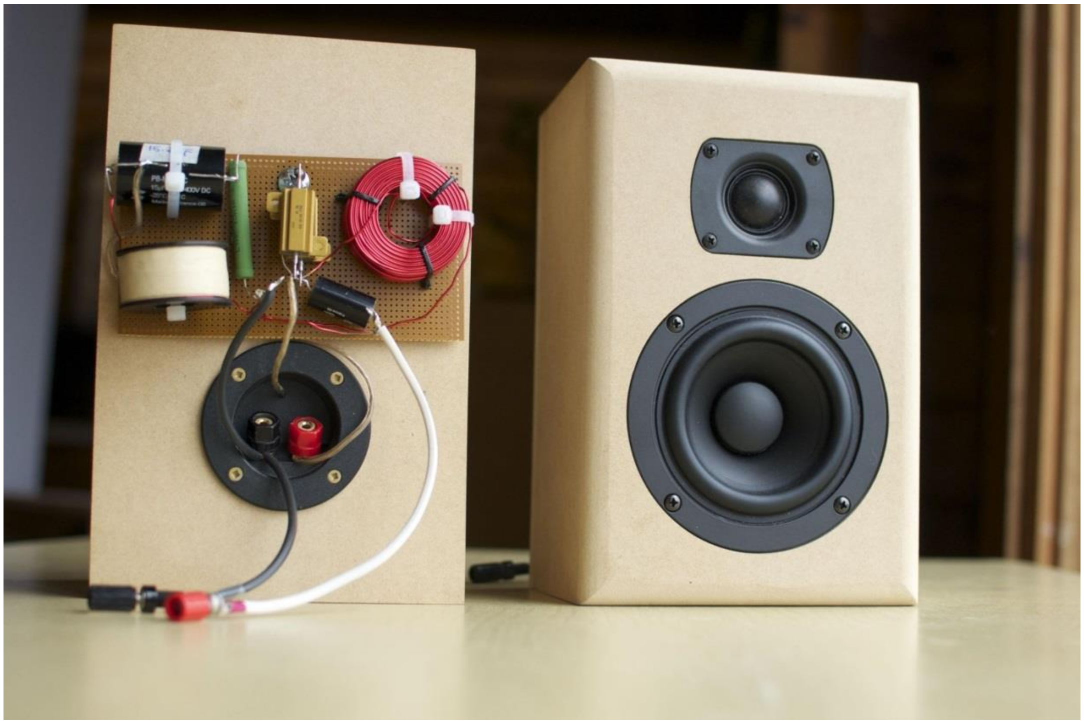
The Napoleons

Small Speakers that punch above their weight



The Napoleons are a small DIY loudspeaker designed to deliver a natural tonal balance and clean loud playback from of a small box optimized for small reflective rooms, but still perform well in larger spaces, at a reasonable price. This write up was in response to requests from the 2013 Ottawa DIY fest, where the speaker was first shown http://www.diyaudio.com/forums/clubs-events/223294-diy-ottawa-winter-2013-a-17.html

Driver Selection

Off axis response irregularities will detract from speaker tonal balance more in a small room than in a large room due to the greater relative strength of indirect sound, compared to direct sound. To help combat this, a tweeter was chosen with some mild horn loading, and a woofer with a well-controlled extended higher frequency response that could take advantage of it.

The Tang band W4-1720 (http://www.parts-express.com/pe/showdetl.cfm?partnumber=264-872) provides powerful and clean mid to upper bass from a very small sealed box. A vented design was avoided to keep the box small and to avoid box/vent unloading which would compromise the high sound pressure levels desired for larger rooms. The mighty little W4-1720 plays ridiculously loud and clean in this application, and mid to upper bass is rich enough to give a pleasant tonal balance. It's smooth mid treble allows a higher crossover point so the tweeter can play loud without strain. This is a good sounding driver and non-fatiguing, but it can still be made to bottom when over driven by drum test discs. Still, it plays clean and loud enough to pass the "I didn't realize it was playing that loud" test.

It is also used successfully with an external subwoofer to create a nice full-bandwidth system.

The tweeter is the Vifa D26NC55-06. It's well-controlled off axis response near crossover and its drooping high frequencies off axis avoid over-cooking the top end in a small reflective room. Its distortion is also very low.

http://www.zaphaudio.com/offaxis.html
http://www.zaphaudio.com/oldversions/

While this driver is officially NLA, examples can often still be purchased from on-line suppliers.

This driver's main challenging is balancing on an off axis response it begins to beam quickly off axis.

Box Dimensions

The sealed box is simple and was built using hand tools and a flush trim bit. Half inch mdf kept the box small which in turn keeps panel vibration under control. The box was made shallow to allow true shelf mounting, which is how I use it daily. Woofer center is 3.5" from bottom, tweeter 7.5". Drivers are centered horizontally.

A different baffle shape (for example due to thicker wood) would change diffraction and affect the response. This could require a crossover change and this design is expressed for 0.5" wood only.

Bracing				
Width	Length	Depth	Qty/spkr	
5 1/2	9	0.5	0	Full length
5 1/2	4 1/2	0.5	0	Shelf

Wall Thickness (Inches)			
Front	Rear	Top/Bottom	Sides
0.5	0.5	0.5	0.5

Outside Box Dimensions (Inches)			Internal Volume	
Width	Height	Depth		
6 1/2	10	5 1/2	3.65	liters

Driver Height		Relief
		drv - drv
Drv 1	3 1/2	4

Bill of Materials	For	2	Speakers	
	Width	Height	Thickness	Qty
Front/Rear Baffles	6 1/2	10	0.5	4
Side Panels	4 1/2	10	0.5	4
Top/Bottom Panels	4 1/2	5 1/2	0.5	4
Bracing	9	5 1/2	0.50	-
Total Sq.ft	3.7	(5x8 Sheet is 40sq ft - 60"x96")		

The prototype has an externally mounted crossover, but of course this can be mounted in the box behind the tweeter. There's no room behind the woofer for the crossover. You can increase the depth by about a quarter inch to compensate for the crossover part volume, but it's not critical.

Bass Alignment

The measured W4-1720 parameters (closed box method) were:

SN034	SN 103
55.325 "Fs Hz"	59.776 "Fs Hz"
4.100 "Re Ohms"	3.900 "Re Ohms"
18.323 "Res Ohms"	17.782 "Res Ohms"
2.308 "Qms "	2.454 "Qms "
0.516 "Qes "	0.538 "Qes "
0.422 "Qts "	0.441 "Qts "
0.149 "L1 mH"	0.142 "L1 mH"
1.007 "L2 mH"	1.111 "L2 mH"
1.515 "R2 Ohms"	1.742 "R2 Ohms"
0.227 "RMSE-load Ohms"	0.218 "RMSE-load Ohms"
57.00 "Area (Sd)"	57.00 "Area (Sd)"
4.222 "Vas liters"	3.430 "Vas liters"
8.944 "Mms(Sd) grams"	9.431 "Mms(Sd) grams"
925.213 "Cms(Sd) æM/Newton"	751.665 "Cms(Sd) æM/Newton"
4.969 "Bl(Sd) Tesla-M"	5.066 "Bl(Sd) Tesla-M"
83.242 "SPLref dB "	83.167 "SPLref dB "

These measurements were taken with several watts input power and are therefore not true "Thiele-Small" parameters, but I find this is a better representation of perceived box tuning at real playback levels.

The compliance and Fs differed for the two woofers. This may be due to batch to batch variation given the difference in serial numbers. By using a sealed design, the differences in the final system response are immaterial due to these driver production differences. The design is also insensitive to small changes in box depth. For example, adding 1" greater depth has no impact on F3.

	SN034	SN103	SN103	
Physical Vb	3.3	3.3	4.3	l
Absorption, Qa	20	20	20	
Leakage, Ql	30	30	30	
Alpha, a	1.206	0.971	0.745	
Vb	3.5	3.5	4.6	l
Fb	82.06	83.89	78.94	Hz
F3	85.51	85.51	85.51	Hz
Qtc	0.664	0.688	0.648	
Response peak	0.00	0.00	0.00	dB
Peak at	none	none	none	

The above alignments are with an 18 gauge air core low pass inductor. A 20 gauge inductor would reduce woofer sensitivity by 0.3 dB and F3 by 4 Hz. Larger gauges give slightly (0.3 dB) more woofer sensitivity. Neither has been auditioned and there is no inherent value to a larger gauge inductor in this application. 18 gauge is recommended.

The box was lightly stuffed with audio poly.

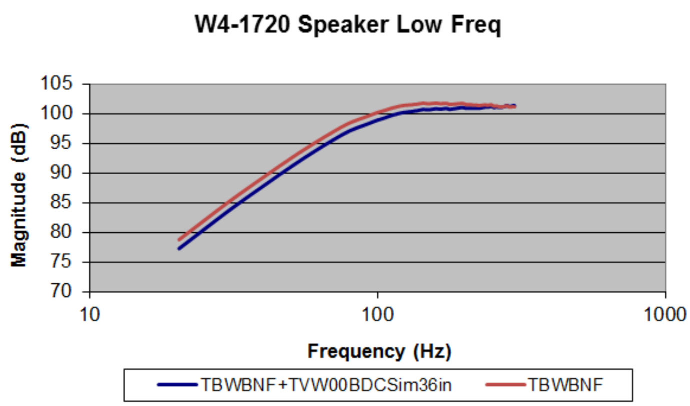
Low Frequency Response

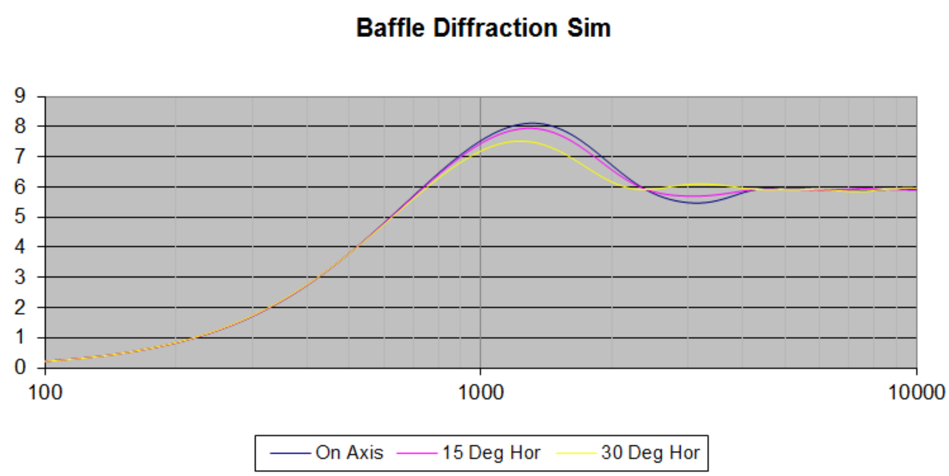
The box alignment was verified by splicing the near field woofer response to the box diffraction. See my tutorial at http://audio.claub.net/software.html for details.

Stereophile and a number of on-line designs don't adjust the near field response for diffraction when splicing but the following graph illustrates that without adjusting for diffraction, the predicted response would have been about 1.4 dB in error too high at frequencies below 100Hz.

The actual system tonal balance would be very different than predicted by the composite curve because the curve would have been inaccurate.

The second curve shows how the diffraction signature varies with observation angle.

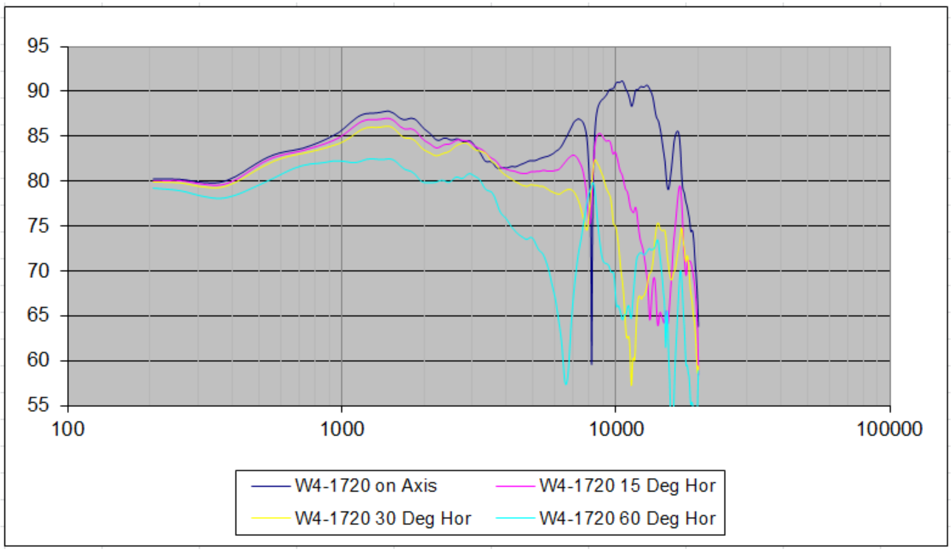




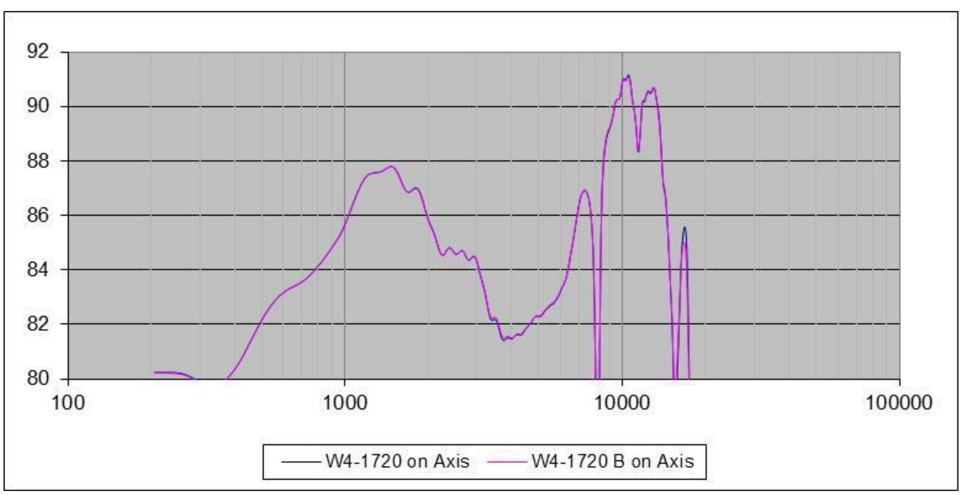
Woofer Frequency Responses

A predictable design approach relies on having accurate driver measurements in box. Quasi anechoic measurements of the W4-1720 were taken above 200 Hz at several angles, and then spliced with the modeled low frequency alignments (unique at each angle) described earlier. Horizontal angles are shown, but +15 degrees was also measured to calculate the response perceived while standing in front of the speaker.

The frequency of the cone's high end notch varies over angle. Since the design is meant to work well in small lively rooms, a smooth off axis response is important to avoid perceived tonal imbalances. It's best to have the response above 4 kHz reasonably well attenuated to avoid significant off-axis anomalies.

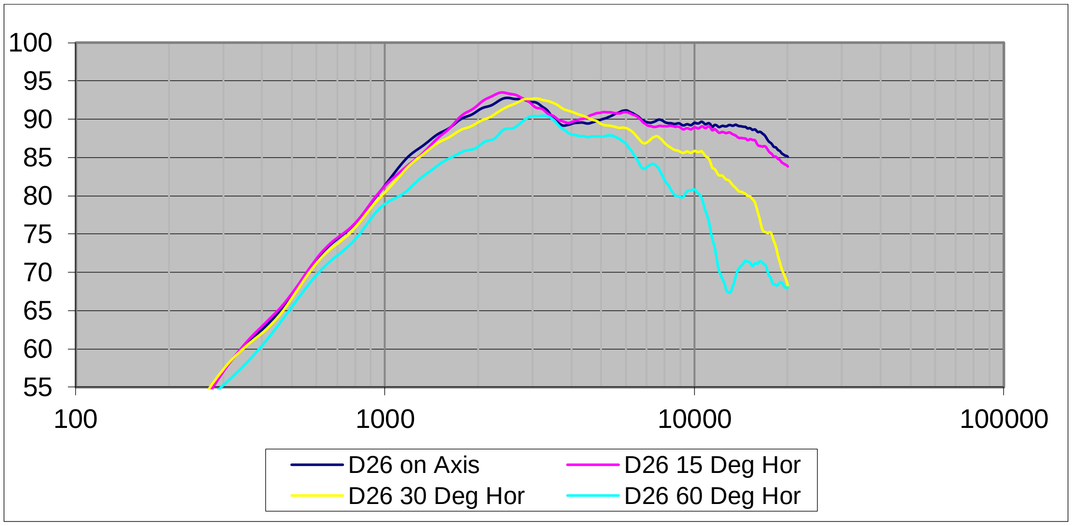


Production consistency was excellent, as shown by the overlay of the two drivers on axis, below. This also validates the consistency of the measurements.

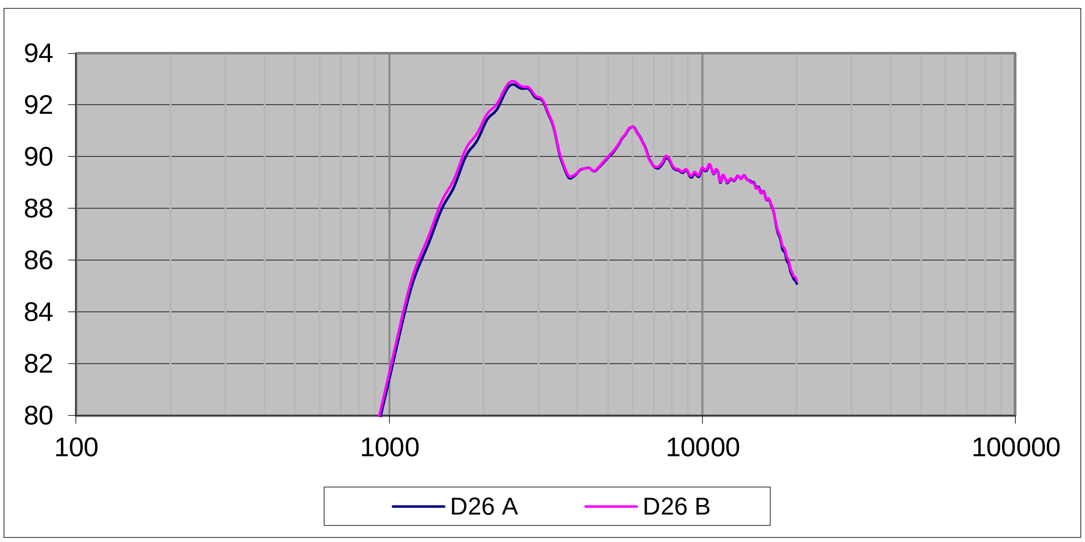


Tweeter Frequency Responses

The D26NC55 was chosen for its well-controlled response and the mild horn loading which controls off axis dispersion. One of its defining traits is how quickly the high frequencies roll off off-axis but this was a desired trait to help avoid an imbalanced tone in a small reflective room, given the design's modest bass response. Another way to think about it, it allows a flattish on axis response (accurate) without overloading the room with high frequencies. It does make the crossover a bit of a challenge though.



Like the woofer, the two tweeters were nearly identical in response



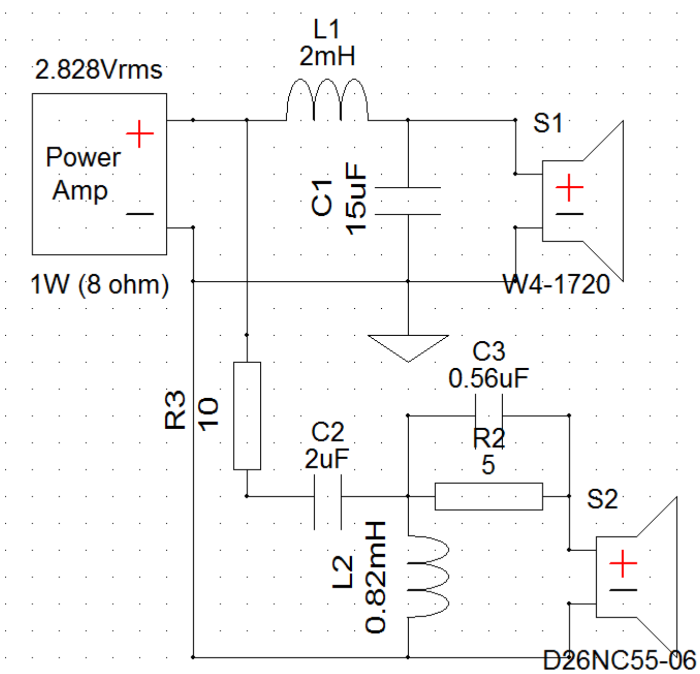
Crossover and Frequency Responses

The crossover is a 7 element second order electrical, in phase driver connection. Special attention was placed on smooth on and off axis response, and a smooth response when standing while listening.

The initial published designs were very good in a large room but I felt could be a bit "hard" on poorly recorded material in a small lively room. This update adds more baffle diffraction compensation and so adds a bit more bass energy around 100Hz, but results in a much more open mid-range. It also adds 5 dB more rejection of woofer break up, which is believed to also contribute to the more open sound.

Low pass
L1: 2 mH inductor, 1.0 ohms dc resistance (e.g. Solen 20 gauge air core).
C1: 15 uF cap (not electrolytic)

High Pass
C2: 2 uF cap (not electrolytic)
L2: 0.82 mH inductor, 0.43 ohms dc resistance (e.g. Solen 18 gauge air core; 20 gauge (0.63 ohm) could be used to as well with no real difference)
R3: 10 ohm resistor, high power (25W or greater)
R2: 5 ohm resistor, high power (25W or greater)
[There is no R1, but due to a bug in Xsim, resistors were not relabelled by the program]
C3: 0.56 uF. This provides a bit of high frequency lift, benefitting off axis

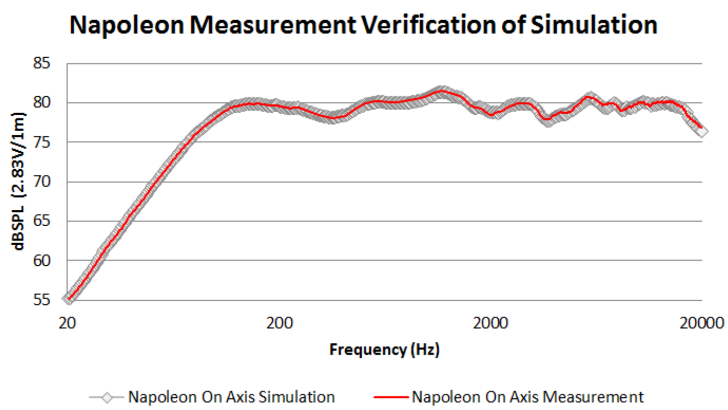


No special treatment for low inductance resistors is necessary. For example, the inductance of a Vishay RH-25 was found to reduce 10 kHz by only 0.03 dB.

Low cost air cores were chosen for their small size without iron core's potential for saturation induced distortion.

The system reflection-free frequency responses in the graphs following were created by measuring the unfiltered individual driver frequency responses in box at each observation position, and then simulating the crossover via Xsim (using measured driver impedances, in box).

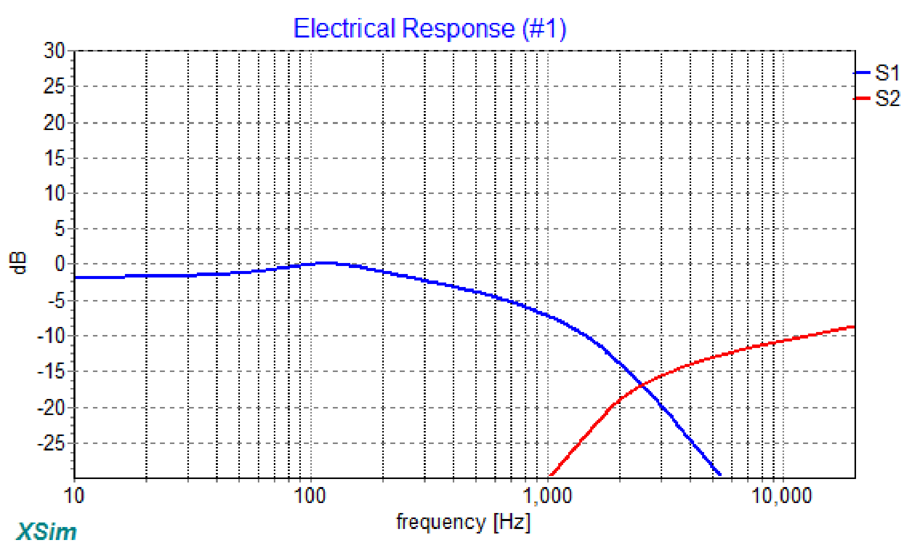
To verify the simulation accuracy, an on-axis measurement of the completed system (Appendix I crossover) was taken and compared to simulation. As shown following, the simulations are effectively dead-on accurate, validating the design approach.



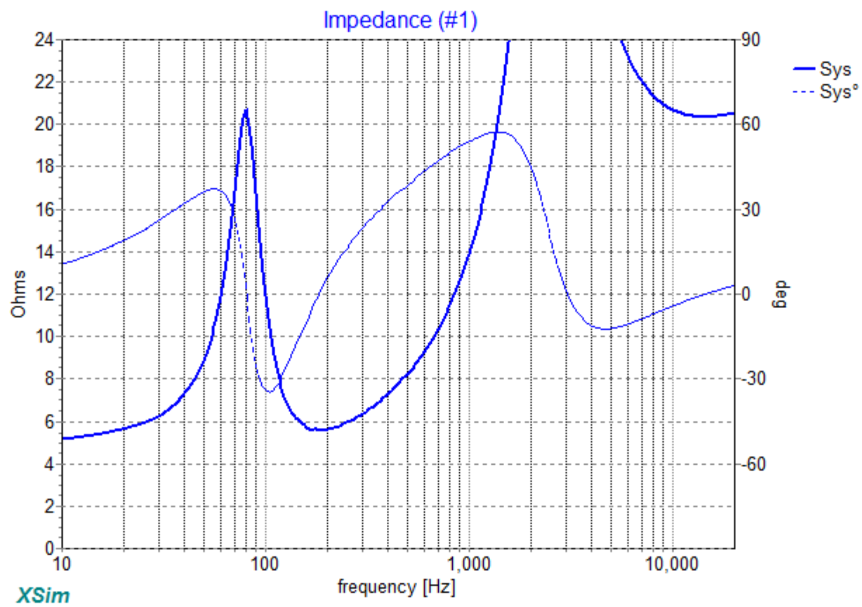
These can be considered highly accurate reflection-free responses. All sensitivities following are at 1 meter, 2.83V.

<u>Filter Electrical Response loaded by the drivers and the System Impedance</u>

Filter shapes were chosen for as high a crossover point as possible while maintaining a good off axis response, acceptable rejection of woofer break up, a good tonal balance standing up, and minimizing off axis tweeter contribution around crossover.

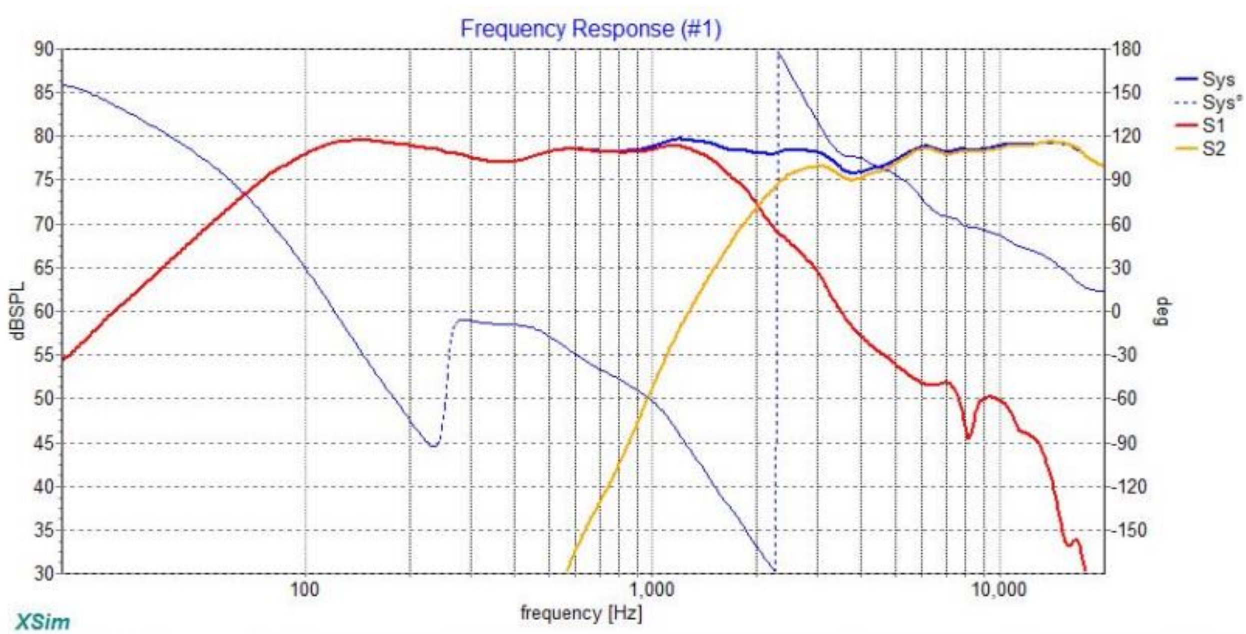


Electrical System Impedance is an easy drive even for chip amps as it never dips below 5 ohms, and never gets too capacitive.

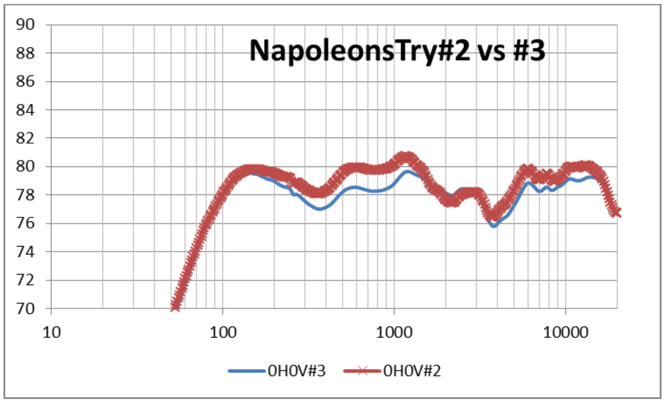


On-Axis

On axis may be a small bit too "hot" for some in near field listening, but works very well in large or damped rooms.

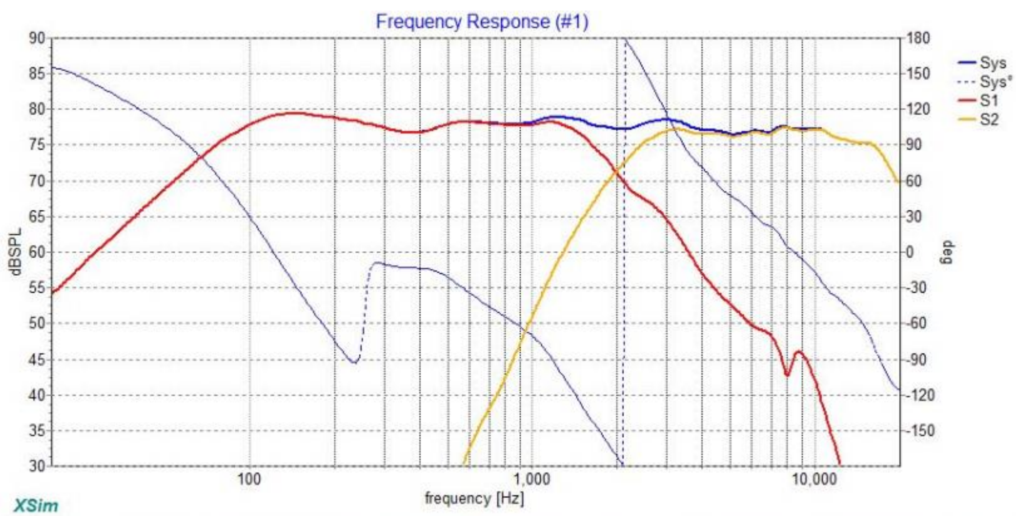


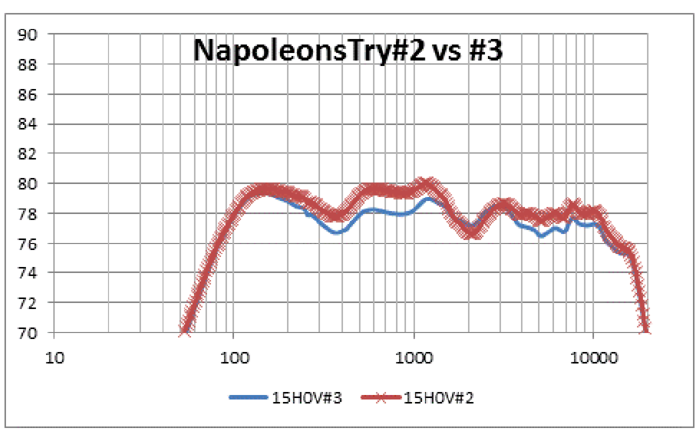
The following illustrates the differences on axis between this crossover and the previous iteration as found in Appendix II. "#2" is previous iteration, "#3" is this crossover.



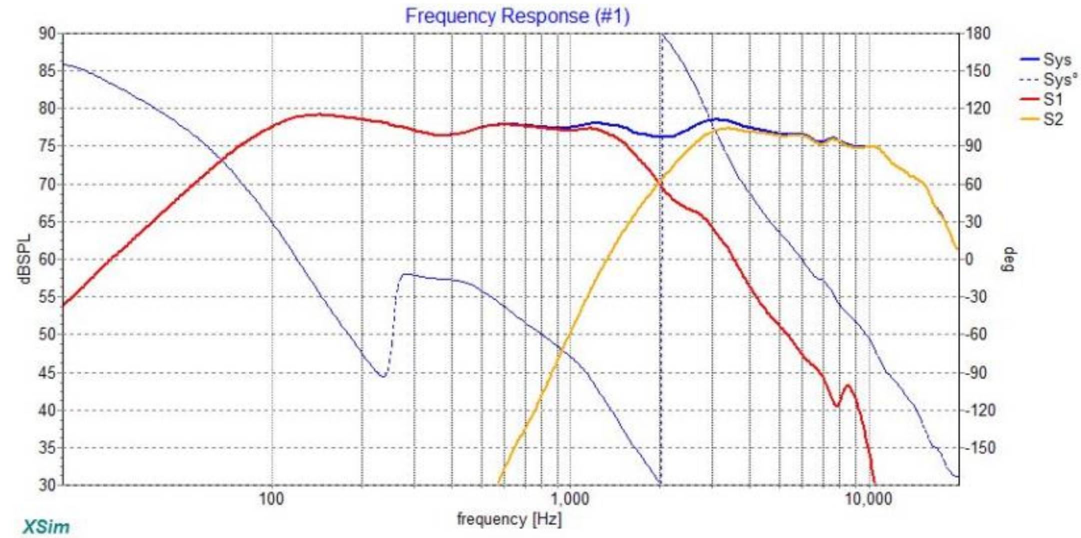
15 Degrees Horizontal

It's recommended that the speaker be toed in, pointing in front of the listener, so to be listening off axis at 10 to 15 degrees. The response is optimized for this angle. In a small reflective room, this toe in also stabilizes the central image and reduces tonal anomalies from side wall reflections.

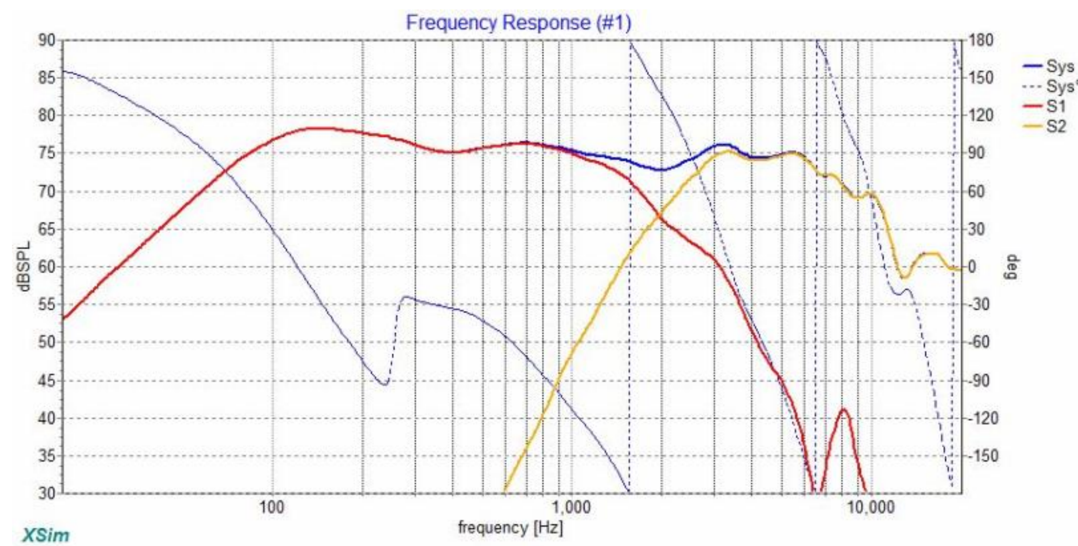




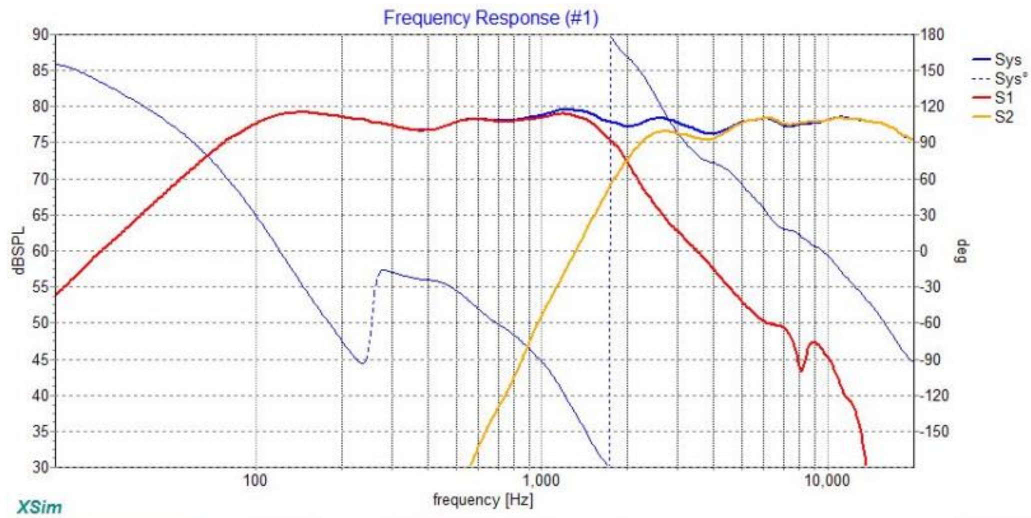
30 degrees Horizontal



60 Degrees Horizontal



+15 Degrees Vertical (represents "listener standing")



On Axis Reverse Null