

Roger, Rick, and Veronica

Small 2.1 Bookshelf Speaker for Mix Monitoring and Entertainment

Designed by: Sam Dykgraaf



Table of Contents

1.0 Functional Description.....	4
2.0 Reference Systems	5
2.1 Overview.....	5
2.2 Specific Loudspeakers.....	5
707 S3	5
Kin Monitor.....	6
KH 80 DSP A W EU	6
3.0 Technical Specifications.....	7
3.1 Cabinet Design.....	7
3.2 SPL	7
3.3 Frequency Response.....	11
4.0 Driver Research	12
4.1 Tweeters	12
4.1.1 Dayton Audio	12
RST28F-4 Reference Series - Selected	12
4.1.2 SB Acoustics	13
SB19ST-C000-4	13
4.1.3 SB Acoustics	14
SB26STAC-C000-4	14
4.2 Woofers	15
4.2.1 SB Acoustics	15
SB15NRXC30-4.....	15
4.2.2 SB Acoustics	16
SB13PFC25R-04	16
4.2.3 SB Acoustics	18
SB15NBAC30-8 - Selected.....	18
4.3 Subwoofers.....	19
4.3.1 GRS	19
10SW-4HE.....	19

4.3.2 Dayton Audio	20
DCS255-4	20
4.3.3 Dayton Audio	21
MX10-22 - Selected	21
5.0 Construction	22
5.1 Boxes	22
5.3 Wiring	23
5.2 Absorption	23
5.3 DSP and Amplifiers	23
6.0 Tuning.....	24
6.1 Unmodified Data	24
6.1.1 Woofer.....	24
6.1.2 Tweeter	25
6.1.3 Subwoofer	27
6.2 Final Tuning	28
6.3 Final System Data	28
6.3.1 Overall System	28
6.2.2 Top Box.....	31
6.2.3 Tweeter.....	35
6.2.4 Woofer.....	37
6.2.5 Subwoofer	39
6.2.6 DSP Settings.....	41
Bibliography.....	44

1.0 Functional Description

This speaker system will be designed for the purpose of being desk placed speakers with a subwoofer on the ground to go along with my computer for mix Monitoring. This speaker will also be designed for computer media output of video games and streaming videos. Because of how close it is to the mixing position, this will then lower the requirements of SPL output, meaning those resources can be put into keeping the system small. Being desk sitting, it will be a little bit below the headline when sitting on the desk so that it is more in line with the computer being used for mixing.

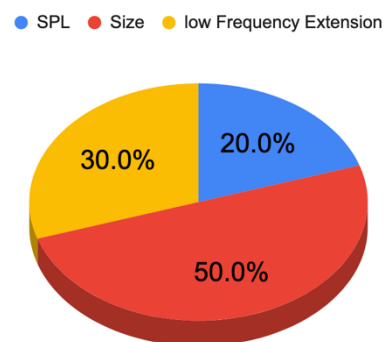
Another thing to note is it needs to be, to an extent, portable. This will influence the design to be segmented into 3 different cabinets so that it is easier to transport when going from location to location. Being able to move the system from place to place will make the speakers useful at most desks on the move while still making it viable for a more long-term arrangement. The weight of the cabinets is also important for transportation and for the sake of the desk so that it will hold the weight of the speakers.

Because of the amount of moving around it will need to endure, it will be built to be durable so that it can take many relocations. It needs to be built in a way that is structurally sound and not likely to be damaged under moderate use. This will be key in the design.

Because of the size requirements, it will be a 2.1 system, where the bass will be a separate cabinet that will either be placed under the desk or nearby on the floor. The Sub will not have an extreme requirement on SPL either because it is meant for those at the desk and keep the disturbance of other members in the house to a minimum when in casual use.

The sound quality will be a priority for making the speakers viable for mixing. The goal is to make it great to listen to for a long time with fatigue for longer mixing sessions while listening backwards.¹ This will be achieved by aiming for a low level of distortion with a flat response to keep the clarity up.

John L. Murphy's three-point design will be used to prioritize the tradeoff of this speaker. The priority will be Size, secondly the Low-end frequency extension, and finally the SPL.²



¹ Moulton, David. P. 313.

² Murphy, John. *end.* P. 55.

2.0 Reference Systems

2.1 Overview

A review of bookshelf speakers with a focus on quality and weight. A variety was chosen to keep the scope relatively wide to review more about what tradeoffs will be the most useful to address. The bookshelf speakers reviewed are summarized by the table below:

Speaker	Woofers Size	F3	SPL peak	Weight (lb)	Dimensions(inch)	Price (US\$)
707 S3	5"	50	104	13.6	6.5 x 9.7 x 11.8	\$1,799
Kin Monitor	4"	65	109	8.25	5.11 x 10.62 x 7.48	\$749
Shape Twin	5"	40	110.5	24	18.8 x 8.3 x 11	\$1,299
KH 80 DSP A W EU	4"	57	108.8	7.5	9.13 x 6 x 7.63	\$549
M126Be	6.5"	53	107.8	22	15.2 x 8.3 x 10.3	\$2,200

Looking them over, the Weight, Size, and Price varies a lot. F3 is all over the place between 40 to 65 with an average of 53. SPL output is from 104 to 110.5. With the main focus on size and weight, the bigger speakers will not be greatly focused on.

2.2 Specific Loudspeakers



707 S3³

The 707 S3 is very good on paper with a 2-way system of a 1 inch tweeter and a 5 inch woofer to give it that range of 45 to 33K Hz. The size a weight also makes it look very good for smaller desk or bookshelf oriented speakers. It also recommends a distance of 1.5 meters to 3 meters apart from each other which would be a problem for smaller desks. Although, there was not any professional measurement data such as a frequency graph after extensive searching. This lack of information is very disheartening with it being one of the main ways to check the flat response and leads to discomfort about the final product.

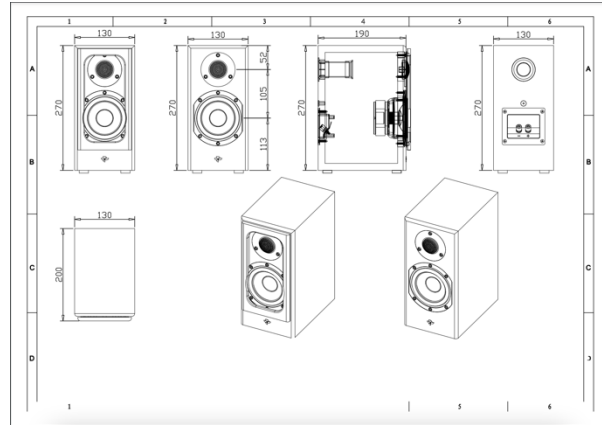
³ "707 S3," 707 S3 Stand-Mount Speaker | Bowers & Wilkins, 2022, <https://www.bowerswilkins.com/en-us/product/loudspeakers/707-s3>.



Kin Monitor⁴

The Kin Monitor is a 2-way with a 1 inch Tweeter and 4 inch Woofer. This keeps it small and only to 8.25 lbs. What really interests me was how it is much lighter than the 707 S3 with the only downside being the low end frequencies not

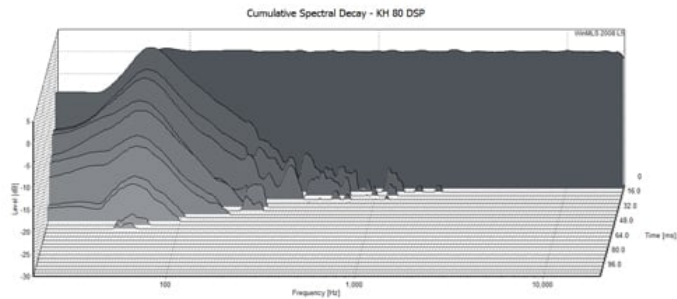
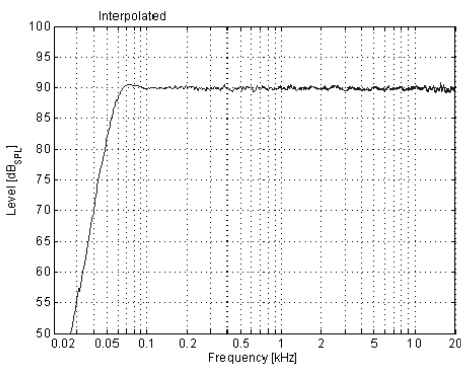
quite getting low enough for the fundamental of a kick drum. This downside can be fixed by getting a dedicated subwoofer and is the main reason why I want to go towards a 2.1 system. Some more documentation was delivered with what I wanted of a CAD drawing of the exact dimensions of the speaker to really get that all settled out correctly.



KH 80 DSP A W EU⁵



The KH 80 DSP A W EU is a 2-way speaker with the usual tweeter and woofer setup with a very flat frequency response. As seen in the waterfall graph, it is very clean and clear with a little bit in the low frequency to help with the low end lacking via a ported design. With it only getting down to 57 Hz \pm 3 dB, the ported design doesn't go very low but will be less of a consideration when the focus is on a 2.1 system and having that subwoofer.



⁴ MxX NOVO, "Kin Monitor," Totem, January 31, 2023, <https://totemacoustic.com/product/kin-monitor/>.

⁵ "Two Way Nearfield Monitor," Neumann, 2018, <https://www.neumann.com/en-en/products/monitors/kh-80-dsp-a-w/>.

3.0 Technical Specifications

3.1 Cabinet Design

Keeping the design small and portable will be a high priority in this design so that it can be easily moved from place to place when necessary. It will be moved often enough that this is a problem that must be addressed. For the size of Roger and Rick, the left and right bookshelf boxes, a good starting point based on having a 5" driver and a 1" tweeter with a 3" casing, the box will be around 6-7" Length, 5-6" Width and 10-12" Height. This height will keep the listening axis more level with my head to keep everything in line. For the weight of the boys, I will be aiming for around 8-15 lbs to keep them carryable in one hand in a tight pinch easily. Usually though I will not be because these will be my babies and keeping them in one piece is a priority for me with zero risk. The Internal volume, using these approximates and accounting for $\frac{3}{4}$ " wood it would be around 190 in³ or 3.11 Liters. This will give plenty of space for both drivers to comfortably have the space to operate.

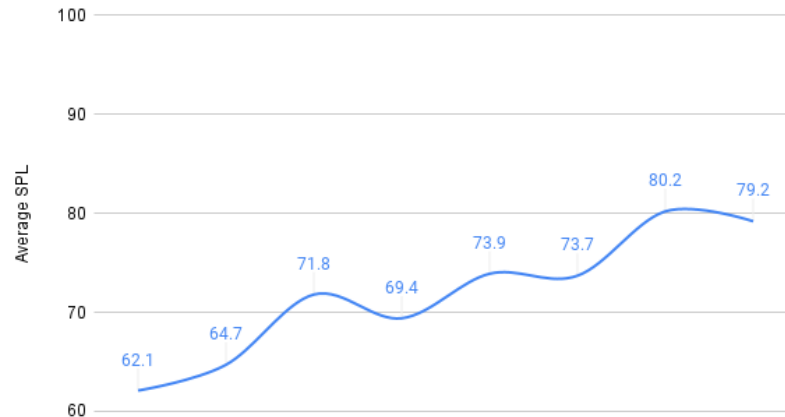
For Veronica, the box with a 10" subwoofer, it will be around 11-12" Length, 15-19" width, and 11-12" Height. This is to make sure that the box is not a square build because that can mess with some of the higher frequencies, but I might go to a square box for the sake of cost. While it does not affect too much, it should still be considered, with listening axis not being too much of a problem because of the wavelength. This box will be put on the floor and utilize the quarter space rule, to further help boost the dB output because it is close to a wall on the floor.⁶ For the weight of the speakers, Veronicas conferrable range of weight would be around 20-30 lbs with more emphasis on the lower end so that portability is kept and being able to easily be carried by two hands without any struggle. The volume would be, 1550 in³ or 25.40 Liters.

3.2 SPL

My personal preference for SPL was gathered from my most common listening environments of my car and my computer speakers in my room. I did some tests on what my preferred low volume and loud volume would be prospectively over a few songs. The graph below shows the average tracking:

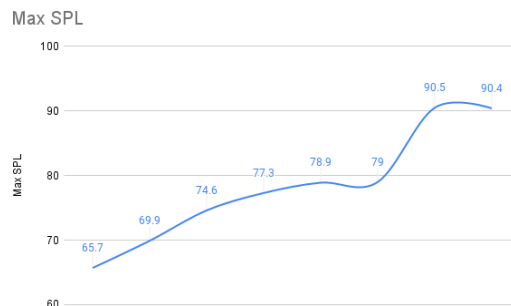
⁶ Philip Newell and Keith Holland, "7.2.1," story, in *Loudspeakers for Music Recording and Reproduction* (New York, New York: Routledge, Taylor & Francis Group, 2019), 202–202.

Average SPL



As you can see, this graph shows both low volume and high-volume listening, with the lower being presented first. With this data including both listening environments, it surprised me with how stable and very similar my SPL levels were in the car and my room. Tallied up, the average volume at lower levels is 67 dB SPL with the louder being an average of 76.75 dB SPL. In reference to the speakers, this will make it relatively easy to keep the cost down by not prioritizing SPL during the build and design work.

Max SPL is important for dynamic range and making sure that the speaker can hit those louder sections without it being a problem. This information is key to keeping the speakers from breaking or deteriorating for a long time. Here is my finding after recording the results of my tests:



As it appears the graph starts off with the lower volumes and then jumps high up when playing the louder, dance songs that I listen to. This is important to note because many of the songs that I listen to have a high dynamic range. The average low volume song is 71.88 dB SPL while on the higher end it is 84.7 dB SPL. The peak of 90.5 dB SPL is important to note because it is a common song I listen to, so that headroom and a little bit more will be what will be aimed for with the system.

Before Continuing, LUFS and the K-System must be defined to properly continue with the data. The K-System is very similar to today's system and was designed by Bob Katz. This system was designed before LUFS was invented and is very compatible with each other. The K-System was created with the idea of how over 0dBFS will overload the recording and distort the sound. With the ear in mind, perceived loudness is the average levels and not peak levels of the tracks. There was then a big push for trying to keep everyone's tracks around the same volume because they kept having the problem of commercials on the television being too loud after a semi quiet show. This is where the K-System came in and established some ground rules. The numbers for standards are -18, -20 and -14. -18 and -20 came from film where the average volumes of 83 dB was tested as the just right volume with 18 to 20 dB headroom, while the -14 was derived from Analogue tapes having that as their peak level.⁷ Bob Katz proposed the K-System to help normalize these volumes so that dynamic range was still preserved. The standard K-20, K-14, and K-12 were perused so that equal levels were achieved. K-20 was used for Film, K-14 for music, and K-12 for broadcast voice. 88-90 dB was tested as being used for a lot more intense moments that don't happen as often in the tracks and is described as the "Meter's Red Zone."⁸ To wrap this up, this was the foundation for today's LUFS scale and how dynamic range is now today's standard.

LUFS, short for Loudness Units Full Scale, is the measurement of the average loudness of a given media with 0dB being the point of clipping. This scale is used for normalizing audio medias so that the audio level will be the same and not jar the listener. Some of the common standards for the system vary from provider and media types. For instance, Spotify LUFS target is -14 dB⁹ while Netflix is at -27 +/- 2 LU dialog-gated, with LU being the Loudness Units.¹⁰ This determines the amount of headroom needed to play the media correctly without the speakers not being able to handle the media.

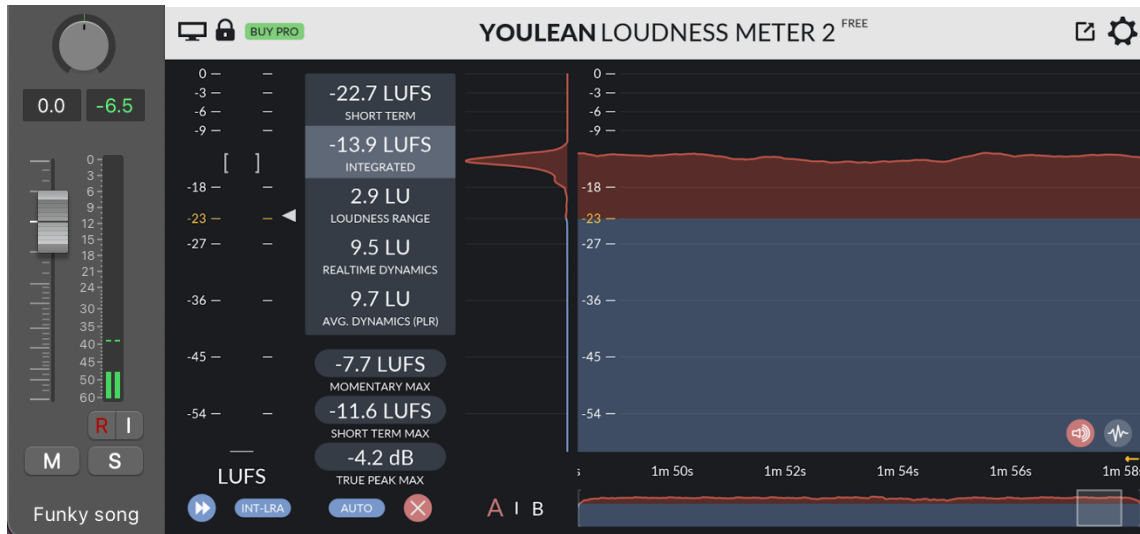
Regarding headroom, to get this information, more testing was required with the use of the LUFS scale and the peak dBFS. This data will give the actual peak SPL that the speakers need to produce to match the listening level desired. Here is one of the tests of what that looks like:

⁷ Bob Katz, "Level Practices (Part 1)," Digidio.com, April 9, 2017, <https://www.digido.com/portfolio-item/level-practices-part-1/>.

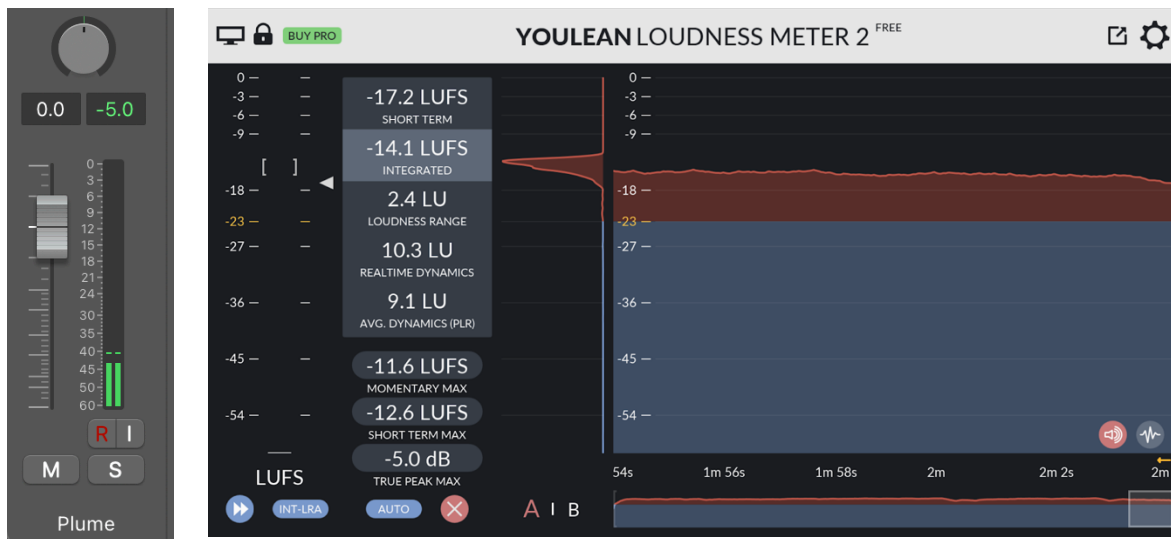
⁸ Bob Katz, "Level Practices (Part 2)," Digidio.com, April 9, 2017, <https://www.digido.com/portfolio-item/level-practices-part-2/>.

⁹ "Loudness Normalization," Spotify, accessed September 30, 2023, <https://support.spotify.com/us/artists/article/loudness-normalization/>.

¹⁰ "Netflix Sound Mix Specifications & Best Practices v1.4," Netflix, April 4, 2009, <https://partnerhelp.netflixstudios.com/hc/en-us/articles/360001794307-Netflix-Sound-Mix-Specifications-Best-Practices-v1-4>.



As seen here, taking that highest peak recording and putting it into Youlean Loudness Meter and through Logic, the meters threw me off at first because I am used to mixing at higher LUFS. This shows that with -4.2 dBFS and a -13.9 dB LUFS. This will be the numbers to beat so that the speakers can handle the output correctly without any worry of clipping. This will be relatively doable to maintain if the target loudness max is around 90 dB. This will make the system available to keep the costs down.



After examining the songs used, they are very well mixed to -14 LUFS and having a high of -5.0 dBFS. These numbers are easy to work with for our purposes of hitting the targeted 90 dB max. I would like to be able to have the ability of more dynamic range though because of being able to mix and listen for a wider range of jobs, so the target will be moved up to 95 dB max.

Listening Distance is also important to define because of the inverse square law and the Toole 3dB draw away curve. With a doubling of distance, under the worst conditions, adds -6dB to the sound to reach its destination. This needs to be factored in because that loss of dB can be very important for how what level the speakers are outputting to get the desired level at the listening position. Keeping in mind that most speakers are measured at a 1 meter distance, this might help me in some ways get more dB because of where the speakers will be placed. After taking some measurements of how far the listening position is from where the speakers will be placed the distance was 2' 9', or to convert to meters, .83 meters. With this number in mind, and for easier math and a small safety net, I will be considering this at 1 meter. This will make my SPL a little lower than actual but I also know myself to move my head a good amount when not doing focused listening. So, my added SPL output will be +0 and not be too much of a factor when figuring out SPL.

Looking into amplifiers it is also important to cover because of the impact dBW it has on the output of overall dB. The range of sensitivity of the drivers I am going for will be around 87 to 91dB. Using an average of 89 dB will help keep everything reasonable for later use across all the different types of drivers. With the formula of $dBW = 10 (\log, \text{base } 10, \text{ Watts})$ with most amplifiers being at 100 watts, this gives +20 dBW. This came to be because of the dynamic range of 20 dB on top was needed for film and very dynamic music. With the highest average SPL desired being 80.2 dB, it would only require 1 watt of power so all good there. Factoring in the highest Max dB output being 90.5 dB, it would require +1.5 dBW, which would be 1.42 watts. This is overall very easy to achieve without any hiccups and make it very easy on the wattage. Although, just for some more safety I will say 95 dB with +6.5 dBW, bringing the wattages to only 4.5 watts. So again, not much to worry about there.

Sensitivity (dB)	89	89	89	89	89	89
Wattage (w)	1	1.42	4.5	10	50	100
Total SPL (dB)	89	90.5	95.5	99	106	109

In conclusion, that target SPL Max will be 95 dB for the speakers to get up to the desired level while still having the headroom for more dynamic audio. This will also help me if Someone else get a hold of my speakers or dives them too loud on accident. This number is relatively low and will not be too hard to achieve and thus, will make it not the primary focus of the speaker system.

3.3 Frequency Response

The Frequency range is very important to the design because it need to be able to get most of the full range to be used for mixing monitors. Because the system is going to be a 2.1 system, this will be easier to cover overall because each driver will be filling its role of frequencies. The range that I am going for is 20Hz-20kHz to get the full range, this can be achieved because of the dB requirement is low and frequency being the main focus. For the

woofer, it will need to go as low as 60 to 50Hz to make sure that the crossover is clear with the subwoofer. The tweeter, on the other hand will be more varied with a crossover frequency of around 1.3k-2.5k so that it can merge with the woofer effectively.

4.0 Driver Research

4.1 Tweeters

4.1.1 Dayton Audio

RST28F-4 Reference Series¹¹ - Selected

Specifications:

Cost: \$37.98

Size: 1 1/8"

+/- 3dB in Bandpass 1.4kHz to 20kHz

Breakup starts at: 8kHz

Breakup amplitude peak: 96dB

Recommended crossover: 1nd order at 1.42kHz

Thermal Power handling: 80watts at 93.5dB SPL



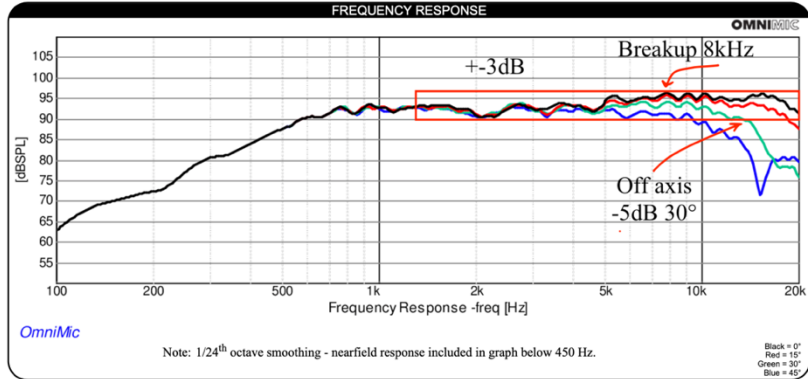
PARAMETERS	
Impedance	4 ohms
Re	3.0 ohms
Le	0.03 mH
Fs	710 Hz
Qms	2.52
Qes	1.46
Qts	0.92
Mms	N/A
Cms	N/A
Sd	6.6 cm ²
Vd	N/A
BL	N/A
Vas	N/A
Xmax	N/A
VC Diameter	N/A
SPL	93.5 dB @ 2.83V/1m
RMS Power Handling	80 watts
Usable Frequency Range (Hz)	1,400 - 20,000 Hz

Narrative:

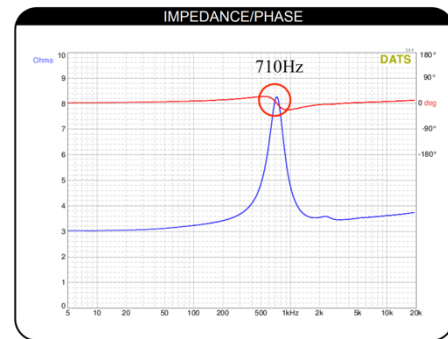
- Visual Aesthetics: It has a slick black design with a grated outwards dome. This will help keep the dome intact while moving around and also being good to look at.
- SPL: With the thermal SPL limit at 112.5 it will be up to the task of getting up to 95 dB easily without and trouble over a long period of time.

¹¹ "Dayton Audio RST28F-4 1-1/8" Reference Series Fabric Dome Tweeter 4 Ohm," Parts Express, accessed October 8, 2023, https://www.parts-express.com/Dayton-Audio-RST28F-4-1-1-8-Reference-Series-Fabric-Dome-Tweeter-4-Ohm-275-141?quantity=1&utm_source=google&utm_medium=cpc&utm_campaign=18197889536&gclid=Cj0KCQjwpompBhDZARIsAFD_Fp_8uheVU_0KdSTVlcwJ9L0M2oyHixPIfFXQok9elvahxnkgAZs5TUYaAkhKEALw_wcB.

- Off-Axis: This starts to spread around 5kHz with a greater decrease when getting up to 10kHz. This will be helpful for it not to have nasty reflections of the side walls and keep the sound forward towards mixing position.



- FR response: This likes to move around a bit with it most noticeable at 5kHz with a 2dB increase. This spot will not be that much of a problem because of being able to use a high shelf filter to bring those frequencies down in line with the rest of the lower range. There is a drop around 18kHz that rolls off up to 20kHz that is not desired but is not the worst tradeoff to have and can be E.Q.ed as well.



4.1.2 SB Acoustics

SB19ST-C000-4¹²

Specifications:

Cost: \$23.60

Size: 3/4"

+/- 2dB in Bandpass 2kHz to 20kHz

Breakup starts at: 3.8kHz

Breakup amplitude peak: 90dB

Recommended crossover: 2nd order at 1960Hz

Thermal Power handling: 30 watts at 88.5dB SPL

Narrative:

- Visual Aesthetics: This one is not as appealing as the one before with it being a smother lighter black and without the grate for less protection.



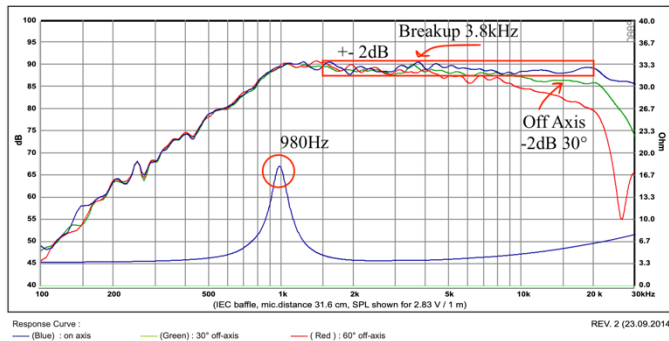
Specs :

Nominal Impedance	4 Ω	Free air resonance, F _s	980 Hz
DC resistance, R _e	3.4 Ω	Sensitivity (2.83 V / 1 m)	88.5 dB
Voice coil inductance, L _e	0.07 mH	Mechanical Q-factor, Q _{ms}	6.45
Effective piston area, S _d	3.8 cm ²	Electrical Q-factor, Q _{es}	1.50
Voice coil diameter	19.1 mm	Total Q-factor, Q _{ts}	1.22
Voice coil height	1.8 mm	Force factor, B _l	1.75 Tm
Air gap height	3 mm	Rated power handling*	30 W
Linear coil travel (p-p)	1.2 mm	Magnetic flux density	1.24 T
Moving mass incl. air, M _{ms}	0.22 g	Magnet weight	0.13 kg
		Net weight	0.32 kg

* IEC 268-5, high-pass Butterworth, 2600 Hz, 12 dB/oct.

¹² Inc. Madisound Speaker Components, "SB Acoustics SB19ST-C000-4 3/4" Dome Tweeter, 4 Ohm," SB Acoustics SB19ST-C000-4 3/4" dome tweeter, July 13, 2023, <https://www.madisoundspeakerstore.com/soft-dome-tweeters-sb-acoustics/sb-acoustics-sb19st-c000-4-3/4-dome-tweeter-4-ohm/>.

- SPL: With being able to reach up to 103.3dB with only 30watts of power, this is the most efficient driver of the bunch while still hitting the required 95dB target. This keeps it low with the ability to push more if needed in smaller amounts of time.



- Off-Axis: This is a lot more pointed with it being -2dB at 30° around 15kHz. It also follows the response of on axis making it easier to manage overall. It also lists after 20kHz with the sides getting way down there to avoid non hearable reflections of the side walls that will help with clericity.

• FR response: This has a few defined soft dips around 2k and 9k that can be flattened out with some broader E.Q. that will not affect the off axis. +/- 2 dB is good for the price while remaining relatively flat overall. This makes the frequency response great for the listed price.

4.1.3 SB Acoustics

SB26STAC-C000-4¹³

Specifications:

Cost: \$48.70

Size: 1"

+/- 2dB in Bandpass 1500Hz to 20kHz

Breakup starts at: 14kHz

Breakup amplitude peak: 93dB

Recommended crossover: 2nd order at 1500Hz

Thermal Power handling: 100watts at 91.5dB SPL



Specs :

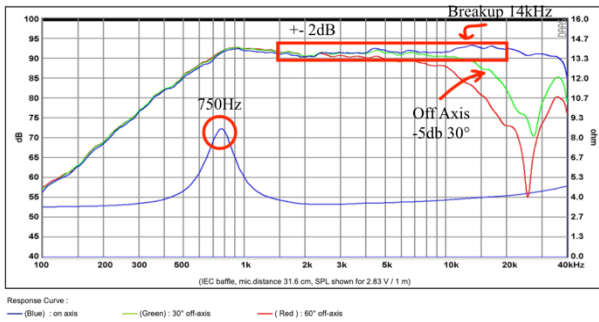
Nominal Impedance	4 Ω	Free air resonance, Fs	750 Hz
DC resistance, Re	3.2 Ω	Sensitivity (2.83 V / 1 m)	91.5 dB
Voice coil inductance, Le	0.04 mH	Mechanical Q-factor, Qms	3.0
Effective piston area, Sd	6.2 cm ²	Electrical Q-factor, Qes	1.78
Voice coil diameter	25.4 mm	Total Q-factor, Qts	1.12
Voice coil height	1.3 mm	Force factor, Bl	1.6 Tm
Air gap height	2.5 mm	Rated power handling*	120 W
Linear coil travel (p-p)	1.2 mm	Magnetic flux density	1.15 T
Moving mass incl. air, Mms	0.3 g	Magnet weight	0.22 kg
		Net weight	0.53 kg

* IEC 268-5, high-pass Butterworth, 2600 Hz, 12 dB/oct.

Narrative:

- Visual Aesthetics: While it is very similar to the one before, it dose have more of a inwards cone shape to the driver and still being that reflective black. Not my favorite but better looking than the SB19ST slightly.
- SPL: With SPL being at 112.3dB at 120 watts this driver can definitely get up there. The only problem with this is that requirement of 120 watts. My amplifier will not get that high as only up to 90 watts, making it more reasonable at 111dB. Not a big difference but dually noted as still being great for the target range of 95dB.

¹³Inc. Madisound Speaker Components, "SB Acoustics SB26STAC-C000-4 1" Textile Dome Tweeter," Madisound Speaker Components, Inc., July 13, 2023, <https://www.madisoundspeakerstore.com/sb-acoustics-soft-dome-tweeters/sb-acoustics-sb26stac-c000-4-1-textile-dome-tweeter/>.



• Off-Axis: This one is interesting to talk about because up until 7kHz it is very much still around each other and close knitted. After that point, there roll off becomes greatly increased with -5dB at the 30° axis. This will make for less side reflections but a narrower listening axis, which should not be much of a problem with the near field listening position.

- FR Response: With a +2dB from 1500Hz to 20kHz this is the flattest of the three looked at here. This makes it very easy to work with only like a 1dB increase towards the lower frequencies. Very good, if only price was not such a big factor in this evaluation.

4.2 Woofers

4.2.1 SB Acoustics

SB15NRXC30-4¹⁴

Specifications:

Cost: \$51.40

Size: 5"

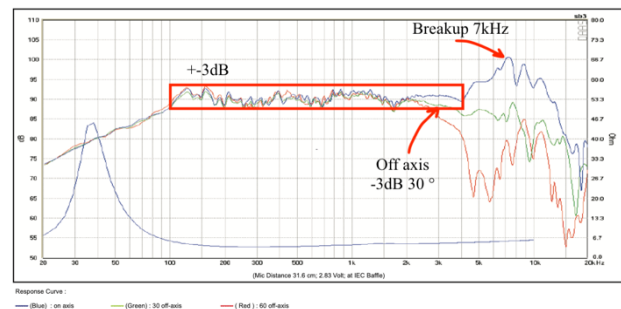
+/- 3dB in Bandpass 100Hz to 4kHz

Breakup starts at: 7kHz

Breakup amplitude peak: 101dB

Recommended crossover: 2nd order at 2.5kHz

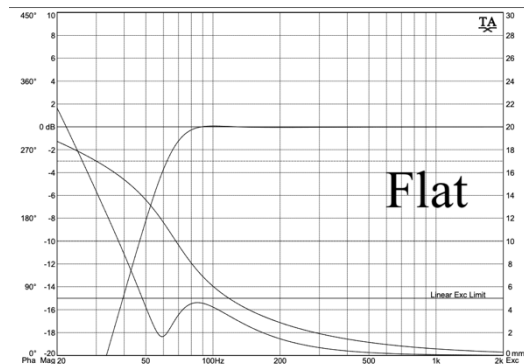
Thermal Power handling: 50 watts at 91dB SPL



Narrative:

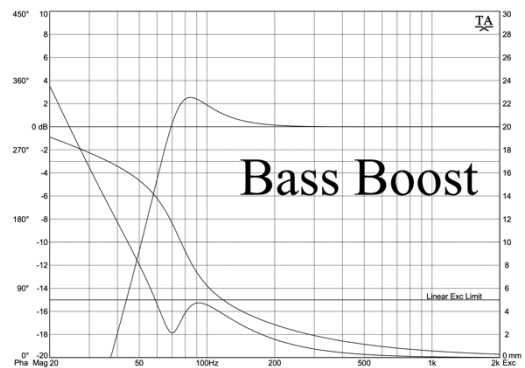
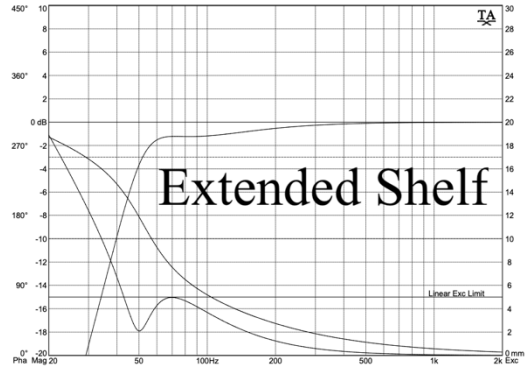
Visual Aesthetics:

- This is not the most stunning design and is very basic with its grey tones. I feel very natural about this design but would like something a little more appealing. With that in mind, it is the last consideration of the driver overall.



¹⁴ Inc. Madisound Speaker Components, "SB Acoustics SB15NRXC30-4 5" Woofer," SB Acoustics SB15NRXC30-4 5" Woofer, September 24, 2020, <https://www.madisoundspeakerstore.com/approx-5-woofers/sb-acoustics-sb15nrxc30-4-5-woofer/>.

- SPL:
 - With the ability to get up to 108dB, this woofer is more than capable of hitting the required 95dB long term. This will be very handy when putting into prospective the -3dB when adding a passive crossover to the driver.
- Off-Axis:
 - With the off axis starting to diverge around 2k, this will not be too big of a problem with the tweeter handling higher, crazy ranges that I was not designed to do effectively. With the breakup frequency being as high as 7kHz this will also give the crossover time to work to get rid of that jump entirely.
- FR Response:
 - With the speaker holding at +3dB up towards 4kHz, this range will give the tweeter time to adjust with a smoother crossover able to be implemented.



4.2.2 SB Acoustics

SB13PFC25R-04¹⁵

Specifications:

Cost: \$34.70

Size: 5"

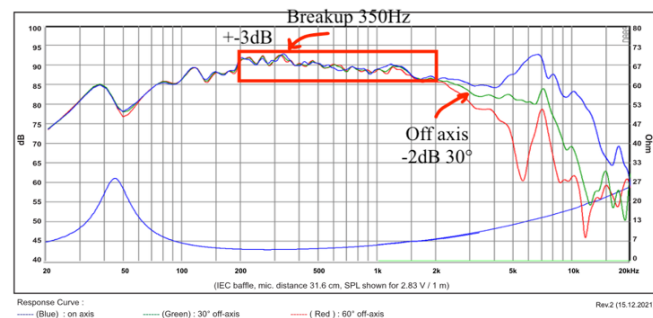
+/- 3dB in Bandpass 200Hz to 2kHz

Breakup starts at: 350Hz

Breakup amplitude peak: 93dB

Recommended crossover: 2nd order at 2kHz

Thermal Power handling: 40watts at 89dB SPL

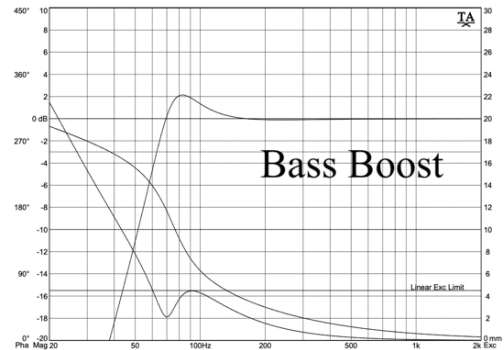
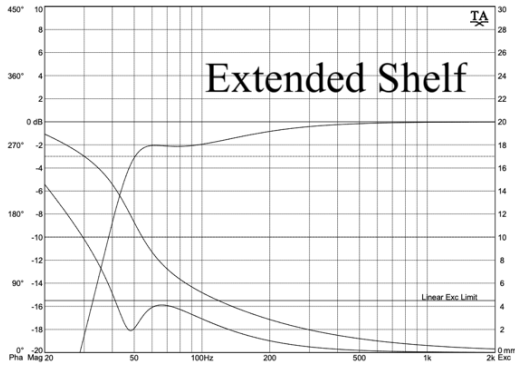


¹⁵Inc. Madisound Speaker Components, "SB Acoustics SB13PFC25R-04 5" Paper Cone Woofer 4 Ohm," ROUND, October 9, 2023, <https://www.madisoundspeakerstore.com/approx-5-woofers/sb-acoustics-sb13pfc25r-04-5-paper-cone-woofer-4-ohm-round/>.

Narrative:

- Visual Aesthetics:

- I like the finish and the color on this one more than the SB15 and it look slicker. It still has that simple design that does not pop out which I feel more content with.



- SPL:

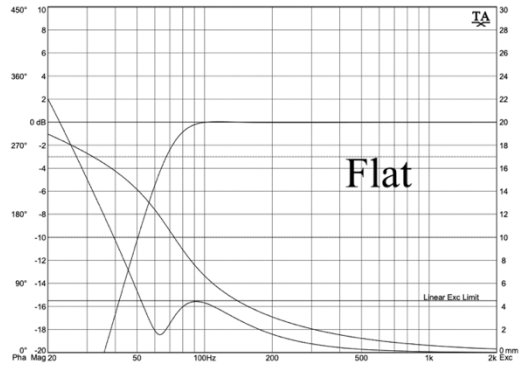
- With the SPL being at 105dB long term, it handles the requirement well and will do great for the system. The 95dB target is easily hit without overexciting the 40 watt long-term.

- Off-Axis:

- This is solid with it spreading out at 2kHz and then also going crazy at 4kHz. Once again, pretty standard with the others, and will not have too many problems with a crossover.

- FR Response:

- Here we go. With it being at ± 3 dB, this is a good range to dance around. Although, it dose has a gradual decline all the way till 2kHz where it levels out. This can be solved by some simple E.Q. and will not be too much of a problem and should not be that much to deal with, good to note.



4.2.3 SB Acoustics

SB15NBAC30-8¹⁶ - Selected

Specifications:

Cost: \$80.50

Size: 5"

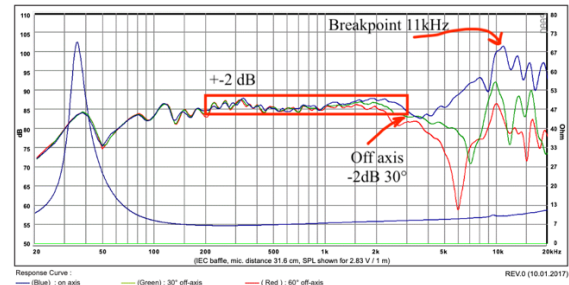
+/- 2dB in Bandpass 200Hz to 3kHz

Breakup starts at: 11kHz

Breakup amplitude peak: 102dB

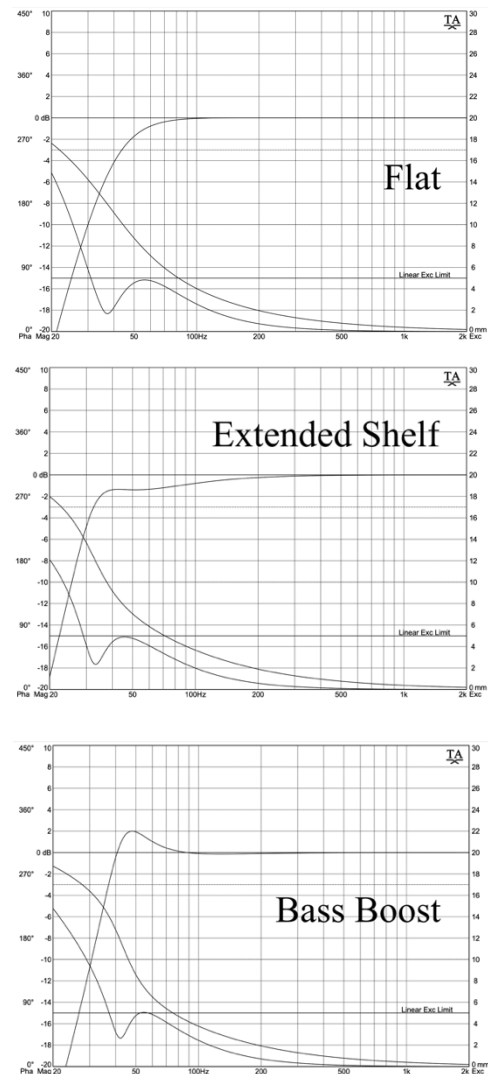
Recommended crossover: 2nd order at 2kHz

Thermal Power handling: 50 watts at 85.5dB SPL



Narrative:

- Visual Aesthetics:
 - This driver is much like the other ones on this list. They all look very similar to me and will not be highly considered like the rest of the options presented.
- SPL:
 - With a long term of 102.5 dB this will be more than enough to hit the 95dB comfortably, with no issues. Great for what it needs to do.
- Off-Axis:
 - This is very stable for the range the woofer will be used for. With only -2dB at 3kHz there is not much to worry about here when the crossover will be used.
- FR Response:
 - Out of the three, this is the most stable of the bunch with only a +/-2dB. This is steady with no major jumps in the middle which will keep the sound clean and flat. Very good with the only concern being the price.



¹⁶Inc. Madisound Speaker Components, "SB Acoustics SB15NBAC30-8 5" Black Aluminum Cone Mid-Bass," SB15NBAC30-8 5" Black Aluminum Cone, January 5, 2022, <https://www.madisoundspeakerstore.com/approx-5-woofers/sb15nbac30-8-5-black-aluminum-cone-mid-bass/>.

4.3 Subwoofers

4.3.1 GRS

10SW-4HE¹⁷

Specifications:

Cost: Cost: \$39.98

Size: Size: 10"

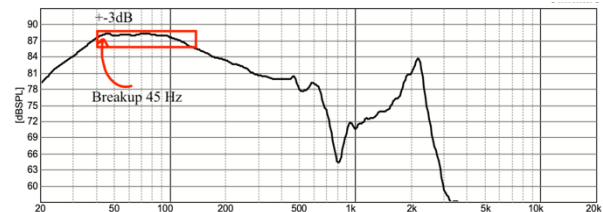
+/- 3dB in Bandpass 40Hz to 150Hz

Breakup starts at: 45Hz

Breakup amplitude peak: 88dB

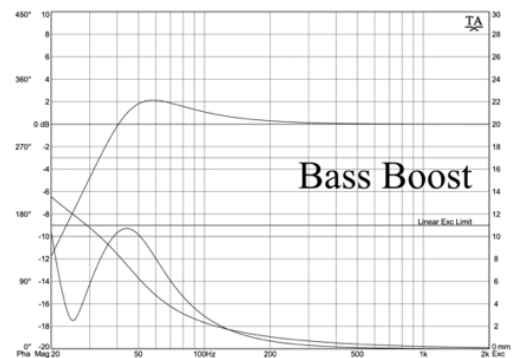
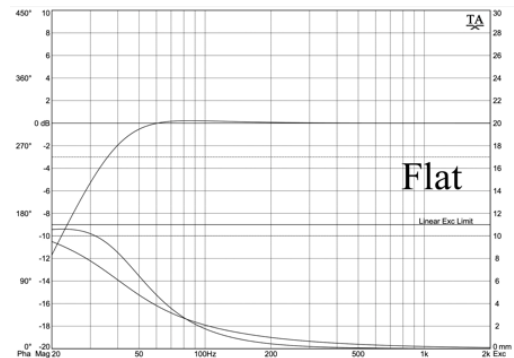
Recommended crossover: 2nd order at 80Hz

Thermal Power handling: 200 watts at 87.5dB SPL



Narrative:

- Visual Aesthetics:
 - This one dose not have much going on but it dose has a band with some interesting different textures in the middle ring. This dose spice it up a bit.
- SPL:
 - With the ability to reach up to 110.5 dB long term, this will do great with hitting the 95 dB that I am looking for.
- FR Response:
 - This will make for e easy time crossing over into the speakers on the desk. It is also only able to go as low as 40Hz. The Vas value is too high for the box that I am going for and is the main drawback for this speaker, meaning that it can't go as low as advertised in a smaller box.



¹⁷“Dayton Audio MX10-22 10" Max-X High Excursion DVC Subwoofer 2 Ohms Per Coil,” Parts Express, accessed October 20, 2023, <https://www.parts-express.com/GRS-10SW-4HE-10-Paper-Cone-Rubber-Surround-High-Excursion-Subwoofer-4-Ohm-292-818?quantity=1>.

4.3.2 Dayton Audio

DCS255-4¹⁸

Specifications:

Cost: \$99.98

Size: 10"

+/- 3dB in Bandpass 40Hz to 200Hz

Breakup starts at: 1.5kHz

Breakup amplitude peak: 97dB

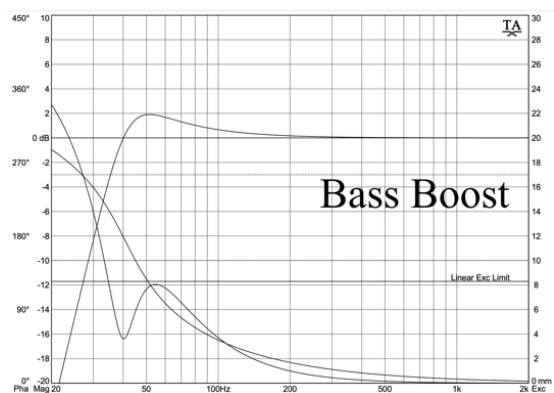
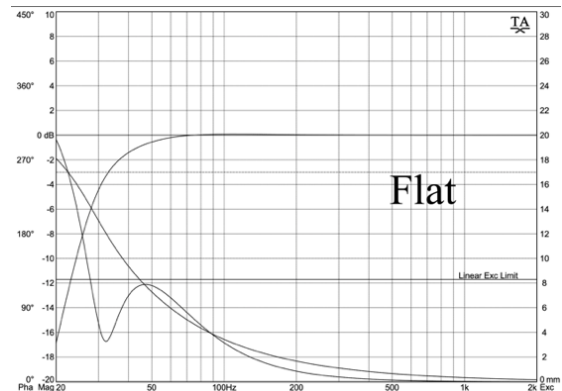
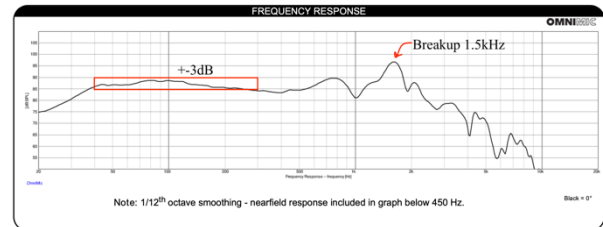
Recommended crossover: 2nd order at 80Hz

Thermal Power handling: 200 watts at 91dB SPL



Narrative:

- Visual Aesthetics:
 - This one has a bubble in the middle with the same black materteral throughout. Design wise, I do not like this as much because of how the bubble pops out which could lead to some accidents with it being on the floor.
- SPL:
 - With the driver able to achieve 114dB long term, it once again hits the mark needed of that 95dB cleanly. Even though it can get hotter than the one before, it is not as factored into the final decision.
- FR Response:
 - It is able to get as low as that 30Hz at -4dB which is almost what I want out of a sub but could be better. Once again, vas has been the most defining factor in how low the driver can actually achieve when working with a max of 1.5 cubic feet. It is very good at higher frequencies but because of the nature of this only being used for the sub frequencies, this only makes it better for crossovers.



¹⁸"GRS 10SW-4HE 10" High Excursion Subwoofer 4 Ohm," Parts Express, accessed October 20, 2023, <https://www.parts-express.com/GRS-10SW-4HE-10-Paper-Cone-Rubber-Surround-High-Excursion-Subwoofer-4-Ohm-292-818?quantity=1>.

4.3.3 Dayton Audio
 MX10-22¹⁹ - Selected

Specifications:

Cost: \$99.98

Size: 10"

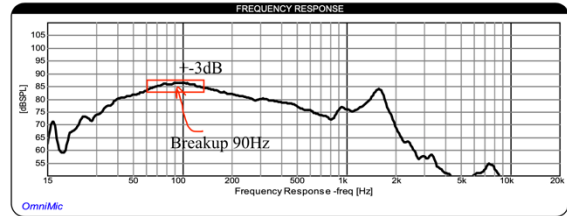
+/- 3dB in Bandpass 40Hz to 150Hz

Breakup starts at: 90Hz

Breakup amplitude peak: 87dB

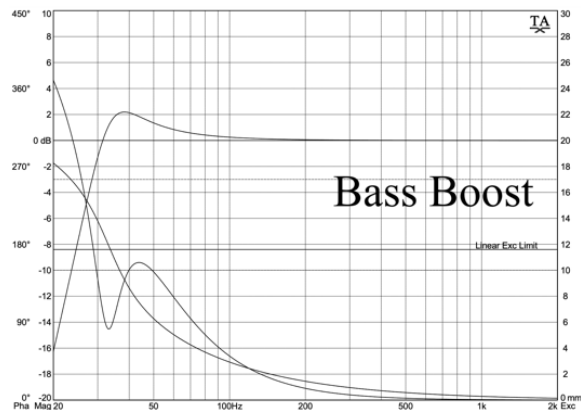
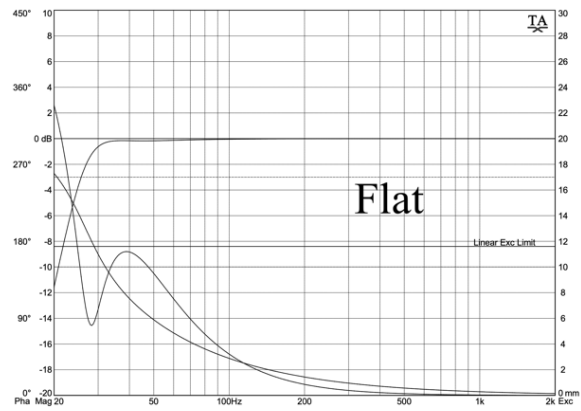
Recommended crossover: 2nd order at 80Hz

Thermal Power handling: 400 watts at 86.1dB SPL



Narrative:

- Visual Aesthetics:
 - Although this is the most basic for the bunch, I like it the most. It does not have anything fancy about it but a slick black front with the same circle over the front. The best of the bunch.
- SPL:
 - With a long term of 110.9dB, factoring in that my amp can only get upwards of 300 watts, this hits the amount needed in a very clean way. All good here.
- FR Response:
 - After modeling, this one came out on top. It was able to get a consistent low of 30Hz with just -1dB making it the lowest of the subs. I can do thing while keeping the dB's up as well making this a great option for keeping everything great for mixing. One thing to note is that it is a 2+2 Ohm driver where the wiring will be done in parallel to keep it as a 4 Ohm driver.



¹⁹“Dayton Audio MX10-22 10" Max-X High Excursion DVC Subwoofer 2 Ohms Per Coil,” Parts Express, accessed October 20, 2023, <https://www.parts-express.com/Dayton-Audio-MX10-22-10-Max-X-High-Excursion-DVC-Subwoofer-2-Ohms-Per-Coil-295-164?quantity=1>.

5.0 Construction

5.1 Boxes

The two top boxes were ordered as precut wood as the Knock-Down MDF 0.56 cu. ft. Bookshelf Speaker Cabinet.²⁰ This did not come with a precut face so by using a circle drill, cut the holes for the drivers with an inset. I also caved away some of the inset wood so that the terminals could sit cleanly and be able to be accessible inside of the box. The binding posts were then bolted into place with some more drilling for the terminals to be accessible and the port on the back side of the tweeter. This was then wood glued and clamped together to create the final box. The tweeter was drilled 1/32" too big so it did create a small gap there and was further created so that both boxes were matched.



The sub box was order as well as the Knock-Down MDF 1.5 ft³ Subwoofer Cabinet for 10" Subwoofers.²¹ This box came with a precut face that ended up being too big for my subwoofer

with the screws missing the wood. To combat this issue, a new face plate was created from some scrap MDF and was rounded, and circle drilled with an inset to match the MX10-22 (see 4.3.3). This caused a small setback but was remedied by checking this before being able to move onto any other section because of parts still being delivered. The binding posts were bolted into place as the top boxes and the port was placed on the side of the box because the port was too long for it to be on the backside, running into the driver.



²⁰"Knock-Down MDF 0.56 cu. ft. Bookshelf Speaker Cabinet," Parts Express, accessed December 12, 2023, <https://www.parts-express.com/Knock-Down-MDF-0.56-ft-Bookshelf-Cabinet-300-7064?quantity=1>.

²¹"Knock-Down MDF 1.5 Ft3 Subwoofer Cabinet for 10" Subwoofers." Parts Express. Accessed December 12, 2023. https://www.parts-express.com/Knock-Down-MDF-1.5-ft-Subwoofer-Cabinet-for-D-300-7080?quantity=1&utm_source=google&utm_medium=cpc&utm_campaign=20348422537&utm_content=149685098334&gadid=664791143238&gclid=CjwKCAjw7c2pBhAZEiwA88pOF4TdFB7Qw6Esp37yijAR4P8-TvGj6RCvigEuYDKCdIPXlnZCnnLjqBoCVFYQAvD_BwE.

5.3 Wiring

The wiring was rather straight forward with it being composed of crimp on connectors for both the drivers and for the binding posts of the top boxes. The Sub box was rather different because of the 2+2 Ohm setup and was then wired in parallel as discussed in 4.3.3. The crimp on connectors were a little finicky and would disconnect so I had to compress them so that they would fit snugger on the connection terminals.

5.2 Absorption



For the top boxes, Roger and Rick could not be stapled down into place because of the woofer hole not being big enough to fit the staple gun in there. To compensate for this, more was used to lock it in place with pressure. This keeps everything in place when moving without the need for staples. I will just have to be more careful with them and not go too fast with them.



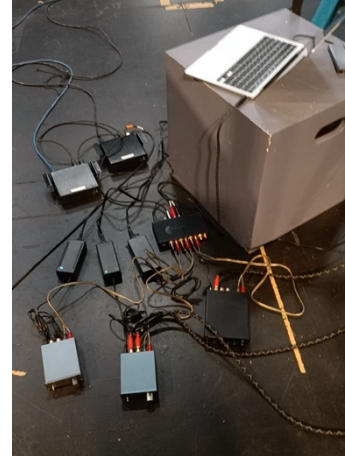
For the subwoofer, Veronica, rock wool was used as dampening material to help remove box resonance and to smooth out frequency response. This was done by cutting the rock wool down to the correct size and stapling it to the box on all sides while keeping the port having free air flow to the driver.

5.3 DSP and Amplifiers

The crossover was scrapped in favor of just using the DSP instead because of running out of time to do a passive crossover properly and I already had the DSP bought, so it was an easy decision. The DSP selected was the Dayton Audio DSP-408 with 4 Inputs and 8 Outputs.²² This made it easy to keep everything separated and flexible while tuning the system.

²²Amazon.com: Dayton Audio DSP-408 4 input 8 output DSP digital signal, accessed December 12, 2023, <https://www.amazon.com/Dayton-Audio-DSP-408-Digital-Processor/dp/B07D3H5X5V>.

Continuing with the information from the selected drivers and the target wattage discussed in 3.2, the amps selected were the Fosi Audio BT30D Pro TPA3255 300W²³ for the Subwoofer and the Fosi Audio TPA3116 50W.²⁴ This made it so that I could use the DSP to its full effect with every driver. The sub amp was bought too early in the process and was not refunded because it would have been a \$20 difference with no time to spare for shipping, but it still works for the subwoofer. 300W for the Subwoofer well as the woofer and tweeter having a max of 50W capacity was more than enough to hit that 90 dB target easily.

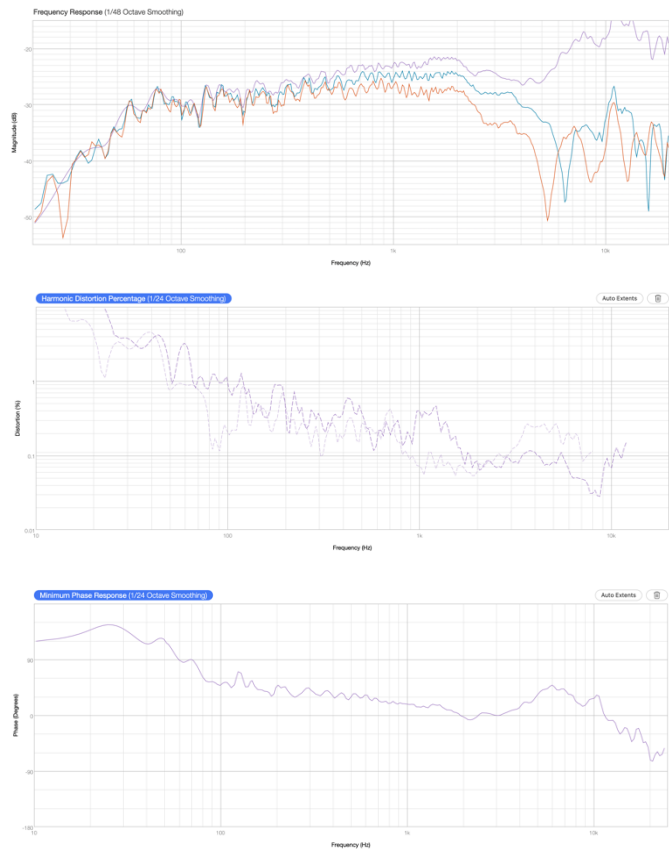


6.0 Tuning

6.1 Unmodified Data

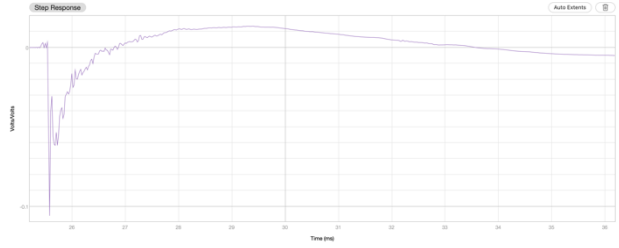
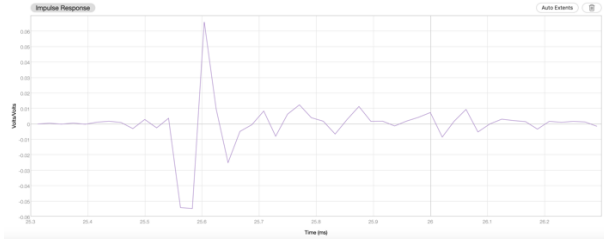
6.1.1 Woofer

With the combination of the box and the SB Acoustics SB15NBAC30-8, Without any work it is already flat and easy to work with. From 100 Hz to 600Hz at one meter, it has a gradual fall off that can be easily EQ'ed to be equaled out and flattened. One thing to note is that the off axis is consistent with each other and does not have any noticeable changes to the wave and is just a consistent dB difference between the 30 degrees and the 60 degrees off axis. The ability to hold together fall away around the 2kHz mark with the off axis becoming more extreme and the high frequencies becoming very wild and unpredictable. The harmonic distortion is great until around 100 Hz on the low end and will liken to a good corroder point with the Subwoofer. This is very workable and can be EQ'ed to flatten out the woofer.

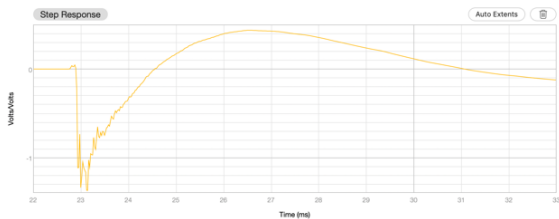
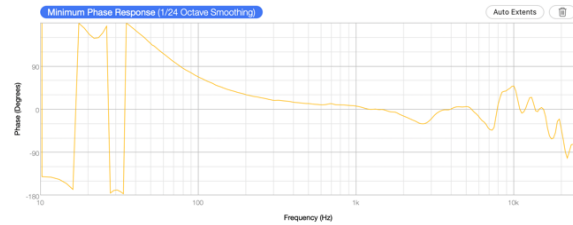
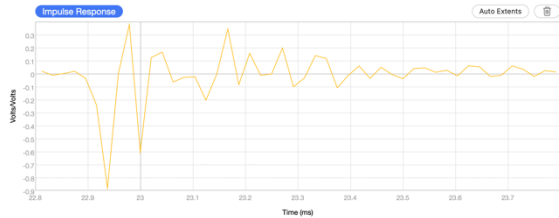
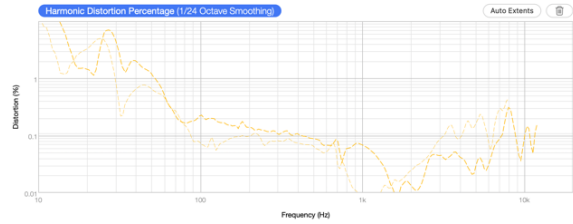
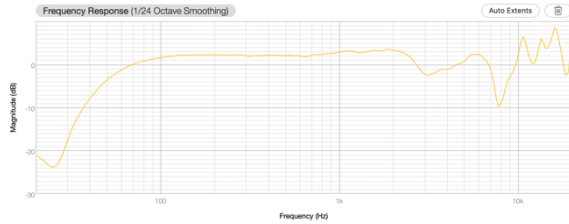


²³“Amazon.Com: Fosi Audio BT30D Pro TPA3255 Hi-Fi Bluetooth 5.0 Stereo,” Amazon, accessed December 12, 2023, <https://www.amazon.com/Fosi-Audio-BT30D-Pro-Integrated/dp/B09YNBHR73>.

²⁴“Amazon.Com: FOSI Audio v1.0g 2 Channel Class D Mini Stereo Amplifier,” Amazon, accessed December 12, 2023, <https://www.amazon.com/Channel-Audio-Amplifier-Professional-Speakers/dp/B071XQGYRJ>.



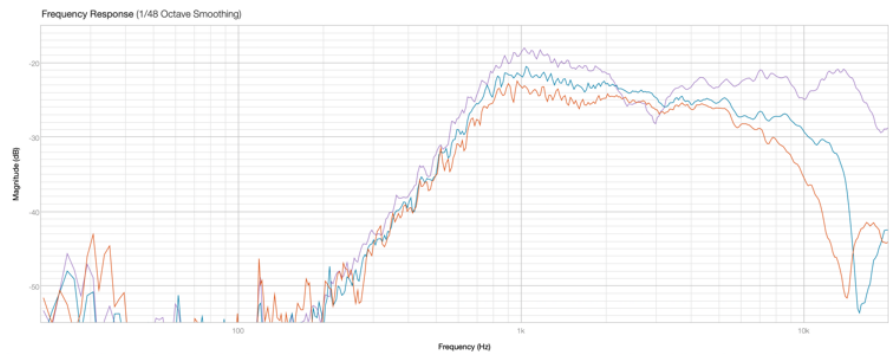
Woofer at 1inch:

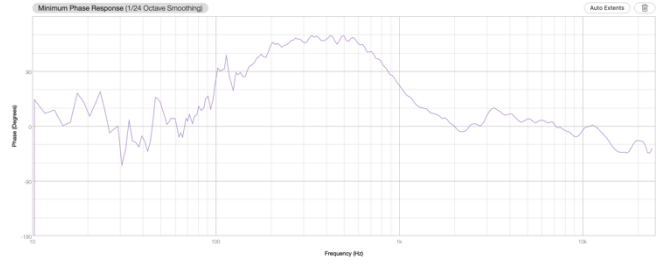
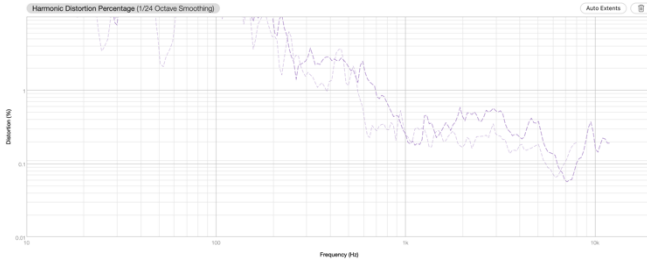
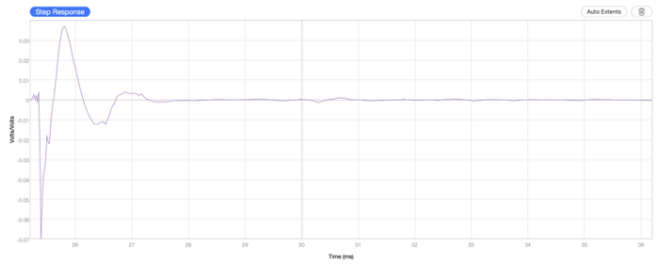
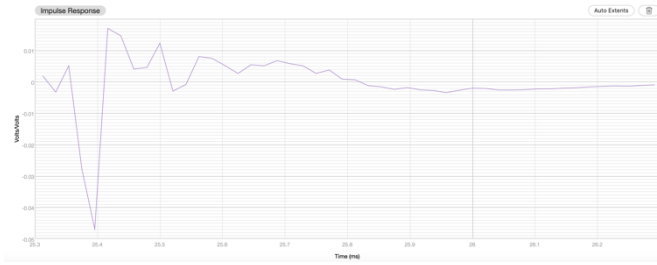


6.1.2 Tweeter

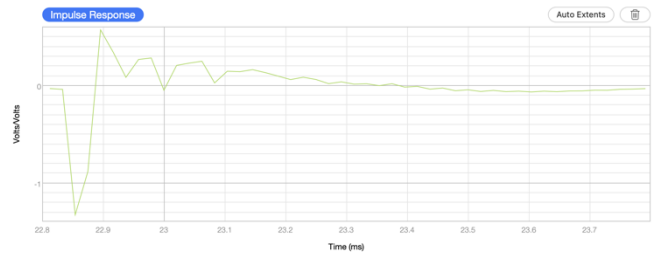
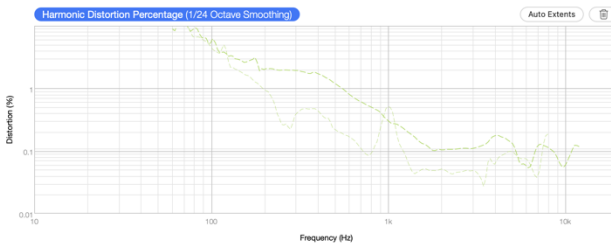
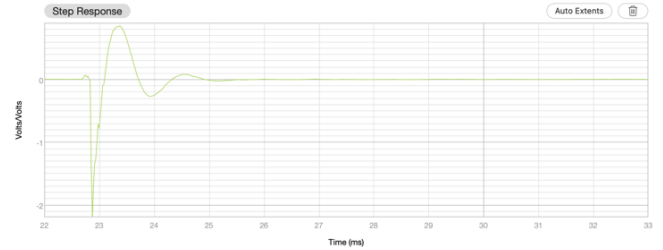
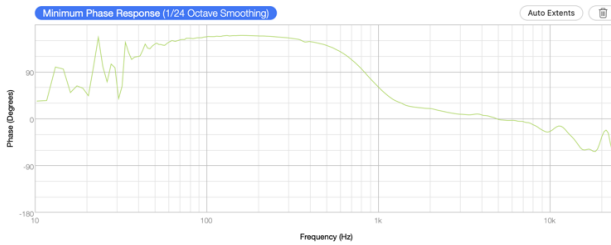
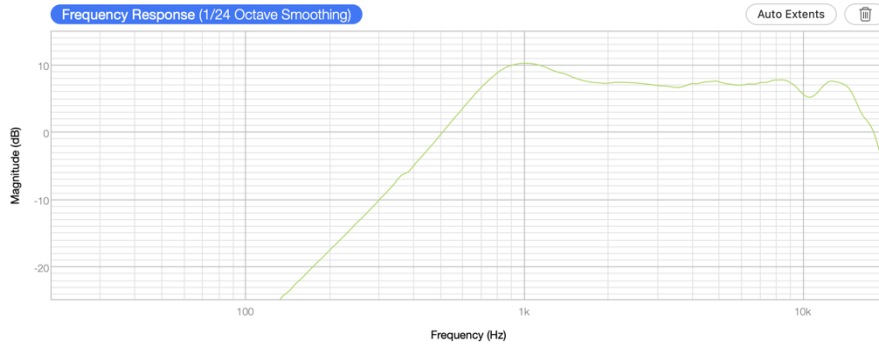
The Dayton Audio RST28F-4 Reference Series Tweeter in the box performed rather good but had some problems. The Frequency range from 2kHz to 15kHz at one meter was the sweet spot but needs

some work. Overall, it needs a lift because of the gradual decline of higher frequencies. Around 10kHz needs a boost to be more inline with the other sections. The big one is that 2.5kHz range where on axis it is -4dB lower than that around it with the greater problem being the off-axis dose not have this problem. If that were to be boosted in the tweeter, it could cause a lot of gain to that area off axis. To remedy this issue, a boost in the woofer will be required to remove this offset. When looking at harmonic distortion and minimum phase next to each other, it is clear there will need to be a crossover around 2kHz to avoid those higher sections of distortion that are not desired.



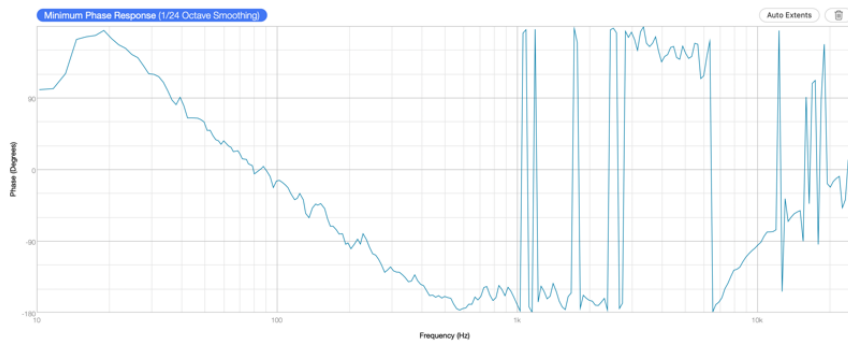
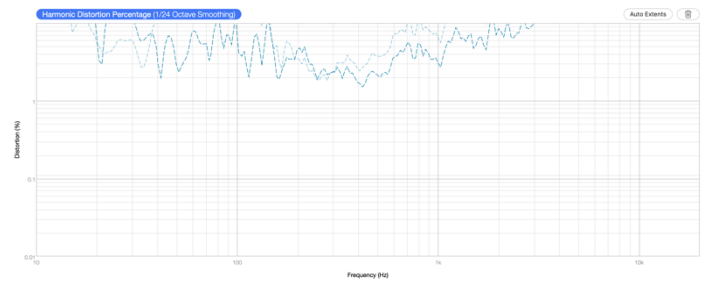
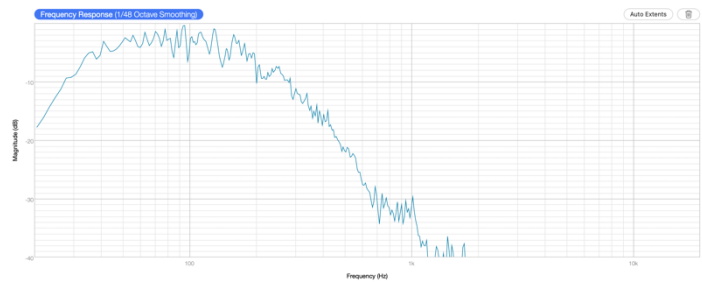


Tweeter at 1 inch:



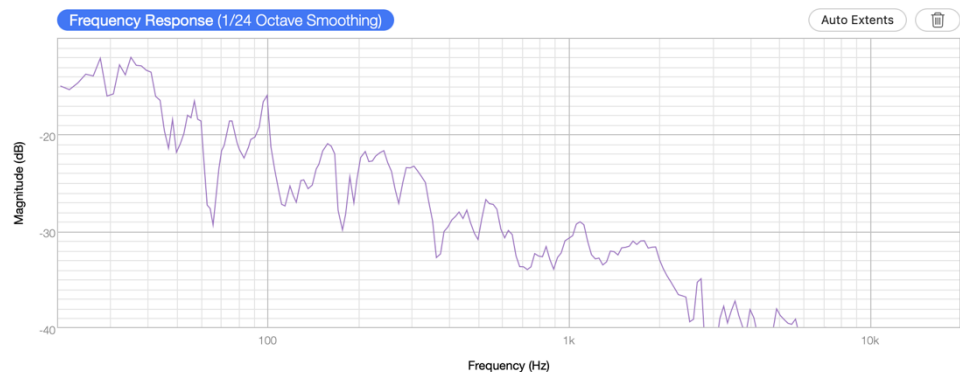
6.1.3 Subwoofer

Because of the nature of Subwoofers, it was hard to get clearly placed graphs for the Dayton Audio MX10-22. The frequency response is rather consistent until 150 Hz where it drops off smoothly and quickly until it is almost unnoticeable at 450Hz. Because of this drop, a good place to put this crossover would be at 100Hz to avoid that drop off and keep it consistent where needed. The lower end of the spectrum will need a little bit of a lift to be in line with the rest with some of the nitpicky frequencies being smoothed out as well. This will have to be done carefully



and with consistent white noise because of the reality of data that low. I just this testing, the low end was oscillating upwards of 2dB of a difference in the lowest areas. So not overdoing the low end will help a good amount in this situation. The

port on the sub was the last thing to look at and it works well for the lower range, although it has some problems. The port hole is too small of a size which leads to pumping air out of the small hole and lead to a fluttering at higher volumes. It is not very noticeable if you are not looking for it but I will be looking into changing that out in the future for a much wider diameter tube.



6.2 Final Tuning

To finish it up, the first thing focused on was tuning the top boxes. This involved using that 2KHz crossover for the tweeter and the woofer to evenly do their jobs. This was then further modified through the use of delaying the tweeter so that it was in phase with each other to make the 3kHz regain better. Even with getting it as close as possible, there was still some dipping in that range because of the off axis of the tweeter having that dip at 3kHz. This was remedied by boosting the woofer in 3kHz range to fill in that gap but was not fully done to preserve some of the off axis response, which is better than having a massive peak in the off axis. The Subwoofer was then given a low shelf to boost some of the lower frequencies and to get them in line with the rest of the drivers.

The final system has a ± 3 dB difference from 20 Hz to 18KHz with a max SPL output of 108 dB. The max dB has not been tested thoroughly because I want to preserve my speakers and they only need to go up to 90 dB, with some great 18dB headroom when necessary. The final cost of the system came out to be \$1,013.99 with around 300 hours of work. Much of the process was researching what to do and what parts to get before the physical labor of building and testing. Overall, Roger, Rick, and Veronica are bookshelf speaker for mix monitoring and entertainment that perform very well for the job at hand.

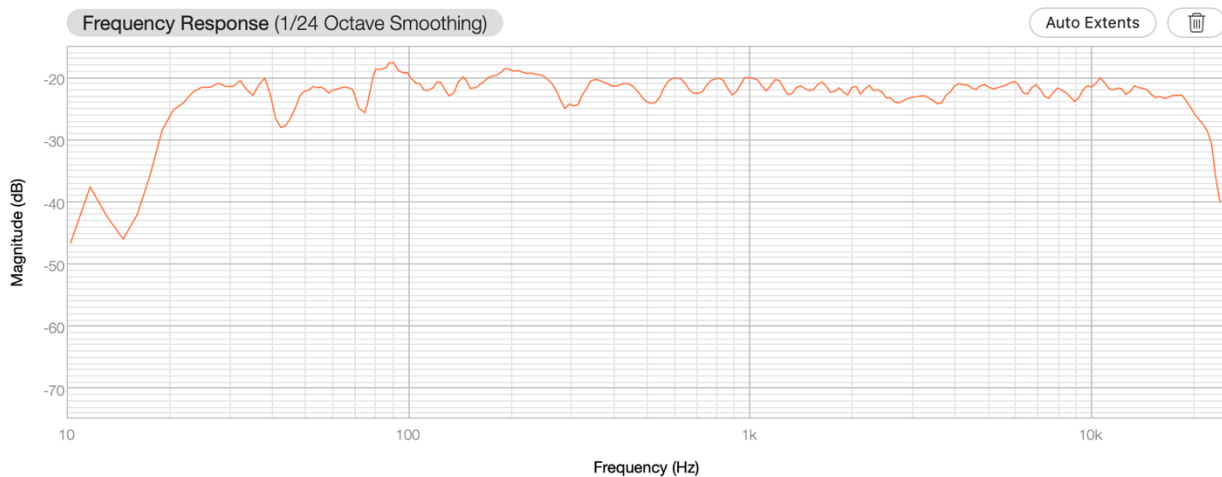


6.3 Final System Data

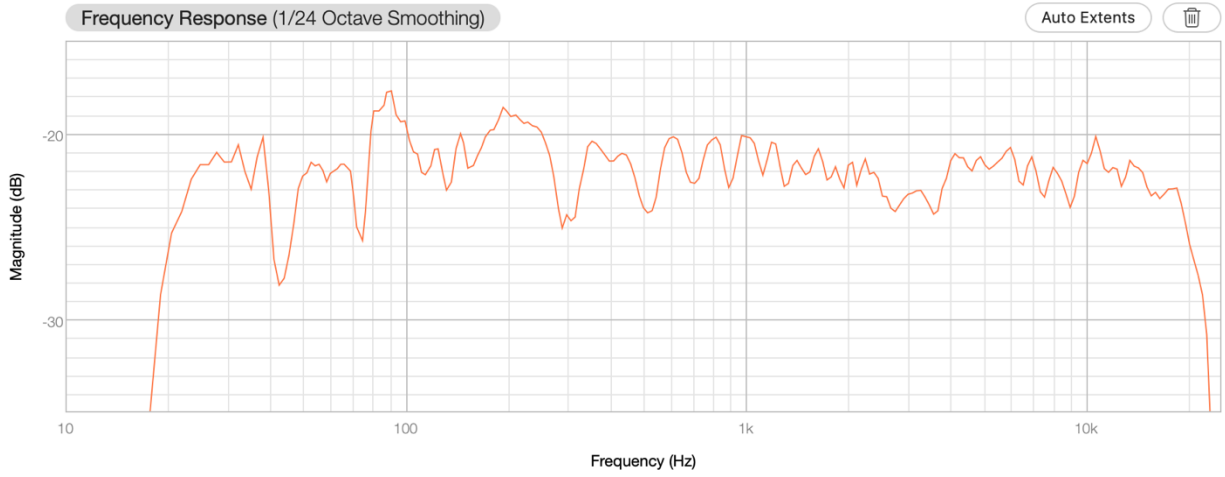
6.3.1 Overall System

*with floor reflections making it not as pretty

Frequency Response 60 dB:

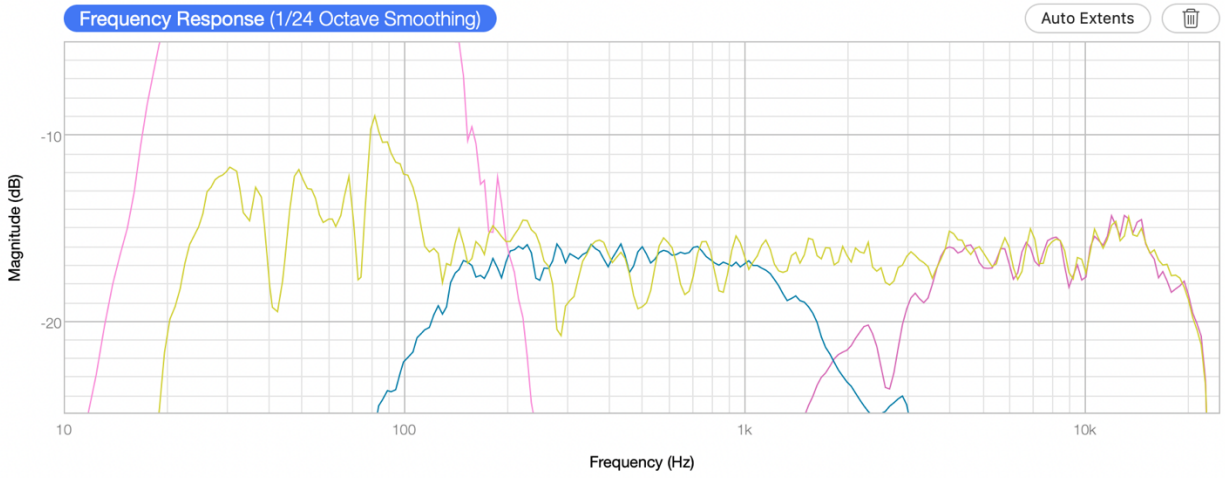


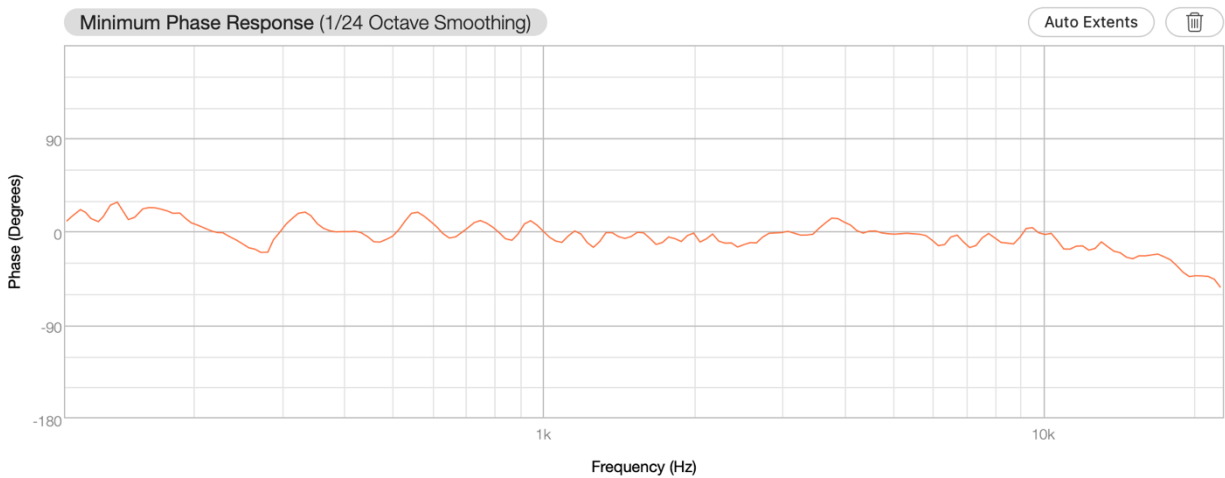
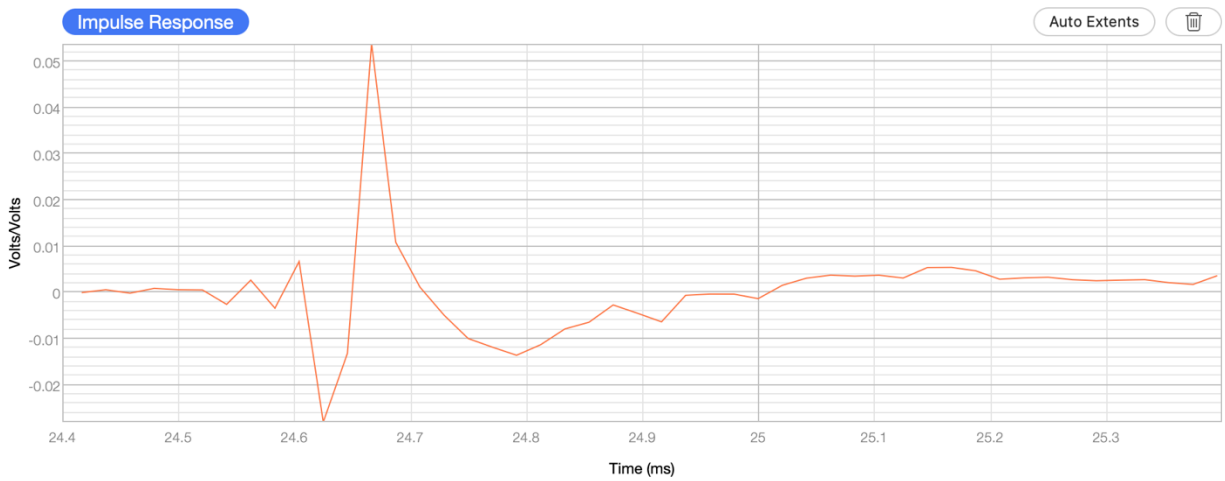
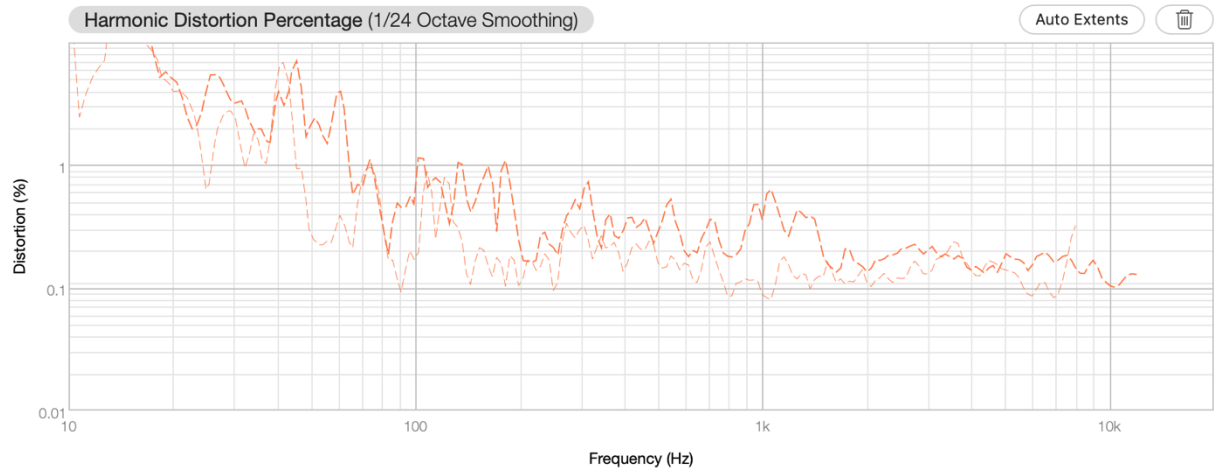
Frequency Response 20 dB:

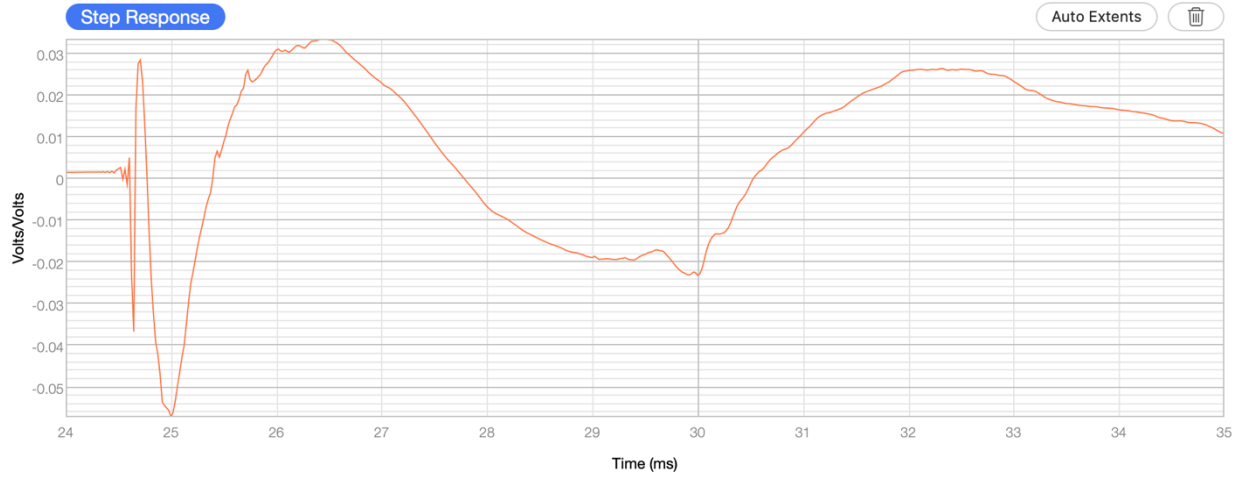


Integrated Frequency Response:

*Subwoofer(pink) at 83 dB according to Earthworks microphone

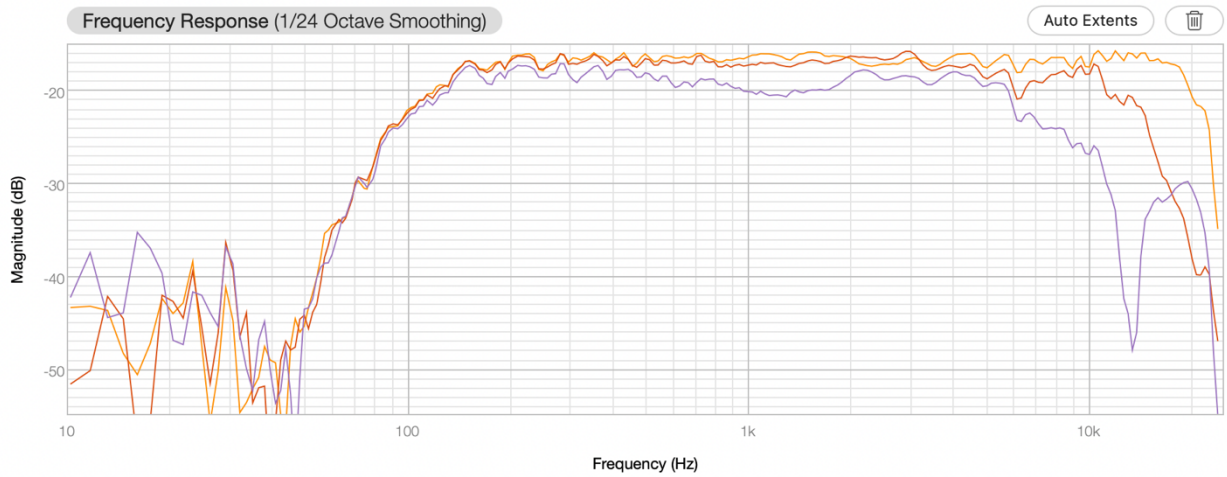




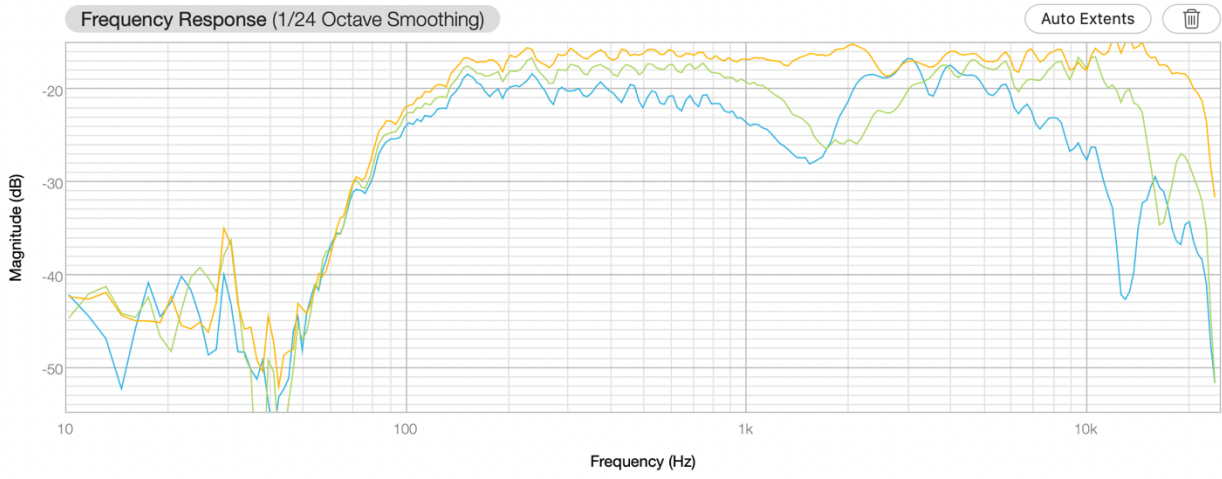


6.2.2 Top Box

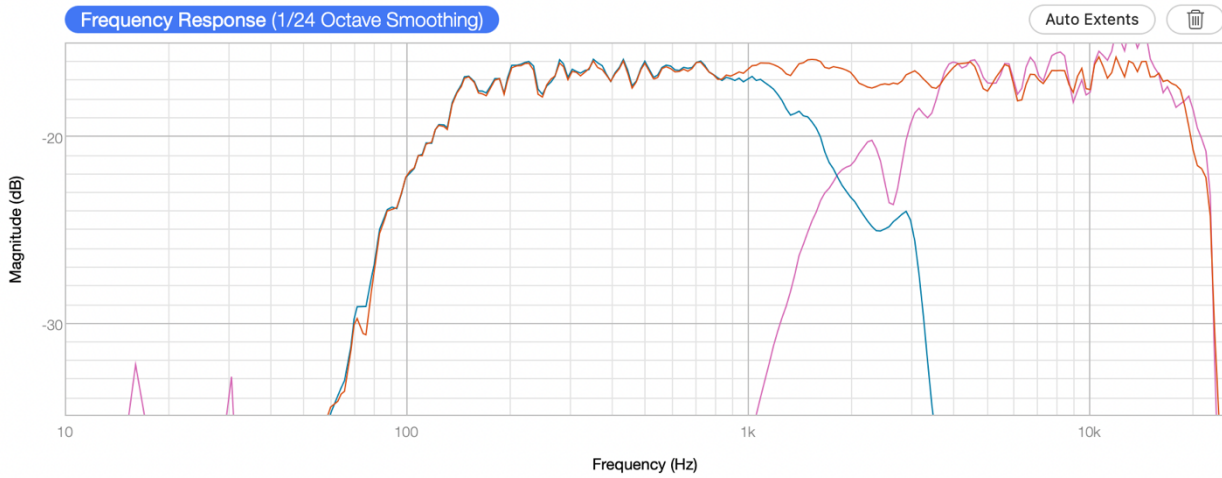
Horizontal Off Axis:

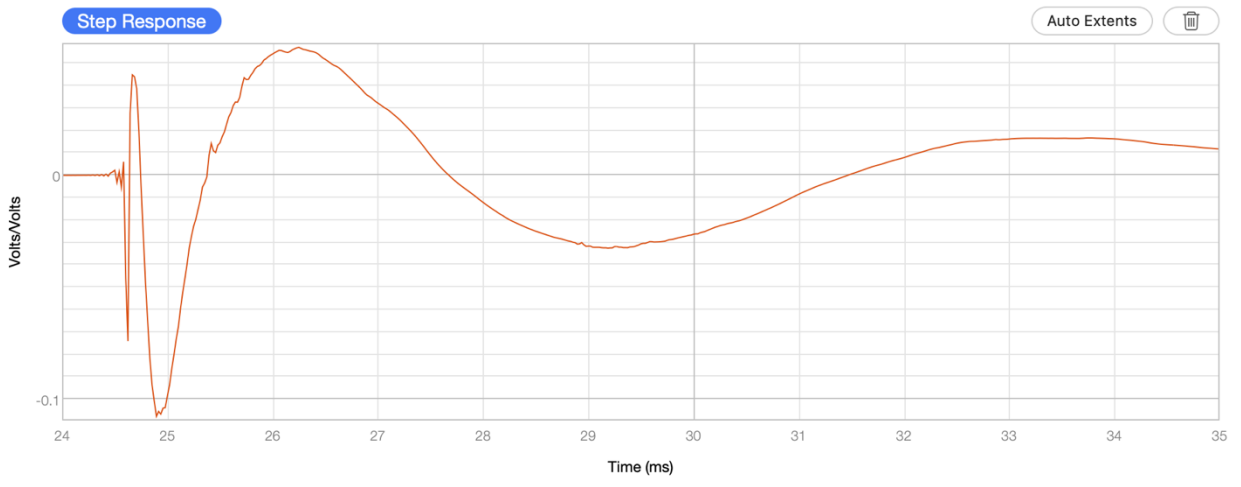
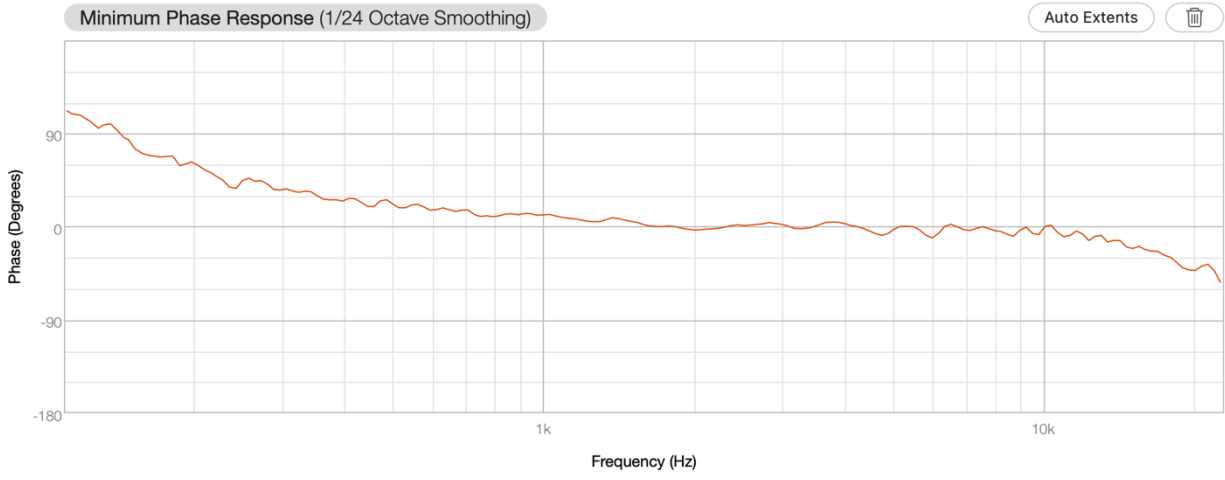


Vertical Off Axis:

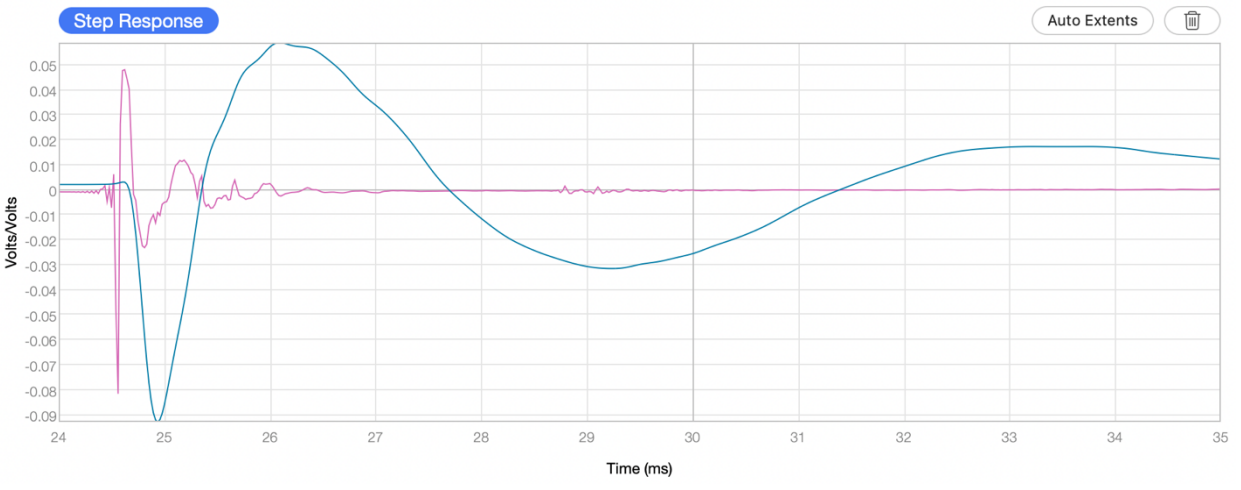


Integrated Frequency Response:

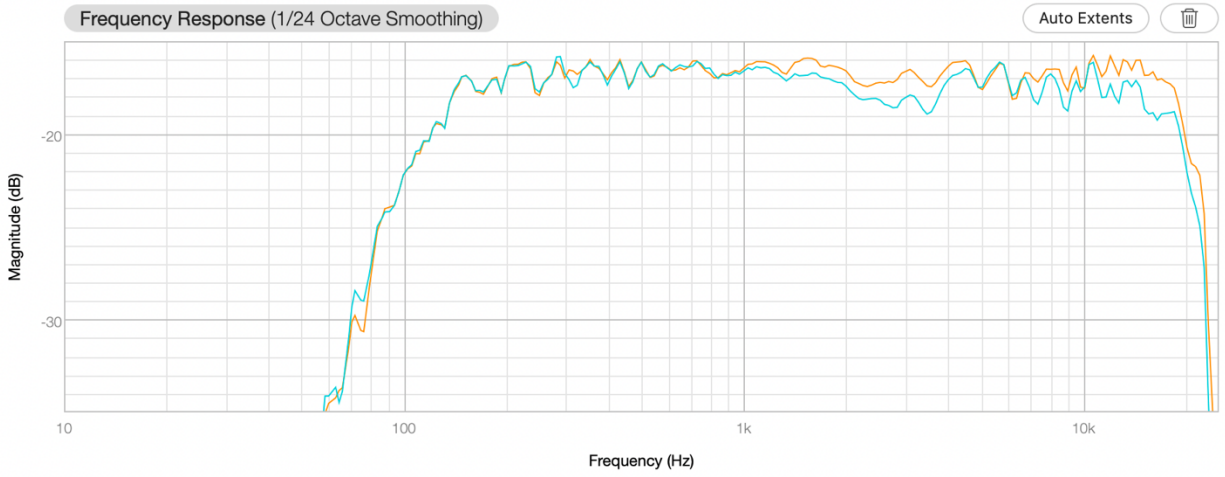




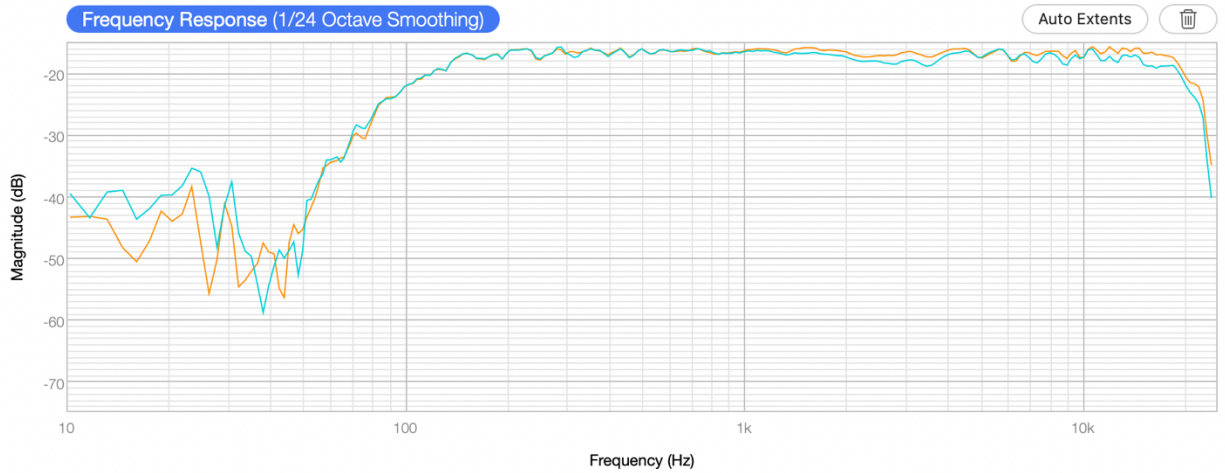
Integrated Step Response:



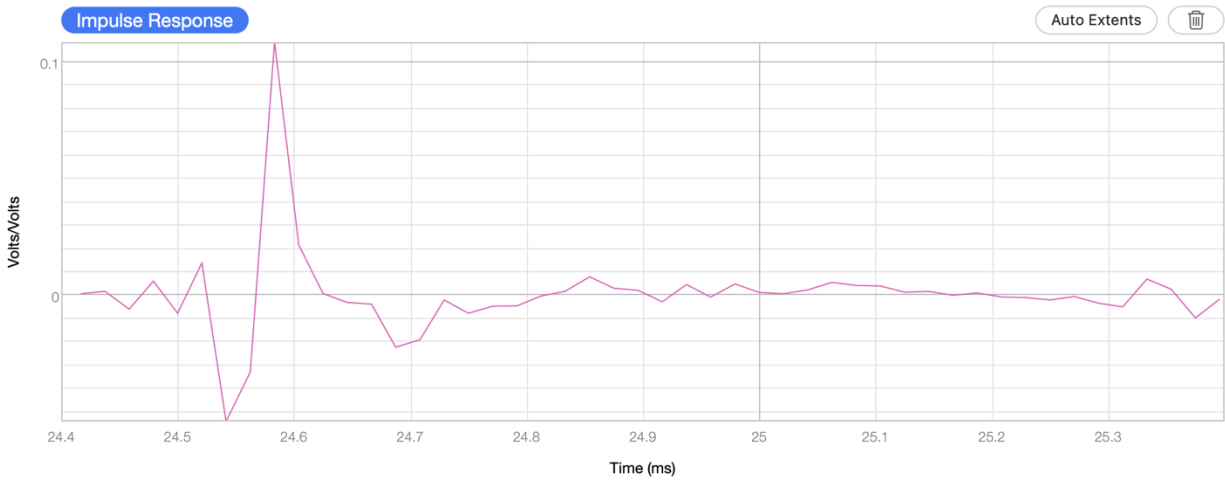
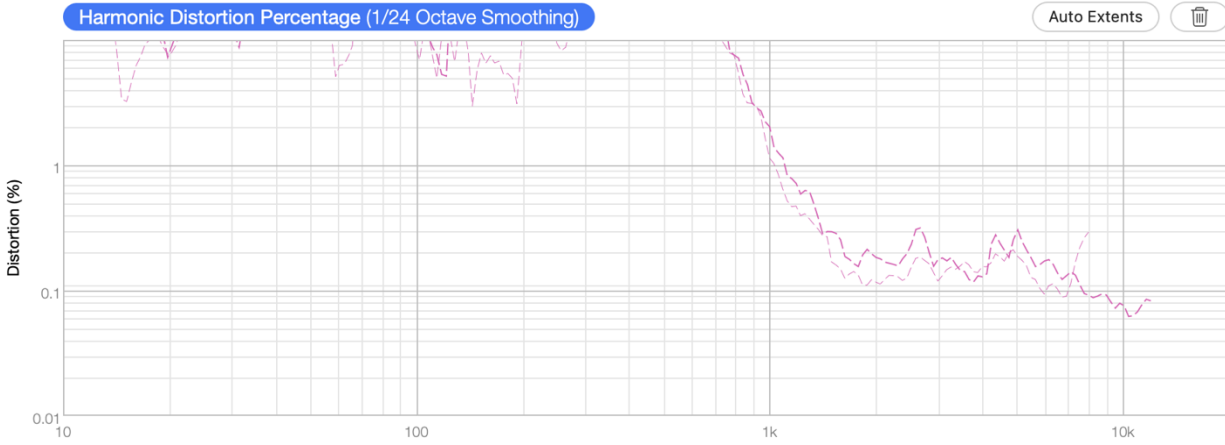
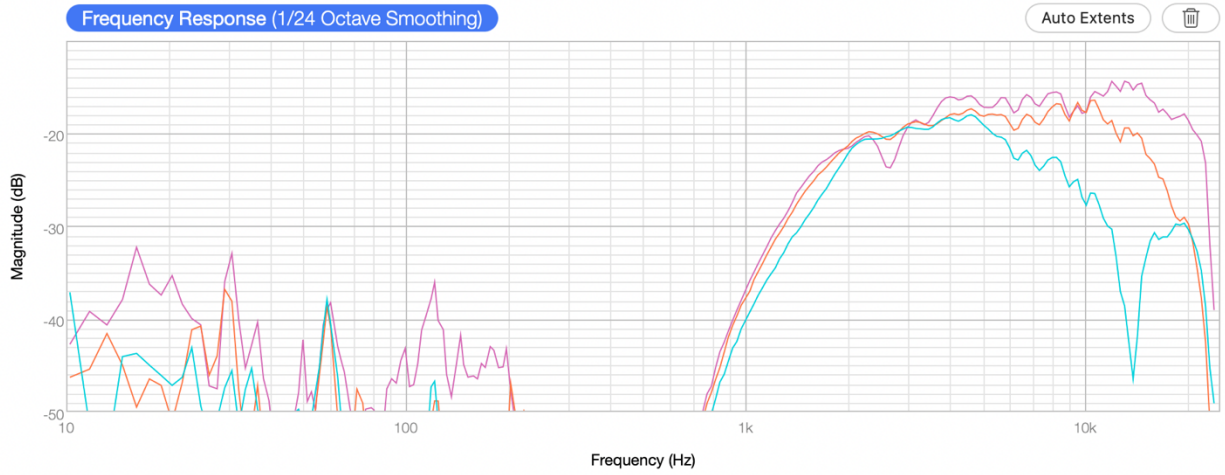
Left and Right comparison 20 dB:

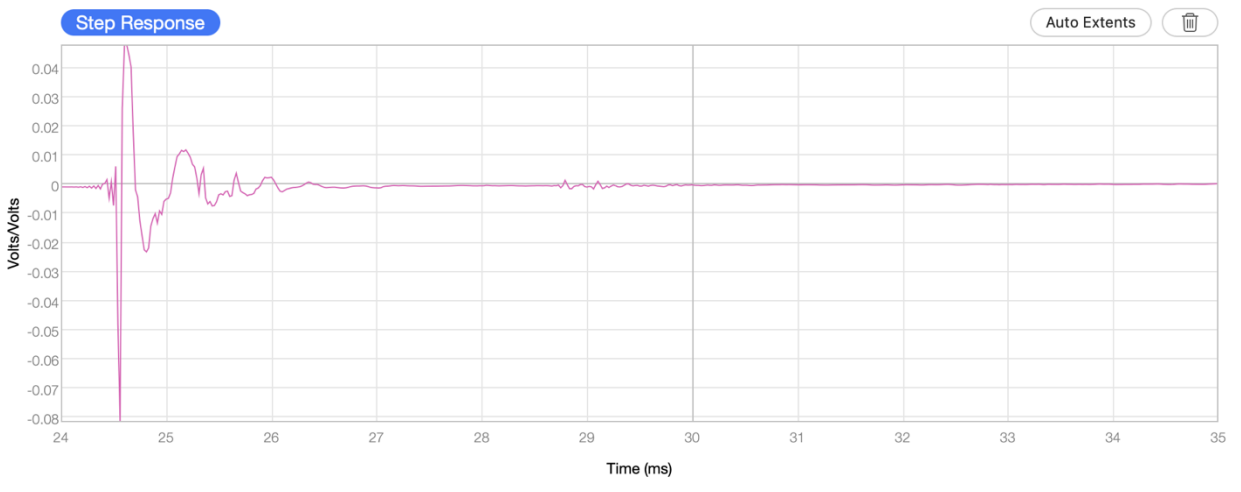
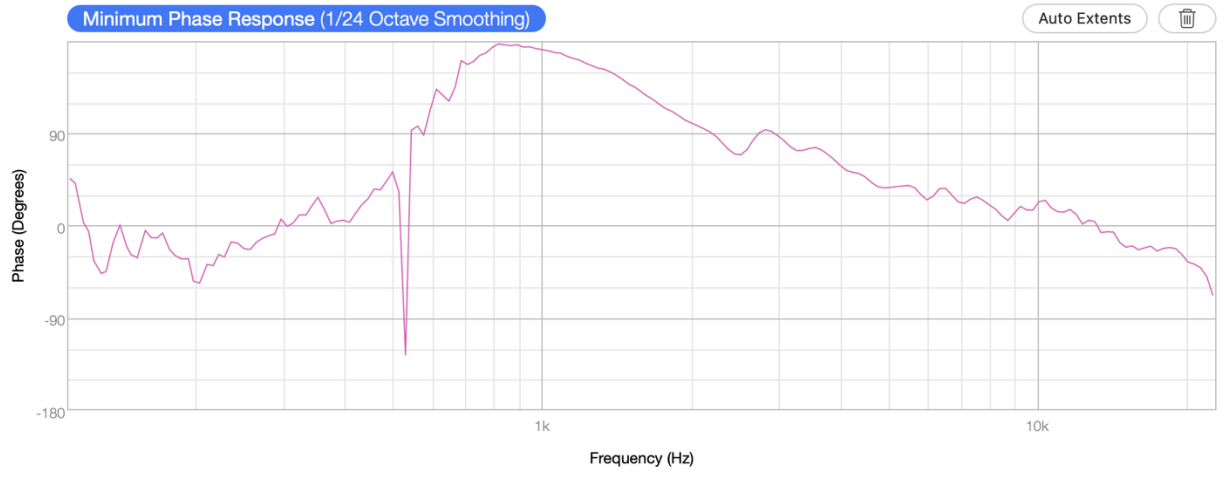


Left and Right comparison 60 dB:

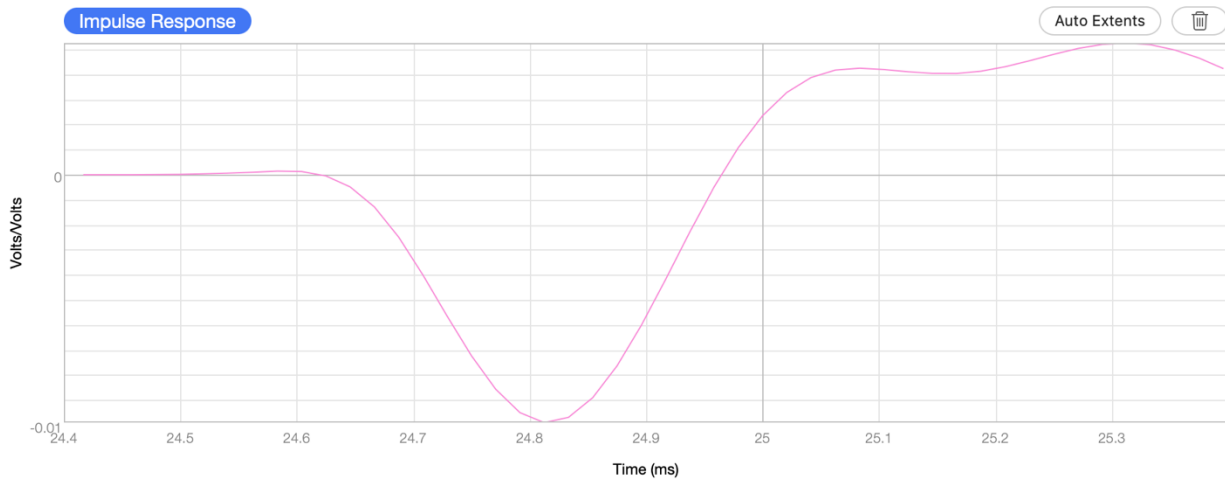
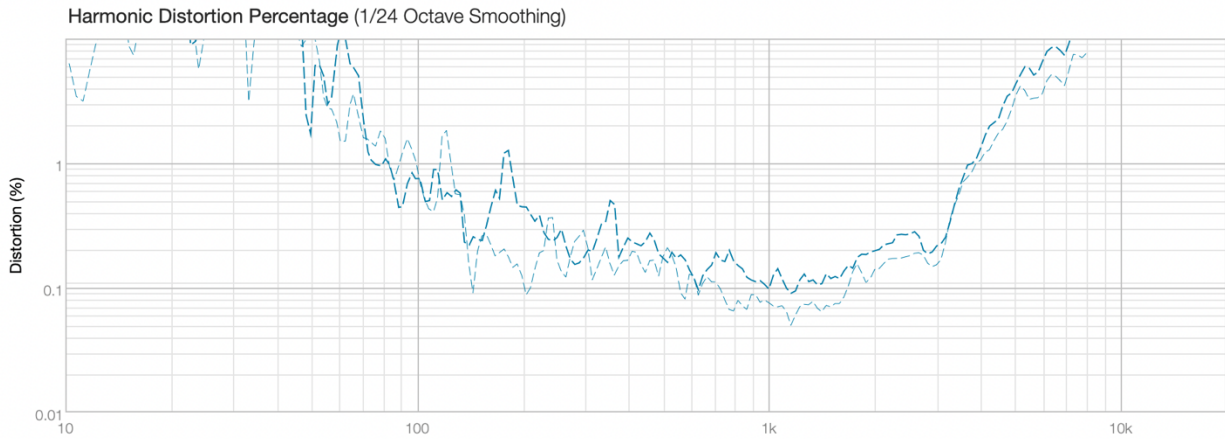
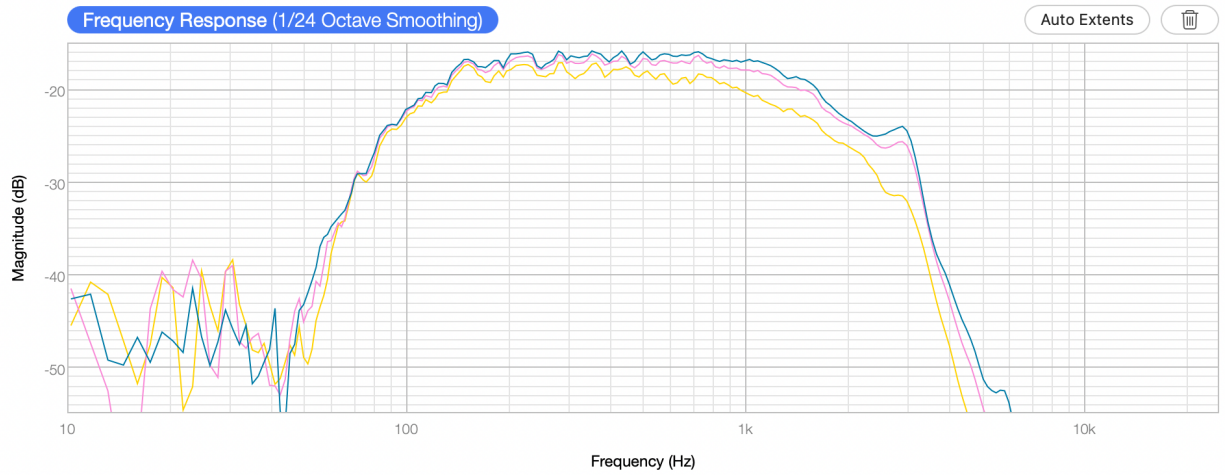


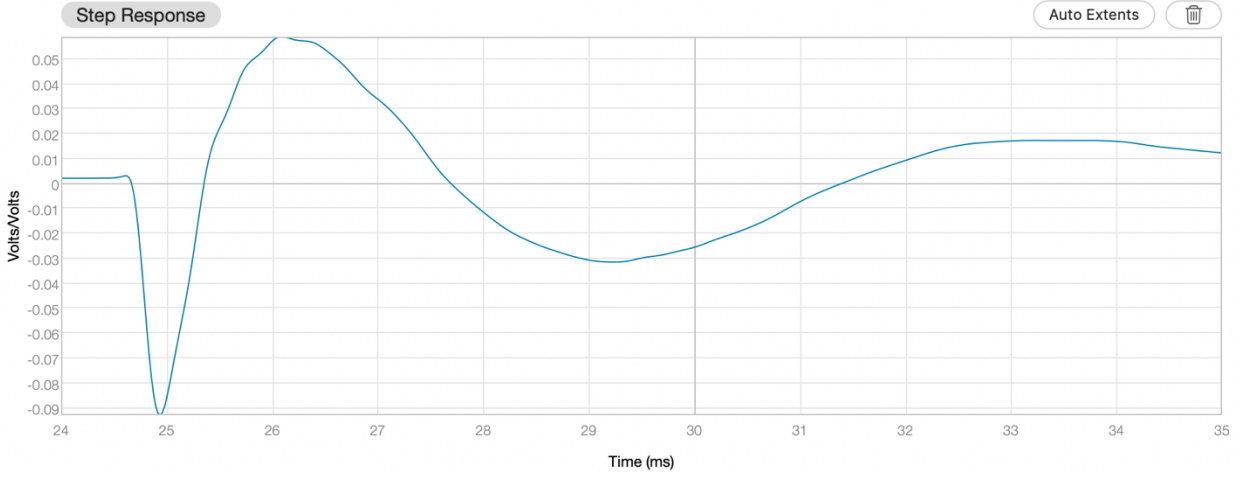
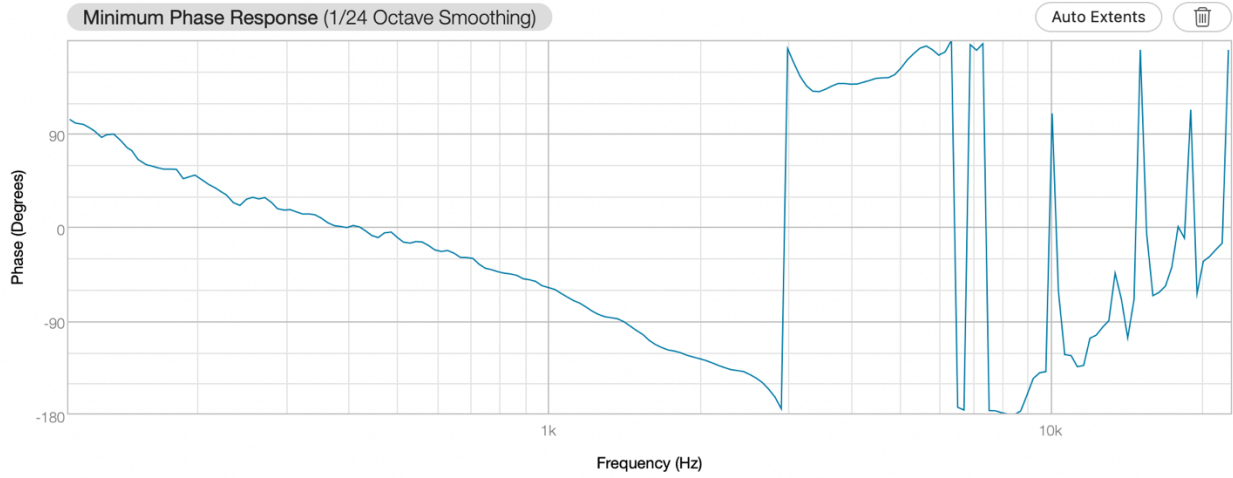
6.2.3 Tweeter



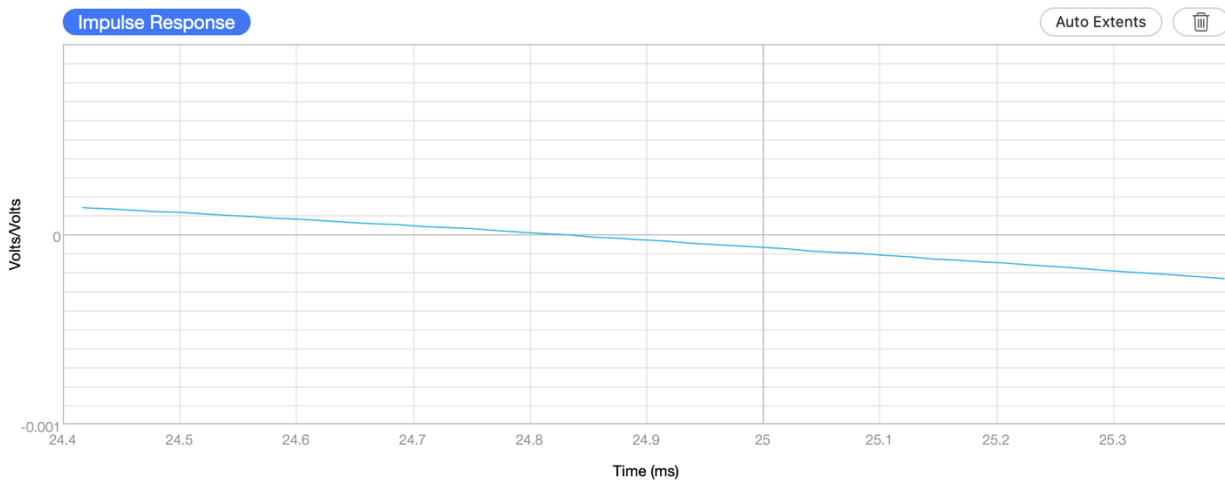
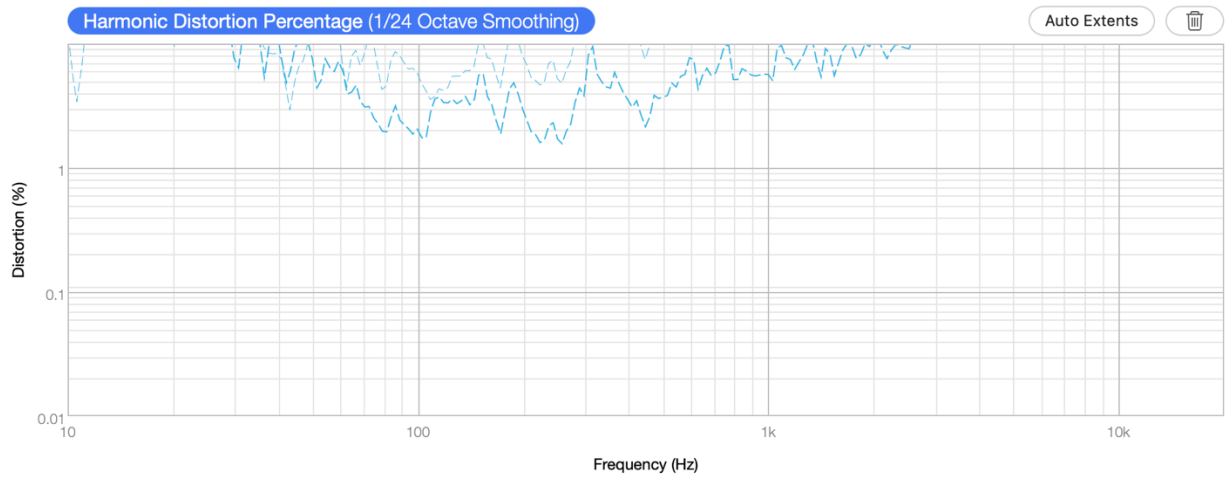
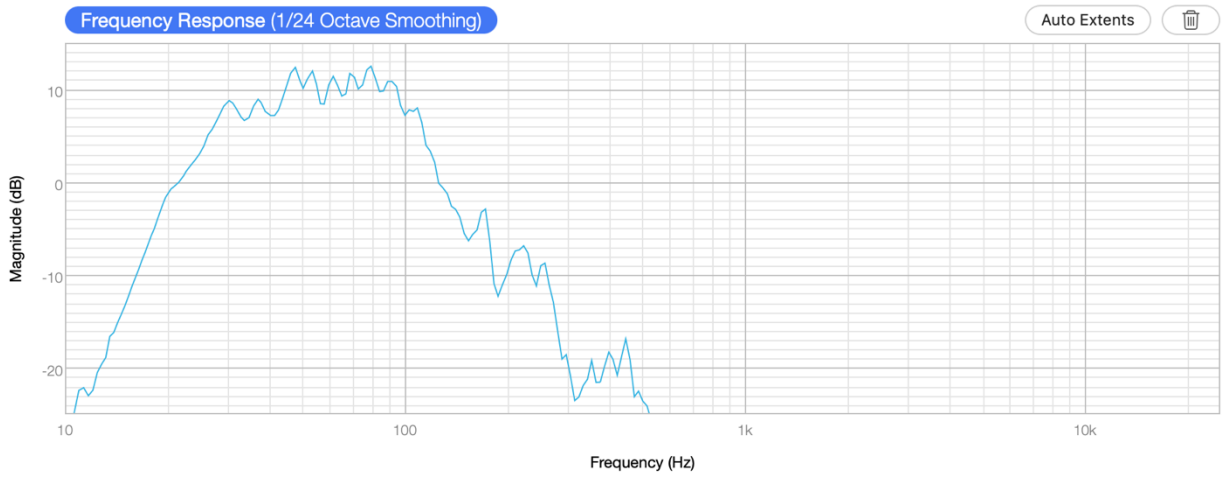


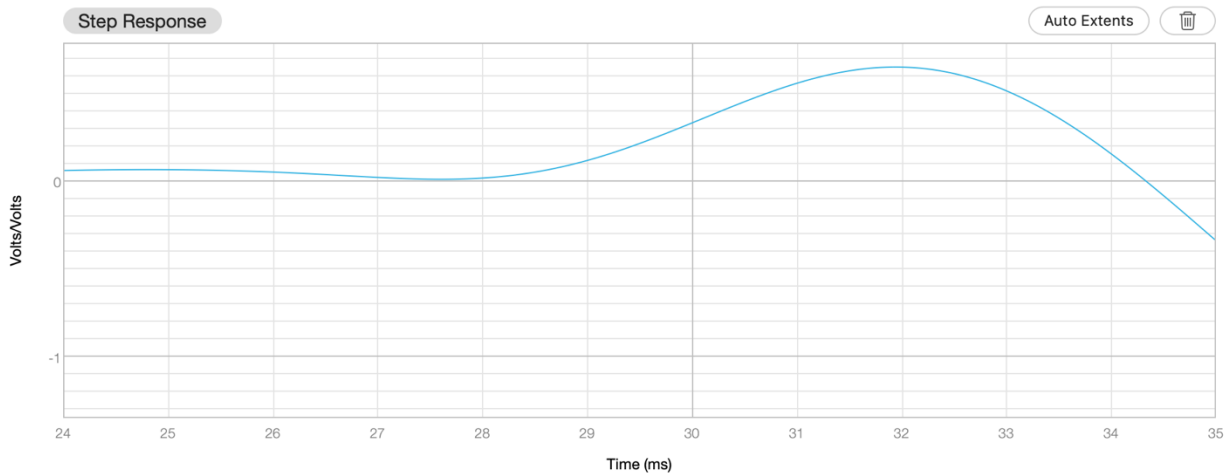
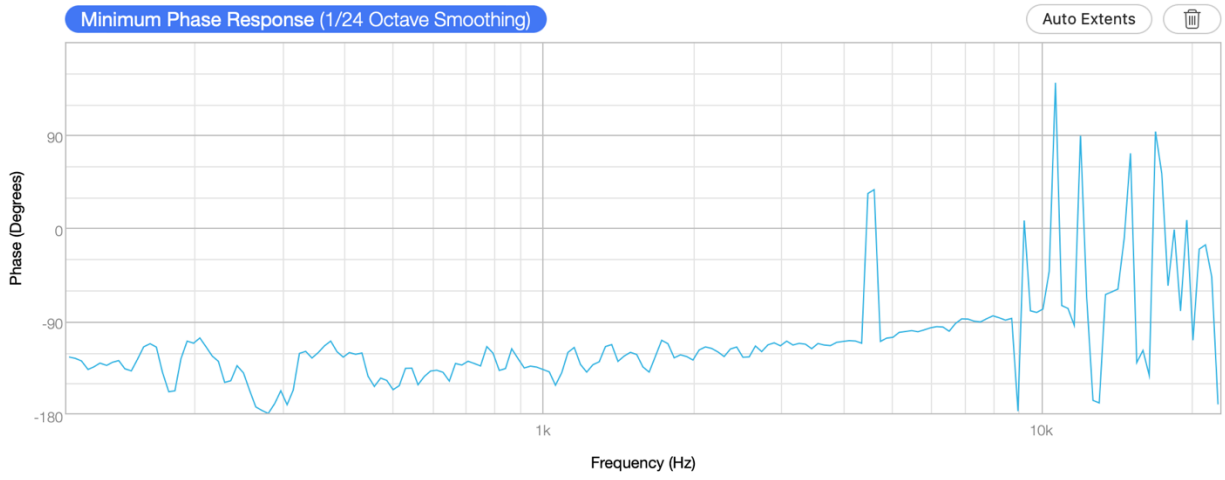
6.2.4 Woofer



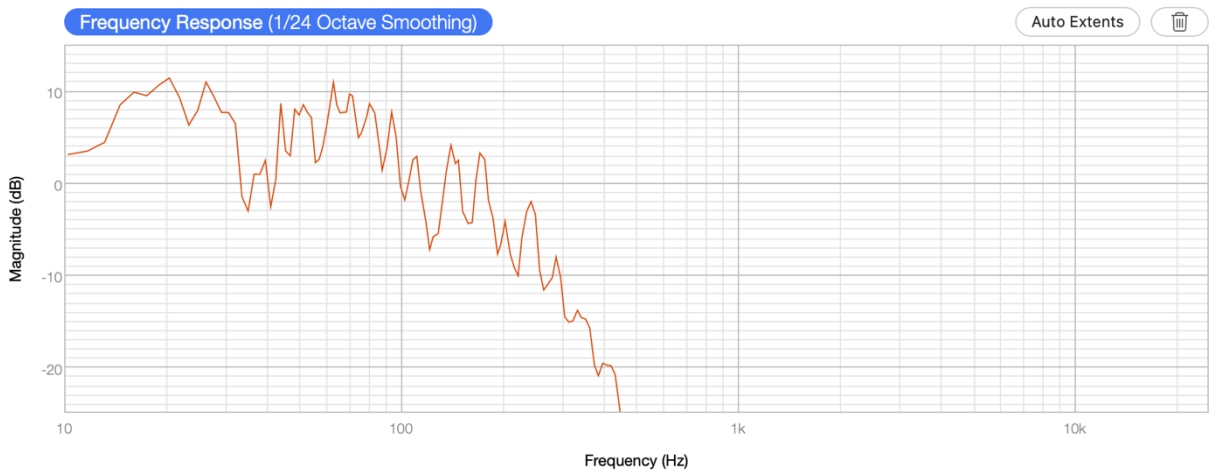


6.2.5 Subwoofer



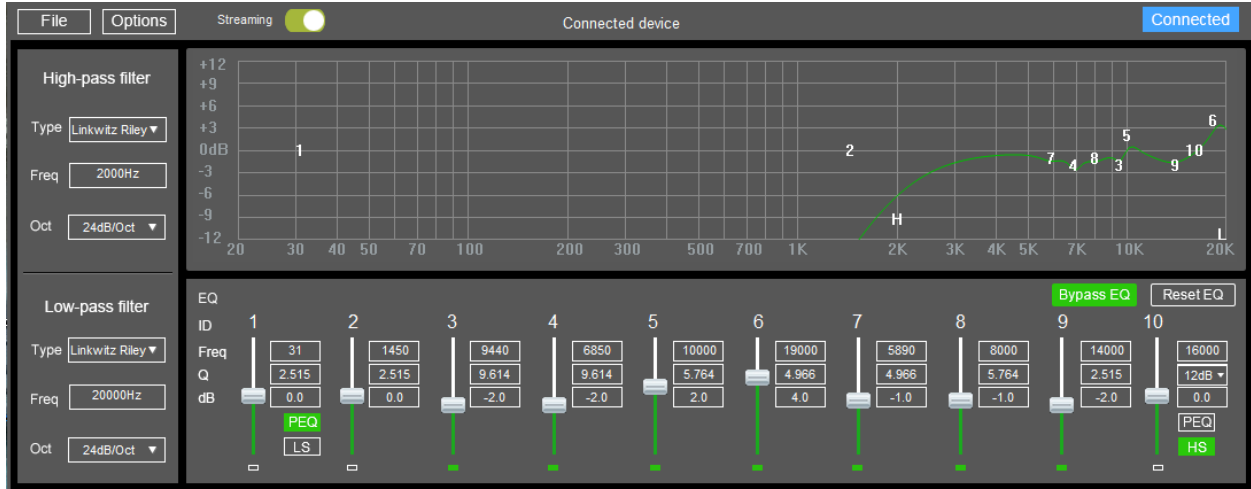


Port Frequency:

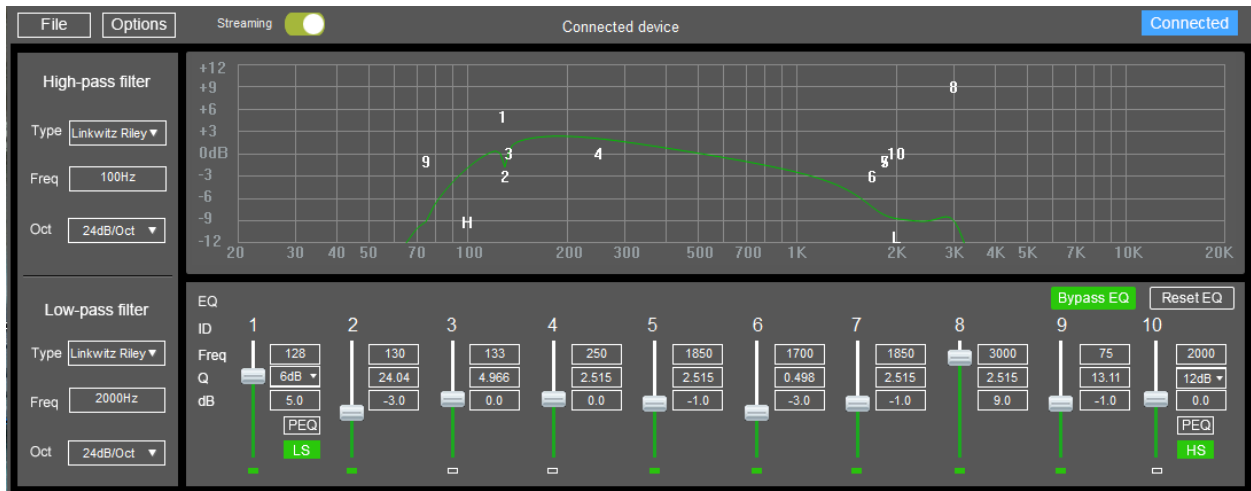


6.2.6 DSP Settings

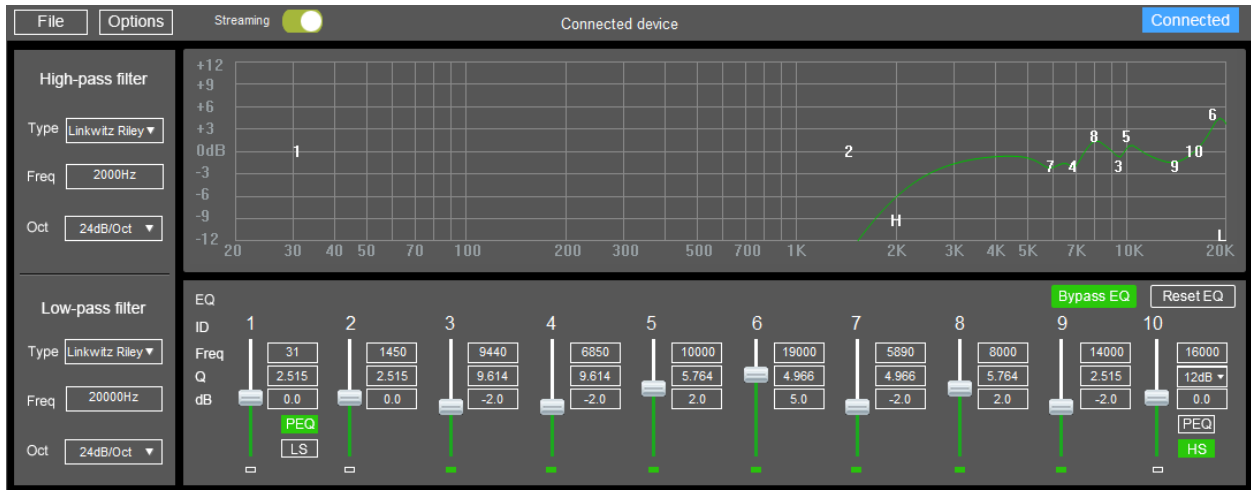
Left Tweeter:



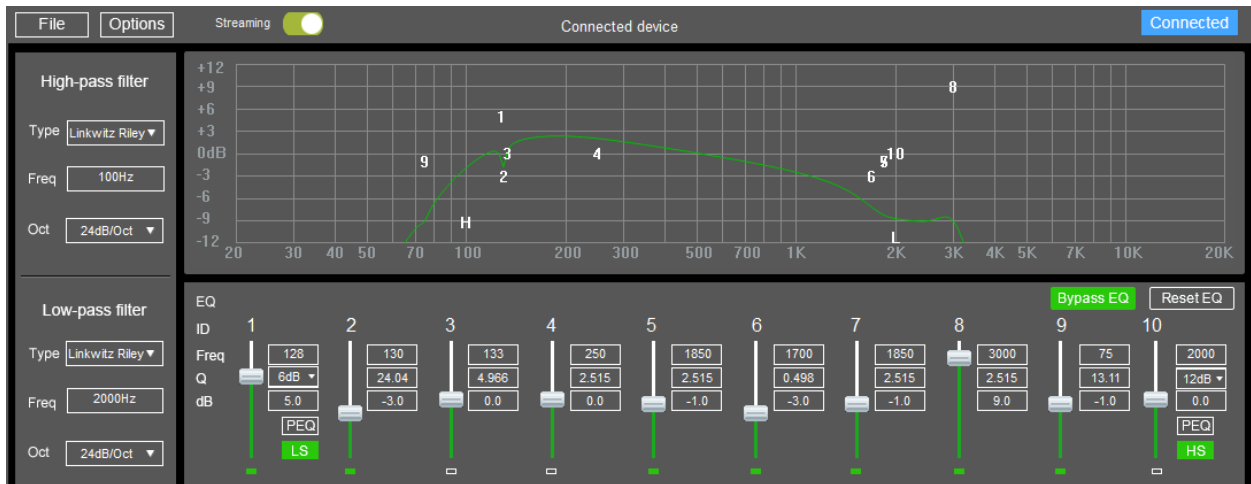
Left Woofer:



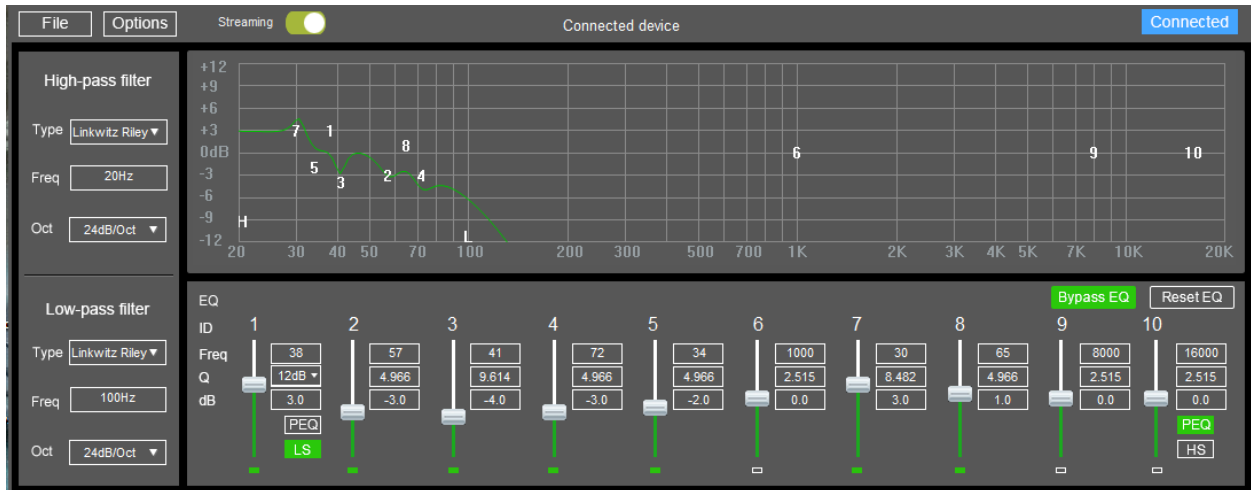
Right Tweeter:



Right Woofer:



Subwoofer:



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