CopperHead: A Loudspeaker Experience

By Scott Bartholomew

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3.0 Functional Description

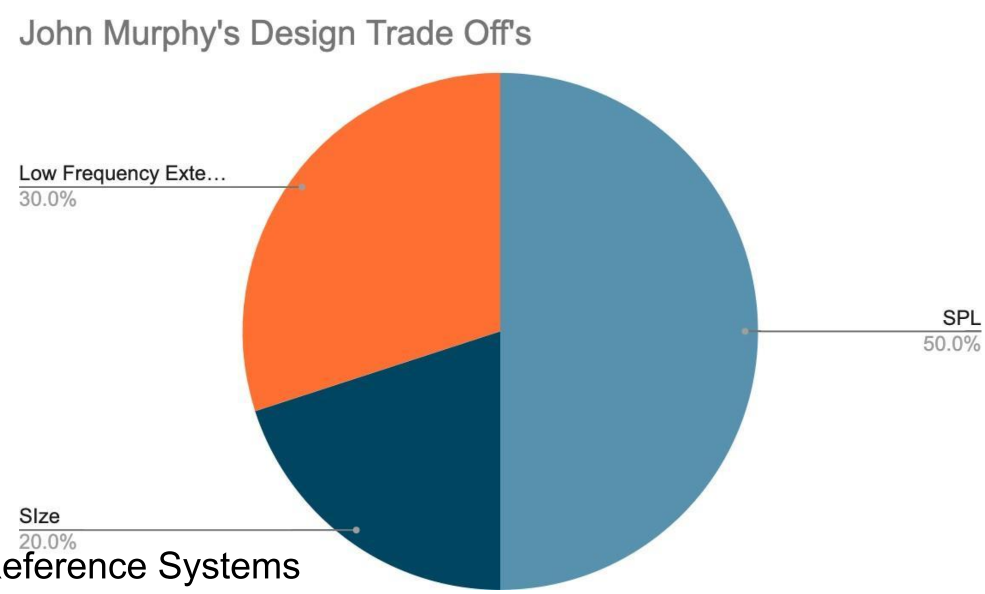
These Speakers will need to be fairly large as they are intended to be floor standing speakers they will function as a stereo pair for a living room setup however these speakers will have multiple uses. Among those uses will be casual entertainment, critical listening for mixing/mastering, These speakers will need to be moderately heavy, one to help the performance however this may cause issues with moving the cabinets.

The speakers I am building will be a pair of tower speakers as part of a 3.2 system. The first feature they will have is a good amount of coverage in terms of directional coverage and coverage of the frequency ranges as each driver will hopefully bring the best out of the 20Hz-20kHz+ range I would like to get out of my speakers.

The tower speakers will be at a moderate distance from the listeners and they will also need to be used as a makeshift party/PA system. So the drivers will need to have a high sensitivity and be able to take a moderate to high amount of watts. As these speakers will be used to entertain people at small gatherings I will be needing something that has possible bluetooth functionality.

From a construction standpoint I plan on using a little cheaper materials and having superior design and building technique to bring my speakers up to the quality of speakers made with better materials. I would also like to use the best drivers I can find and try to tune the drivers to hopefully an exceptional quality.

Now overall the main goal of my project is to produce as high quality of a set of speakers as I can while keeping the costs as relatively low as I can. If possible with those constraints ideally these speakers would be able to be used as hi-fi quality speakers with great clarity and tone. I want these speakers to produce a great listening forward experience.



4.0 Reference Systems

Speaker	Frequency	Peak	Dimensions HWD	Weight	Price
Neumann KH 310	34Hz-21kHz	100 dB SPL	10’’x15.125”x 11.5	28.7lbs	$2495.00
SabrinaX	31Hz-23kHz	Unknown	38’’x12’’x15 5/16”	290lbs	$6650.00
RP-8000F II	30Hz-30kHz	125 dB SPL	43.10” x10.84” x 18.25”	61.4lbs	$1048.00
JBL A170	44Hz-40kHz	112dB SPL	190x255x930 mm	31.61lbs	$259.98
D&B 24C-E	110Hz-17kHz	128 dB SPL	27.6x4.9x4.8 8	15.4lbs	Unknown

4.1 JBL A170

The JBL A170 definitely looks like a good option for A home set of speakers as it’s a relatively low cost for a 3.2 system tower. At a cost of 259.98 for a pair of For Speakers that could function as very nice home theater speakers. One positive about these speakers Is that they only weigh about 30 lbs each and the frequency response is very wide at a range of 44Hz to 40kHz. The sensitivity for these speakers is fairly decent at 89 dB at 2.83v at 1 meter. Now one of the Downsides of the A170’s by JBL is that they are not the sharpest looking speakers on the market by far.

Crutchfield. “Crutchfield JBL Stage A170.” Pinimg.com, 2023. https://i.pinimg.com/originals/c1/09/82/c10982d6d13f19850e5a7fa385900e0c.jpg.

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4.2 RP-8000F

The RP-8000F is already on the outside a wonderful looking pair of speakers. Now that beauty comes at a cost as the speakers weigh 60 lbs a piece. Now the frequency range on these speakers is not quite as large as the A170 from JBL, but it does go lower all the way down to 35Hz and all the way up to 25kHz. The RP-8000F are also very large speakers at getting close to almost 4 ft tall at 43 inches. One cool feature about the RP-8000 F is that they are set up so that they can be used in a bi-amp setup. These speakers are also really easy to upgrade with Dolby Atmos and they are meant to be used as home theater speakers. Also one of the most Impressive things about these speakers is that the sensitivity of them is 98dB @ 2.83volt/1 meter. Now Unfortunately you do pay for the performance of these speakers in the expensive price of $1048

Klipsch. "RP-8000F II 2.0 DUAL FLOORSTANDING SPEAKER." www.klipsch.com, 2023. https://www.klipsch.com/products/rp-8000f-ii-2-0-dual-floorstanding-speaker.

Neumann KH 310

The Neumann KH 310 come in at a pretty Great frequency response especially for the size of the speaker at a range of 34Hz to 21kHz. Now these are different from the other speakers featured on this list because these are studio monitors. These speakers are not tower speakers they ever they do provide an Insight for designing tower speakers in that There are things that studio monitor speakers

[1] Klipsch. "RP-8000F II 2.0 DUAL FLOORSTANDING SPEAKER." www.klipsch.com, 2023. https://www.klipsch.com/products/rp-8000f-ii-2-0-dual-floorstanding-speaker.

do that towers don't unfortunately don't. One
example of that is well most studio monitors are
small so they move easily and can be positioned
easily as well with each speaker weighing 28 lbs.
These speakers also have a very flat frequency response which is what is mainly desired from studio monitors as they are meant for listening backwards.

Neumann. "KH 310 a L G." Neumann.com, 2018.

https://www.neumann.com/en-en/products/monitors/kh-310-a/

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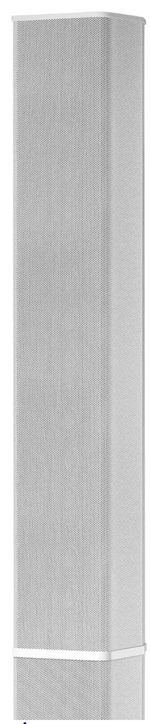
SabrinaX

The SabrinaX is a set of speakers that is all their own by Wilson audio. The frequency range is extremely low at 31Hz to 23kHz for only having an 8 inch driver as a sub. The reason I have included these speakers in to research and reference is because these are a great example of what a system can do when the most important factor is the overall design and performance of the loudspeaker over anything else. The loudspeakers are also a great Example of engineering and design for a specific purpose As many of the components of the speaker were designed for the SabrinaX and no other speaker.

https://www.wilsonaudio.com/products/sabrina/sabrinax

24C-E



The 24C-E is an array column loudspeaker that that is mean to be used as a PA speaker or for sound reinforcement

This speaker is a great speaker to help with the design process of The system I will be building as it is very light and very loud. Those are both very important qualities I am trying to incorporate into the speakers I am building. This speaker is a great choice due to its wide dispersion pattern.

https://www.dbaudio.com/global/en/products/series/xc-series/24c-e/?prerender=1#tab-applications

5.0 Technical Goal

5.1 Size

The size of the cabinets I intend to build for this system will be a small to medium size tower loudspeaker system 42” in height so they could be level with any kind of TV or display on an entertainment center or table. They should be 12” in depth and 9.5” in width. The depth is not a hard deadline as the width is, as these speakers need to be able to fit close to a TV and not be in the way visually or physically. Despite the fairly large size, I will be attempting to build the system to weigh less than 30 lbs per channel, as that seems to be a weight I can move with relative ease. The size and weight of the speakers should also keep them grounded mechanically. However if they end up being 50 lbs they will still be fairly moveable. and due to the material of use being ¾” MDF the full cabinet Dimensions will be H x W x D 42.5” x 9.5” x 13.5”.

Ideal Dimensions for Enclosures
H x W x D 41” x 8”x 12”’ = 2.27ft^3
Maximum Enclosure Dimensions
H x W x D 6’ x 10 x 1’= 5 ft^3
Full Cabinet Dimensions
H x W x D 42.5” x 9.5” x 13.5” = 3.11ft^3

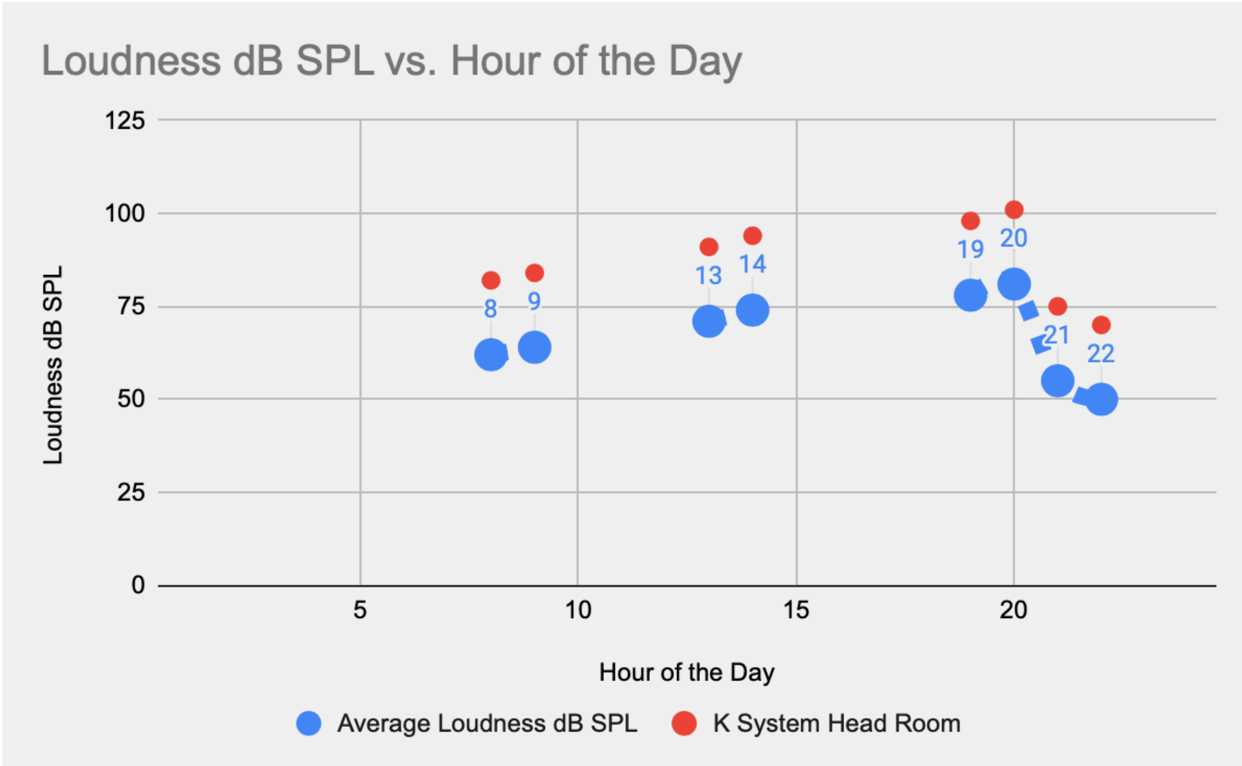
As an attempt to help increase the low frequencies produced by the system the speaker enclose will have a port on the rear wall of the close toward the bottom of the cabinet to provide as much absorption of the upper frequencies as possible leaving low frequencies to be the main range of frequencies to be resonating and exiting the port.

5.2 SPL

This speaker system will one for personal entertainment purposes need to be able to play at a loudness of at least 86 dB SPL. This is because my average listening level is 71dB SPL throughout the day as shown in the data below. Now to account for the spotify streaming standard of 14 dB of headroom the speakers need to be able to play at 86 dB SPL as this would be the main use of these speakers. I also want these speakers to meet similar standards that are described by the k-system, specifically the k-20 system. The main reason for this would be to give the music played on the system as much dynamic range as possible. This would mean that the speakers would actually have to play at a loudness of from 91 to 104 dB SPL as the K-20 system requires 20 dB of headroom and as shown in my data below my max listening level is 101 dB SPL as well as accounting for the listening distance of 2 meters away from the speakers.

Acceptable SPL Range 86-104dB SPL

However due to the modeling and wiring of the circuits for this system it should be able to reach 112 dB SPL.



This chart is meant to show as the hours of the day progress how loud I like to listen to music and tv.

https://www.digido.com/portfolio-item/level-practices-part-2/

https://youlean.co/loudness-standards-full-comparison-table/

5.3 Amplification

As most amplifiers have a rating of 100 watts. With this in mind I want my speakers to be able to play at the required loudness level off of 100 watts using dBw = 10Log(100) to calculate the loudness added by a 100 watt amplifier we see that it adds 20 dB SPL to the speakers loudness. Given this I will be giving my speakers a target sensitivity of 90dB SPL so my system can play at a max level of 110 dB SPL. Now as many of the drivers I have been considering to put in my cabinets for this system are rated at a peak power of around 160 watts maximum for the woofer drivers in the system. I will be using two class D amplifiers, each having 300 watts per channel. Eventually I would like to put a limiter on the system, but I chose the amps I did to give plenty of headroom for the drivers in the system. The amplifiers I will be using for this system are a TDA7498E by Fosi and a BT20A Pro amp also by Fosi. The BT20A Pro was picked for the ability to easily test the speakers with a mobile smartphone as a source.

5.4 Frequency Response

These speakers are meant to be for casual listening and entertainment purposes so they do not need to by any means have a flat frequency response. For a casual system I would find +-3dB and acceptable range. Ideally I would like to have as wide of a frequency response but through the restrictions of size budget I would like to try and design these speakers to have as wide as I can. That being said as it is also difficult to design a loudspeaker system to go down to 20 Hz I would like to be able to at least build a system that can get down to 40Hz and potentially 35Hz as the port will be tuned to 35Hz.. I would like to also have the system go up to 15kHz minimum and 20kHz maximum. The reason for not including the full human hearing range of 20Hz to 20kHz is that most songs I listen to simply don't have very much content in the outer range of the audible human hearing range specifical the first and last octaves of 20-40Hz and 10-20kHz.

Target Frequency Response 35Hz to 20kHz +-3dB
Acceptable Frequency Response 40Hz to 15kHz

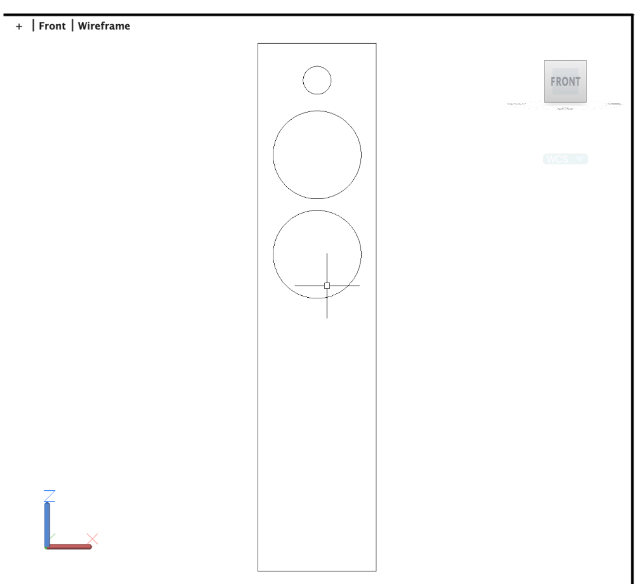
5.5 Mounting/Rigging

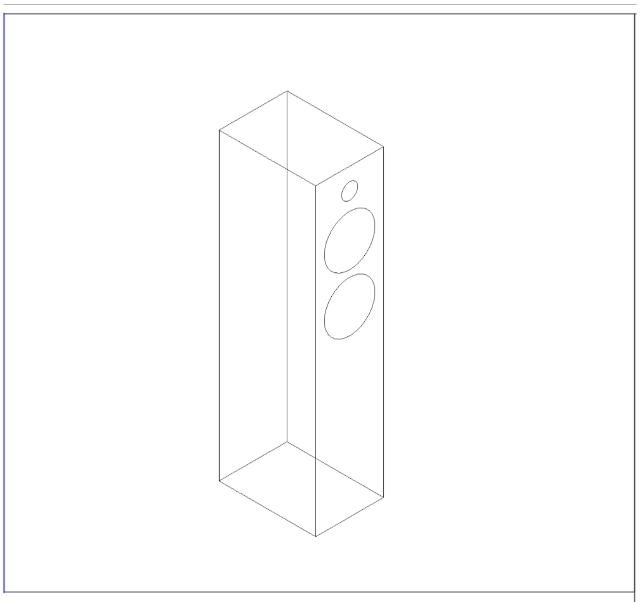
Now because these speakers will be 30lbs potentially instead of using any kind of rigging or mounting from an overhead position they will be equipped with no mounting or rigging hardware so the cabinet can resonate with as much of the floor as possible. The only possible mounting or rigging that these might possibly have is rubber feet mainly so the bottom of the cabinets don't get banged up by the floor they are on while possibly being moved.

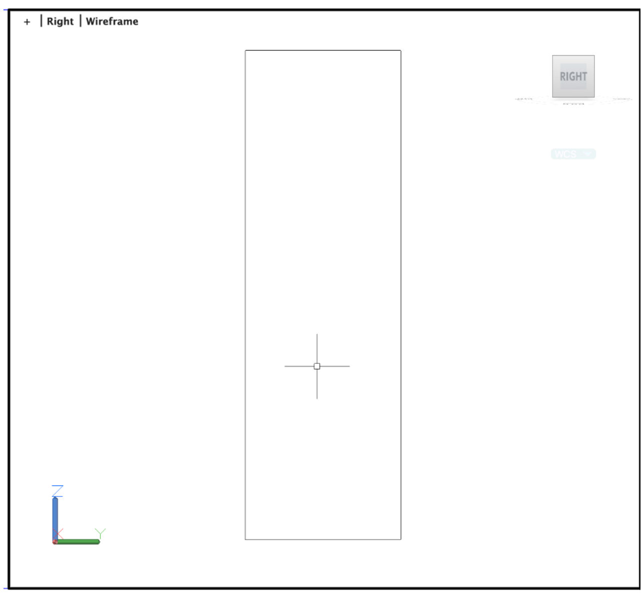
5.6 Cabinet Construction

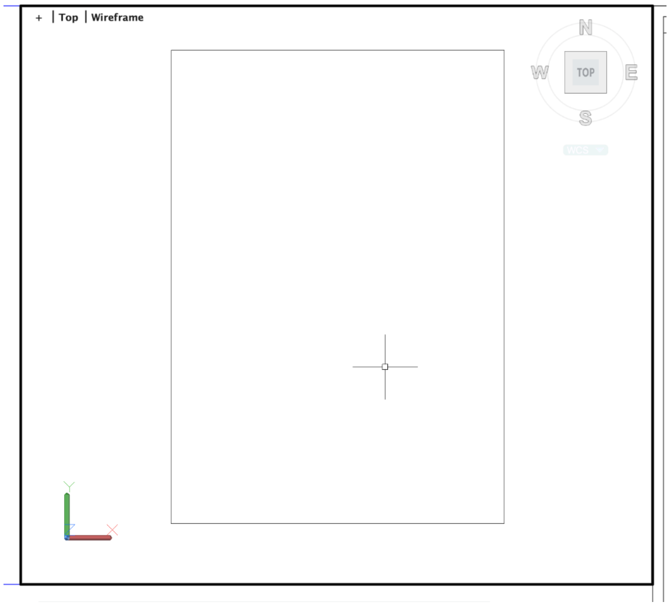
The interior of the cabinet will have recycled denim for dampening material and a port 6 inches from bottom of the cabinet with a 3 inch diameter and 5.75 inches in length. The cabinets will also have rabbits on each edge of each cabinet panel to help them fit together tighter and have a good seal with glue and staples to hold the cabinet and prevent movement once glued.

Below are the different view of the project drafted in AutoCAD to give a visual representation of the cabinet the drivers will be housed in.



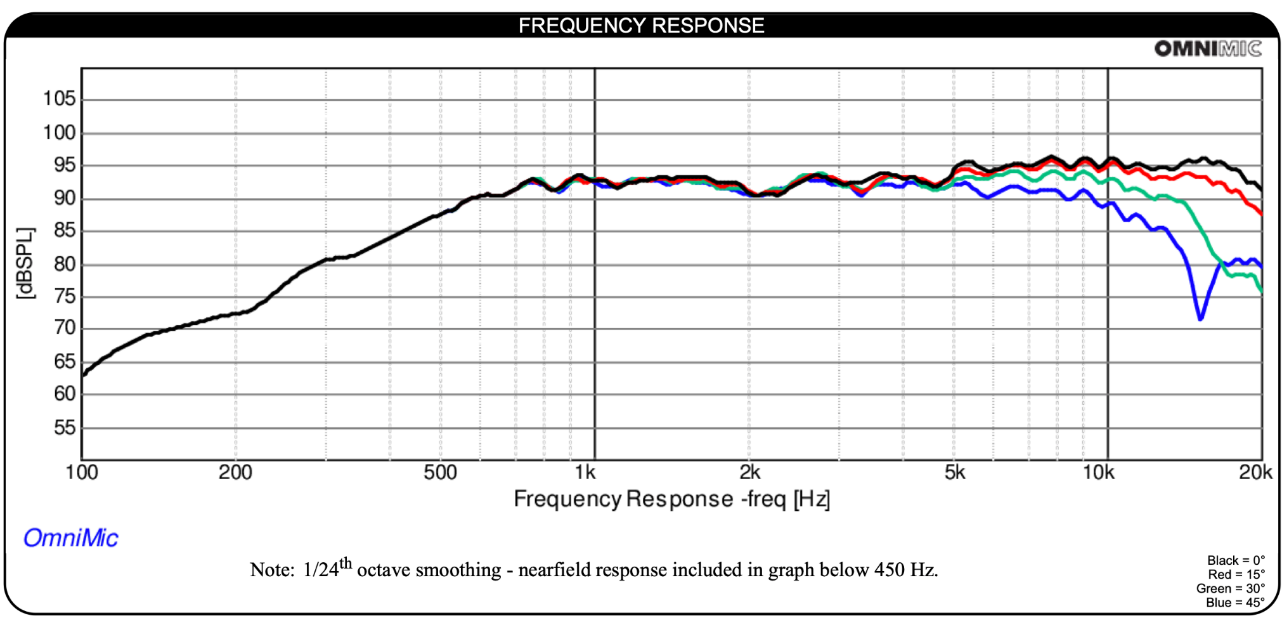



+ Right Wireframe
RIGHT
Z
Y



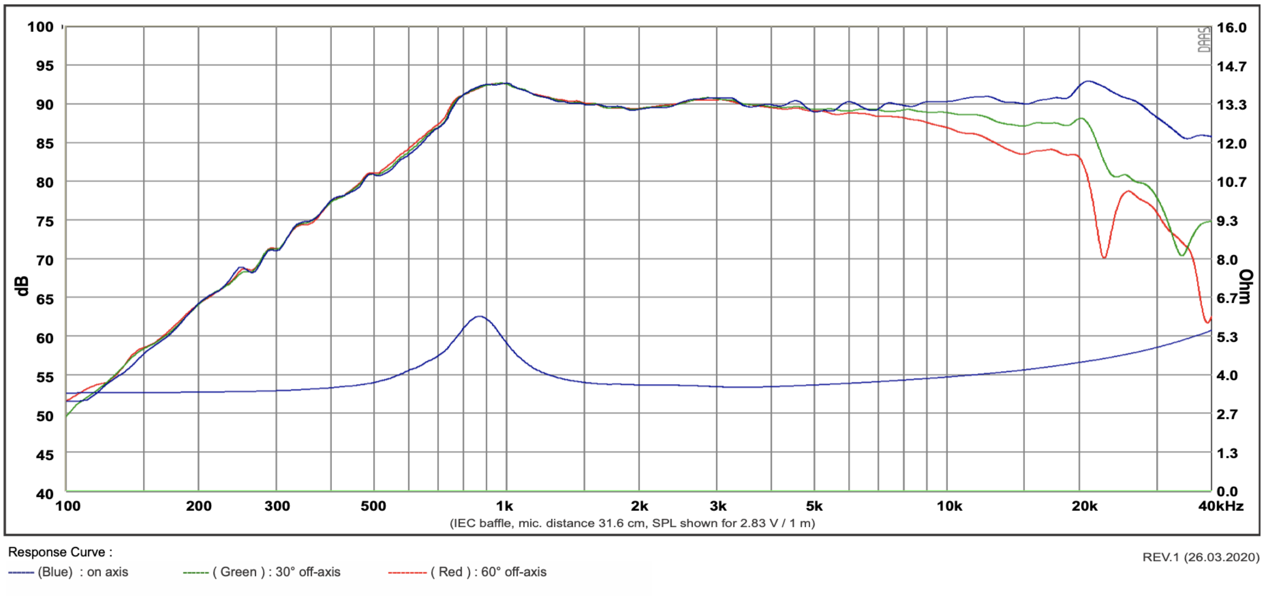
5.7 Driver Selections

For this speaker project there were three drivers for woofers and tweeters that I heavily considered to create the Copperhead towers. Starting with the first tweeter I considered this was the Dayton Audio RST28F-4 1-1/8" this tweeter has a silk dome and with a 93.5 dB SPL sensitivity it makes for a great

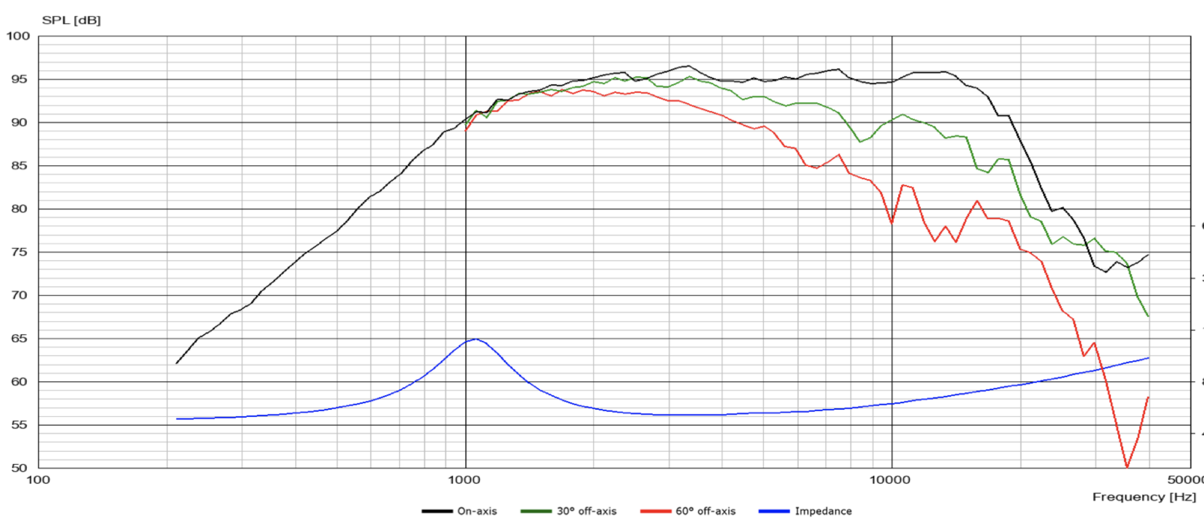


choice for multi use speakers as it has plenty SPL output as well as a pretty tight frequency response as shown below.

For my second tweeter choice I chose SB Acoustics SB21SDCC000-4 this tweeter have a 21 millimeter cone and is the smallest of the tweeters I considered the driver has a sensitivity of 91dB SPL which is less than both my other choices, however as shown in the graph the SB acoustics tweeter has very tight off axis response as it goes into the higher frequencies.



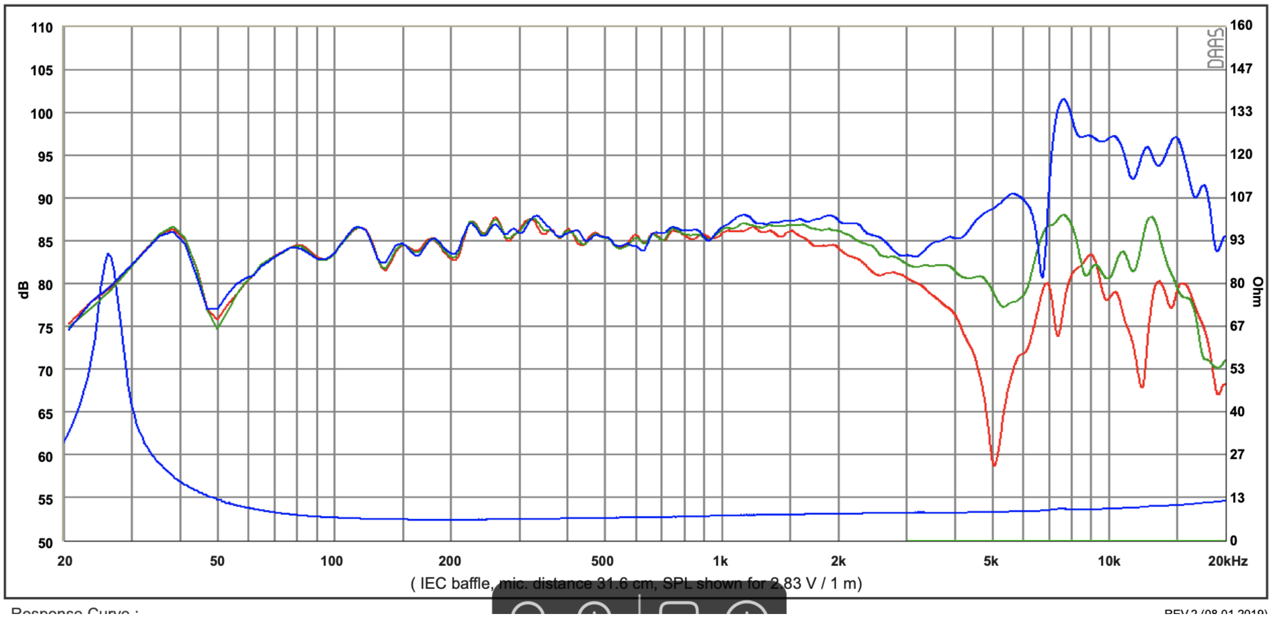
My third driver choice was the Scan-speak Discovery H2606/9200 the reason for this choice was as it is a horn tweeter it has the greatest sensitivity compared to the other tweeters I considered at 95 dB SPL, however this tweeter also had the greatest power handling capabilities with its long term power rating at 200 watts. Unfortunately the reason I didn't pick this driver was because unfortunately it didn't have quite the frequency response I was looking for compared to the other two as shown below.



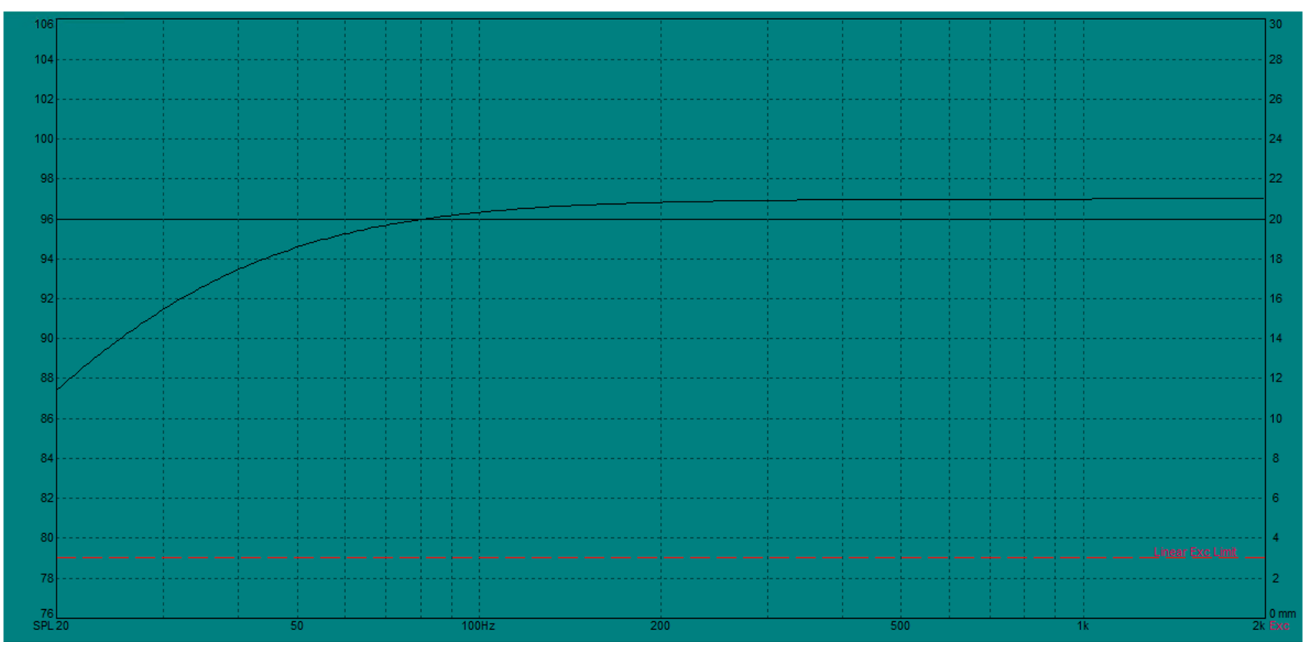
Now even though the frequency response of this tweeter is still very good I did want the tweeter for this system to be able to get down to about 1 kilohertz before it started to roll off in dB SPL and unfortunately this driver doesn't fit that need.

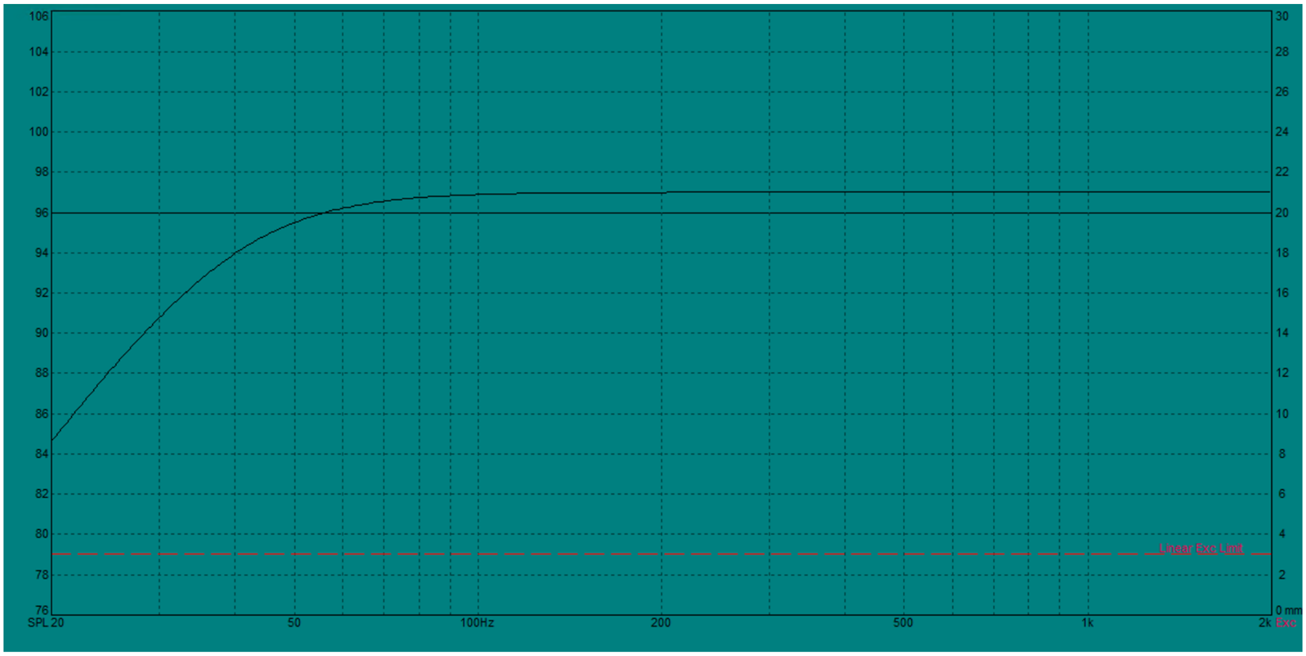
Moving on to my woofer choices the first woofer I considered for this project was the SB Acoustics

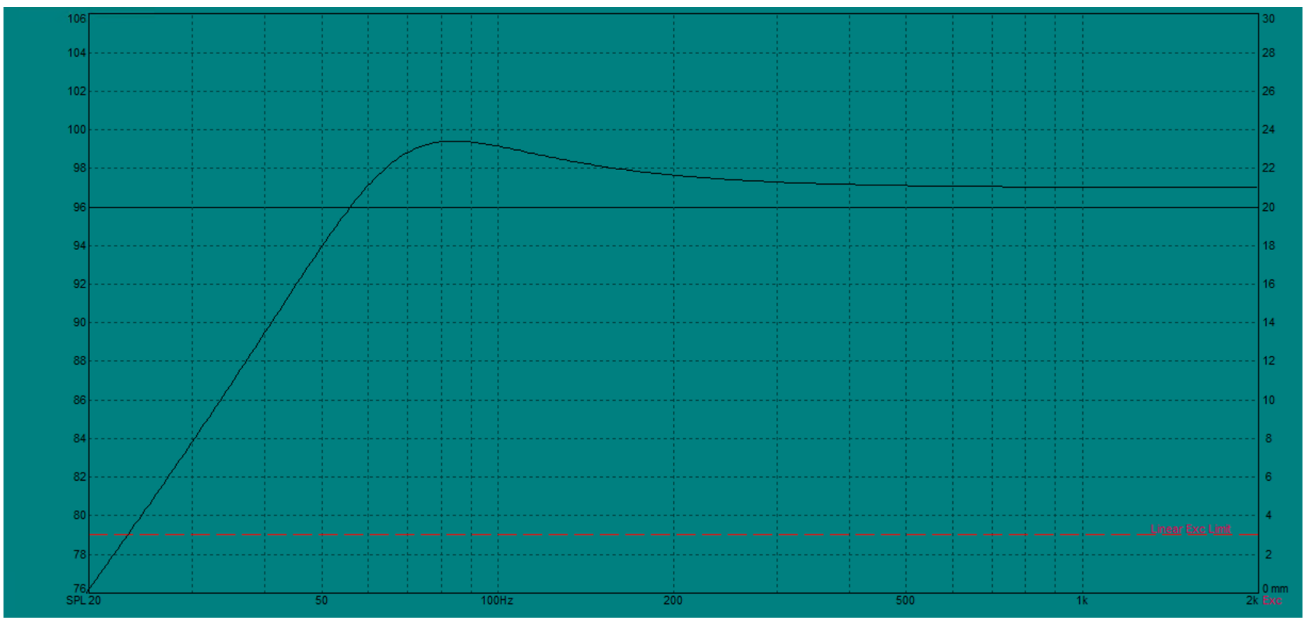
SB17CAC35-8 this driver is a 6 inch woofer with a ceramic cone. My reason for this choice was I thought the driver was visually appealing as well as. It has a very desirable frequency response for what I was looking for.



However the one downside to this driver was the cost, it was 1.7 times the cost of the other woofers I was considering for this project and as I am trying to do this build with some form of a smaller budget it is likely this will not be my woofer choice. Although, despite the higher cost with the speaker modeled in a cabinet it does look very good in terms of performance inside different volume boxes as seen below.

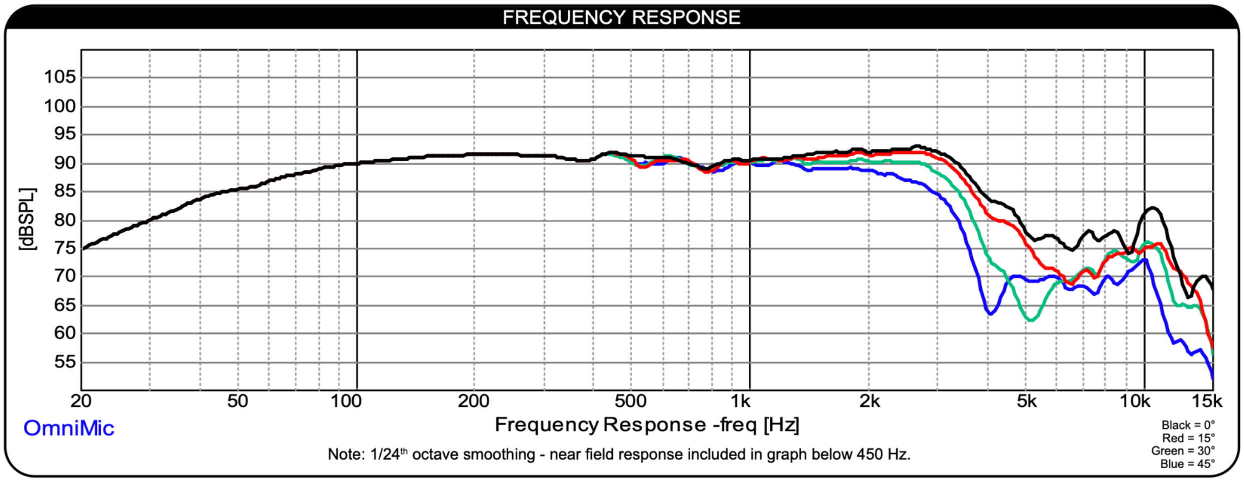




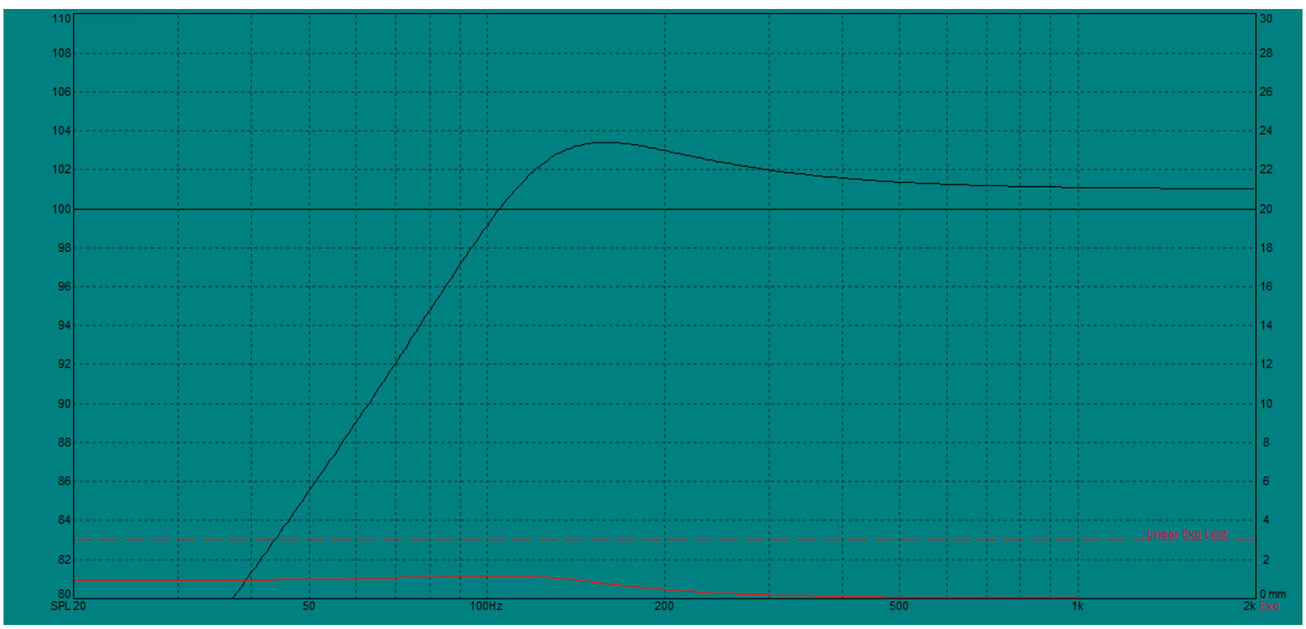


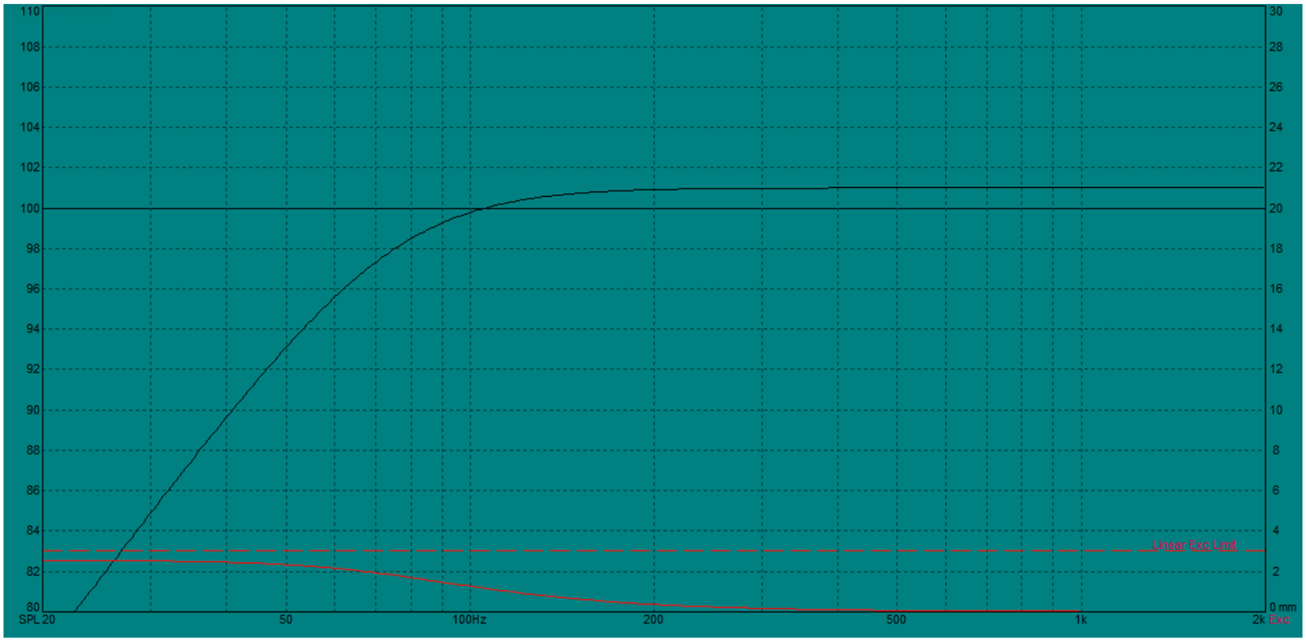
Each one of these graphs starting at the top have a Q value of .5 then .707 and finally 1.2 this is to show the bass response of these drivers in different sized enclosures as well as SPL limits.

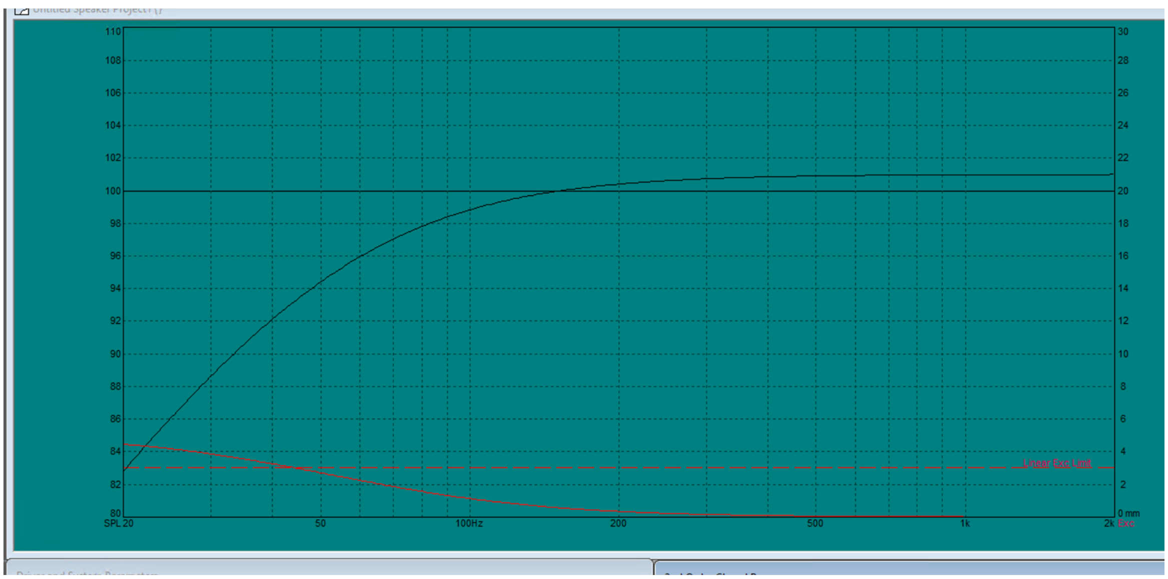
The second choice for my woofers is the Dayton Audio SIG180-4 this is a 6.5 inch 4 ohm woofer now it is cheaper than the previous choice but the main reason I was attracted to this driver was because it is a part of dayton audio’s new signature series and I was curious about the performance of the driver at its price point. As the frequency response and power handling look very decent.



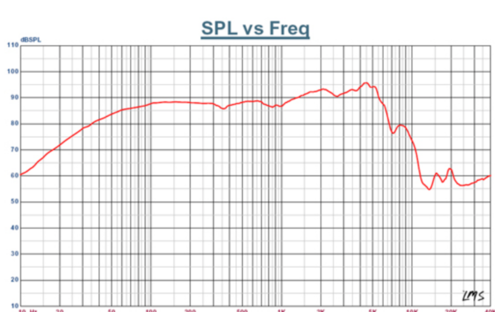
Below is also some modeling to show this second choice woofer in different enclosure volumes as well with the same .5 .707 and 1.2 quality factors.

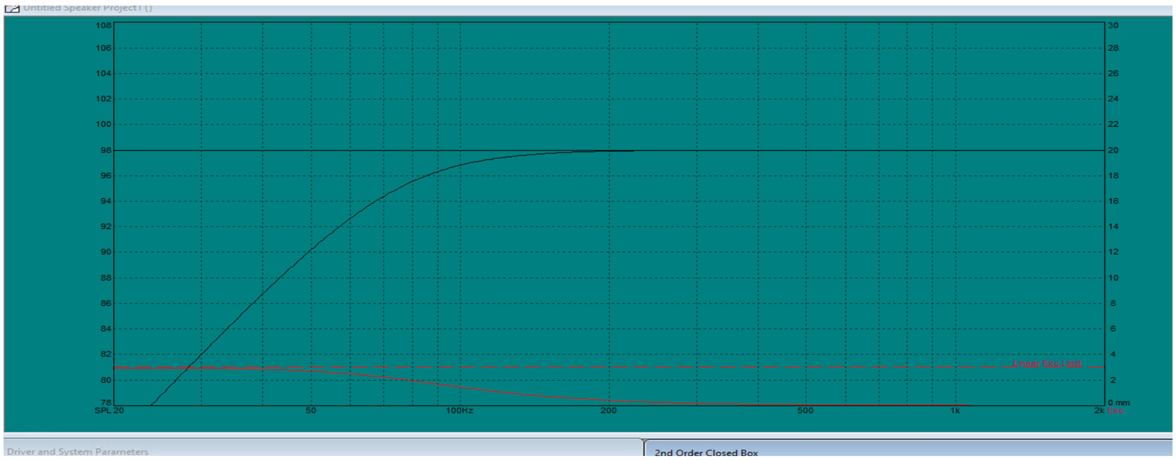






My third woofer choice was the Hi-Vi L6-6R, this driver interested me because it was made out of kevlar. I was curious to see how it stacked up to other driver cone materials, which it actually measures up in terms of frequency response however it is not the best woofer in terms of power handling as its makes power handling is 60 watts while the second choice woofer has 160 watts at peak power handling. Below are more graphs to show the drivers performance which follow the same information as the graphs for the other drivers above.




Untitled Speaker Project1 ()
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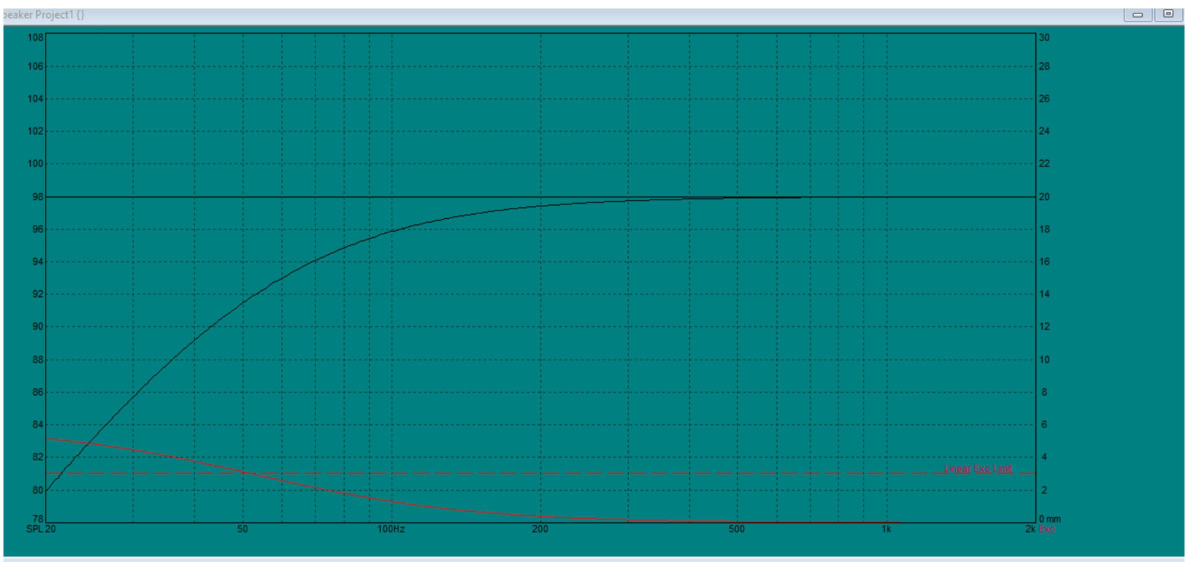
2nd Order Closed Box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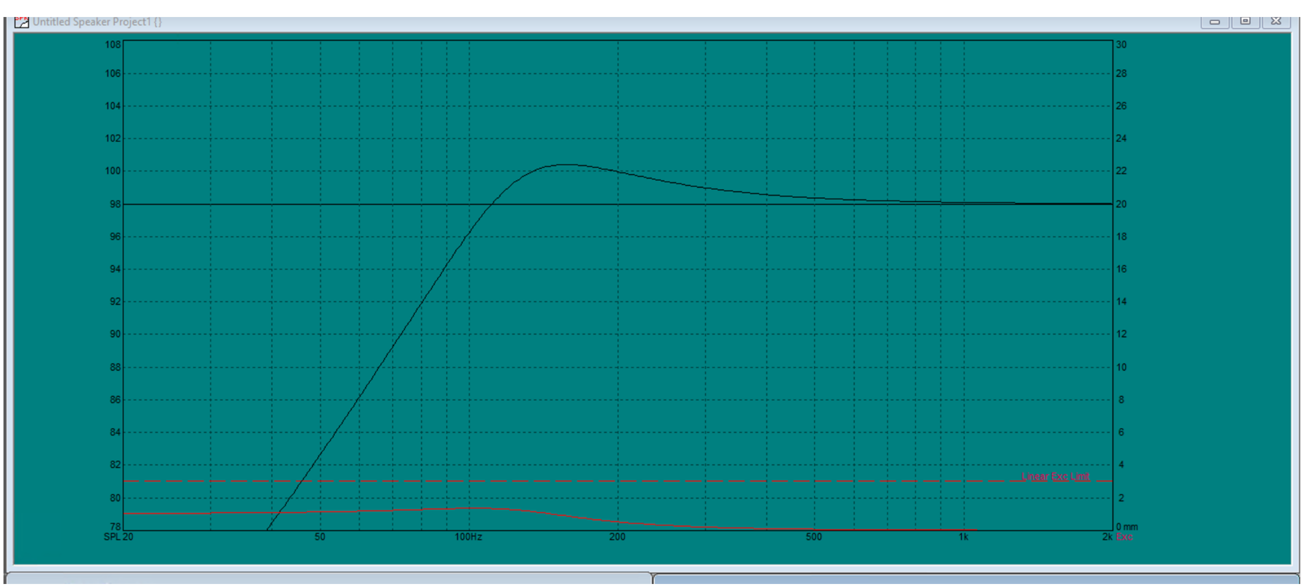
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100Hz
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1k
2k
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Linear Exc Limit

Despite each driver having their upsides and downsides the final selection for this build was of woofer and tweeter was the SB Acoustics SB21SDCC000-4 and the Dayton Audio SIG180-4.

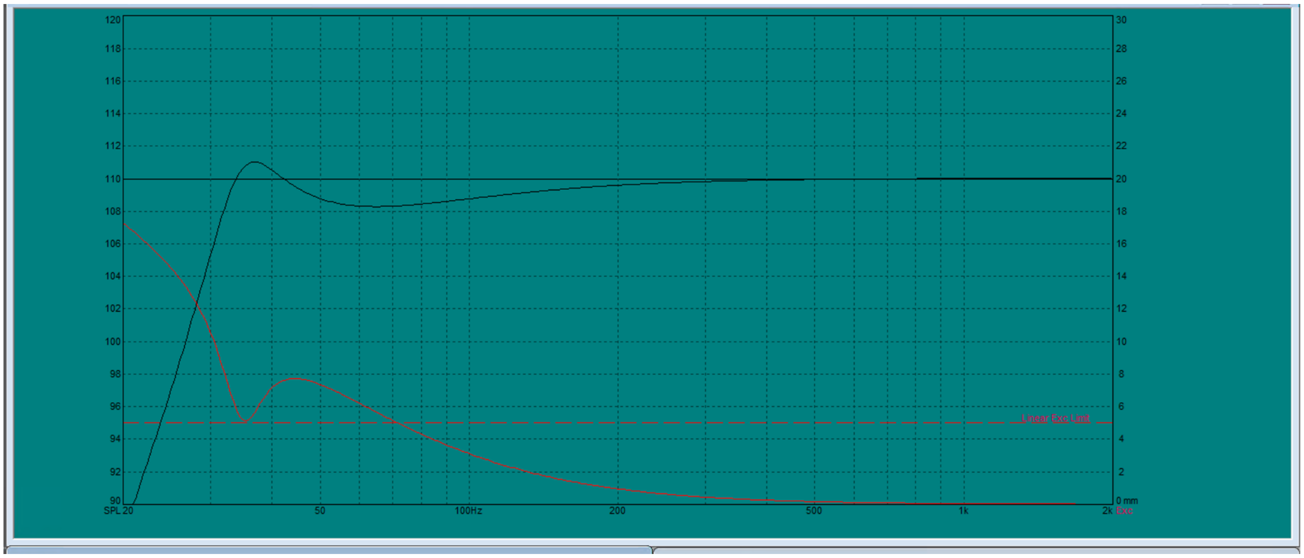
5.8 Processing

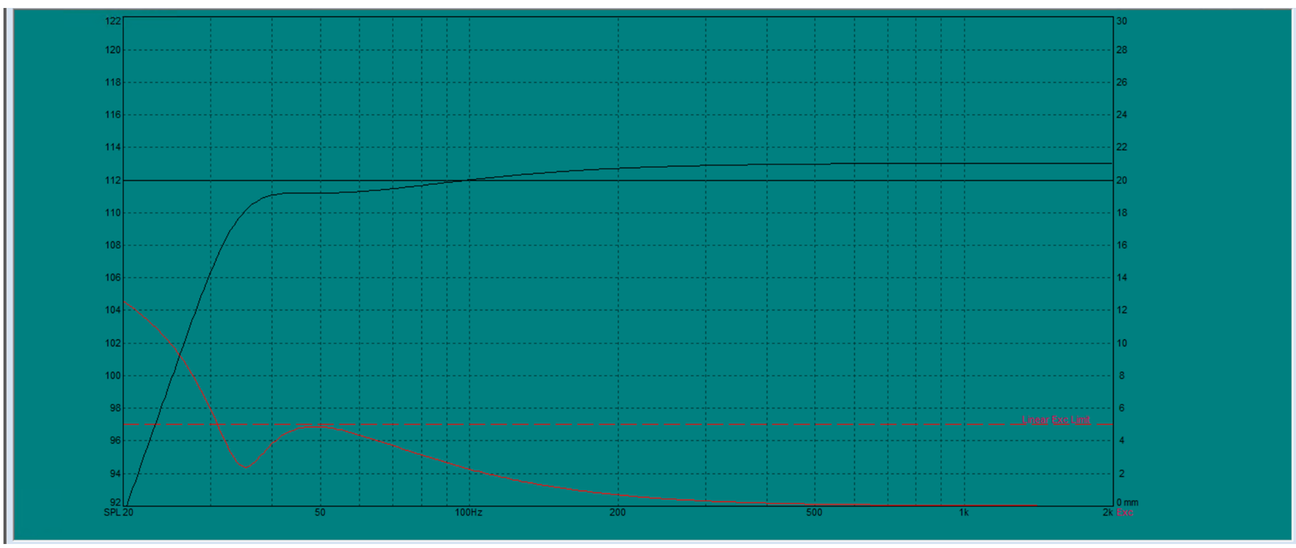
The Processor or DSP that this system will rely on will be the Dayton audio 4 x 8 DSP. The thought process for this decision was to try and keep the cost of my loud speaker build under budget. Unfortunately the downside to using a lower cost Digital Signal Processor is that it gives less available options for tuning my loudspeakers as the dayton audio DSP really only has delay and EQ as far as different features goes. Also with the dayton audio DSP one of the upsides to it is with the proper usb connector and remote it becomes a bluetooth device that can be adjusted with an app from a smartphone. This makes tuning on the fly much easier as I create very easy access to adjusting any settings on the system's DSP. Another downside to the Dayton audio DSP due to the bit size. It makes it so you are unable to set delay on channels to specific amounts of time in milliseconds, however the minimum amount of time you can set delay for is small enough that it is still very much usable while tuning loudspeakers and setting delays for a crossover between drivers.

5.9 System Wiring and Crossover

The Wiring Configuration of the Driver inside the cabinet woofer drivers will be a parallel circuit. This will one help with the power handling of the drivers increasing the amount of watts that the drivers can take before hitting their excursion limit. In between the start of the second branch of the circuit and the second or lower woofer in the system there will be an inductor. This inductor will help roll off the higher frequencies for the bottom woofer around 300 Hz for a 1.061 millihenry inductor. Along with the parallel circuit this will also help with power handling for the lower woofer as it shouldn't need to work as hard as the top to recreate the frequencies below the crossover of the tweeter and the woofer. The crossover is going to be an active crossover through the Dayton audio DSP as I have mentioned above in the previous section. The crossover will be a fourth order butterworth crossover around 2-3 kilohertz.

Shown below are the added power handling and SPL I would get from adding a second woofer to each cabinet.





As shown above the extra driver significantly increases the power handling limit this increase makes it so the drivers can go from handling 40 watts before the excursion to 80. On top of that the dual woofers also give an extra 3dB of SPL.

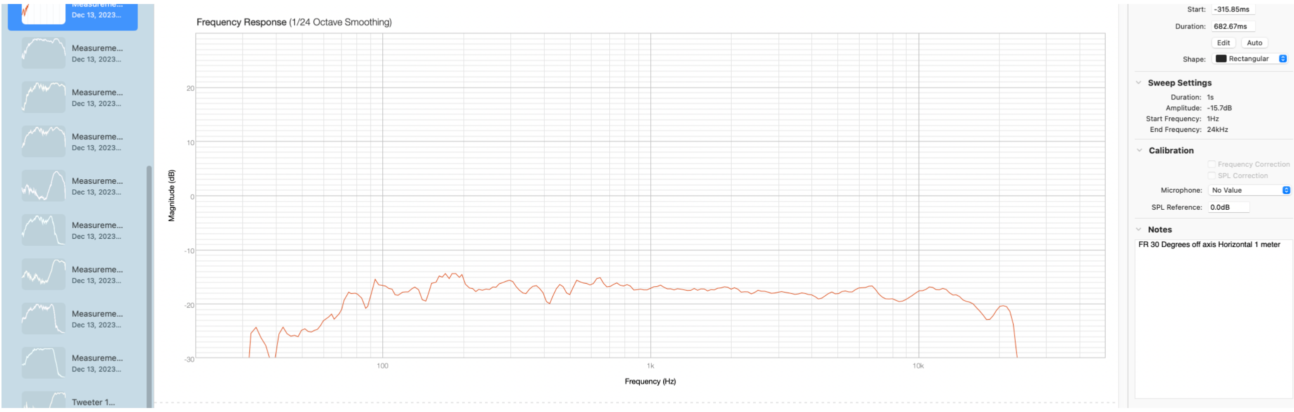
6.0 Testing Tuning and Measurement Documentation

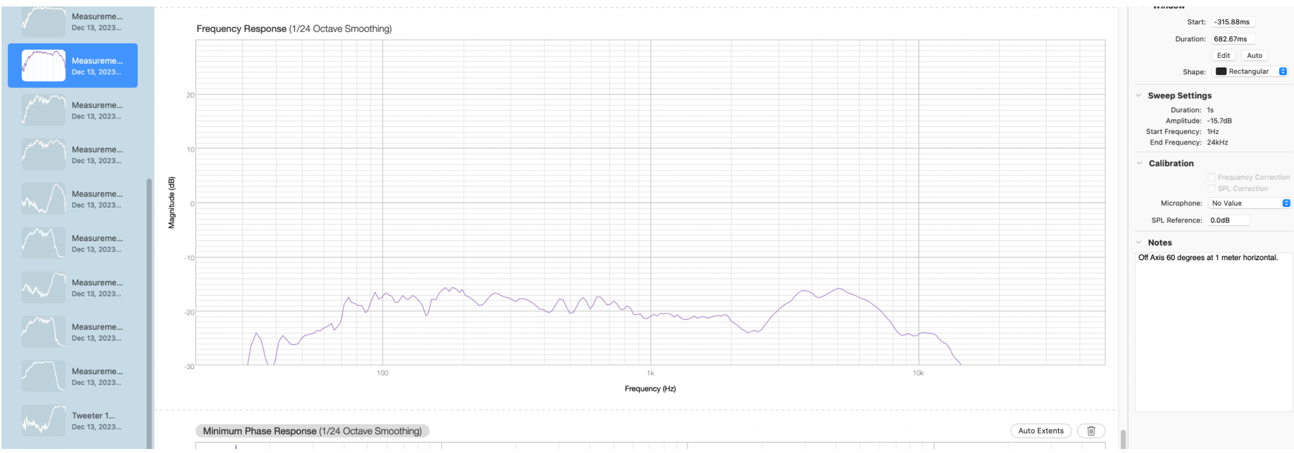
As the speakers were completed it took only a short period of time to test the initial connections due to the BTA20 Pro Fosi Amplifier. Shown Below is a rough frequency response with just a basic crossover and no tuning using Smaart V8 Software.

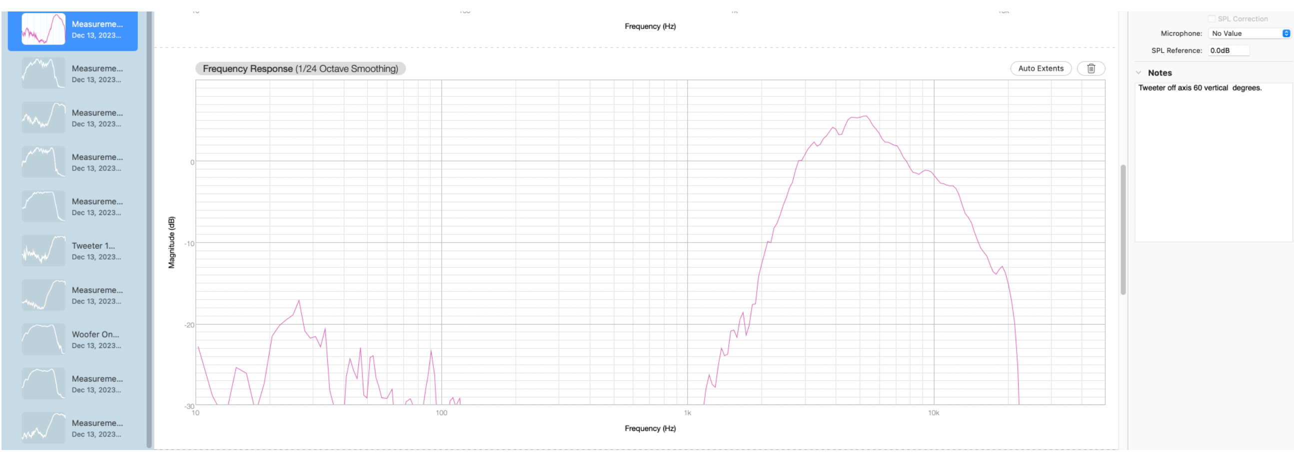
Over the course of the process I used Smaart to phase align the drivers by setting the delay on the tweeter so that it was able match the woofer and I ended up taking out the big dip shown above in the frequency response chart. There was also some light EQing I did in the midland upper frequencies to try and keep the frequency response as flat as I could.

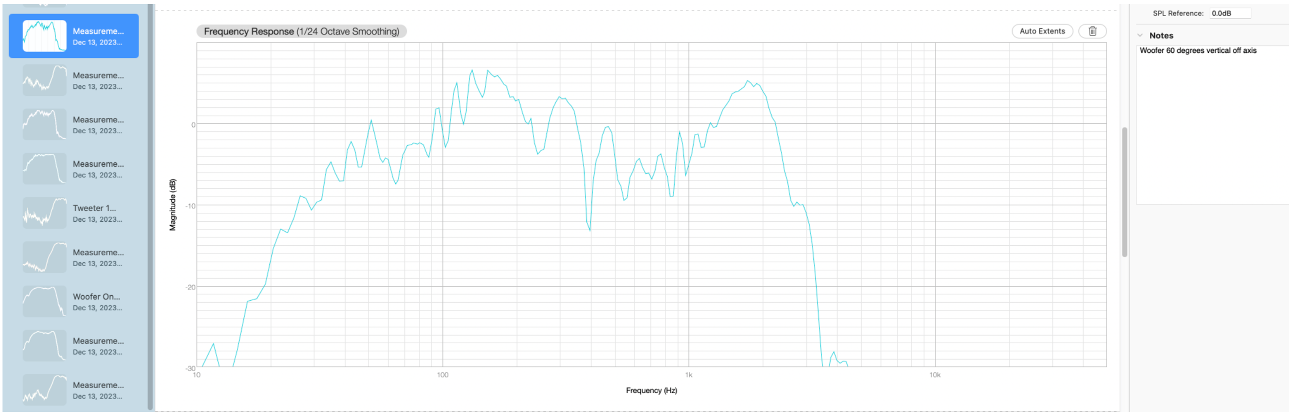
Below is the integrated frequency response however unfortunately it is not the best example as I didn't realize at the time that I had taken each measurement at various volumes.

Below are the off axis responses of the system vertically and horizontally at 30 and 60 degrees off axis. As well as the driver off axis response. This will really show what frequencies roll off as the off axis angle increases.

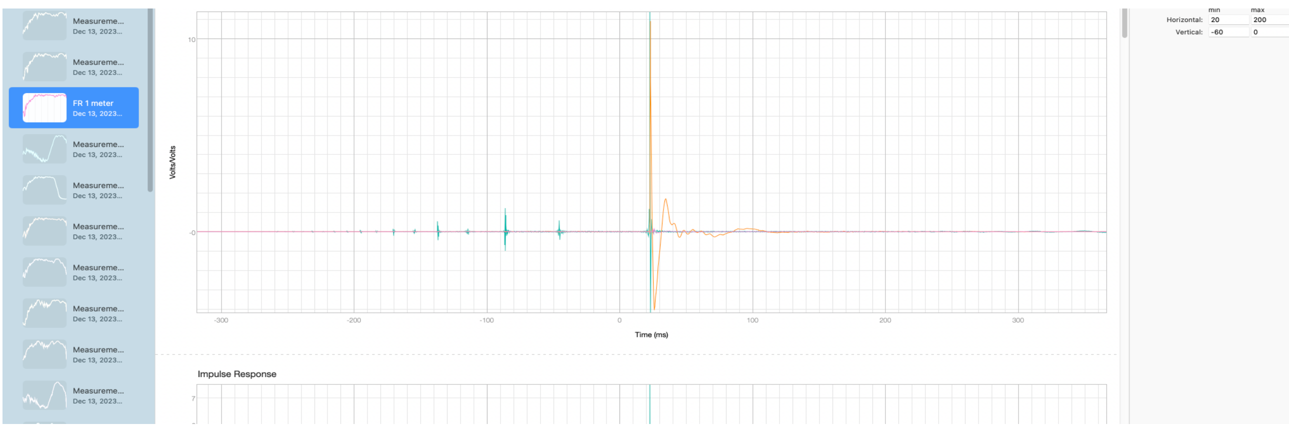

Frequency Response (1/24 Octave Smoothing)
Magnitude (dB)
Frequency (Hz)
Start: -315.85ms
Duration: 682.67ms
Edit
Auto
Shape: Rectangular
Sweep Settings
Duration: 1s
Amplitude: -15.7dB
Start Frequency: 1Hz
End Frequency: 24kHz
Calibration
Frequency Correction
SPL Correction
Microphone: No Value
SPL Reference: 0.0dB
Notes
FR 30 Degrees off axis Horizontal 1 meter


Frequency Response (1/24 Octave Smoothing)
Magnitude (dB)
Frequency (Hz)
Minimum Phase Response (1/24 Octave Smoothing)
Auto Extents
Start: -315.88ms
Duration: 682.67ms
Edit
Auto
Shape: Rectangular
Sweep Settings
Duration: 1s
Amplitude: -15.7dB
Start Frequency: 1Hz
End Frequency: 24kHz
Calibration
Frequency Correction
SPL Correction
Microphone: No Value
SPL Reference: 0.0dB
Notes
Off Axis 60 degrees at 1 meter horizontal.

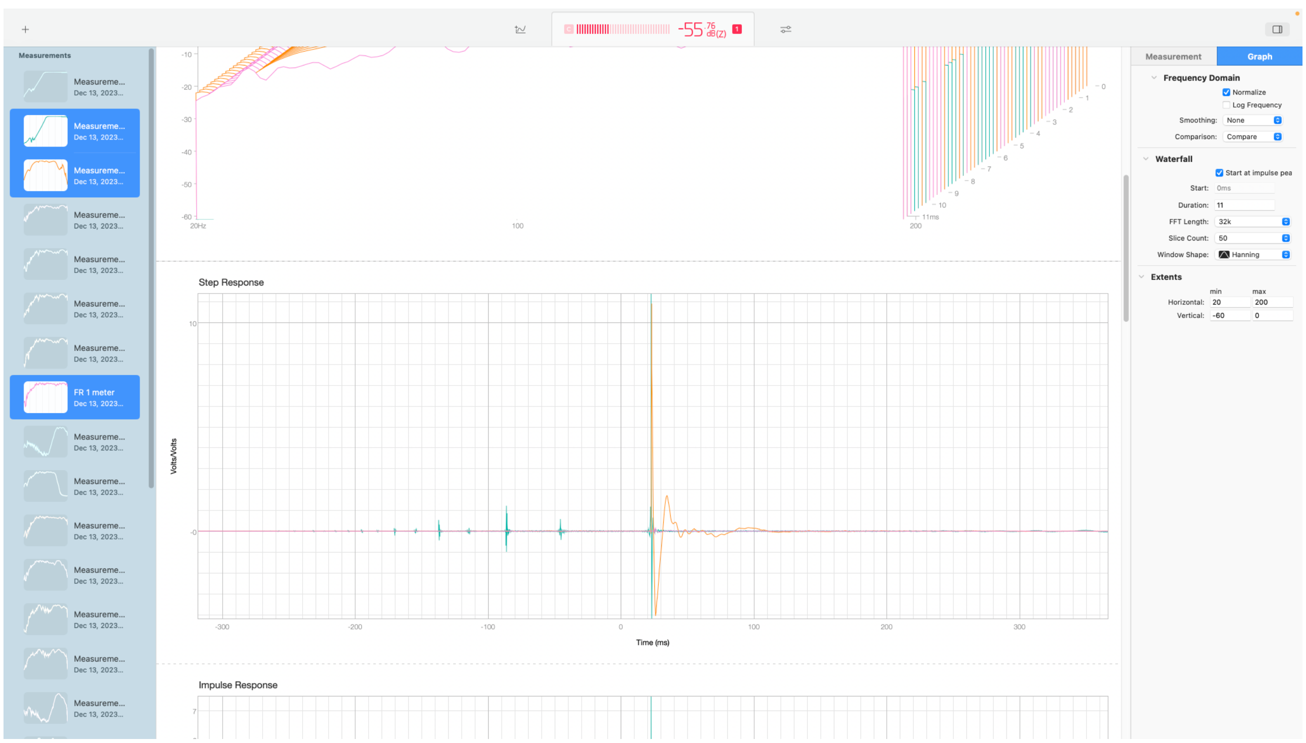

Frequency (Hz)
Frequency Response (1/24 Octave Smoothing)
Auto Extents
Magnitude (dB)
Frequency (Hz)
SPL Correction
Microphone: No Value
SPL Reference: 0.0dB
Notes
Tweeter off axis 60 vertical degrees.



Below are the impulse and step responses to show how the drivers hand off the signal to each other or how well they work together. For the first graph green is the tweeter and orange is the woofer.



Measurements
FR 1 meter
Impulse Response
Volts/Volts
Time (ms)
Harmonic Distortion Percentage (1/24 Octave Smoothing)
Measurement
Graph
Delay
Delay: 25.46ms
Distance: 8.66m
Window
Start: -315.85ms
Duration: 682.67ms
Edit
Auto
Shape: Rectangular
Sweep Settings
Duration: 1s
Amplitude: -15.7dB
Start Frequency: 1Hz
End Frequency: 24kHz
Calibration
Frequency Correction
SPL Correction
Microphone: No Value
SPL Reference: 0.0dB
Notes
Frequency Response 1 Meter Listening Axis.



Measurements
FR 1 meter
Step Response
Volts/Volts
Time (ms)
Impulse Response
Measurement
Graph
Frequency Domain
Normalize
Log Frequency
Smoothing: None
Comparison: Compare
Waterfall
Start at impulse pea
Start: 0ms
Duration: 11
FFT Length: 32k
Slice Count: 50
Window Shape: Hanning
Extents
min
max
Horizontal: 20 200
Vertical: -60 0

Next in my measurement is my harmonic distortion which shows how clearly my speakers replicate their signal.

6.1 Measurement Considerations:

When taking measurement it is extremely important that you are being very clear and concise with every aspect of the measurement whether it be calibrating the microphone making sure your levels are the same across the board because it will make the tuning process a lot easier because you can figure out a lot more of the tuning process based on measurement like harmonic distortion minimum phase and frequency response. Another thing to consider is the levels of your signal pushing your gear to hard can result in unfortunate consequences like breaking drivers.

6.1 Project Reflection and Final Cost

Looking back at this project from the beginning there are very many things I would do differently, for starters I would probably pick a larger driver as the drivers I picked did not provide the low end support I was looking for in this system. I would also familiarize myself with every single tool and piece of equipment I haven't used before as many of the tools I used to build these speakers I was unfamiliar with and due to that I took a lot of extra time in redoing steps because I messed up and I had to go back and fix things. I would also go with speaker cable hookups instead of binding posts because they are easier to install and a lot harder to break as long as they are inset.

Continuing on another thing that I would do differently is I would use smaller amplifiers as unfortunately due to poor measurement practices I accidentally melted the voice coil of one of my tweeters. Another item on the list of mistakes was gluing in my port after inserting it because it made it impossible to adjust the port for tuning. Despite the many things I would do differently I used this project to teach myself how to design speakers not to actually design extremely nice speakers and I feel like going forward I am more than capable of building a high end pair of speakers and after all the extra cost the cost of my speakers ended up being $760