Chicken Feet

Transducer 2013

Nathan Prouty

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Functional Description

These speakers will be used for mixing and casual listening. The sound produced should not have any type of coloration or boosted frequencies. Every genre of music should sound great when played from the loudspeakers. Being able to reproduce great recordings across the genres is my highest priority. Easily being able to transport these speakers around is another aspect of design I want to incorporate. I have a small Ford Focus so they will have to fit in it. The smaller the better but I will be willing to sacrifice size for extended frequency response. I will also be having other people/clients listen while I finalize a mix so the people sitting around me should also get a nice clean sound. For overall aesthetics, I enjoy customization on items I own so the speaker box should not just be a single color. I want my speakers to stand out and be easily remembered by people.

Design Goals

Size and Shape

A rectangular box will be used for ease of transporting the speakers in my vehicle. While listening, these speakers will be sitting on a desk or a stand behind a desk. I will design my box to have a closed box Q around 0.7 for an overall flatter frequency response in the low end.[1] The effects of having a larger box would just be slower roll off of the lower frequencies and if it is smaller than that there is a slight bass boost.[2]

SPL Level

These speakers will be used for mixing audio as well as listening for enjoyment. Film studios mix at a level of 85 dB with enough room to go 20 dB past that.[3] Speakers can play with out distortion about 15 dB lower than the rated max[4]. While experimenting with low frequency extension I found out that music at a volume of 80 dB tends to cause ear fatigue at a fast rate. While casually listening to music I tend to have a volume of around 70 dBs so

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[1] (Newell and Holland 2007)

[2] (Newell and Holland 2007)

[3] (Moulton 2000)

[4] (Holman 2010)

this and the ear fatigue make the priority for louder volumes not that important. I hope to reach 90 dBs but everything about that is an added bonus.

Bandwidth

These speakers will be for mixing and listening to many different genres of music witch makes the bandwidth an important factor. 20Hz to 20kHz is a common goal when designing speakers. Because the speaker box is going to be smaller it is fine for it not to go all the way to 20Hz but the cutoff of the low end should be at least 60Hz. In listening to some of my favorite songs, ranging from hip-hop songs with thunderous low end to fast paced rock songs where the bass is not as present, I added a low cut filter in Logic and slowly increased the frequency of the filter. Here are my results.

Song	**Noticed change**	**Lacking bass**	**Unacceptable bass**
Childish Gambino - Bonfire	48Hz	57Hz	64Hz
Lil Wayne – A Milli	50Hz	63Hz	78Hz
The Mars Volta - Goliath	58Hz	63Hz	78Hz
Led Zeppelin – Dazed and Confused	59Hz	70Hz	80Hz
The White Stripes – Seven Nation Army	56Hz	63Hz	68Hz

I concluded that there was a significant difference when everything less than 60 Hz was cut out. Being unspecific to a genre of music, these speakers should pack a punch no matter what song they are playing. This experiment gave me the goal of reaching at least 60Hz with the low end. Anything lower than that would be an added bonus. Producing the lower

frequencies will be done through the driver instead of having a port. Ports increase the transient responses therefore giving you a slightly muddier bass range.[5]

Directivity

The mixing position should not be one small specific spot. The listener should not get a large change in sound if they move off axis from the speakers. These loudspeakers should retain a nice frequency response to up around thirty degrees off axis. Anything better would be an added bonus.

Visual Aesthetics

The visual aspects are another important factor. A simple paint job is not desired for these. The design should stand out compared to the usual speaker. Black and green will be the main colors of the speaker box.

Design Priorities

My main priority is bass response. The bandwidth should be able to pass 60 Hz I mentioned before. The next priority is the size because they have to be small enough to fit into my car for easy transportation. Transient response and clarity is another priority for me. I hope to achieve that with no coloration because I listen to many genres of music and I hate when only a certain type of music sounds good on a pair of speakers. The total SPL of the speakers are a lower priority.

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[5] (Newell and Holland 2007)

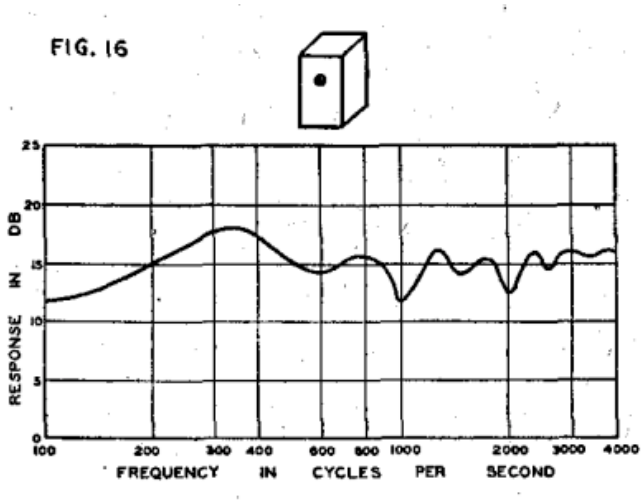
Technical Details

Baffle Step

The front baffle will cause curtain frequencies to resonate in half space causing a boost of 6 dB. For finding out the frequencies where this cuts off you simply use this equasion: $f_3 = 4560/W_b$(width of baffle in inches). My front baffle is 10.5 inches so everything above about 434 Hz will be boosted. To compensate for this I will have rounded edges on the front and a shelf filter in the crossover design.

Diffraction Effects

I will have a taller rectangular box. According to Harry Olsen the box will naturally create certain frequency characteristics.[6]



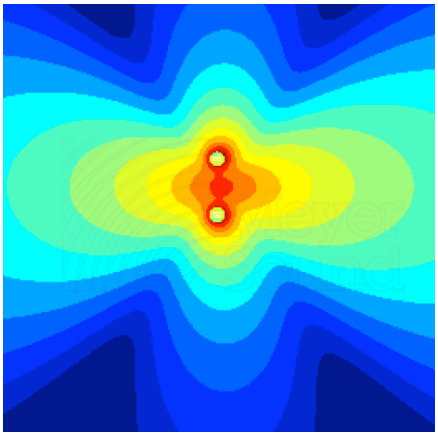
A perfectly rectangular box gives a naturally frequency response with dips in the response. If the front of the speakers extrudes out and gets thinner the frequency response flattens

[6] (Olson 1950)

out. Rounding the edges will help flatten out the bumps seen in the perfectly rectangular box. The drivers will also be flush with the front baffle to not obtain diffraction effects from the edges on the driver.

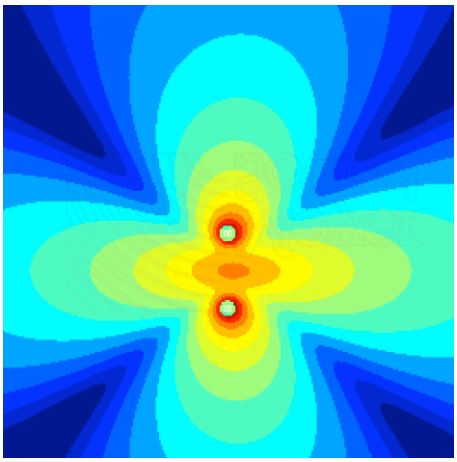
Driver size and spacing

The crossover frequency will be somewhere around 2500 Hz. This will be when both drivers are playing the same frequencies. To account for weird cancelations, the drivers should be placed about seven twelfths of a wavelength apart (based on the 2500 Hz) so those frequencies will cancel out.



This image shows two sound sources spaced about seven twelfths of a wavelength apart and the volumes are significantly less in the vertical direction. To achieve this at the crossover frequencies the distance between the drivers has to be around 3.2 inches apart. Speaker tweeters are about four to five inches in diameter(including the housing for the dome) and drivers are about six to eight inches so the distance cannot be that physically close. The drivers either have to have a lower crossover frequency or a smaller tweeter to achieve this desired effect. If that is not possible I would be fine with the distance being

about three quarters of a wavelength creating a boost in the vertical direction. (Shown in the image below)



Wall Construction and Bracing

The outside layer of the speakers will be constructed form high quality plywood in a taller rectangular box. The back panel of the enclosure will have a diffusion effect so sound waves going straight back from the driver do not create time delayed signals coming out at the driver. To get a diffraction effect the back wall will have strips of plywood stacked on each other to create a diffuser panel effect like the image below.

(http://www.auralex.com/sustain/quadratec.asp)

Sealed boxes tend to sound "boxy"[7] so the diffusion of the sound inside the box will make the box sound livelier with sound bouncing around the walls. The lengths of the panels are as listed:

Diffuser Length	Total Length
3.533	48.676
3.337	
2.748	
1.766	
0.393	
3.14	
0.981	
2.944	BRACE
0	
1.178	
1.963	
2.355	
2.355	
1.963	
1.178	
0	
2.944	
0.981	
3.14	BRACE
0.393	
1.766	
2.748	
3.337	
3.533	

(Prime seed of 23 and a 1500 Hz Design Frequency)

(http://www.mh-audio.nl/diffusor2.asp#calcul)

I will be adding a brace instead of a section of the diffuser on the 2 sections with the brace next to it. I added them to the total because even they will not be used, the extra wood

[7] (Newell and Holland 2007)

would be nice incase of error. In the drafting, I showed these as just two 24.5 by 9 inch rectangles instead of every rectangle in my drafting section. I will cut the smaller pieces from these 2 rectangles.

Driver Selection

Woofer Selection

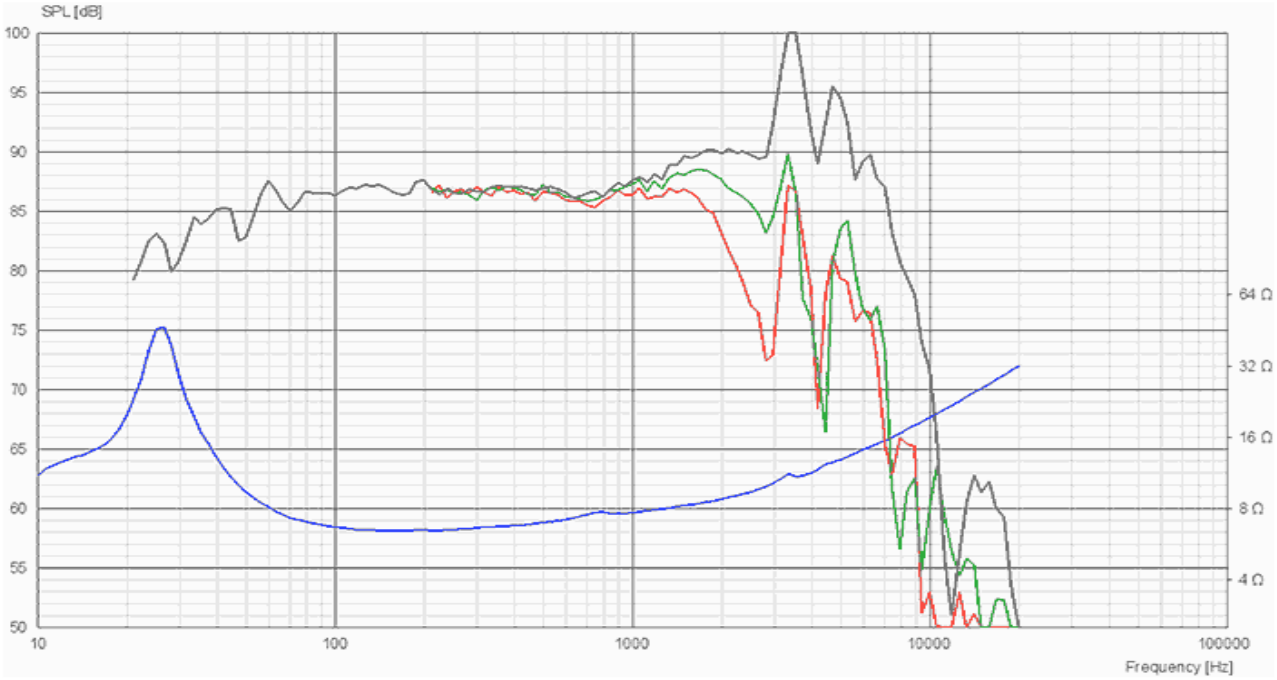
While choosing a woofer a low F3 in a sealed box is the highest priority. As mentioned before I want to achieve an f3 of at least 60 Hz. Anything below that would be an added bonus. I also would like higher range in the driver hopefully going up to about 2 – 2.5 kHz because I do not want a mid range driver. Here are some specs of the drivers I looked at.

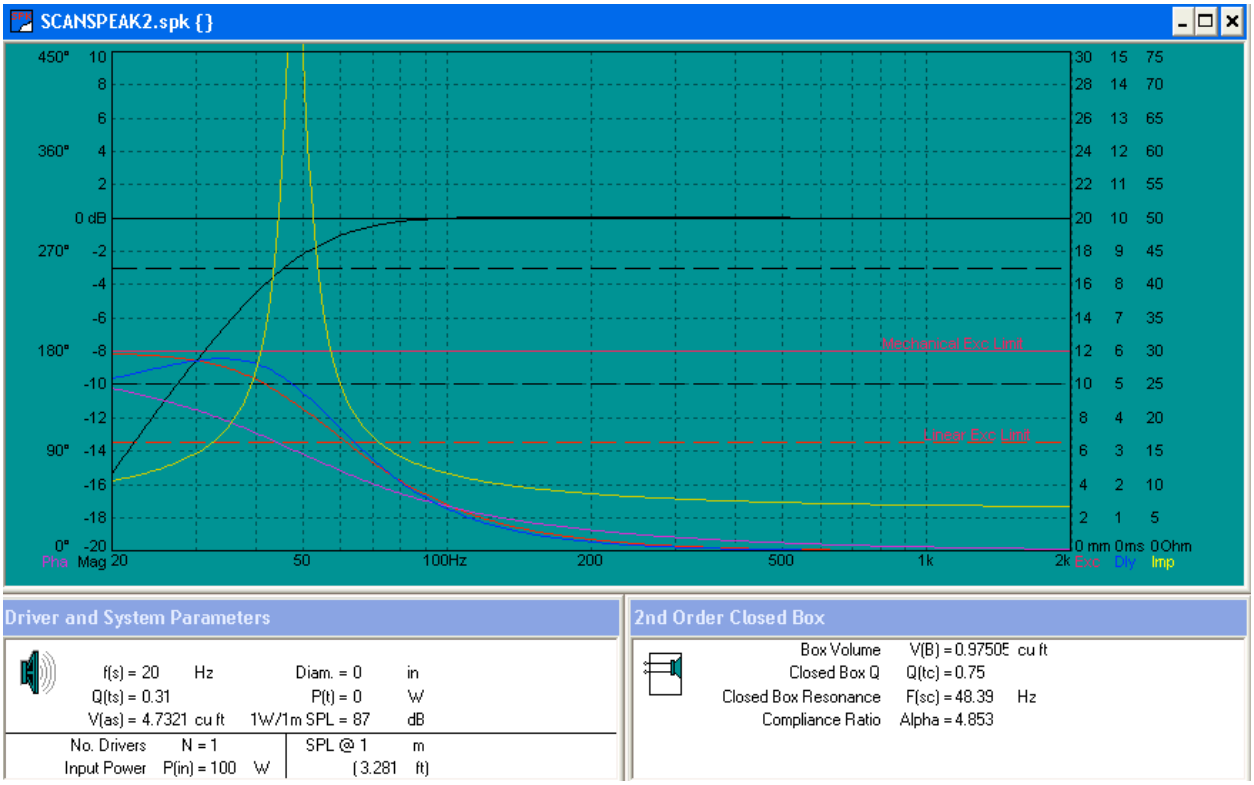
Woofer	Sensitivity	F3	Box Size	Power Handling	Price
ScanSpeak 21W/8555-00	87 dB	45 Hz	0.9 Ft^3	100W	$250
SB Acoustics SB23NRXS45-8	88.5 dB	50 Hz	1.3 Ft^3	60W	$100
Audax HM210C0	90 dB	56 Hz	1.3 Ft^3	70W	$137
Morel MW166	86 dB	56 Hz	1.2 Ft^3	150W	$122
ScanSpeak 22W/8534G00	88.8 dB	55 Hz	1.2 Ft^3	70W	$88

ScanSpeak 21W/8555-00 Classic

The Scanspeak classics are 250-dollar drivers. They have a really nice frequency response up to one kHz. It jumps up about 4 dB and right after 3 kHz there is a really large spike. The low end on this driver is however really good. In a box with a sealed box Q of 0.7 it was able

to produce an F3 of 45 Hz. The downside of these drivers is the high price.

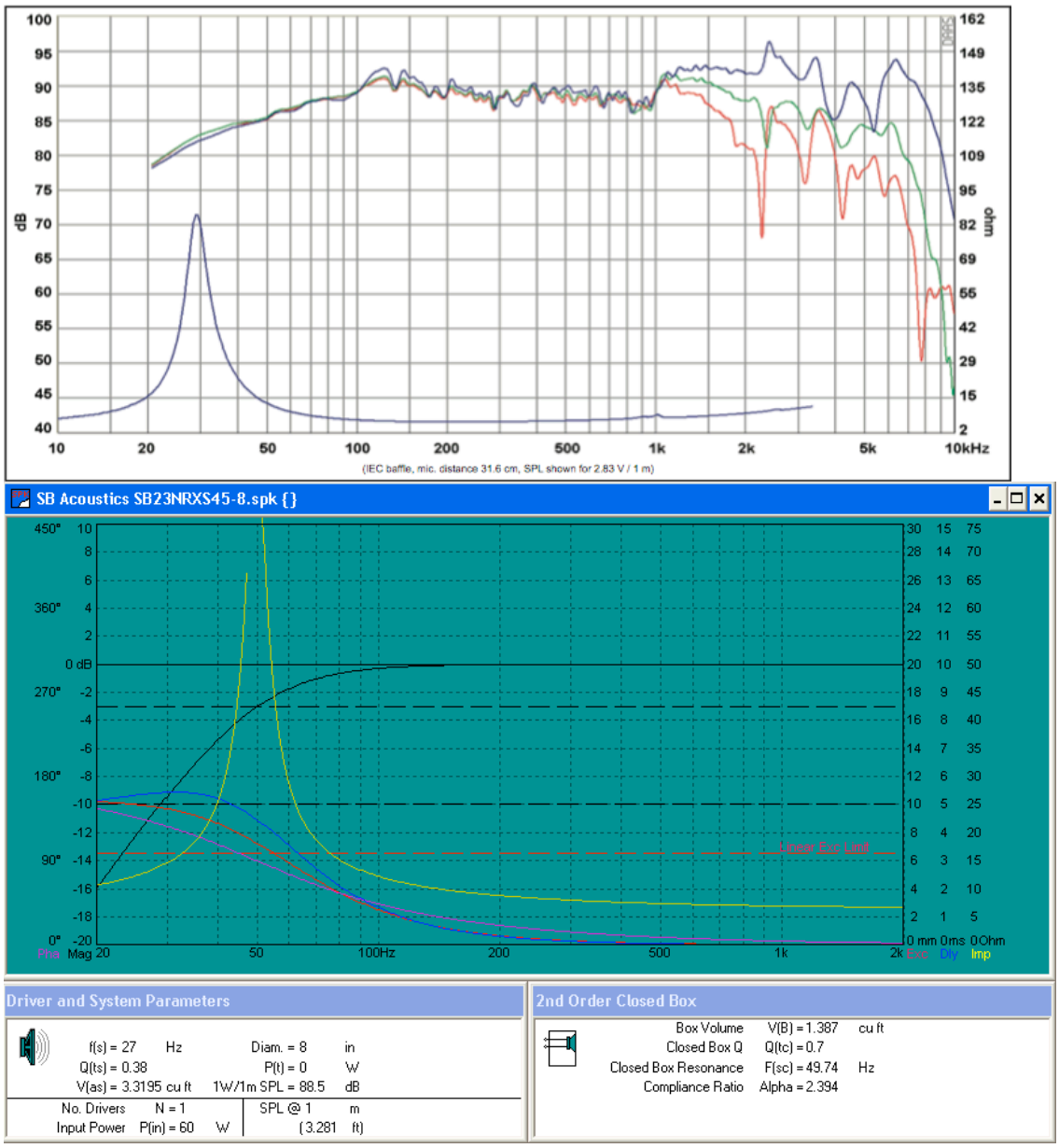




Specs: http://www.scan-speak.dk/datasheet/pdf/21w-8555-00.pdf

SB Acoustics SB23NRXS45-8, 8" Woofer

This SB Acoustic driver is a hundred dollar driver. It has a good frequency response up to one kHz. There is an increase in volume after 1 kHz but a crossover could counter that. The impedance does not increase much after 100 Hz so this will make the crossover require fewer parts. In testing these speakers in WinSpeakerz, they were able to produce the lower frequencies I want for my loudspeakers. In a 1.387 cubic foot sealed box it was able to produce a F3 of fifty hertz.

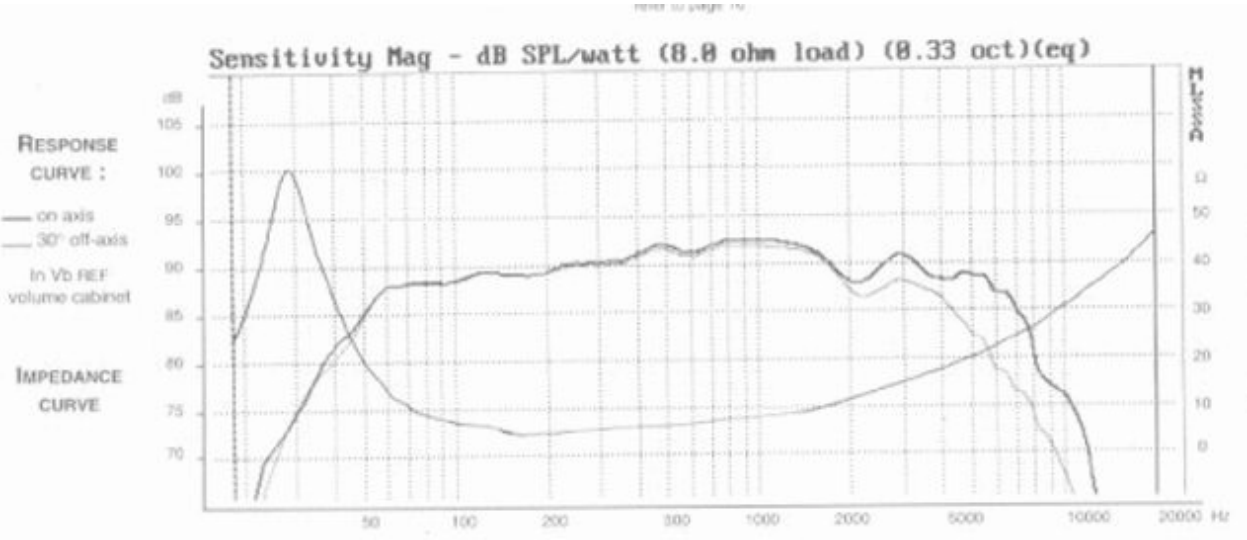


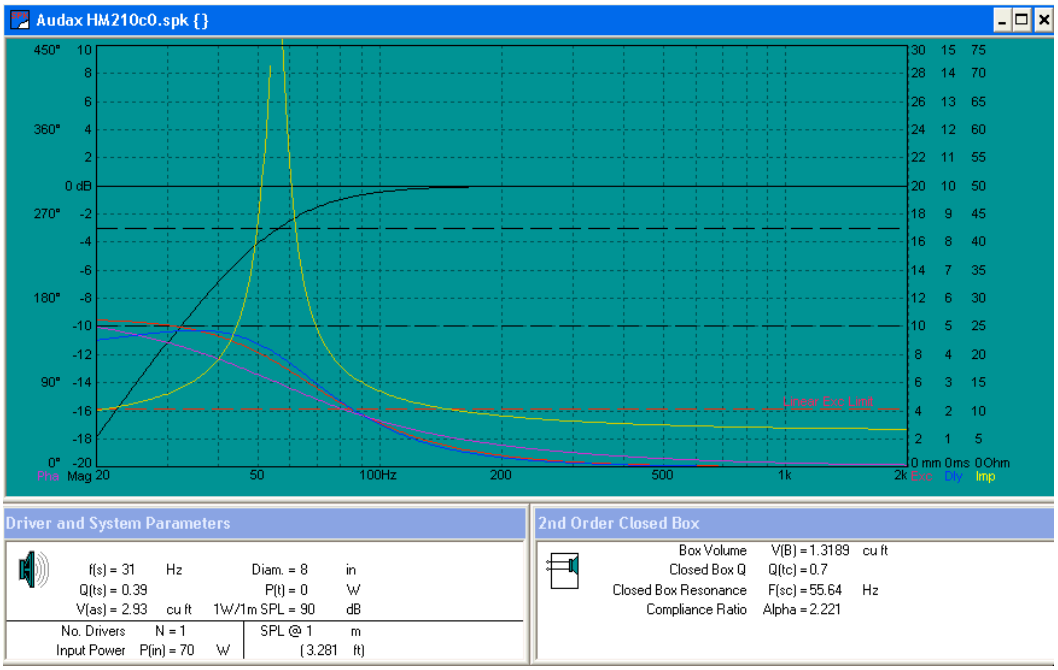
Specs: http://www.madisound.com/store/manuals/SB23NRXS45-8.pdf

Audax HM210C0 8" Carbon Fiber Woofer

These are $137 drivers. Reading the spec sheet, it says it has a nice transient response. The frequency response slightly goes higher as it goes up to 1.5 kHz. There is a dip at 2 kHz but it can reach up to the 2 kHz I hope to achieve on the crossover. On the lower spectrum, it can reach as low as around 55 Hz. That frequency can be achieved in a

1.31 cubic foot box. The impedance rises faster on these than the SB acoustic driver but the Audax frequency response doesn't have a large jump after one kHz.

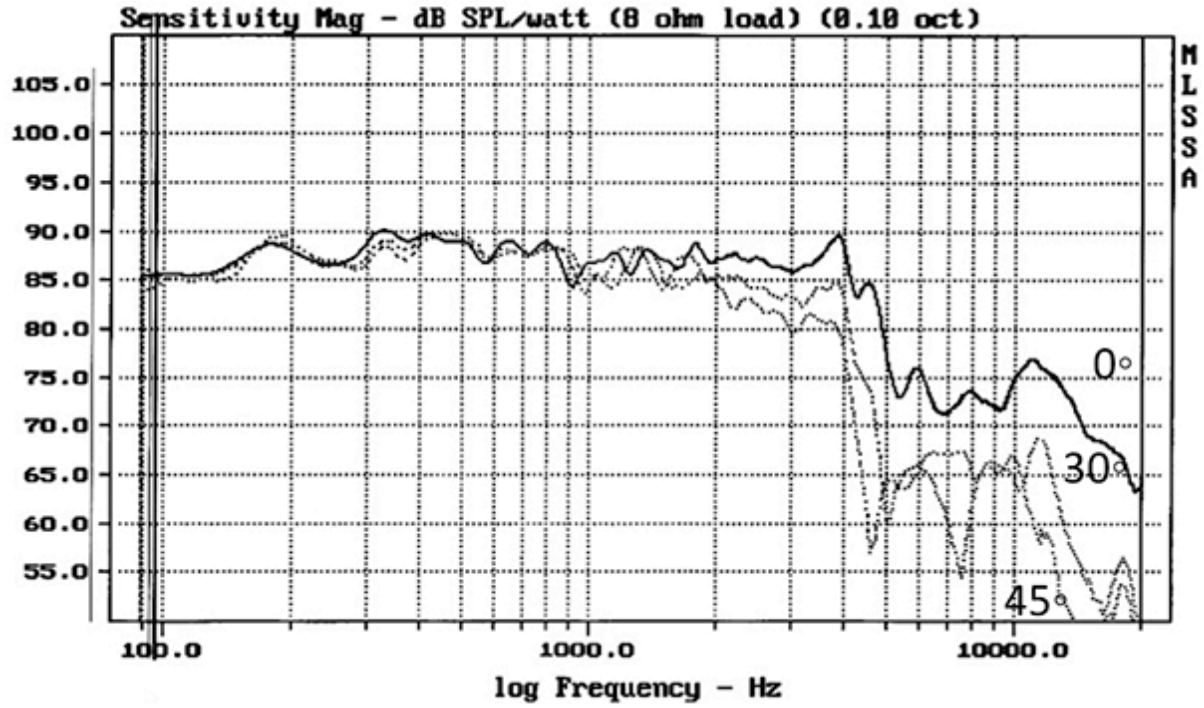


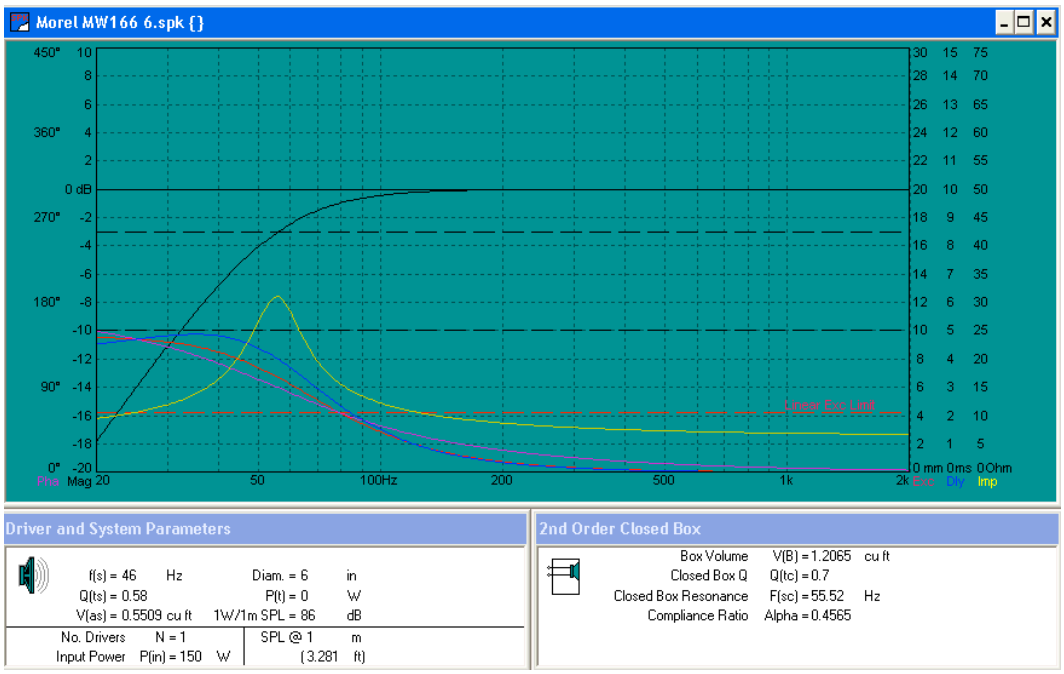


Specs: http://www.madisound.com/store/manuals/HM210C0.pdf

Morel MW166 6" Woofer Damped Polymer Composite Cone

The Morel MW166 drivers are $122. These speakers achieve a nice high frequency response. They can easily reach two kilohertz with ease. There is a slight dip at one kilohertz the upper end of these drivers surpass the other two drivers. It also has a surprisingly nice low end for a six-inch driver. In a 1.2 cubic foot sealed box it is able to reach a F3 of about 55 Hz. These drivers work well but the SB acoustics have a lower F3 and have a better price.





Specs: http://www.madisound.com/loudspeaker_specifications/mw1668.pdf

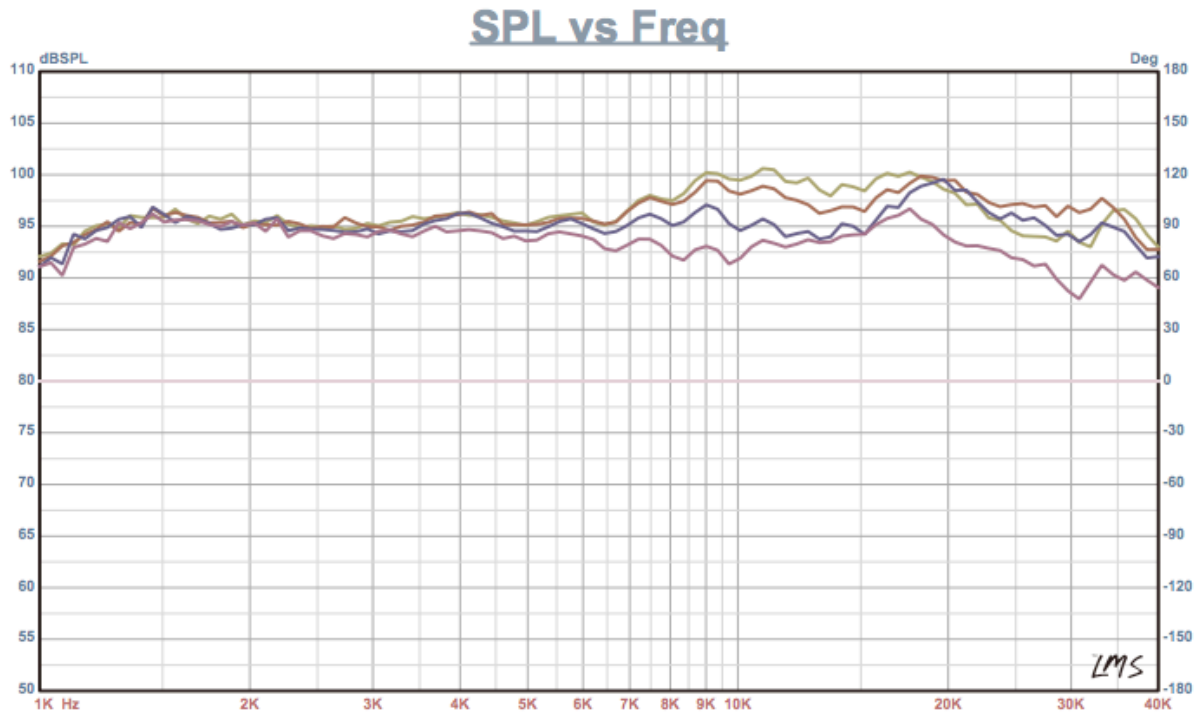
Tweeter Selection

In choosing a tweeter my main preferences are lower resonant frequency, overall flat frequency response, transient response off axis response and ability to achieve frequencies above 20 kHz. The order of importance is exactly in the order listed above.

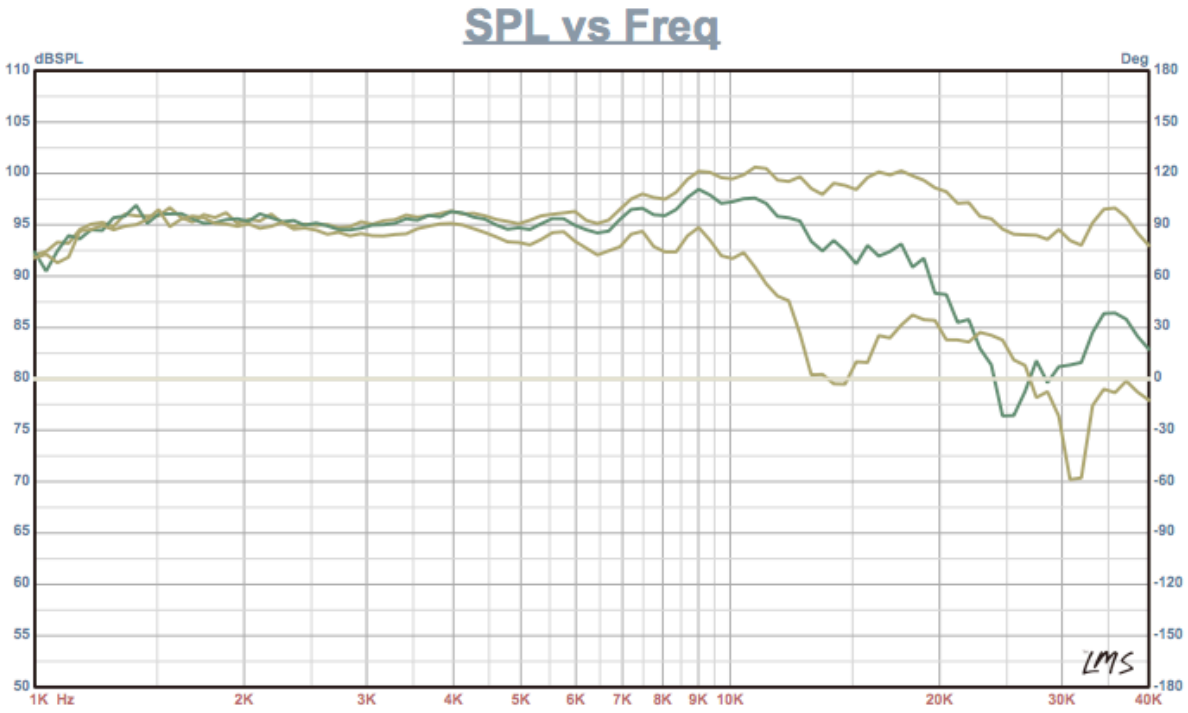
Tweeter	Sensitivity	Resonant Frequency	Power Handling	Price
Fountek NeoCD2.0	87 dB	N/A	20W Nominal 50W Max	$119
Hi-Vi RT2-Pro	99 dB	N/A	30W Nominal 50W Max	$189
ScanSpeak Illuminator D3004/6020-00	89.2 dB	700 Hz	50W Nominal 130W Max	$124
Morel Elite ET448	92 dB	750 Hz	120W Nominal 1000W Max	$117
Satori TW29R	92 dB	600 Hz	80W Rated	$144

Fountek NeoCD2.0 True Ribbon Tweeter

This Fountek ribbon tweeter is 120 dollars. It has a nice extended high range and has a recommended crossover frequency of around 2.5 kHz with a third order crossover. Because it is a ribbon there are no weird impedance jumps and the transient responses are really tight. There is a slight volume bump above 7 kHz but that could easily be countered with a shelving filter. The vertical off axis response is poor on most ribbon tweeters and this one lives up to that. I originally wanted a ribbon tweeter but the drastic change as you move vertically away from the tweeter drove me away from them.



horizontal diffusion: on-axis, 15 degree , 30 degree, 45 degree



vertical diffusion: on-axis, 5 degree , 10 degree

Specs: http://www.madisound.com/store/ma/neocd2-v2.pdf

Hi-Vi RT2-Pro Isodynamic Tweeter

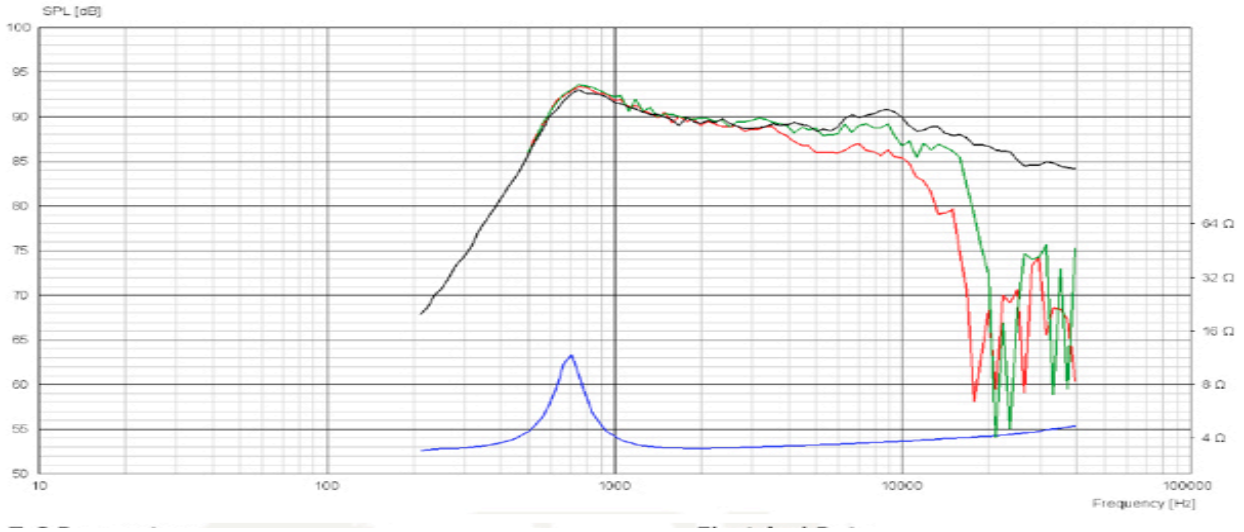
The Hi-Vi ribbon tweeter is a 189-dollar driver. There is a slight bump around 7 kHz. The low end it rolls off at 2 kHz. The high end reaches 40 kHz but there is a dip around 15 kHz. I like the visual aesthetics of this driver but the frequency response does not seem

better than the cheaper Fountek ribbon.

Specs: http://www.madisound.com/store/manuals/rt2pro.pdf

ScanSpeak Illuminator D3004/6020-00 Tweeter Textile Dome

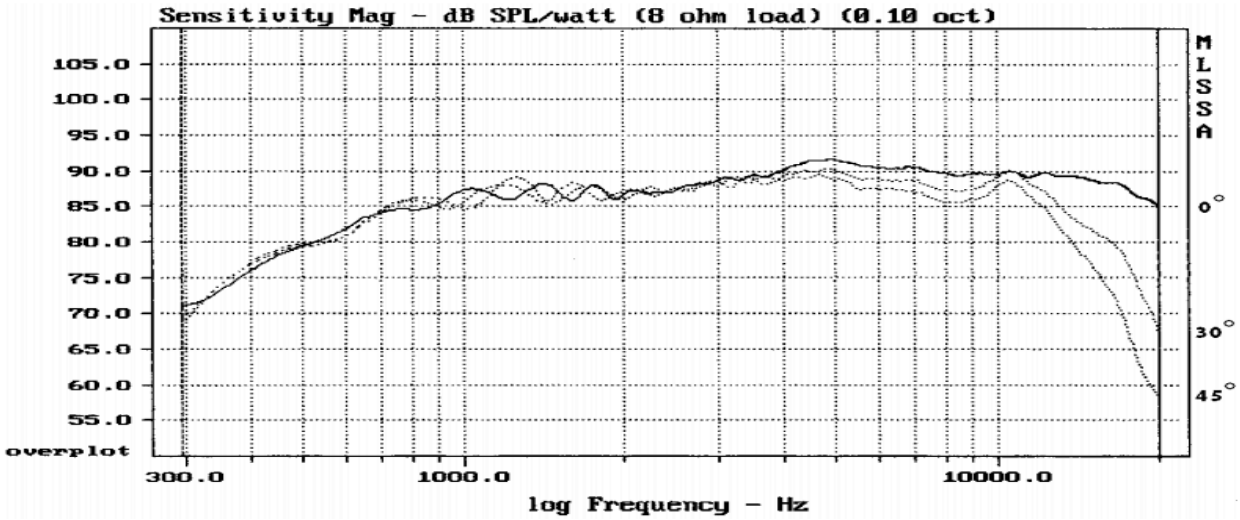
This ScanSpeak tweeter is 125-dollar tweeter. I like the protective grill on this driver. The off axis frequency response is good but gets weird after 10 kHz. There is also a slight roll off after 10 kHz. An advantage to this driver is its ability to go lower than 1 kHz.



Specs: http://www.madisoundspeakerstore.com/scanspeak-soft-dome-tweeters/scanspeak-illuminator-d3004/6020-00-tweeter-textile-dome/

Morel Elite ET448 Tweeter

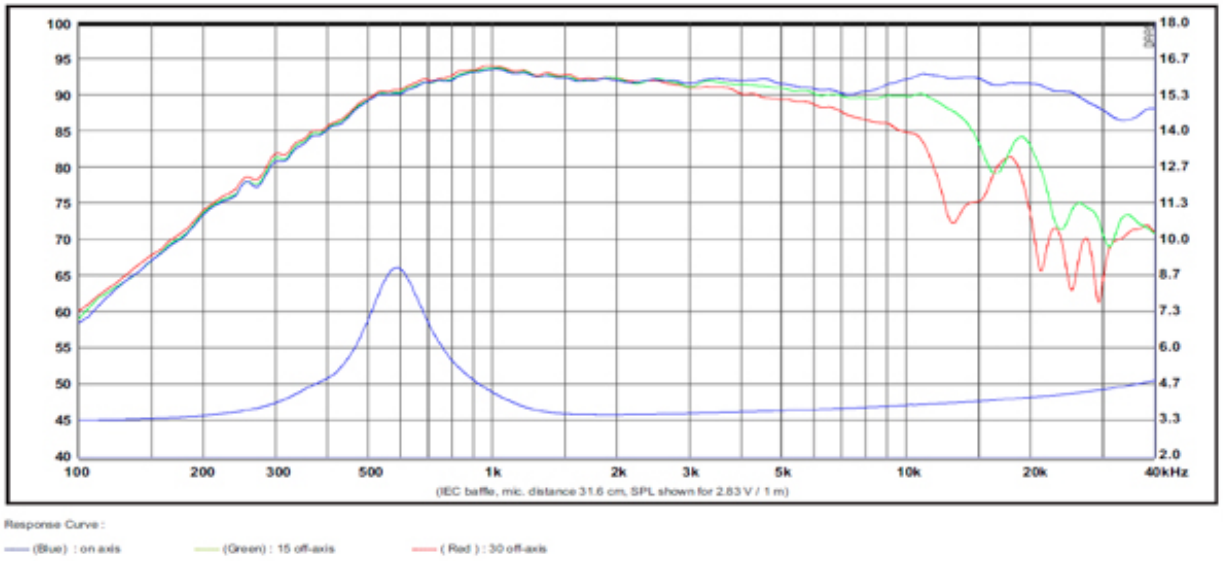
This Morel Tweeter is 117 dollars. It has a relatively flat frequency response and really good off axis listening. It bumps up around 3 kHz but that could easily be fixed with a shelving filter. On the low end it works out fine because this driver has a low resonant frequency of 750 Hz.



Specs: http://www.madisound.com/loudspeaker_specifications/ET448.pdf

Satori TW29R Ring Dome Tweeter

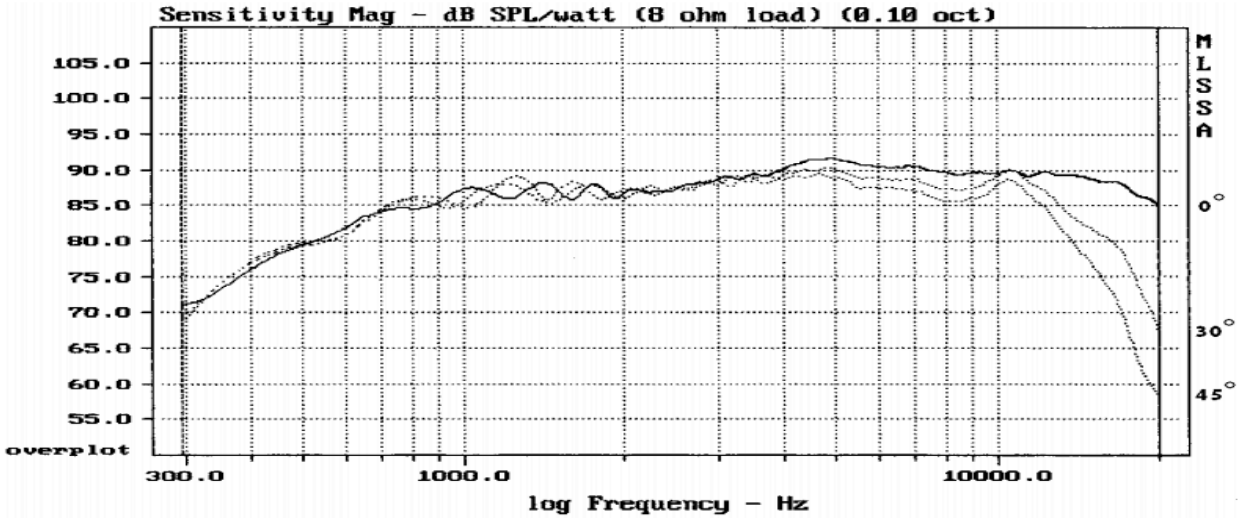
This Satori tweeter is a 144 dollar tweeter. It also has a low resonant frequency like the Morel tweeter. Above 10 kHz the off axis response gets weird but other than that it's pretty good. There is a slight dip in the 7 kHz range.

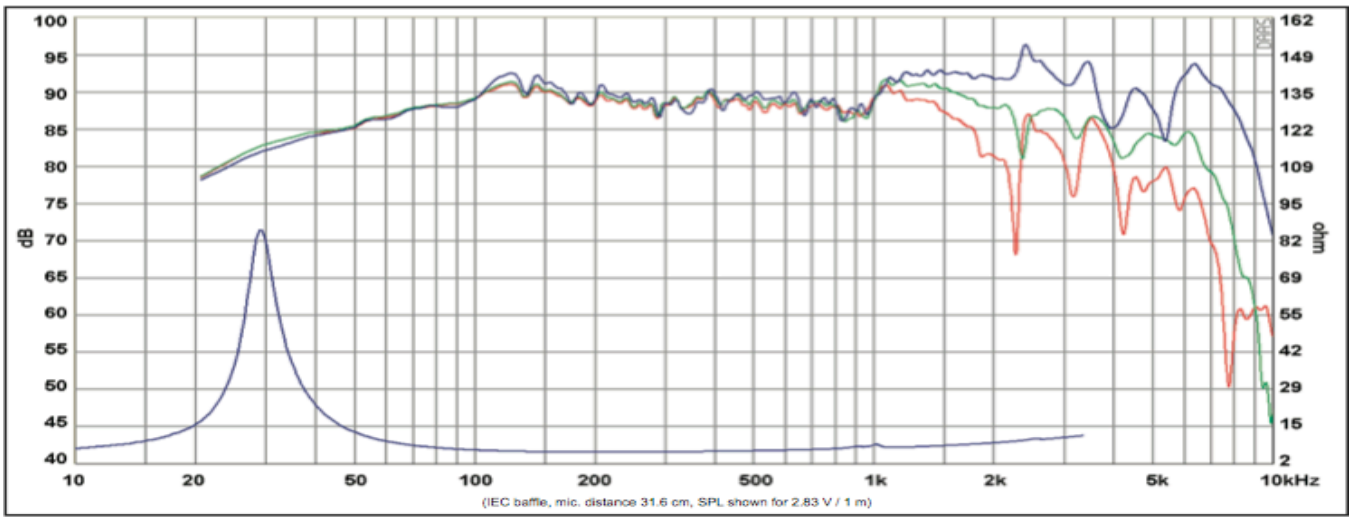


Specs: http://www.sbacoustics.com/index.php/products/tweeters/satori-tw29r/

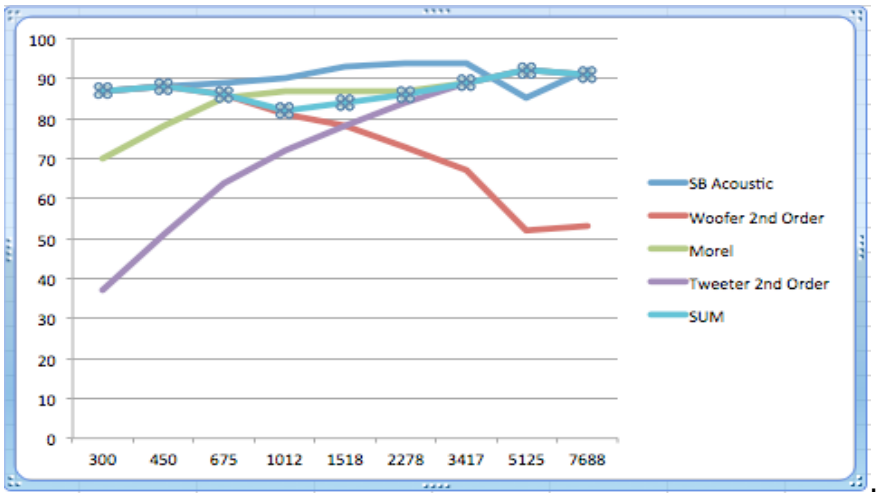
Selected Drivers and Crossover Circuits

I have selected to use the Morel Elite ET488 tweeter with the SB Acoustics SB Acoustics SB23NRXS45-8, 8" woofer.





I will have a second order crossover around 675Hz on the woofer and another second order crossover around 2270Hz on the tweeter. This will produce this frequency response:



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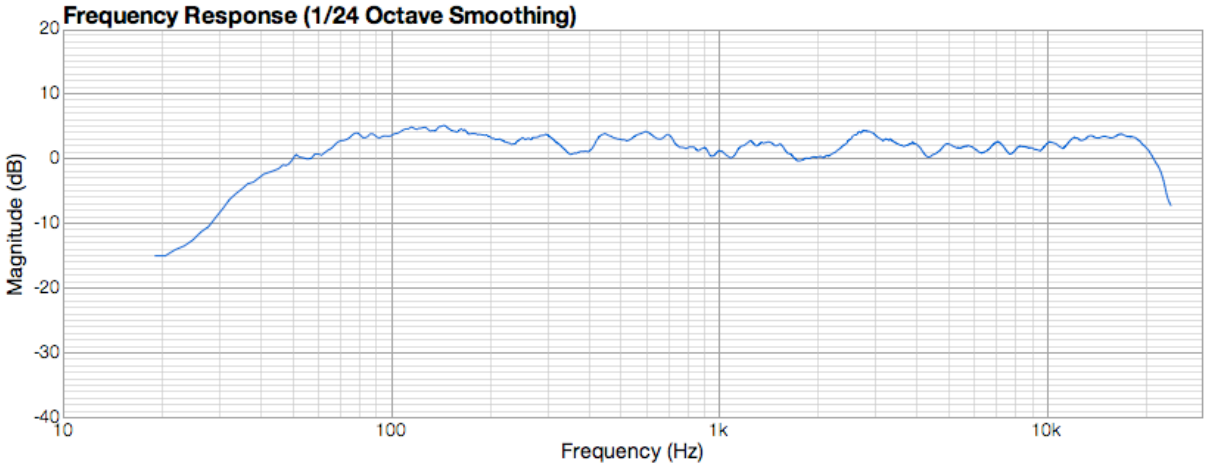
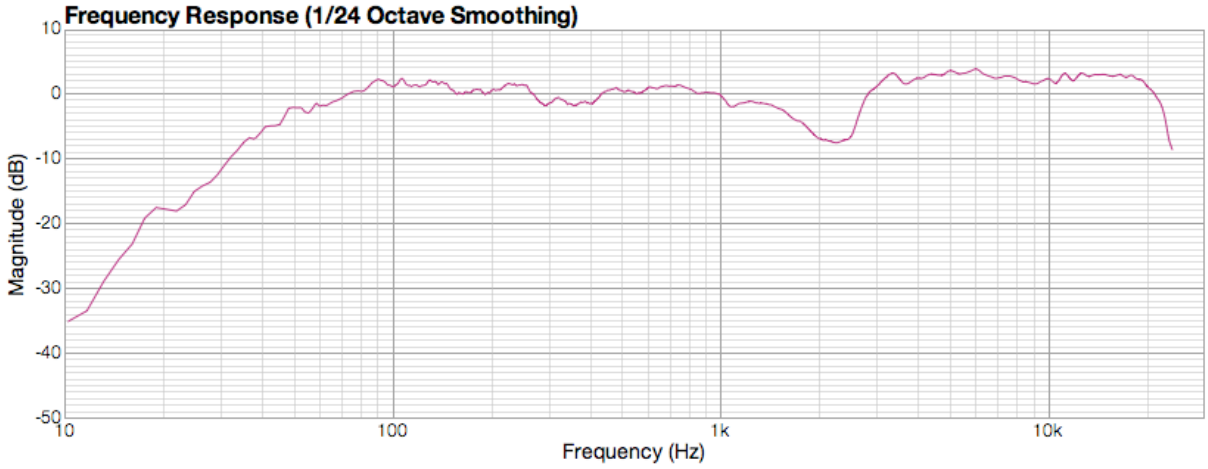
and requires a 20.83 uF capacitor and a 2.67 mH inductor for the woofer and a 6.19 uF capacitor and a 0.79 mH inductor for the woofer. This does not need to level out the impedance because the woofer has a flatter impedance response.

Testing Documentation

I initially tried for a +/- 3 dB response of the overall frequency response. As I mentioned before I did not want any coloration in my speaker. My initial crossover design did not factor in the tweeter naturally being louder than my woofer. When first listening I quickly realized my tweeter was louder and that I was slightly pushing the low end of my tweeter as well(there was distortion near the crossover frequency). I added a simple baffle step correction circuit to try and account for my volume boost but that also brought some of the volume of my woofer down. For my next try I used a simple L-Pad circuit on the tweeter to bring it down 6 dB but that just made the slight dip around the crossover frequency even larger. I went back to the frequency response of the tweeter and noticed that the increased in volume started around 2.5 kHz so I decided to put a shelf filter starting around that frequency. That worked the best and I used a 3-ohm resistor and a 0.1-mf capacitor in parallel. To fix the slight distortion I changed the previously mentioned crossover circuit slightly and ended up with a 18-uF capacitor and a 2.5-mH inductor for the woofer and a 6.8-uF capacitor and a 0.75-mH inductor. This circuit gave me this frequency response.



I then purchased these parts from Madisound and upgraded some components with higher quality crossover parts. I did not change the values but ended up with a different frequency response

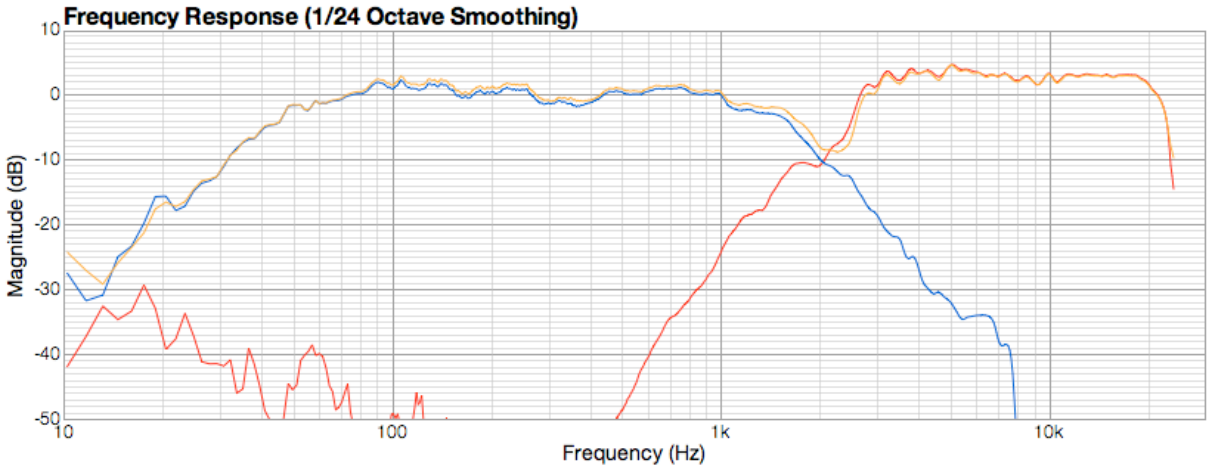


In listening with the new crossover the large dip at 2K just made the overall sound appear less harsh then before. It was not that noticeable but I would like to experiment with the crossover more to make these more viable mixing speakers.

Overall Loudspeaker Performance

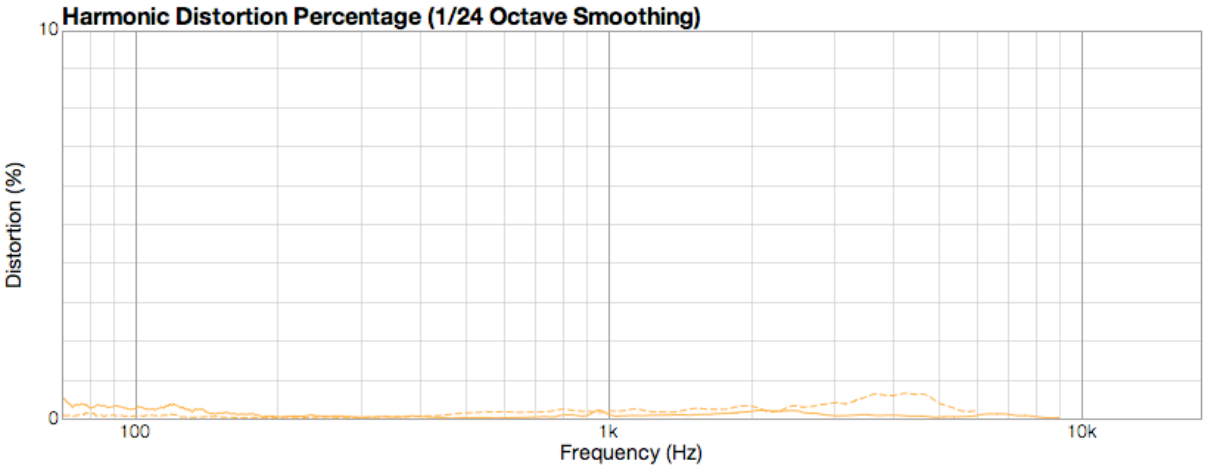
All measurements were taken at 16 inches away from the midpoint between the drivers in a 4646 square foot black box theater.

Integrated Frequency Response

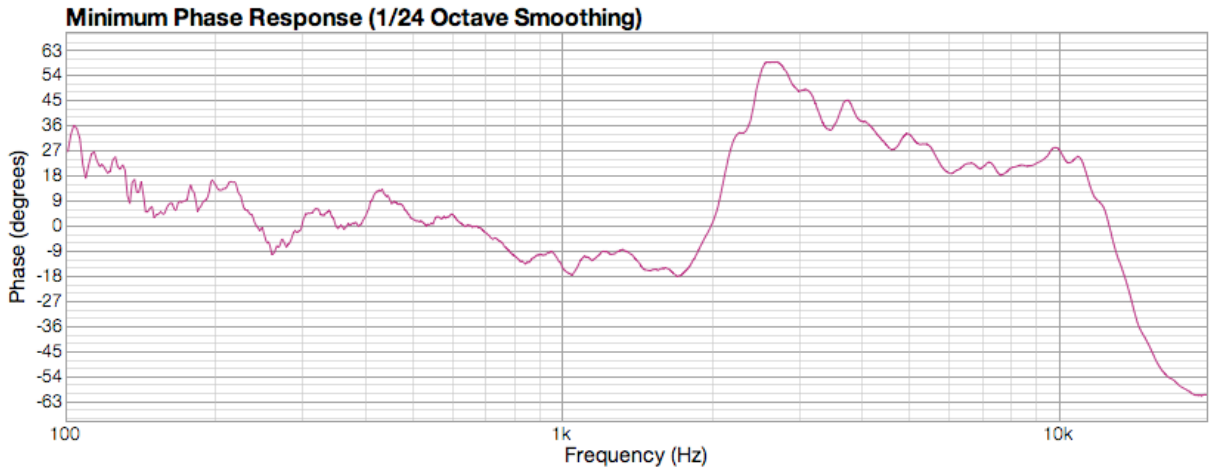


Blue = Woofer, Orange = Tweeter, Yellow = Full Range

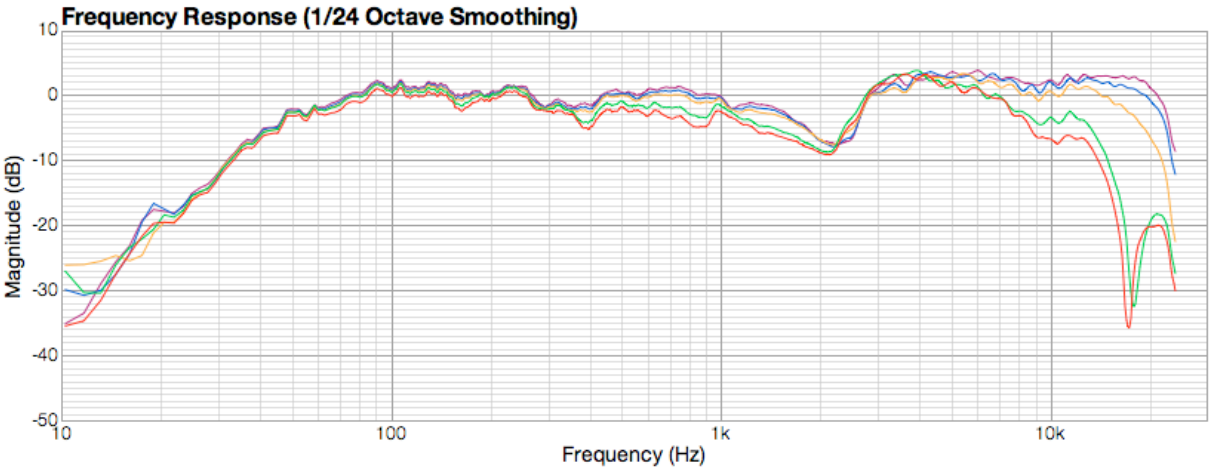
Harmonic Distortion



Minimum Phase

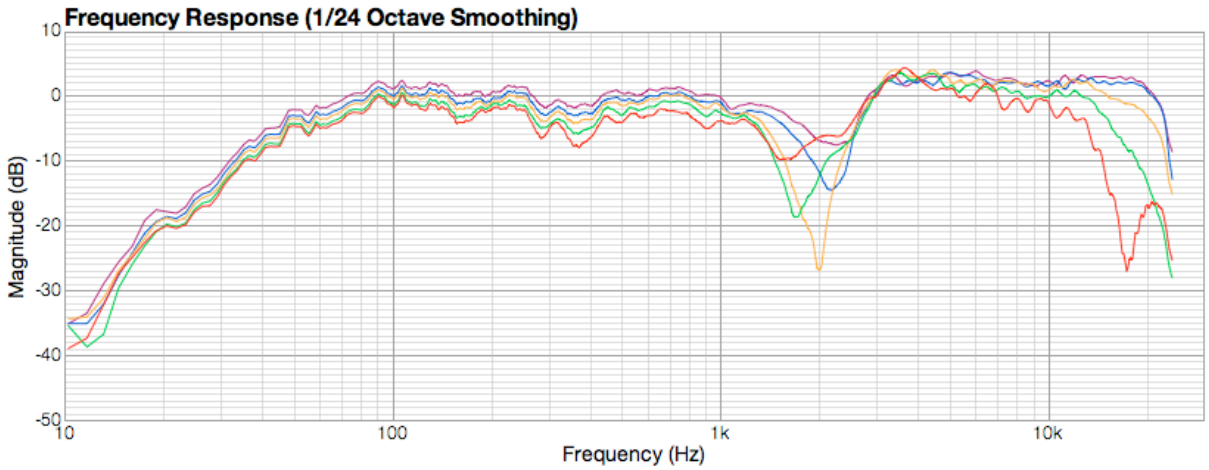


Horizontal Off-Axis



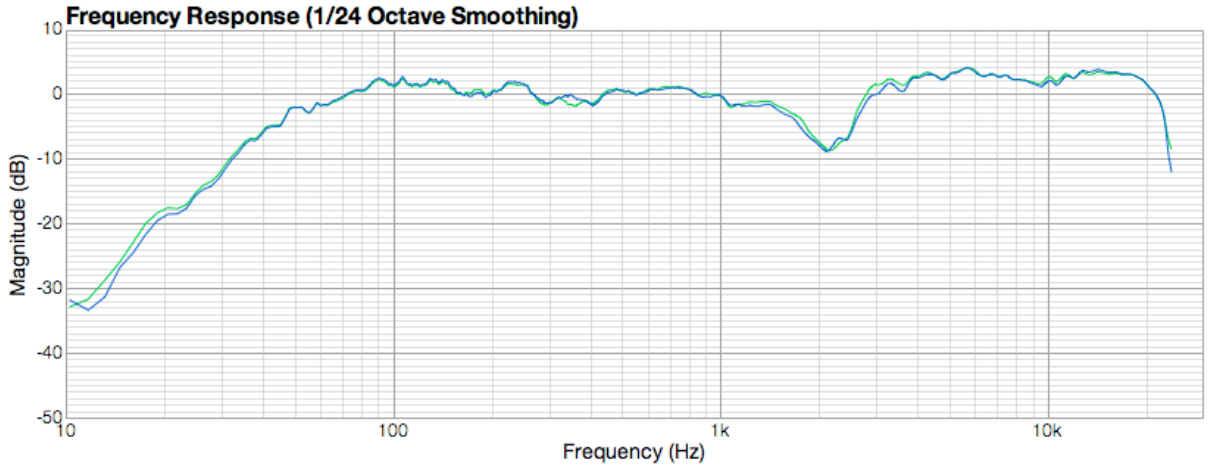
Blue = 15°, Yellow = 30°, Green = 45°, Red = 60°

Vertical Off-Axis



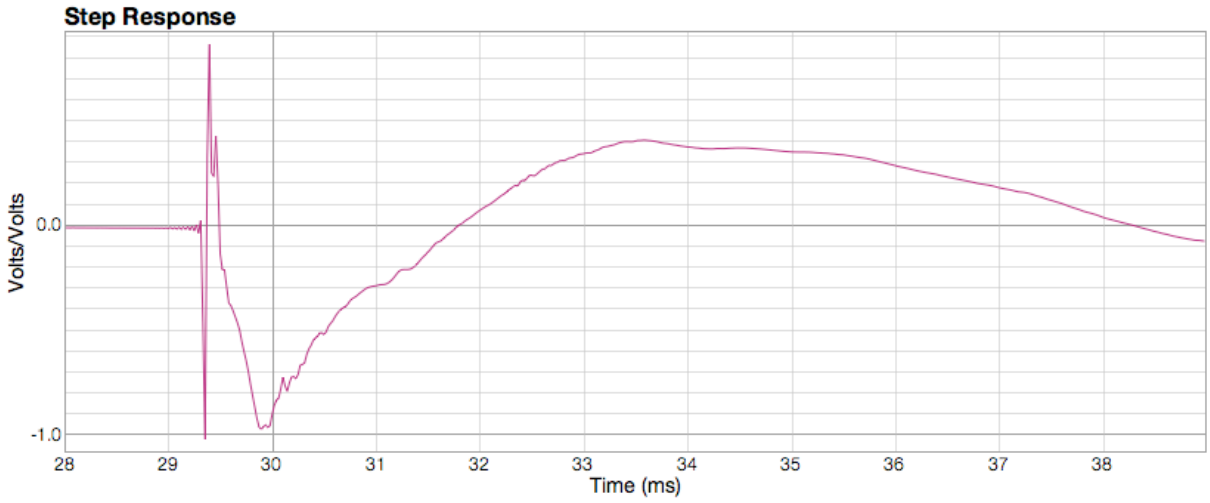
Blue = 15°, Yellow = 30°, Green = 45°, Red = 60°

Difference Plot

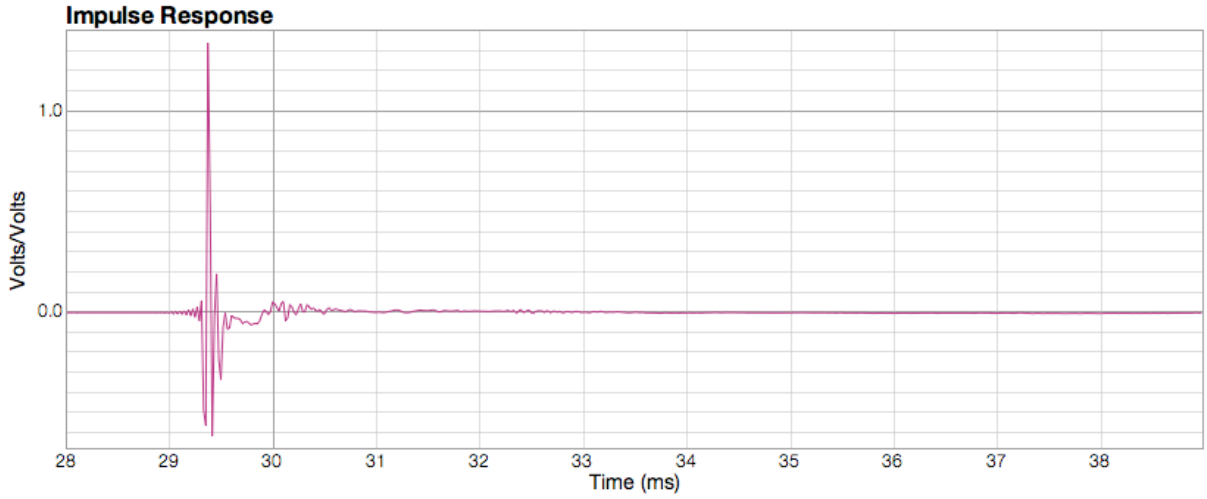


Blue = Left, Green = Right

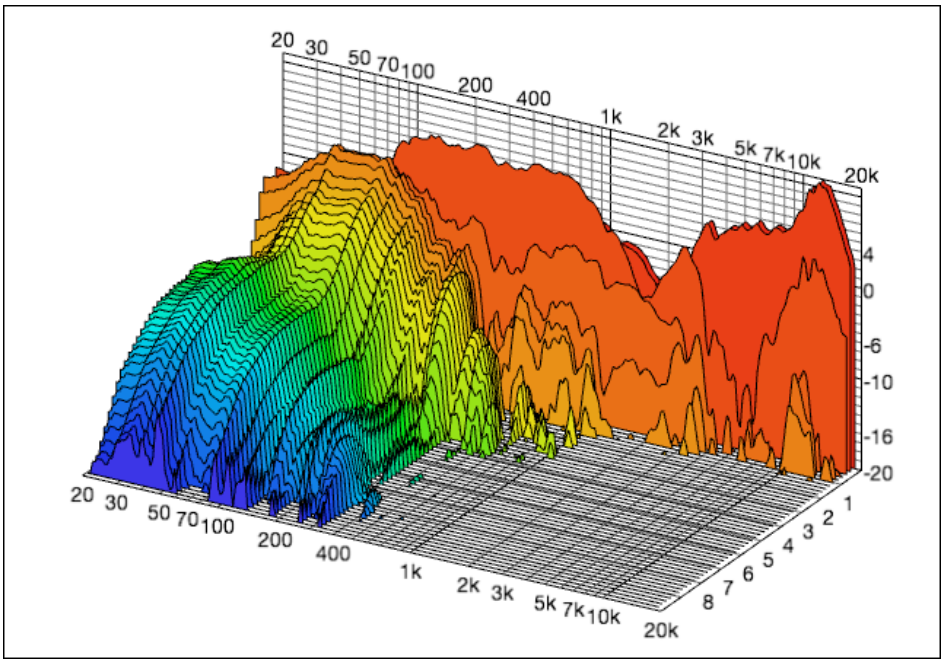
Step Response



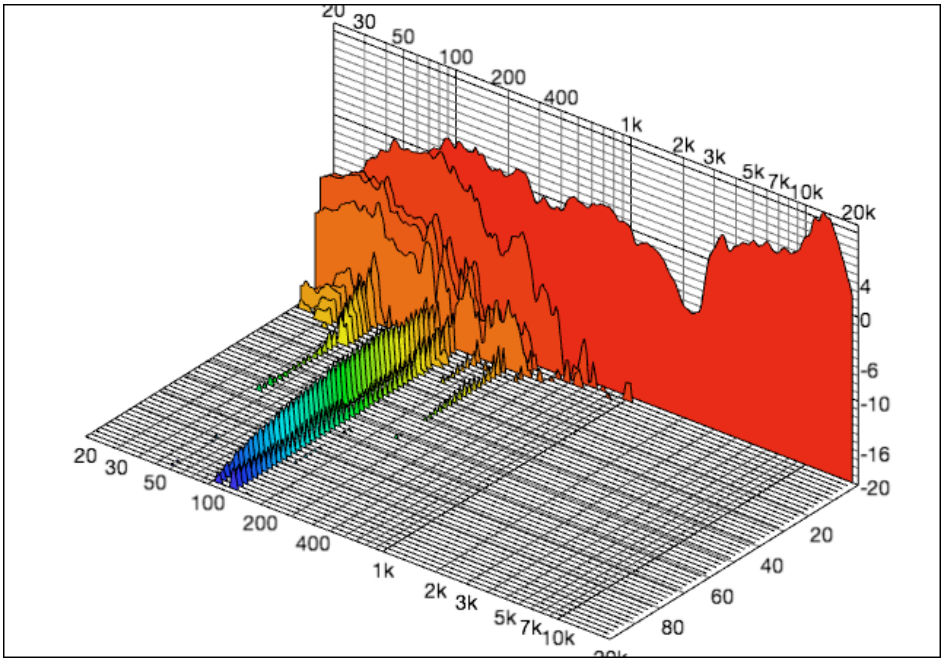
Impulse Response



Waterfall Plot



10ms



100ms

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