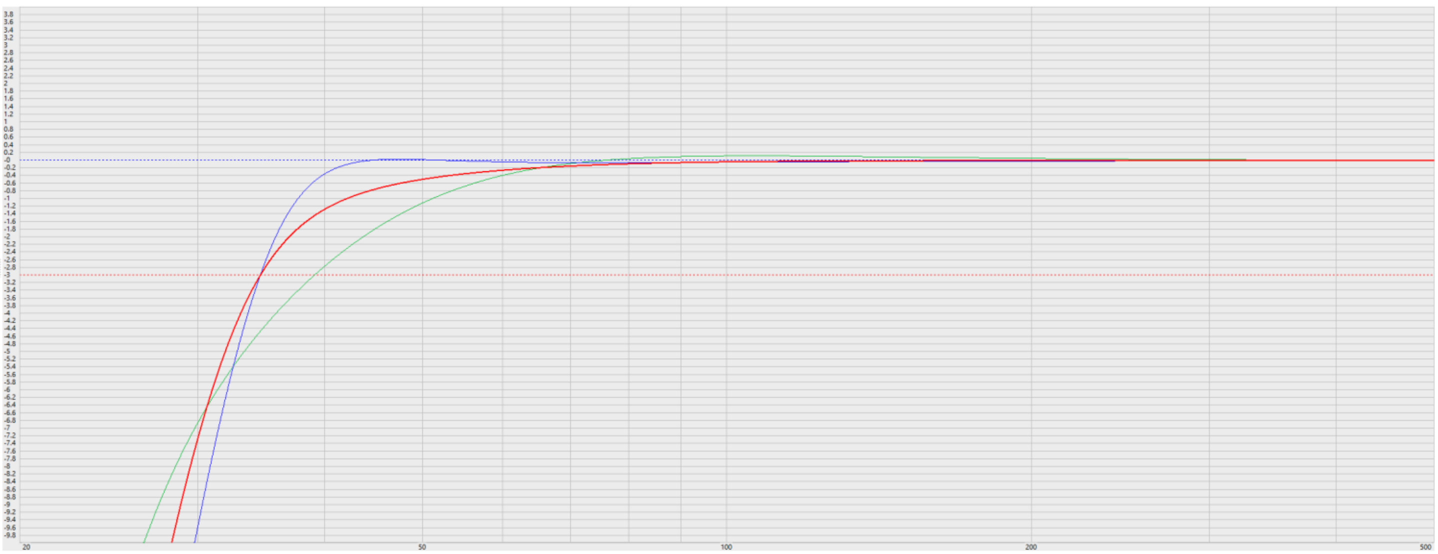
This led me to a further self-imposed constraint. There are DIY 8-inch two-way designs that are known to sound good, but they are also typically on the large side for stand-mount speakers. So, even though the event rules allowed up to a 1.5cf cabinet, I restricted myself to a stand-mount cabinet less than 0.90cf. This restriction drove several of the design/construction choices I made.

Design goals conclusion: An 8-inch two-way, in an isobaric configuration, less than 0.90cf using Dayton Audio RS225-8 woofers and Satori TW29RN-B-8 tweeters.

2. Box Modeling and Cabinet Construction

Using actual Thiel-Small parameters, I modeled the RS225-8 in WinISD and it does very well in a 1.5cf cabinet, easily producing an F3 in the low 30s. An isobaric configuration allows me to attain the same output in half the volume, 0.75cf. This is going to be GREAT!! But then I calculated the volume that would be lost due to bracing, drivers, ports, and the isobaric tunnel – nearly 0.40cf of lost internal volume. And a net volume of 0.50cf (equivalent to 1.0cf with a single driver) does not produce nearly as appealing low frequency output.

Figure 1: Alternative Box Modes (0.50cf, 0.67cf, 0.75cf with Isobaric configuration)



So, I needed to save space, so I chose to (1) use 5/8" particleboard rather than the typical 3/4" material I would use,[1] (2) use a passive radiator (which I had never used before), and (3) make the isobaric tunnel an hour-glass shape (or maybe more like a car wheel, see Figure 3) to take up as little volume as possible. I then backed into the net volume that I would have available (0.67cf) and determined that a tuning of 33Hz would give me an F3 in the mid-30s with a slightly falling response (red line in Figure 1). Based on my final measurements and merging nearfield results, I think I ended up with an F3 closer to 38/39hz.

Another issue that came up with other DIY two-way isobaric attempts that I found online, was midrange leakage or simply unsatisfying midrange. It was conjectured that maybe having as little air in the isobaric tunnel as possible, and maybe some damping in the tunnel, would be beneficial. But this was usually discussed in a thread where the person was not satisfied with the final results and they did not pursue their build any further. In general, I did not find a DIY build thread attempting a two-way isobaric design where the builder was satisfied.[2] But I remembered the Totem Mani 2's and pushed forward. So, this was another factor in designing the hour-glass shaped tunnel, which I then lined with ¼" wool felt. ¼" felt is pretty thin, so I'm skeptical that it made much of a difference, but I assumed that even if it didn't help, it wouldn't hurt.

So, some build pics of the baffle and isobaric tunnel…

[1] The front baffle is 1 1/8" thick (5/8" + 1/2" particle board glued together).

[2] At InDIYana there were two other isobaric two-way designs (by jhollander and 4thtry) that both sounded very good. So, it should be concluded that an isobaric two-way design done well can sound good.

Figure 2: Front baffle – inside cutout with a cove bit rather than 45-degree chamfer

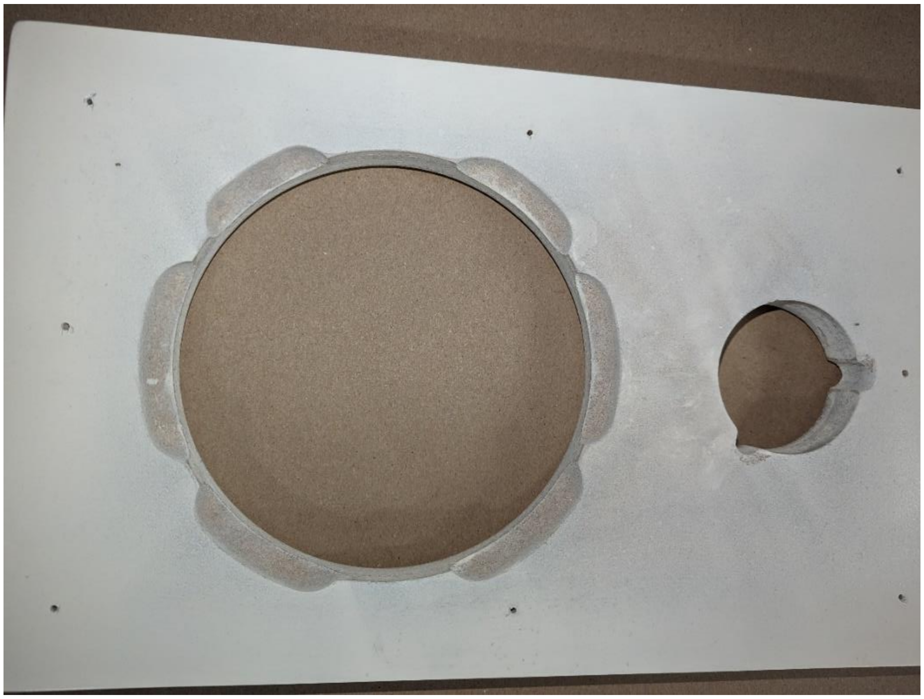


Figure 3: Isobaric chamber – cove bit where inner driver will be attached. Inside edges have 45-degree chamfers

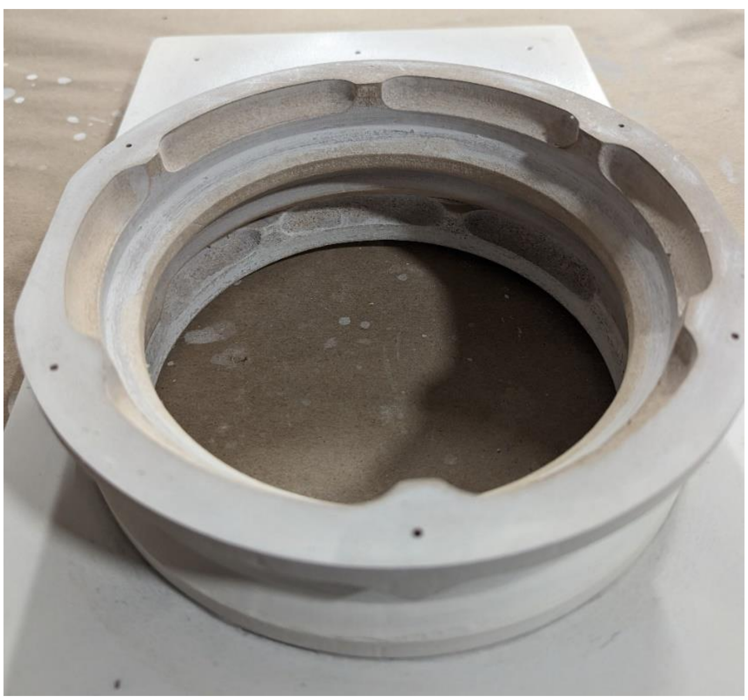


Figure 4: Isobaric chambers - inside lined with 1/4" wool felt

Figure 5: Isobaric tunnel - rear view with front woofer installed on baffle[3]

[3] The depth of the tunnel is only 1/8" deeper than the back of the magnet. However, due to the concavity of the woofer cone, the rear cone will not come close to the magnet even near xmax.

Figure 6: Inside/rear-woofer attached to isobaric tunnel (the light & shadows are playing some weird tricks here)

The cabinet is made to be reusable for other designs and prototypes, as this build was not intended to be a permanent build. The front baffle is removeable so I can make a new baffle for a different combination of drivers. Additionally, the rear panel is ½" particleboard plus another ½" removeable rear baffle so I can use a passive radiator or a port. The baffles are attached from the inside so that no screws show – I reached through the back to attach the front baffle from the inside, then reached through the passive-radiator hole to attach the rear baffle from the inside and finally attached the passive radiator when complete. (Of course, this did not work as planned and accessing the screws around the isobaric tunnel and then twisting my hands around inside the PR cutout to attach the back baffle took several hours and many curse words. It's interesting how strong those RS225 magnets are when you do NOT want them to attract a small #8 screw in their direction.)

Since the front baffle is removable, bracing front to back is not feasible, so I have two side-to-side braces that tie into the back as well as the top. The braces are not quite symmetrical and are spaced so that no unbraced dimensions are the exact same distance to attempt to disperse any panel resonances. Bracing was "skeletonized" to save internal volume (although an immaterial amount, but they look cool) and reduce solid, flat reflecting internal surfaces. For the largest unbraced area on the sides, I added some butyl rubber damping material, then 3/8" F13 felt from McMaster-Carr for the main areas on the sides and bottom around the woofers, and then 1" cotton insulation (cheap Frost King insulation that is closer to ½" thick) on top of the felt and on the remining sides and top that did not have felt. (I did not attach felt to all of the interior walls because it is expensive, and I am ~~cheap~~ frugal. I also argue that this "variable density" absorption might be beneficial to reduce standing waves to justify my ~~cheapness~~ frugality.) Once the baffle and isobaric tunnel were attached there is only an inch or two between the magnet and the brace, so I took some 1" Dacron batting from Meniscus Audio, folded it in half and stuffed it between the magnet and the brace to reduce any reflections off the brace.

To reduce diffraction as much as possible, I put a 1" roundover on all 4 sides of the front baffle.

Some of the cabinet build pics…

Figure 7: Cabinet with removeable front and removeable rear baffle (cutaway view)

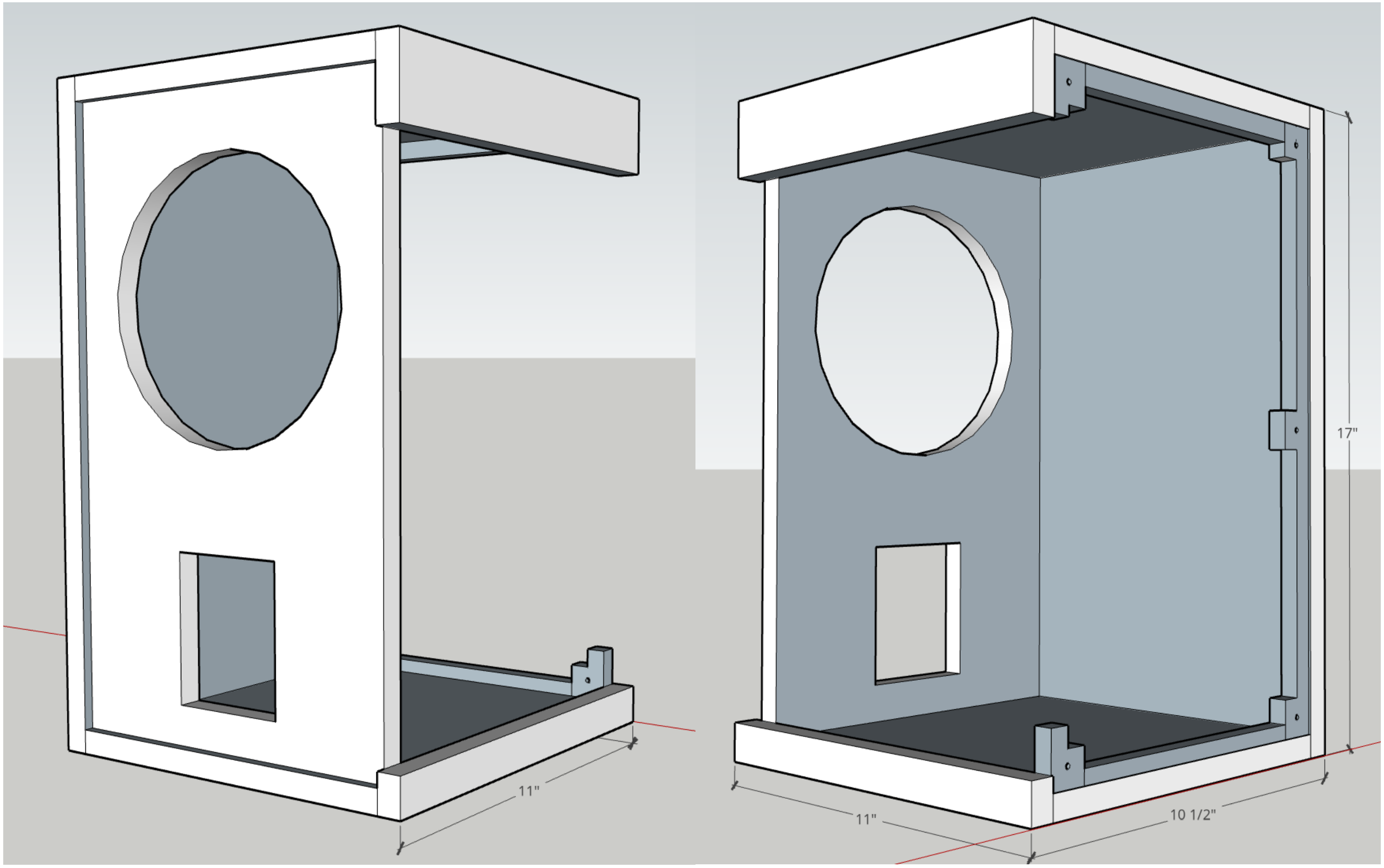


Figure 8: 1-1/8" front baffle with driver positions and 1/2" rear baffle

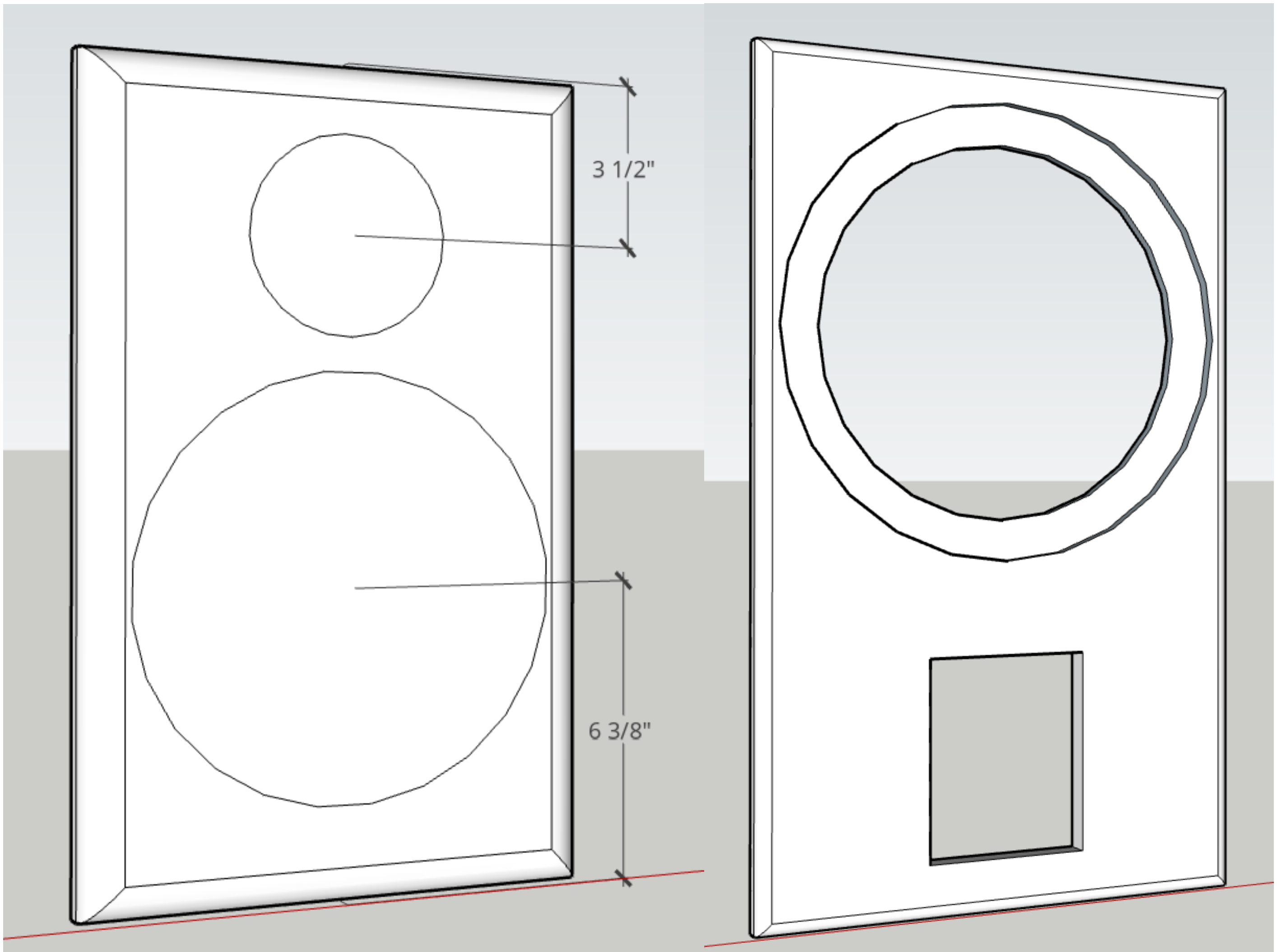


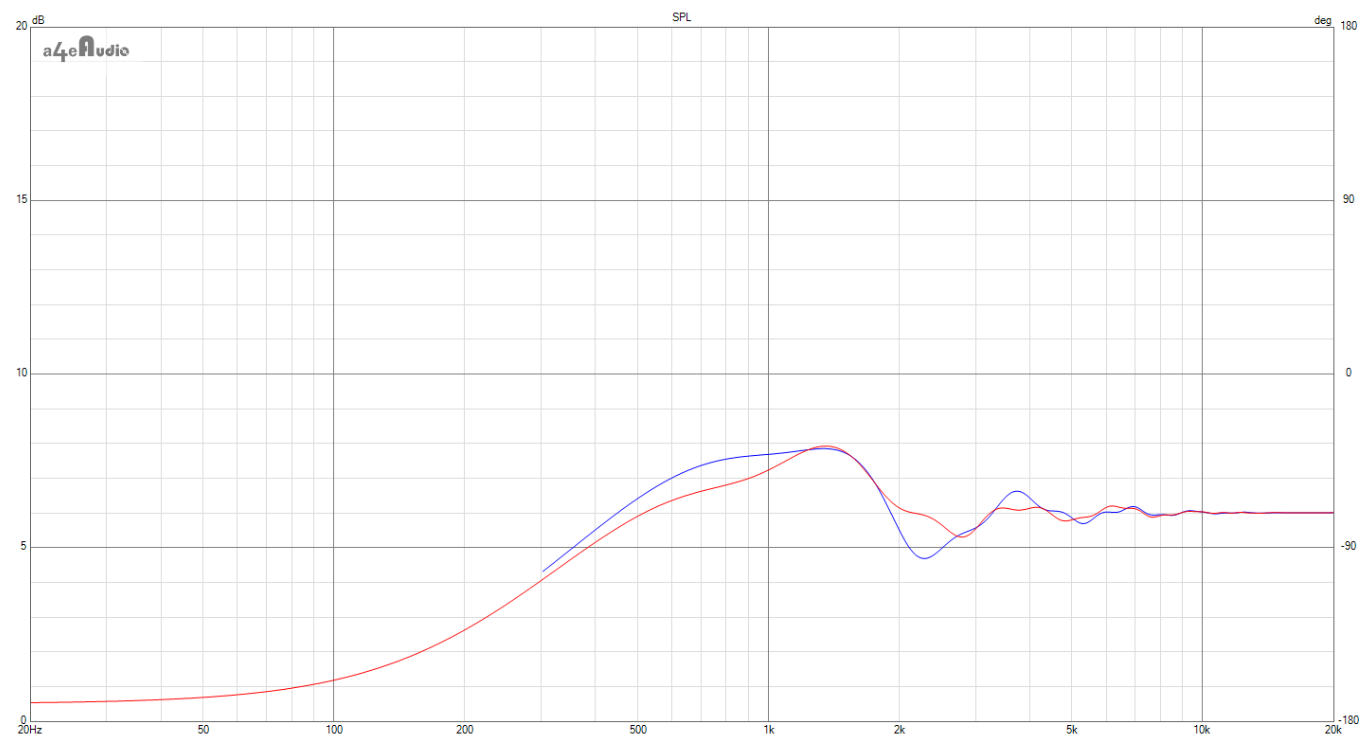
Figure 9: Skeletonized bracing, butyl rubber damping material, F13 felt

Figure 10: Cotton/recycled denim insulation, front baffle with isobaric tunnel and driver attached

Normally, driver selection would be an important step in setting design goals, but as mentioned in the beginning, I simply used what I had on hand. My baffle width (10½") was determined by the width of the woofer, plus an extra 1 1/8" to allow for the 1" roundovers that I knew I would use.

But what about driver placement? The rule-of-thumb I have typically seen over the years is to have a center-to-center ("CtC") distance between drivers no more than the length of a wavelength at the crossover point. More recently, a CtC spacing of 1.2 times the wavelength at the crossover-point has been promoted by some people. Assuming I was going to crossover between 1.2 and 1.4khz, either of these rules would imply a CtC spacing of 10 to 13 inches. I had already committed to the cabinet height, so that wasn't going to happen. But what I did do, was simulate the diffraction and baffle-step effects in VituixCAD. My baffle height is 17" and below are simulations of a 1" dome tweeter 3½" (red line) and 5" (blue line) from the top with 1" roundovers. I went with the smoother response of 3½" from the top which produced a CtC spacing of 7-1/8".

The other thing to notice is the hump around 1.4khz. My 10½" baffle has baffle step loss starting around 1.3khz but before that there is a buildup of energy producing a broad peak. The 1" roundovers are helping, but this is still 2db higher. This is the case for the woofer also and I'll have to deal with this in the crossover.



3. Crossover Design

As we know, the "magic" of the speaker is in the crossover. I posted some iterations of the xo online and got valuable feedback from users dcibel, jhollander, Wolf and 4thtry. It is hard to imagine how bad these would have sounded if I had used my original version without getting multiple rounds of valuable advice. I am sincerely appreciative of the entire DIY community that so generously shares their knowledge and advice.

I use VituixCAD2 for xo simulation. There are plenty of fine tools available, but this program just amazes me. There are a lot of tradeoffs in speaker design, so here are some of the steps I took designing the crossover:

1. Set targets for axial response of each driver. In this case, I set Linkwitz-Riley 4th order acoustic slopes ("LR4") at 1,450Hz.[4]
2. Try to get as flat an on-axis response as possible (which may mean deviating from those target acoustic slopes in (1)).
3. Check phase alignment around the crossover point and make minor changes to component values to improve phase alignment if possible.
4. Set a target for Listening Window ("LW") of –0.15db/octave from 300Hz to 10khz. Tweak components to improve LW as long as it doesn't cause the overall on-axis response to deviate *too much* from target, and in particular try not to create any broad increased output in the 1khz to 5khz range chasing an LW target.
5. Set a target for In-room Response ("IRR") of -0.7db/octave from 300Hz to 10khz. Tweak components to improve IRR as long as it doesn't cause the overall on-axis response or LW to deviate too much from target, and in particular not create any broad increased output in the 1khz to 5khz range chasing an IRR target.
6. Look at directivity using line graphs and polar heat map. Tweak components to improve directivity as long as it doesn't cause the overall on-axis response, LW or IRR to deviate too much from target.
7. Go back and check phase and tweak component values to improve phase alignment as needed.
8. Check system impedance and tweak component values as needed. (Although I have two 8-ohm woofers wired in parallel for a 4-ohm impedance, with the 8-ohm tweeter and xo components selected the system impedance never created an issue that I had to worry about.)

The "spinorama" approach of VituixCAD focuses on directivity. And the challenge of crossing large diameter woofers in a two-way is the directivity imbalance. Below are the raw driver responses on and off-axis. The RS225 does not have nice off-axis responses up to 1.2khz and thus I was not going to be able to get what is considered good directivity. At this point I seriously thought about breaking my self-imposed constraint to use only drivers on hand and go out and by some nice paper or poly cone driver with good off-axis behavior beyond 1.2khz. But rules are made not to be broken.

[4] In reality, I spent a few weeks trying different configurations of 4th and 8th order targets at 1000, 1100, 1200, 1300, 1400 and 1500.

Figure 11: Raw tweeter response - 0 to 90 degrees in 10-degree increments

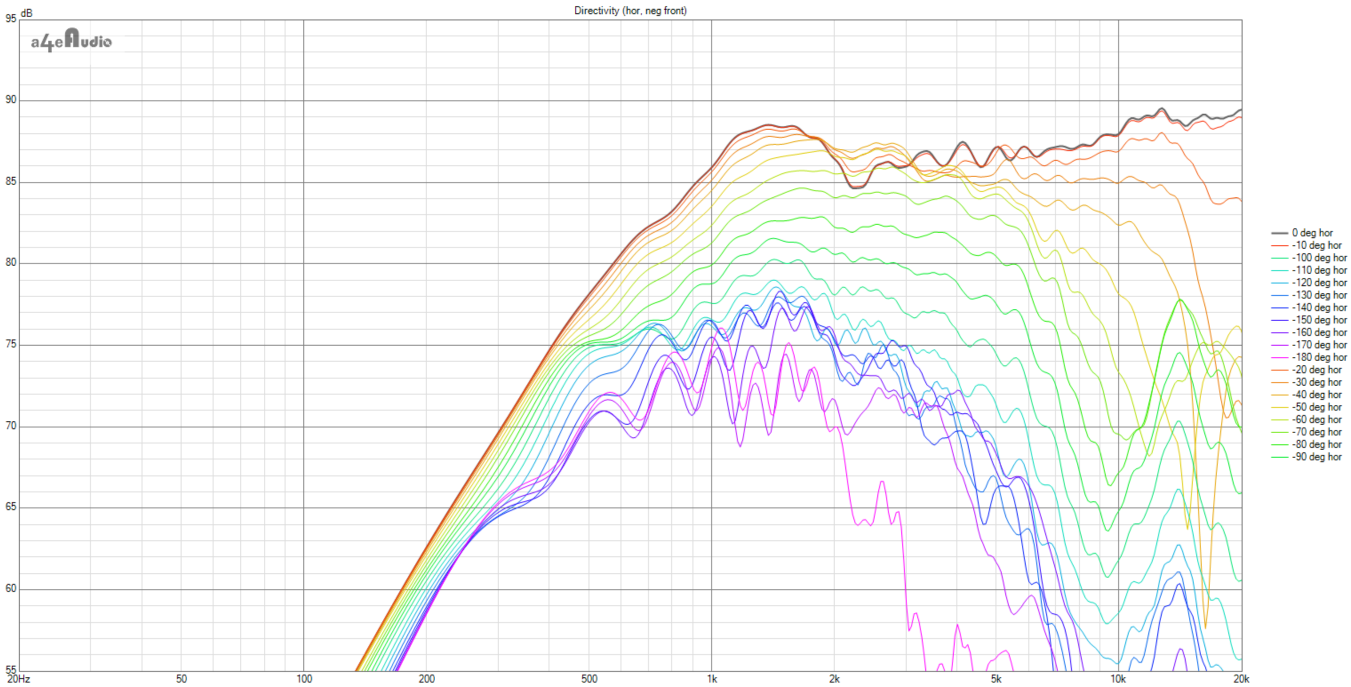
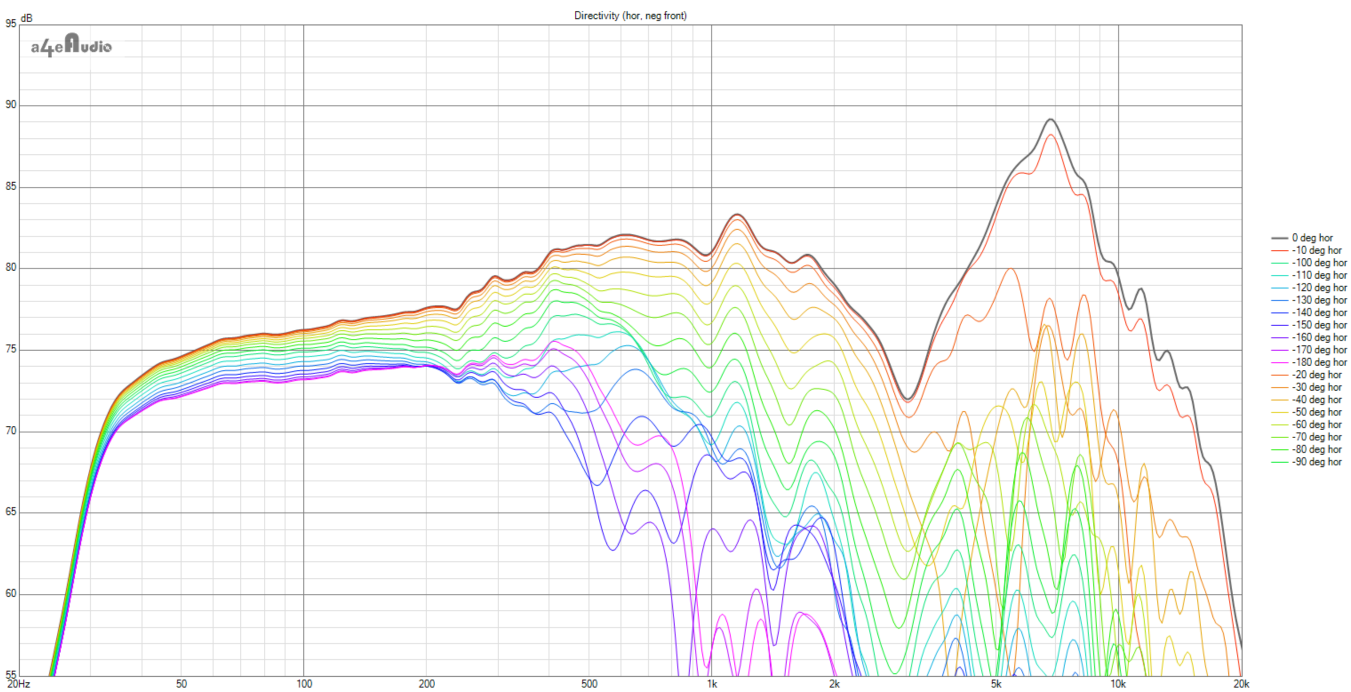


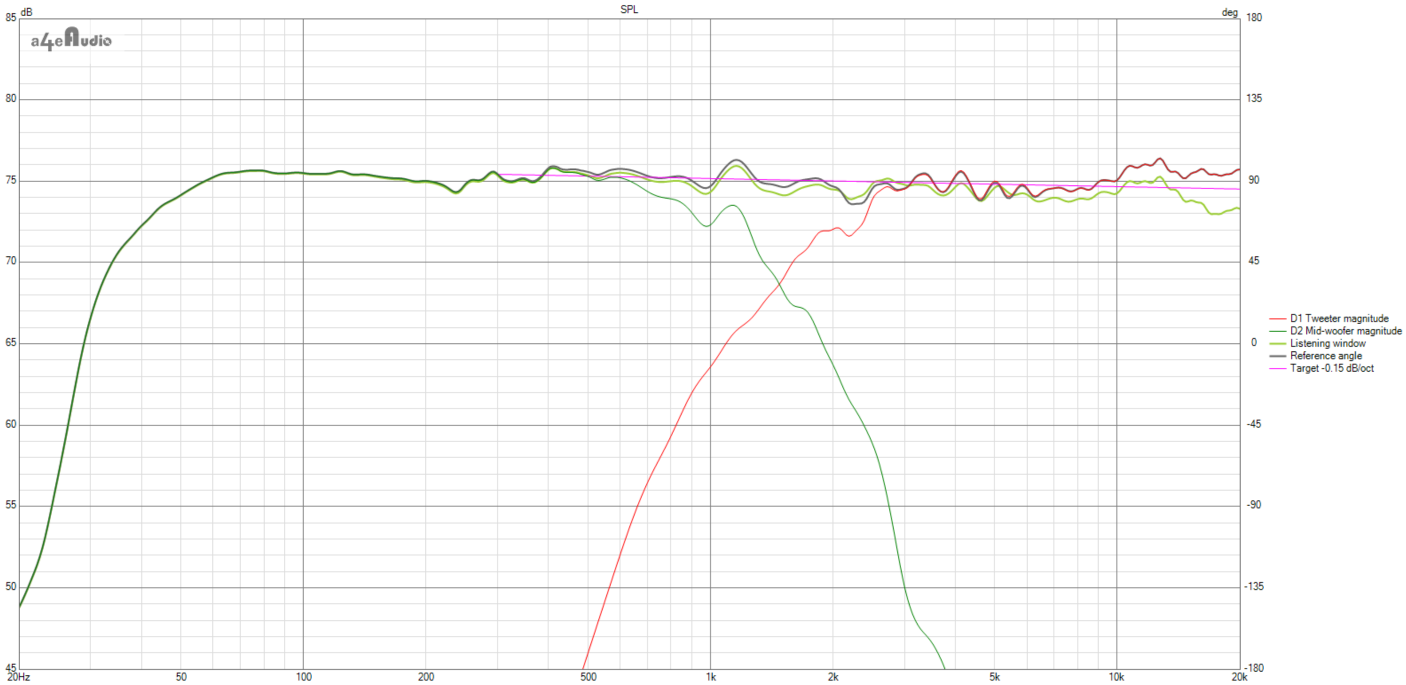
Figure 12: Raw woofer response - 0 to 90 degrees in 10-degree increments



The ~~horrifying~~ ~~mountain~~ peak from 3 to 7khz is the breakup of the aluminum cone. No wonder MarkK used an elliptic filter. I spent the first few weeks working with the elliptic filter but discovered I could get to the same place with a more normal crossover topology. For every crossover iteration I tried, I made sure that I was 40db down by 5khz.

Here is the final output response and crossover schematic. There is a small peak around 1.1khz but it is only about 1.5db higher for a quarter of an octave. While ruler flat was not my goal, this is what I ended up with when taking on-axis response, LW, IRR, directivity, etc. into account.

Figure 13: Final on-axis SPL response and listening window (LW target in magenta)



Quality control on the Satori tweeters is excellent, as it should be on high-end drivers. Here is speaker 1 and speaker 2 actual measurements.

Figure 14: Speaker 1 and 2 actual measurements (@ 4 ft, 1/6 oct smoothing)

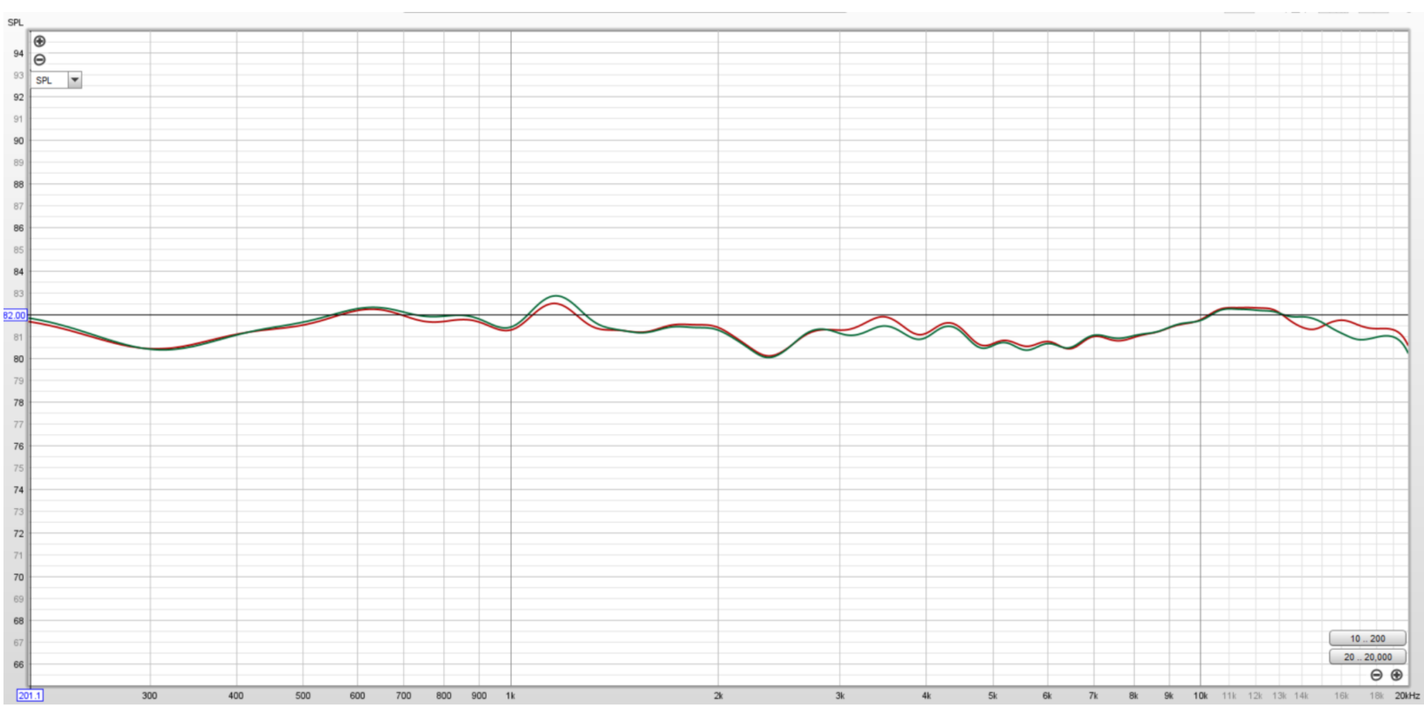
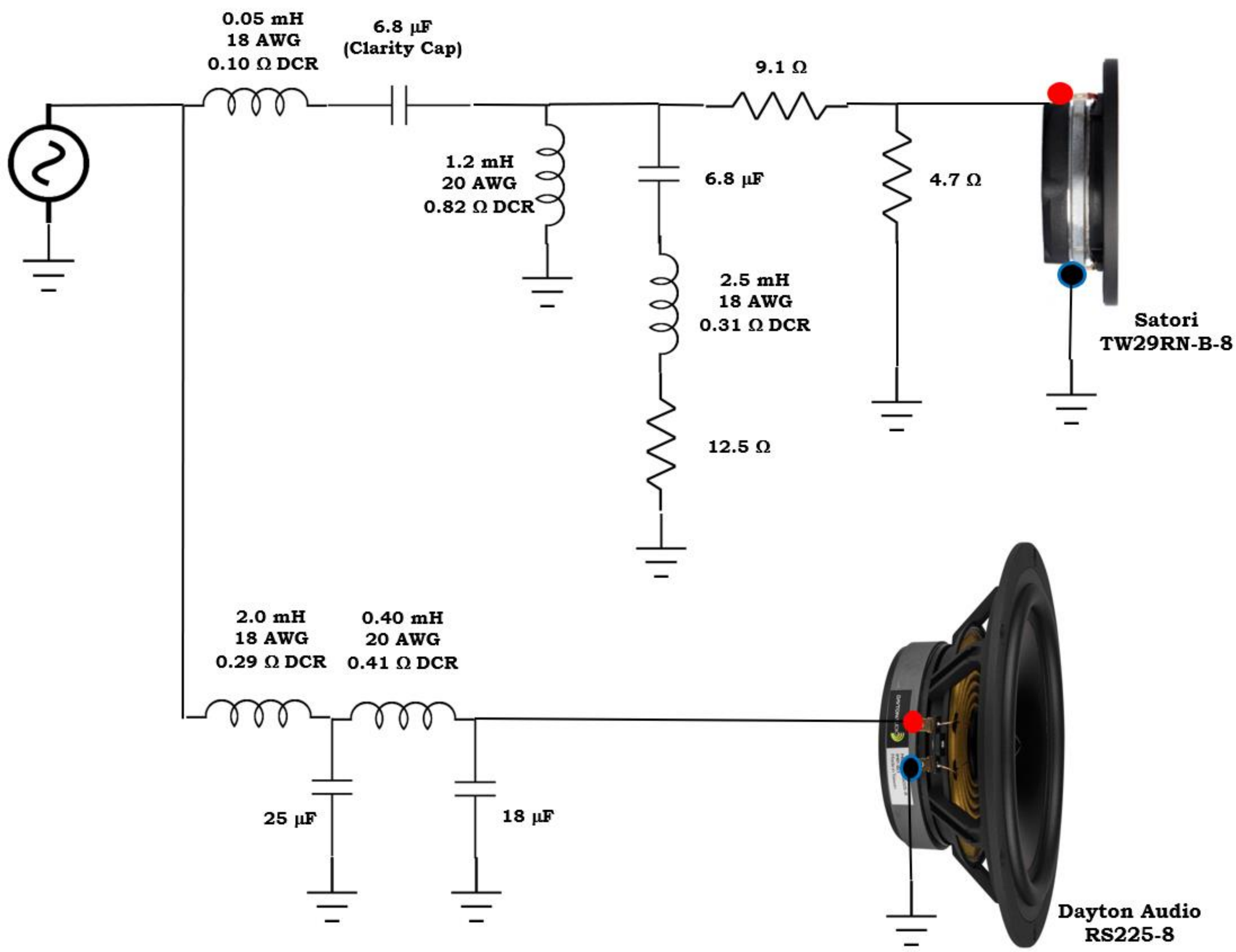


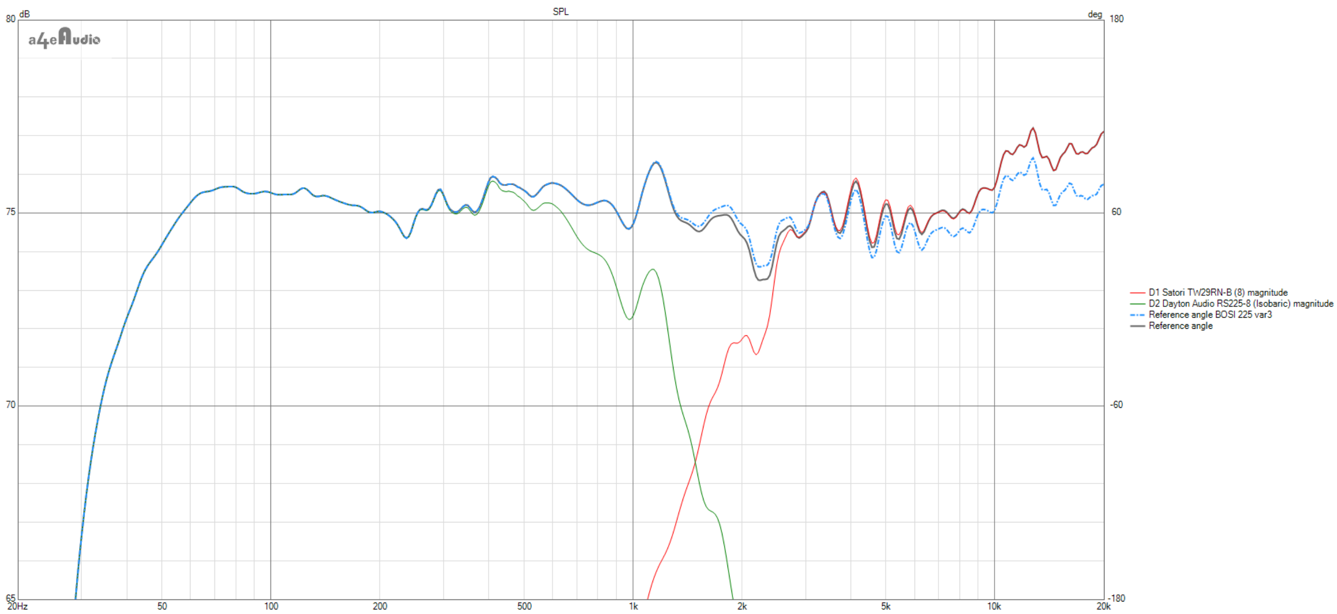
Figure 15: Crossover schematic



A few comments on the crossover. I had no goal of keeping the crossover simple or the number of parts low. I have the components on hand, so there was really no cost to adding components if it would improve the output response.

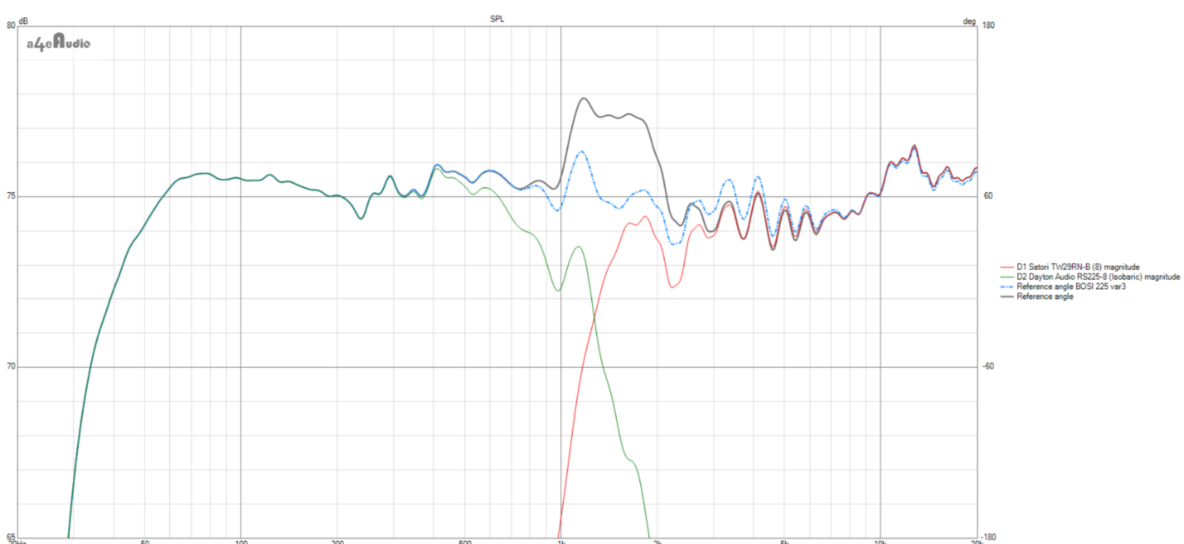
The 0.05mH inductor is typically used to pull down a rising response of the tweeter. While this is true here also, I was not really concerned with the extra 1db above 10khz (I can't hear above 13khz anyways). But it also evened out the response just a little bit from 1.5khz to 5khz so I added it.

Figure 16: Final response (blue) and response without 0.05mh inductor on tweeter



As mentioned earlier, the baffle step is causing a peak around 1.3khz which combined with the crossover point of 1,450hz appears to be creating a 2db hump pretty much across the entire octave of 1khz to 2khz. The notch filter brings the grey (un-notched) response down to the final dashed-blue response. The Satori tweeter measured F_s of 620hz, so I did not do anything to notch the resonance.

Figure 17: Final response (blue) and response without notch on tweeter



Below are some more comments and graphs, for those who like lots of pretty-colored lines.

As mentioned above, I started with target LR4 acoustical slopes and then considered other aspects and adjusted components accordingly. Once I was focused on LW, IRR and directivity I didn't spend too much time going back and worrying about acoustical slopes named after people who developed them decades before we had crossover software. BUT…I still ended up with something pretty close to the original targets.

Figure 18: Final tweeter response and an LR4 acoustical target 1,450hz

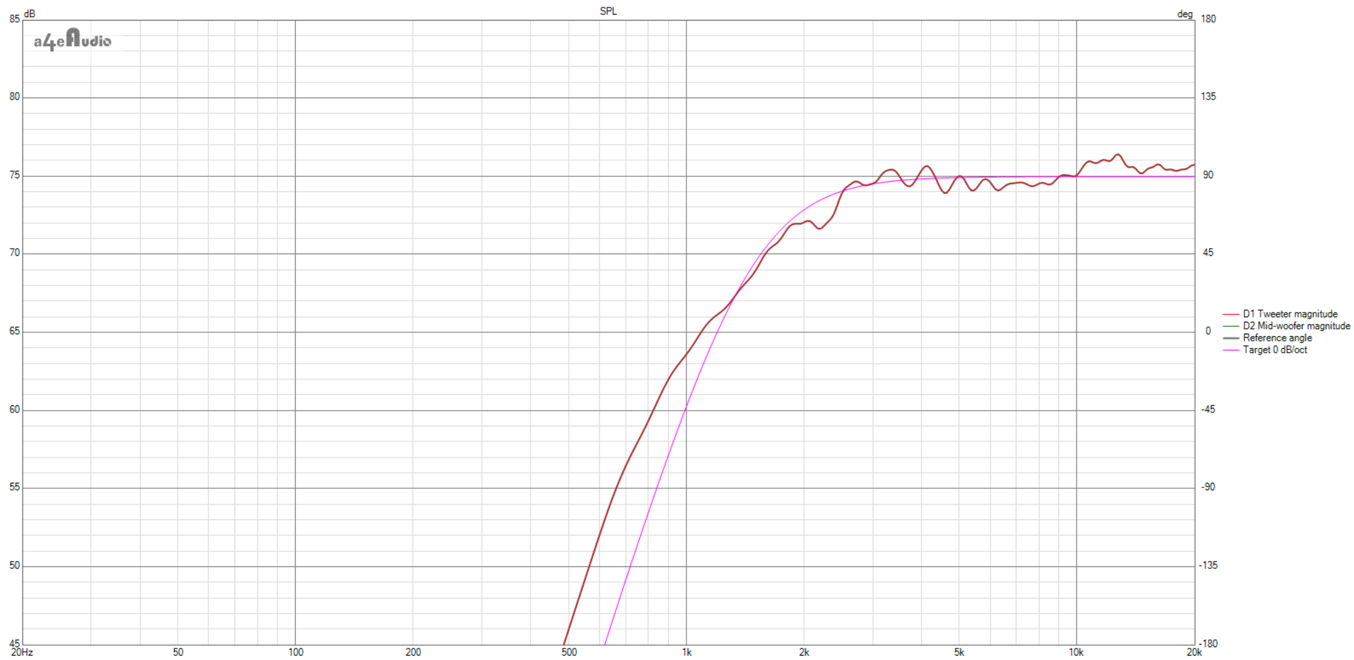


Figure 19: Final woofer response and an LR4 acoustical target 1,450hz

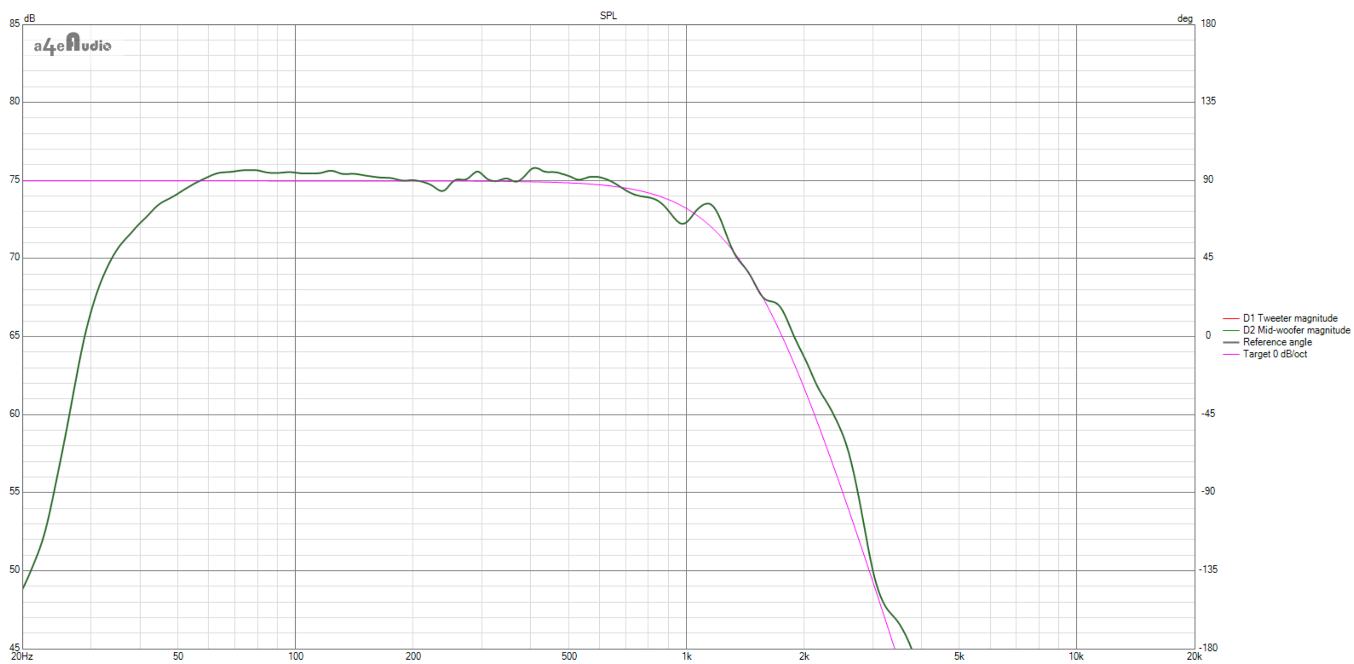


Figure 20: Final phase

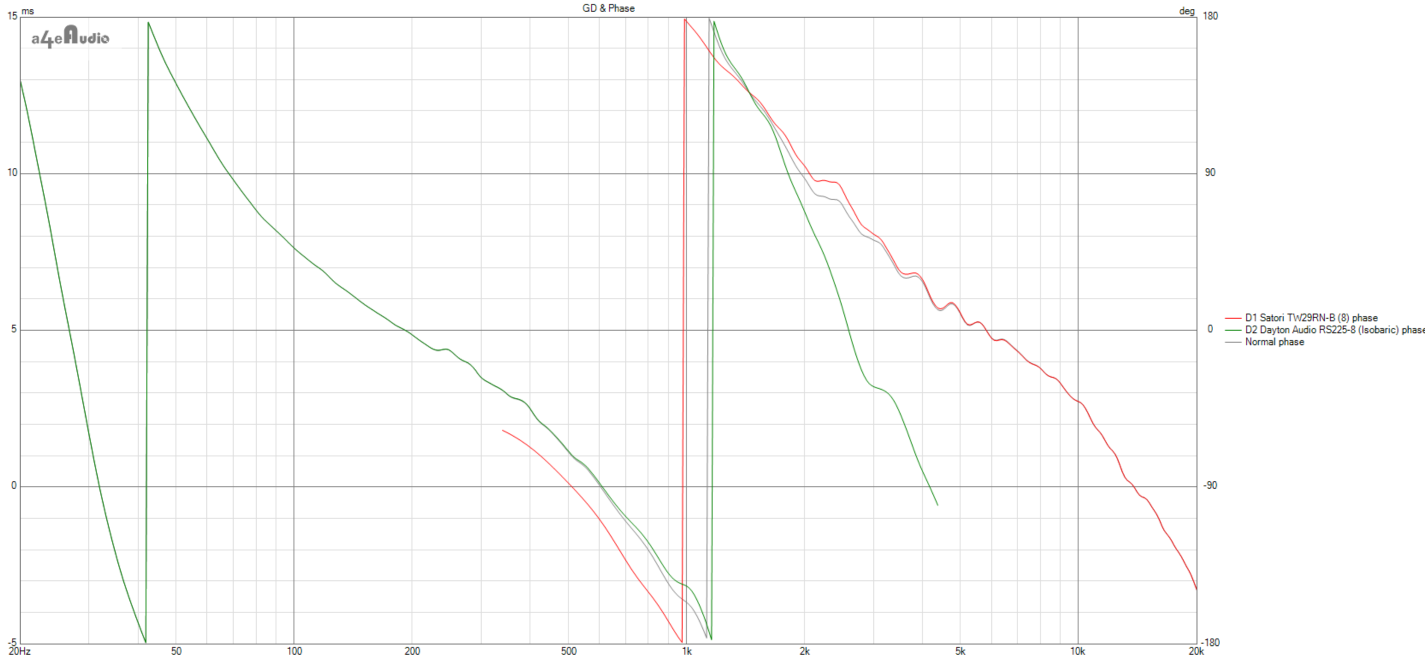


Figure 21: Reverse null with tweeter wired in reverse polarity

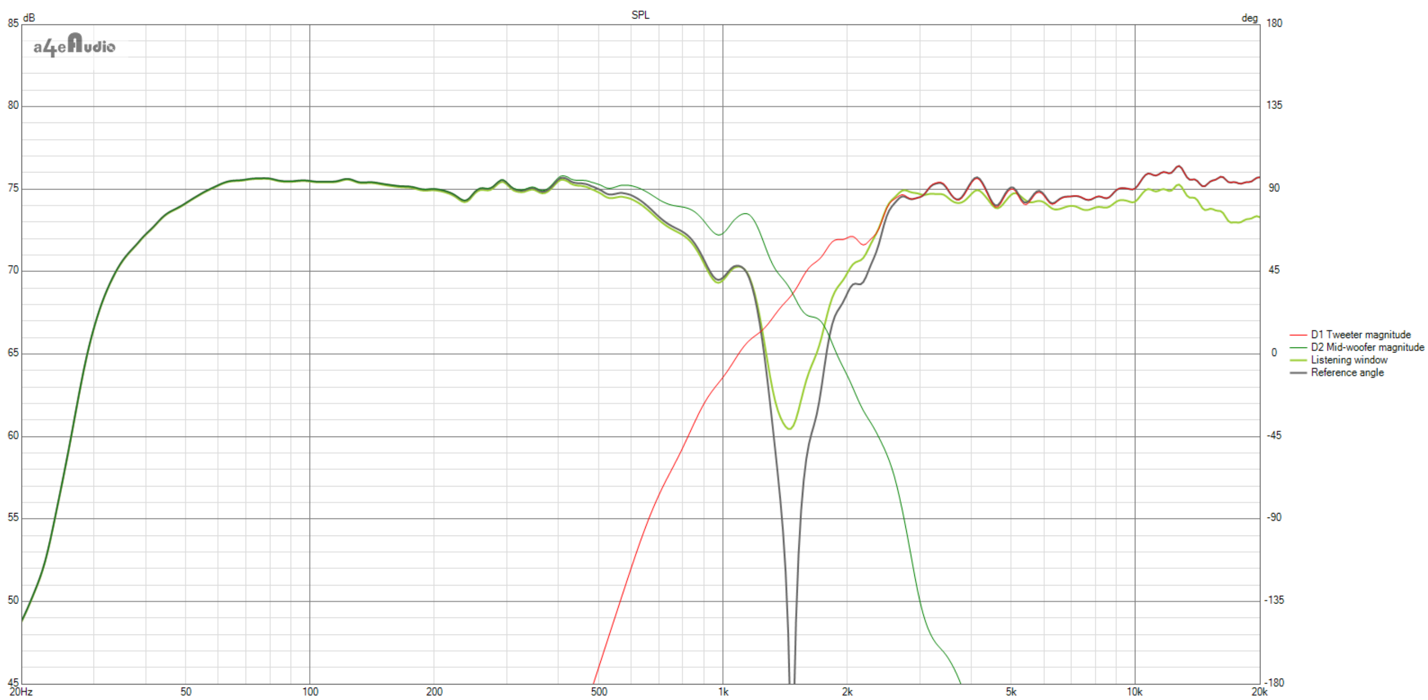


Figure 22: System impedance

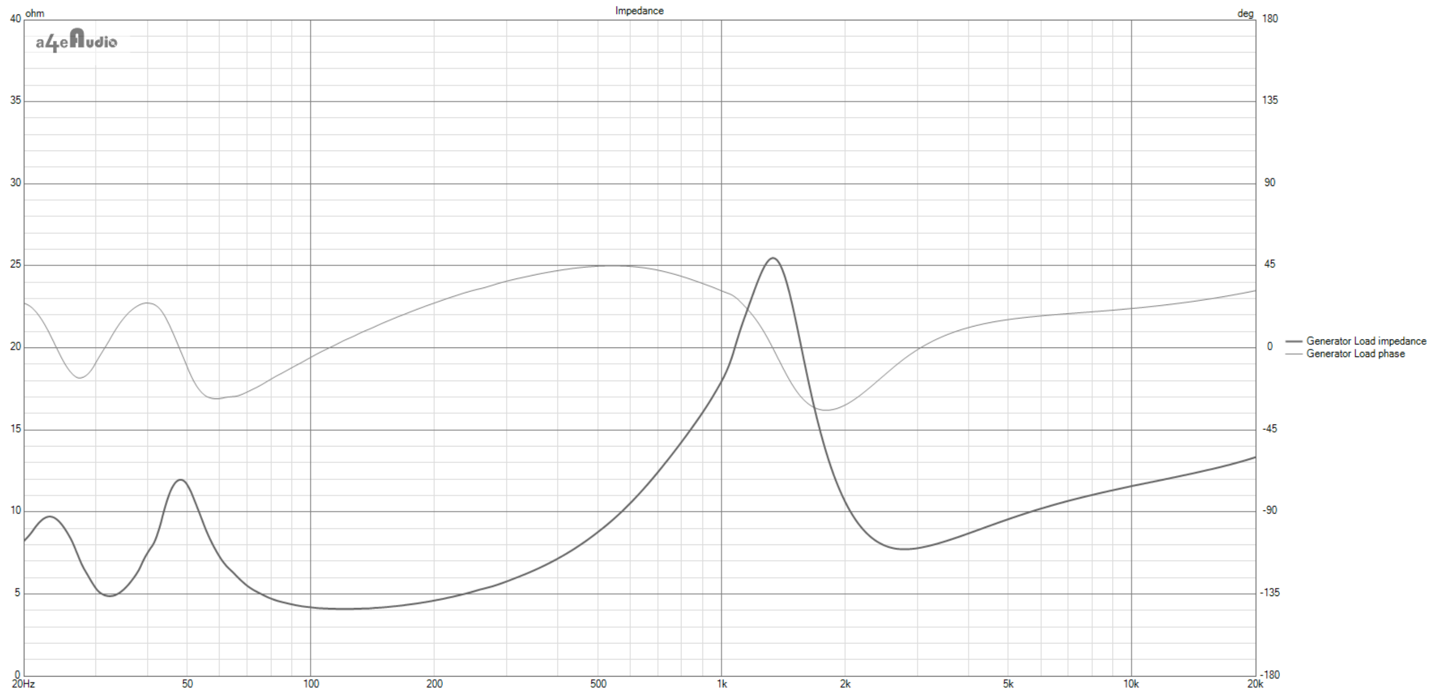


Figure 23: Early reflections, In-room response (orange), power and directivity indices (In-room target in magenta)

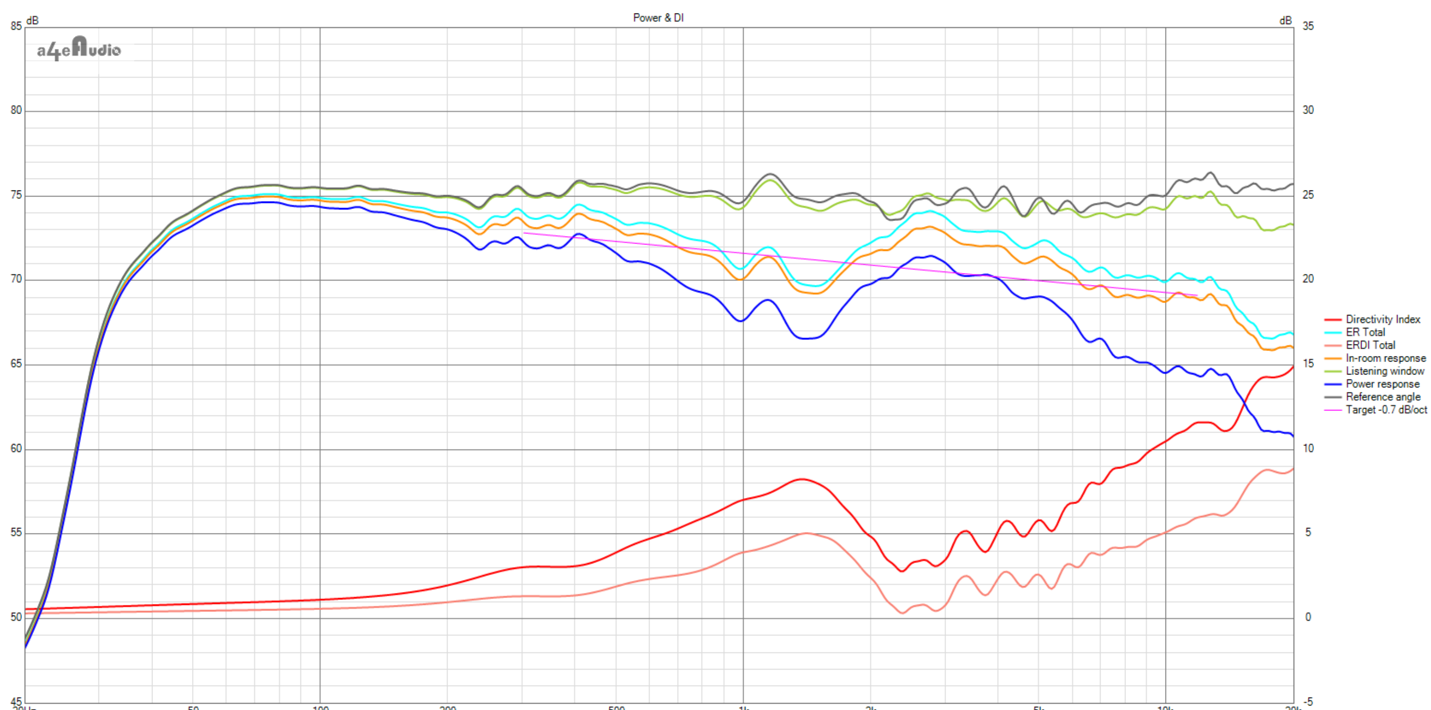


Figure 24: Directivity - Line graph

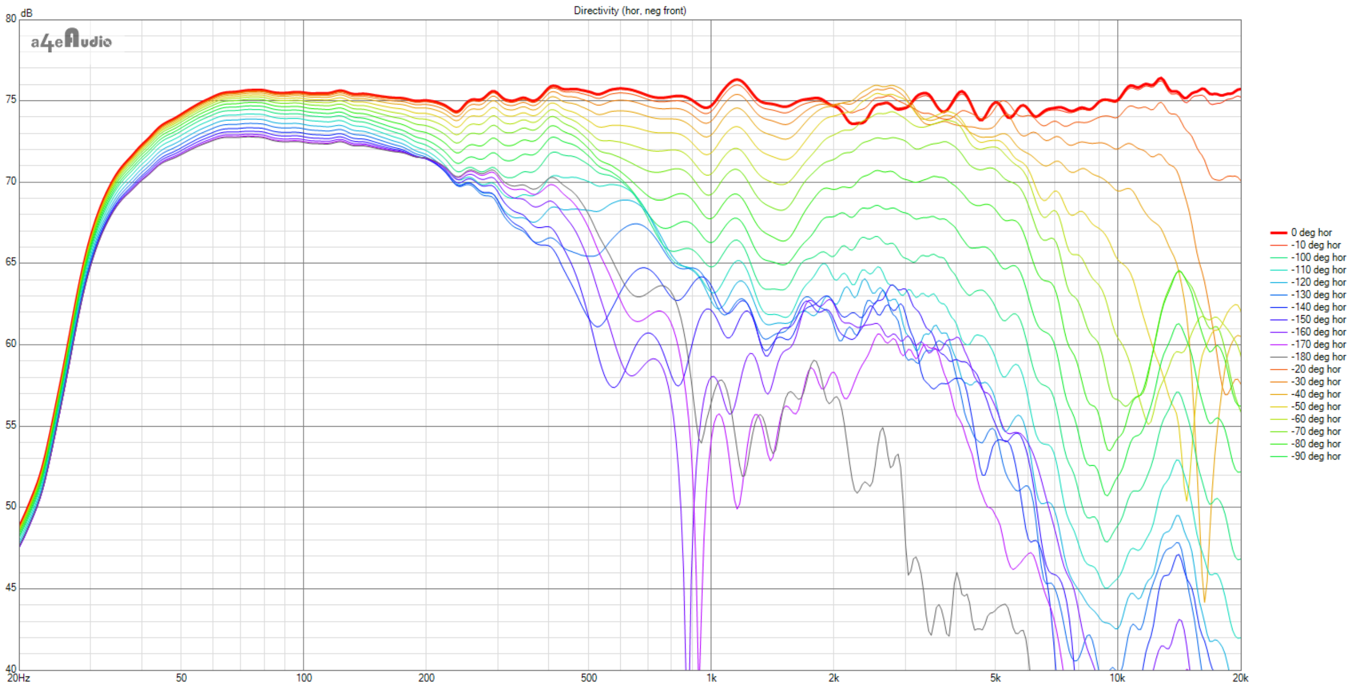
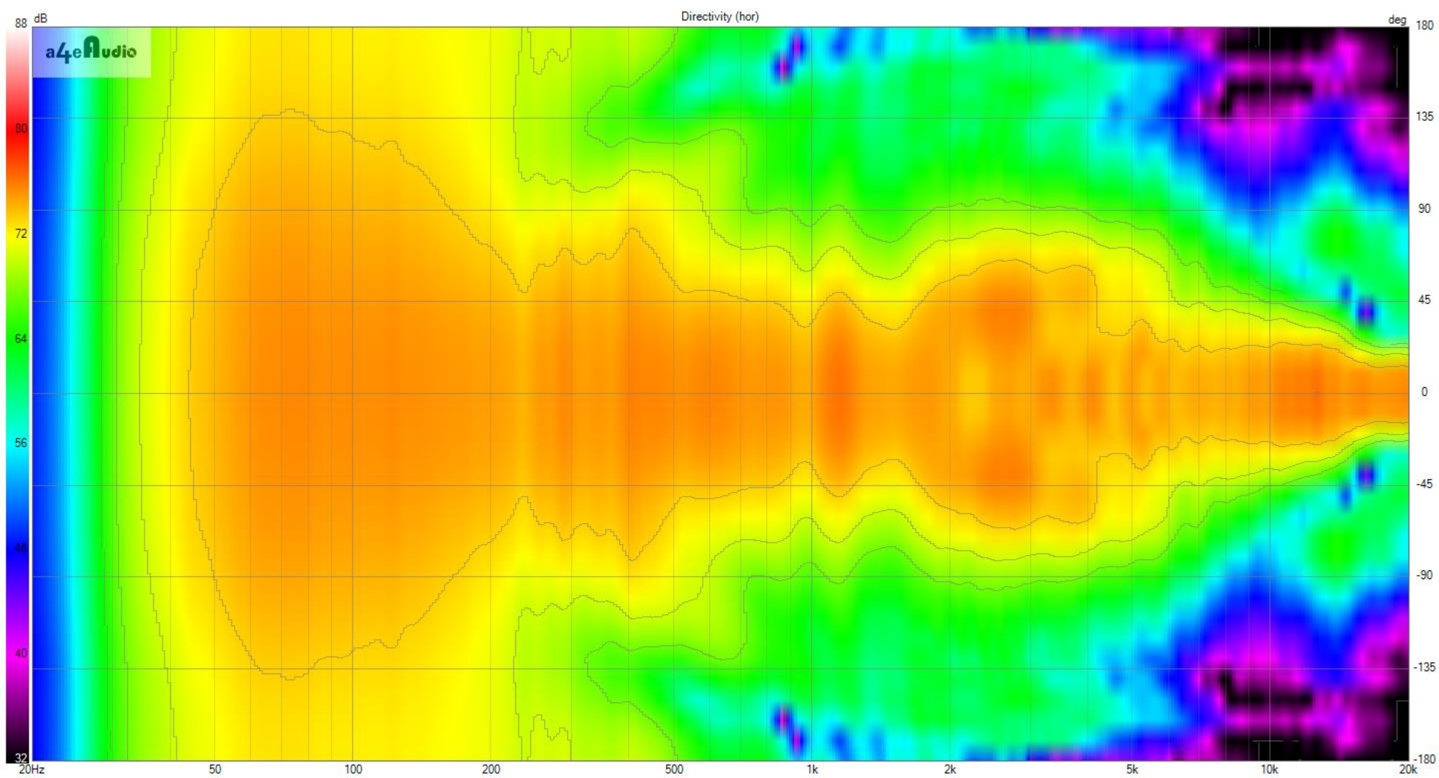


Figure 25: Directivity - Polar heat map



4. Conclusions

The purpose of the theme competition each year for InDIYana is to present a challenge to builders. Despite months of frustration, I learned a ton from this build. For those who have never attended InDIYana but just follow it on the forums, the “competition” is a pretty non-rigorous, laid-back affair. All the speakers sounded good, although the demo tracks did reveal the weaknesses in some designs. As someone relatively new to speaker building, my goal was to have a few people (other than my wife and kids) raise their hands to vote for my speaker. Winning the contest was super-rewarding for me, not because I “won”, but because a room full of speaker builders who I respect thought my speakers sounded above average.