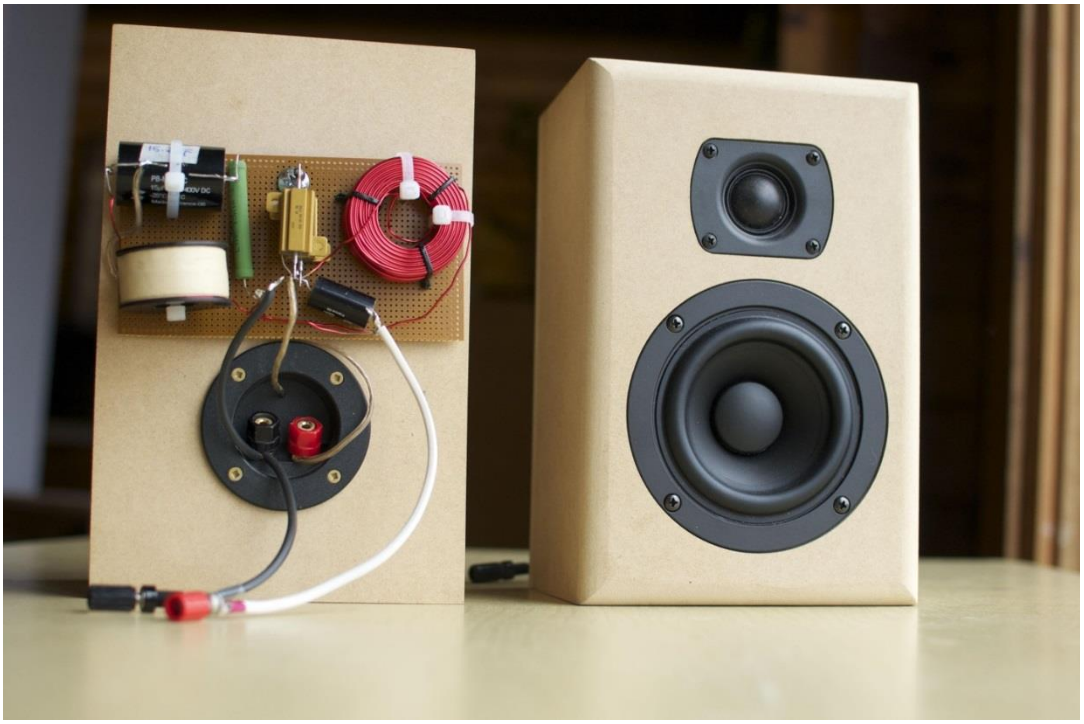
The Napoleons

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's 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 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 and off axis response, as 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	

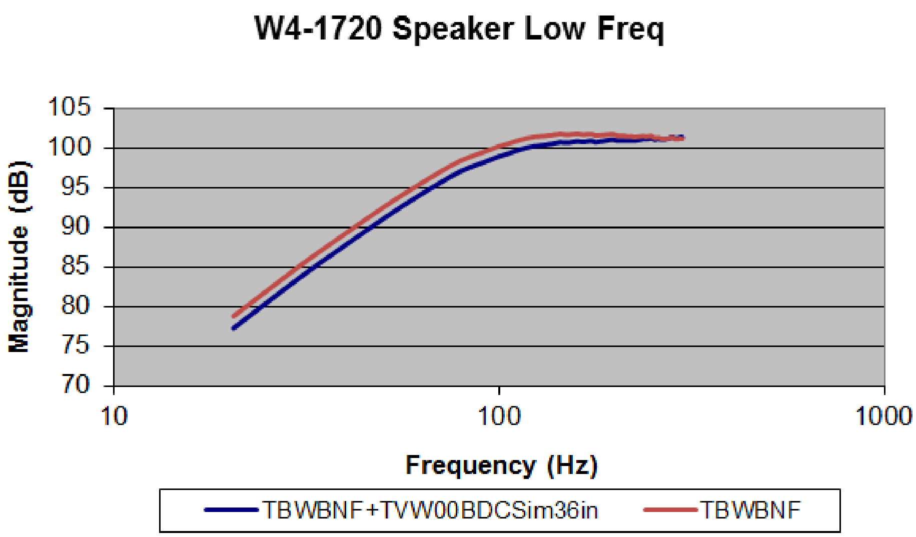
The above alignments assume 0.7 ohms dc inductor resistance, to keep crossover costs down. The 20 gauge inductor used in the final crossover reduces woofer sensitivity by 0.3 dB and F3 by 4 Hz.

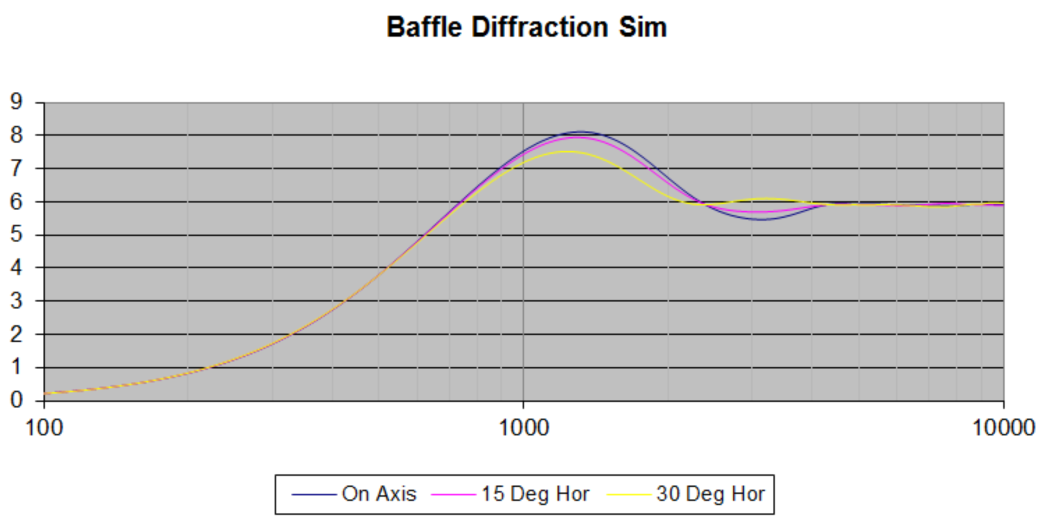
The box was lightly stuffed with audio poly.

Low Frequency Response

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

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

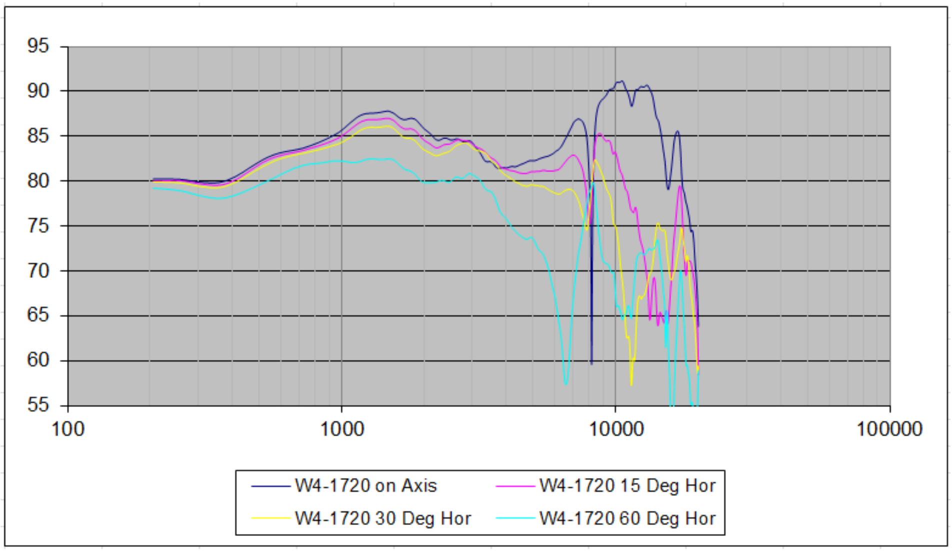




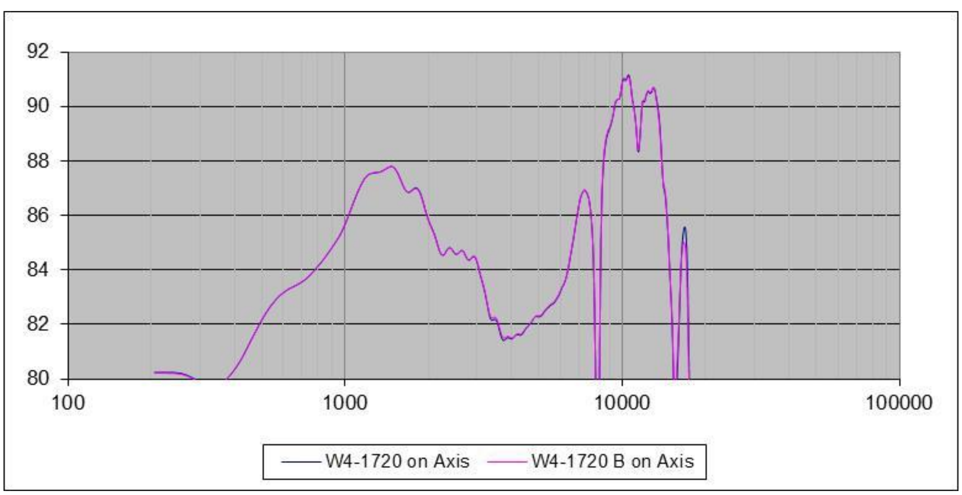
Woofer Frequency Responses

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 (at each angle) described earlier. Horizontal angles are shown, but +15 degrees was also measured to calculate the perceived response 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.

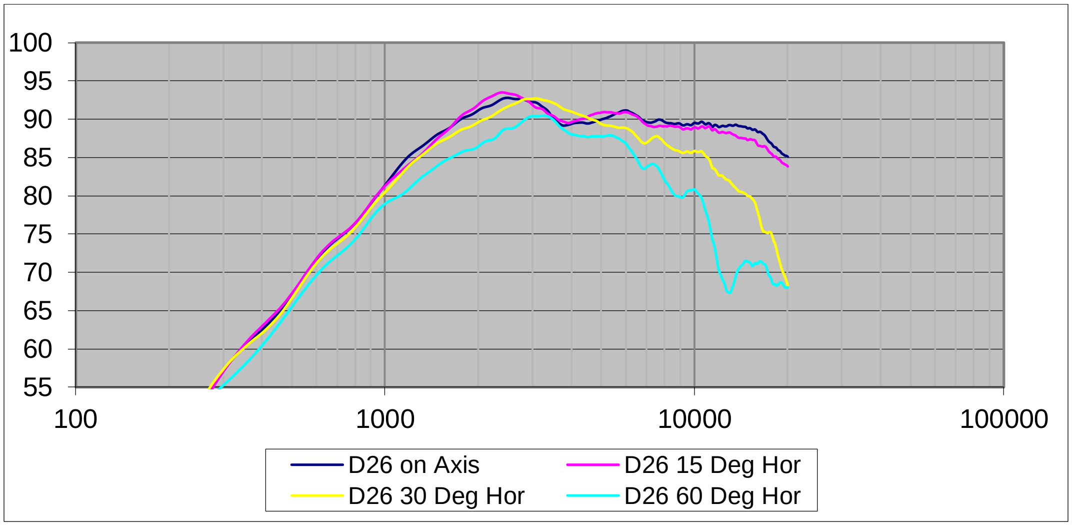


Production consistency was excellent, as shown by the overlay of the two drivers on axis, below. This also validates the consistency of the measurements.

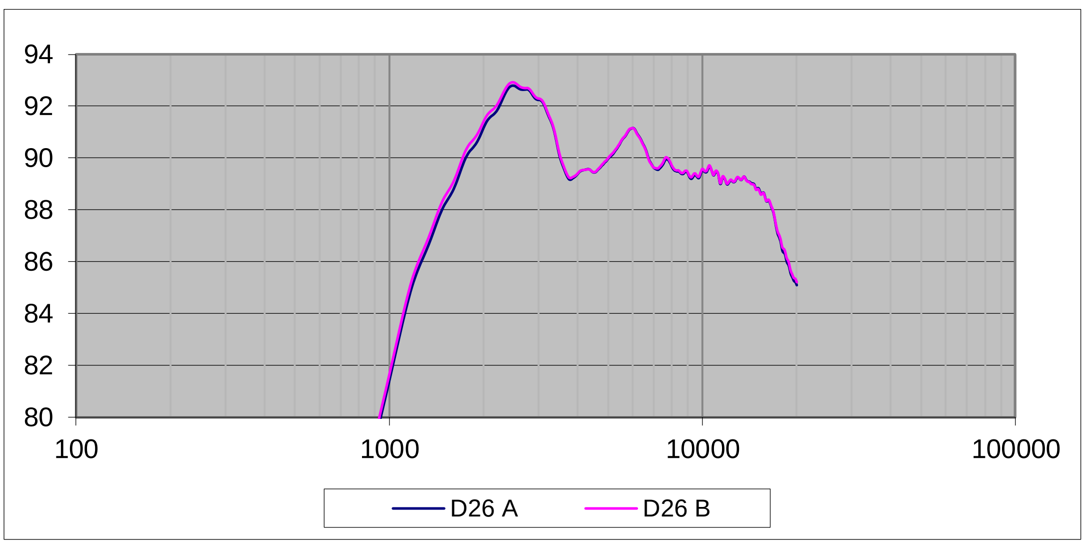


Tweeter Frequency Responses

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.



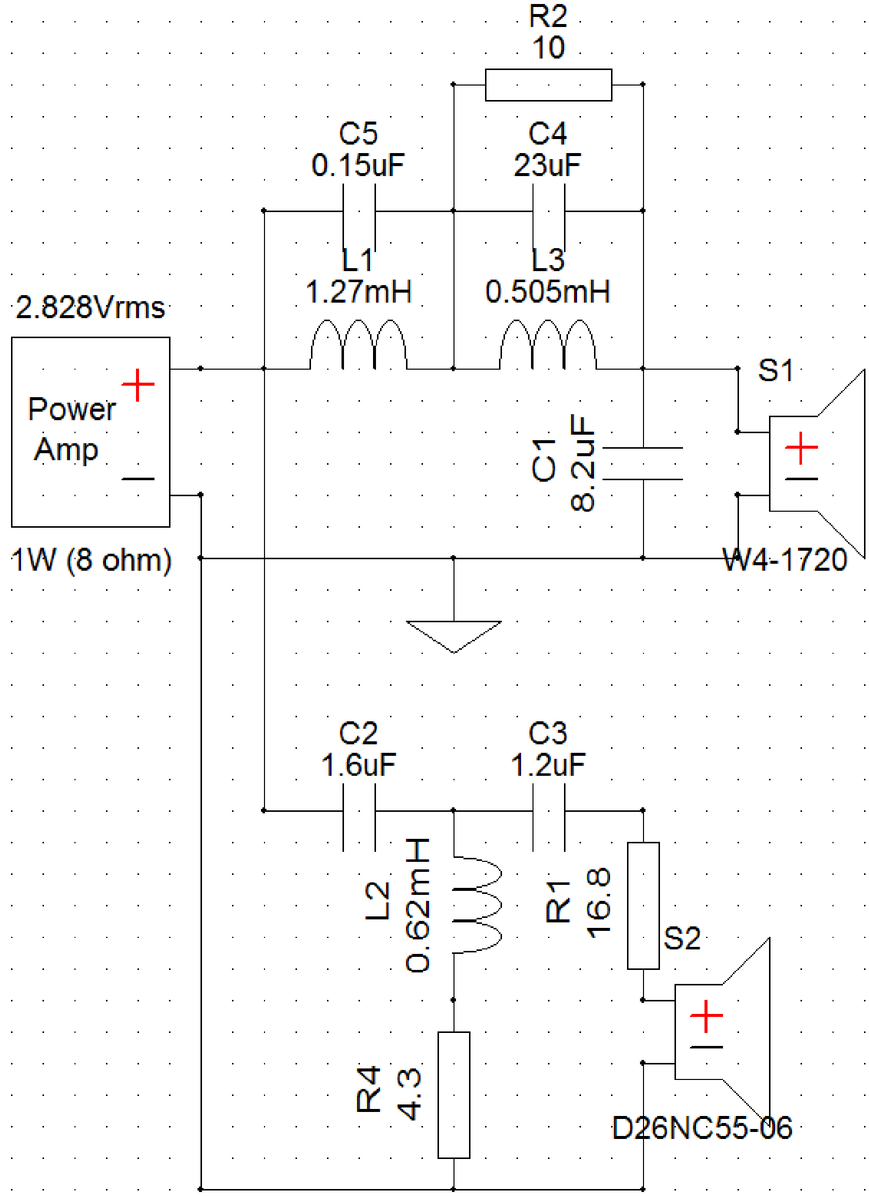
Like the woofer, the two tweeters were nearly identical in response (in box before eq).



Crossover and Frequency Responses

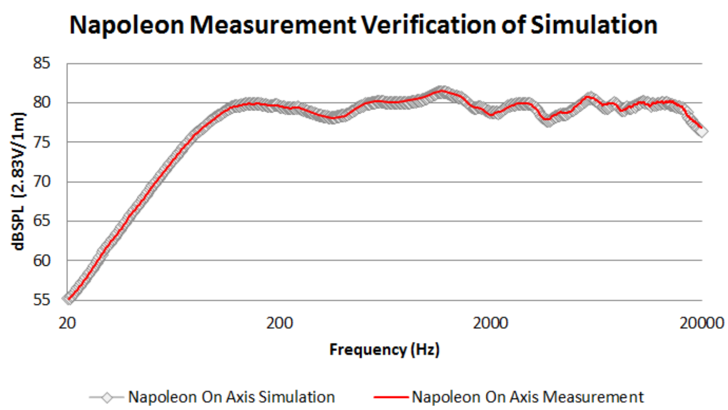
Earlier iterations of the design are shown in Appendix I – III, illustrating the thought process and steps used in voicing, and might be interest. This crossover is final, increasing tweeter power handling and making design completely free of any fatigue even over all-day listening.

Low cost air cores were used:
L1: 0.7 dc ohm
L2: 0.36 dc ohm
L3: 0.37 dc
[There is no R3, but due to a bug in Xsim, resistors were not relabelled by the program]



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.

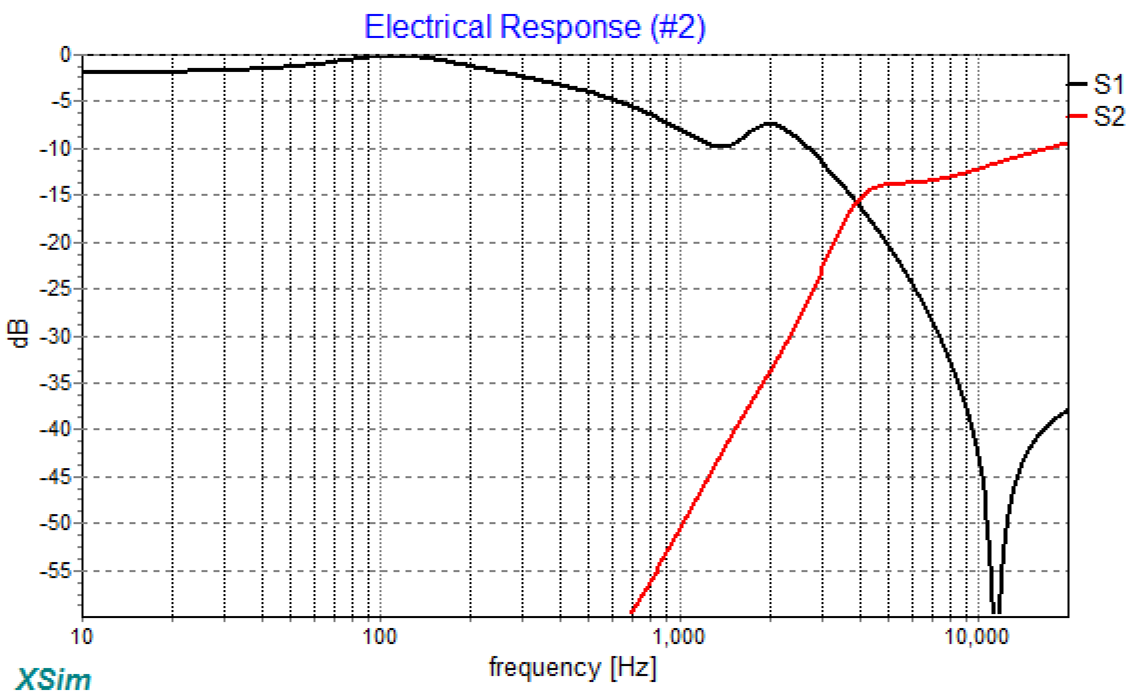


These can be considered highly accurate reflection-free responses. All sensitivities following are at 1 meter, 2.83V. Measurements were taken in 15 degree increments 0 to 90 degrees off axis horizontal, and 0 & 15 degrees off axis vertical to be used in crossover design. A few examples follow to help explain some of the crossover choices made.

Filter Electrical Response loaded by the drivers

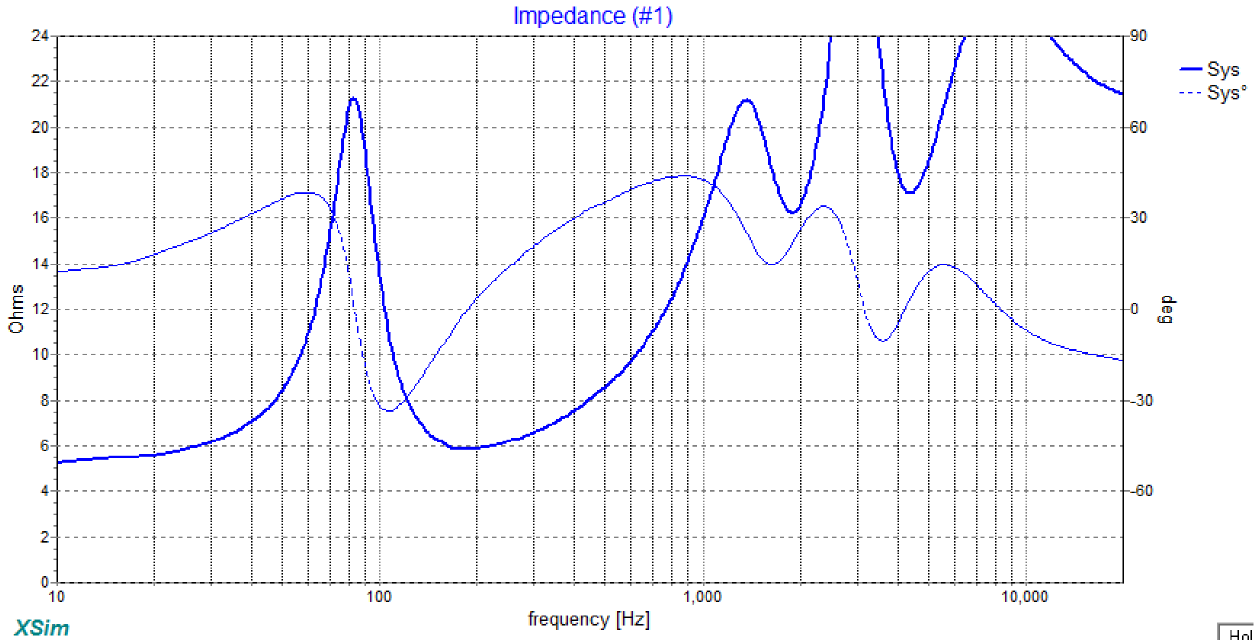
Filter shapes were chosen for as high a crossover point as possible while maintaining a good off axis response, acceptable rejection of woofer break up, a good tonal balance standing up, and minimizing off axis tweeter contribution around crossover. A few special needs for these drivers:

- In the final crossover iteration, a notch was added to remove the woofer's break up ~ 10kHz, and this made the sound notably clearer and more open. The W4-1720 has poorly behaved break up as evidenced by the very different high frequency responses off angle.
- The woofer's native response peaks at 1 to 2 kHz and needs to be suppressed.
- Based on subjective listening, the tweeter does not handle power well, and needs to be crossed high. Tweeter roll off is almost third order electrical, and the tweeter is happier for it



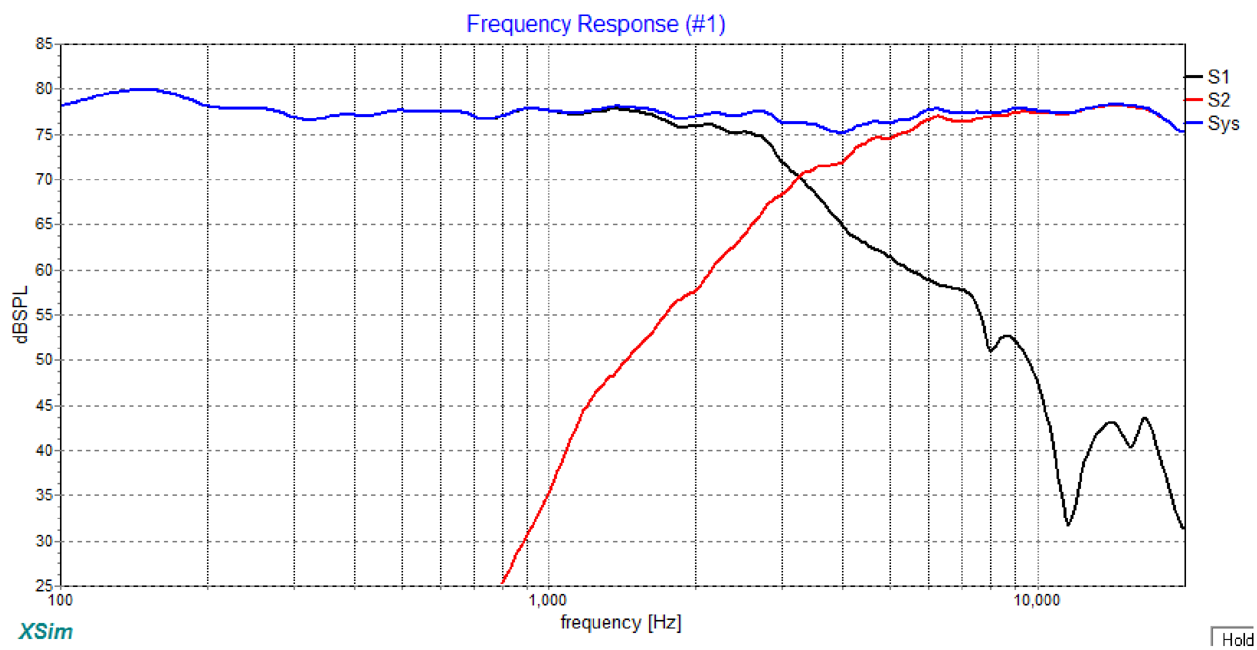
Electrical System Impedance

This is an easy load even for chip amps as it never dips below 5 ohms, and never gets very capacitive.



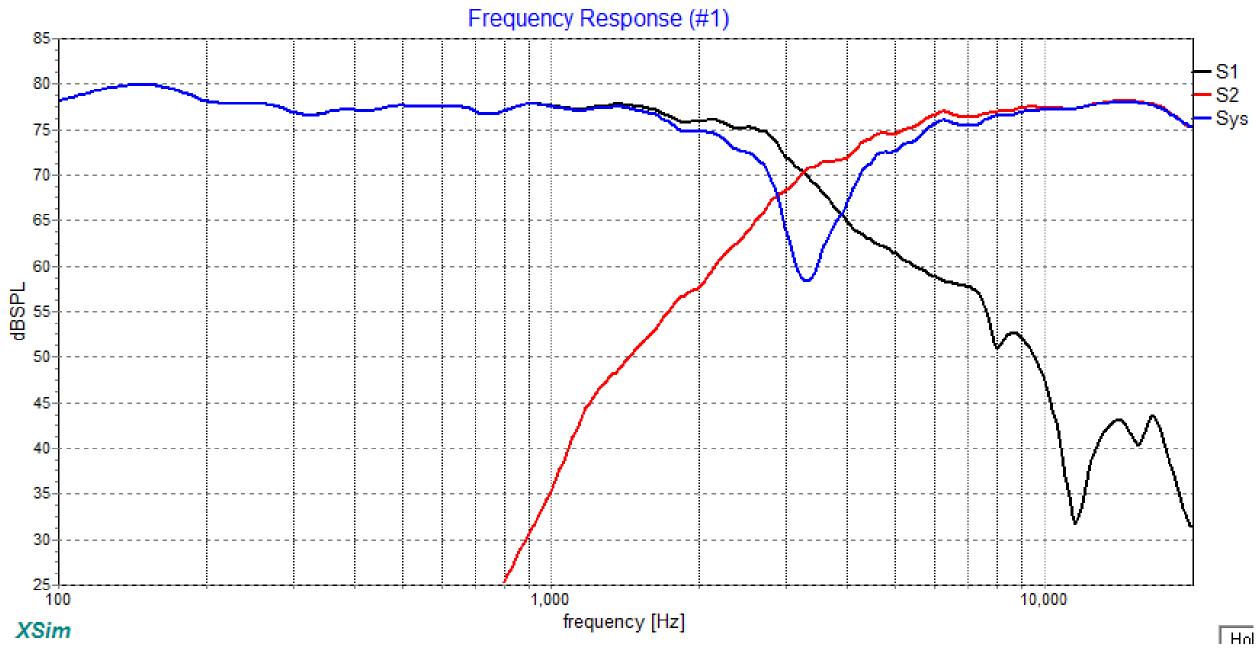
On-Axis System Response

Response was balanced for zero fatigue in a small lively room and still open and clear in large room. Tweeter has a very easy time, ≥ 40 dB down at 1 kHz for low distortion and high power handling and woofer breakups are notched out for clarity and openness.



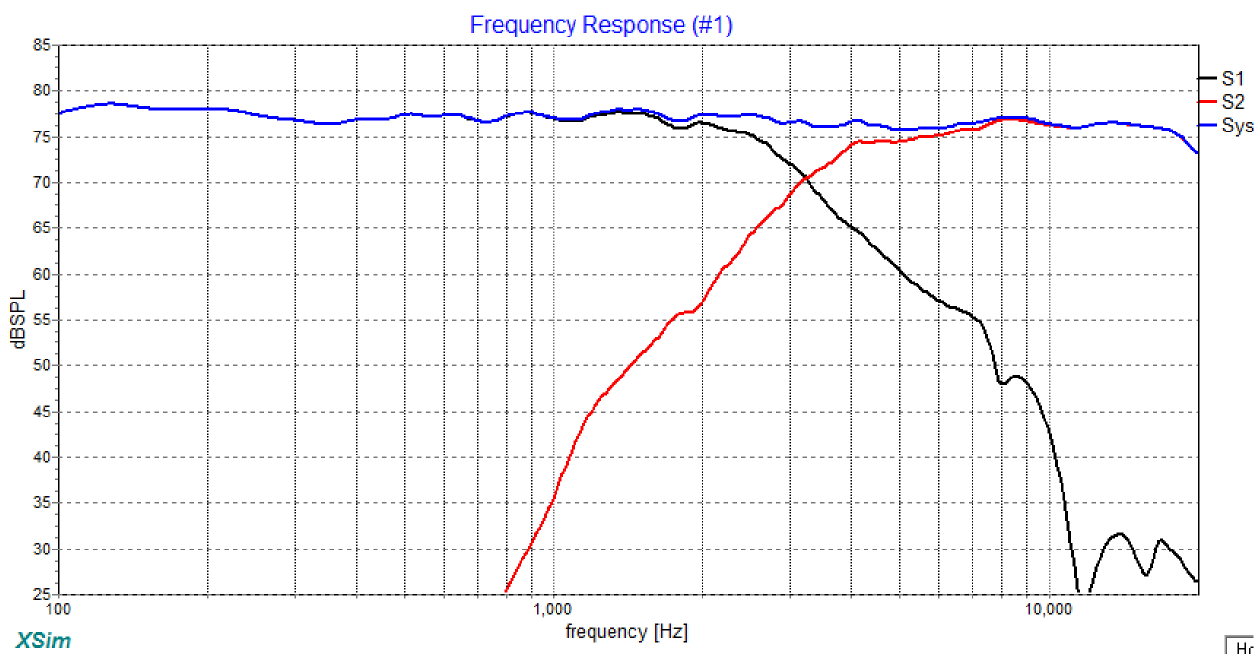
On-Axis System Reverse Null

This shows the fairly broad overlap used through crossover which in my experiences help improve off axis response and tonal balance in a lively room.



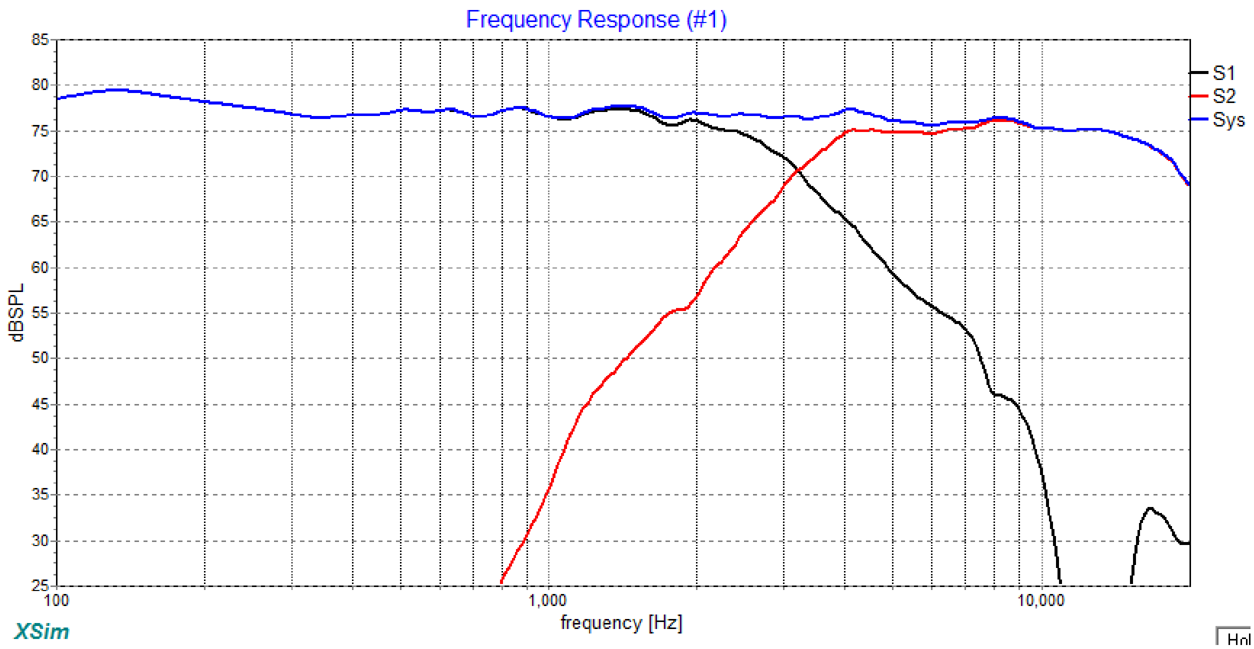
15 Degrees Horizontal

It's recommended that the speaker be toed inwards 15 degrees. The response is optimized for this angle with a very flat response featuring a gentle downward tilt that sounds especially well balanced in small lively rooms. Toe in also stabilizes the central image and reduces tonal anomalies from side wall reflections.



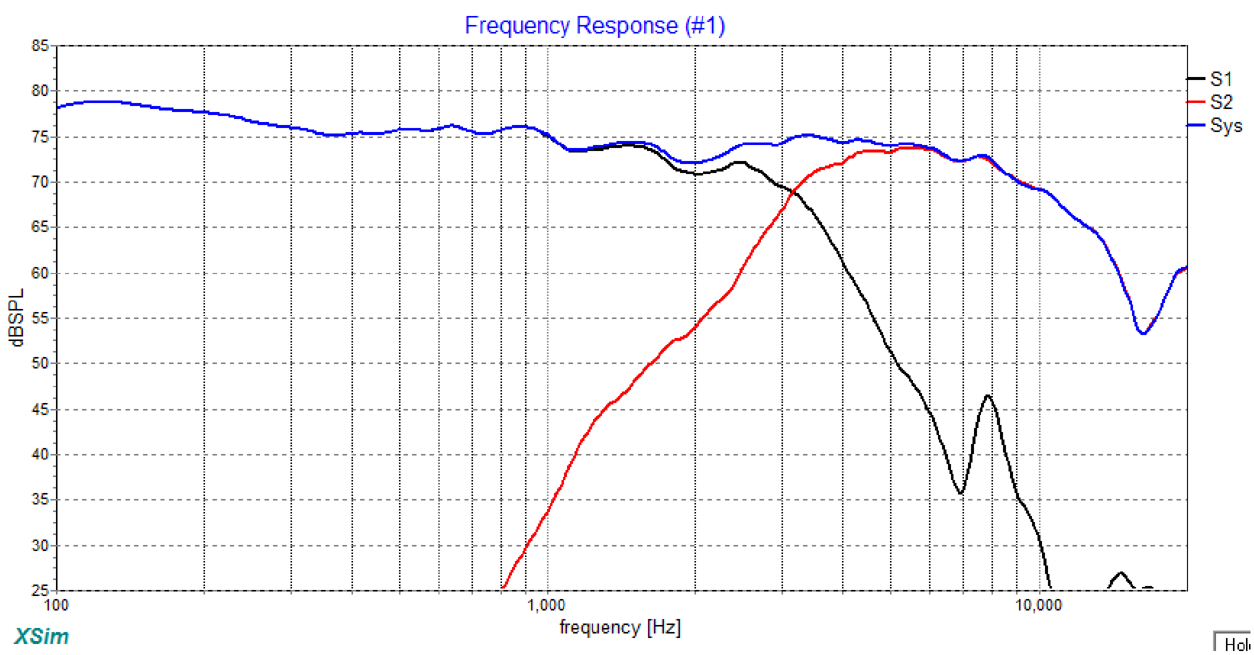
30 degrees Horizontal

Response is still exceptionally smooth, woofer break up is completely gone, and tweeter is still holding its own almost to 20kHz.



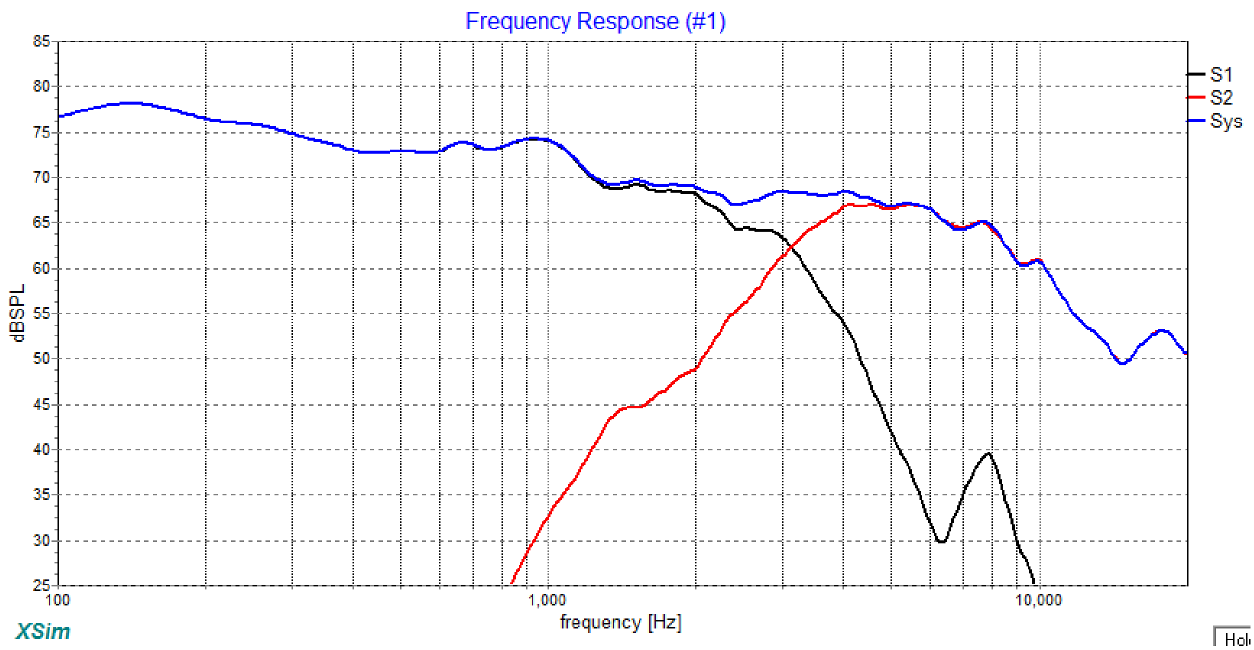
60 Degrees Horizontal

Tweeter's natural response is checking out. This helps sound from getting zingy in a small lively room. Response is still smooth.



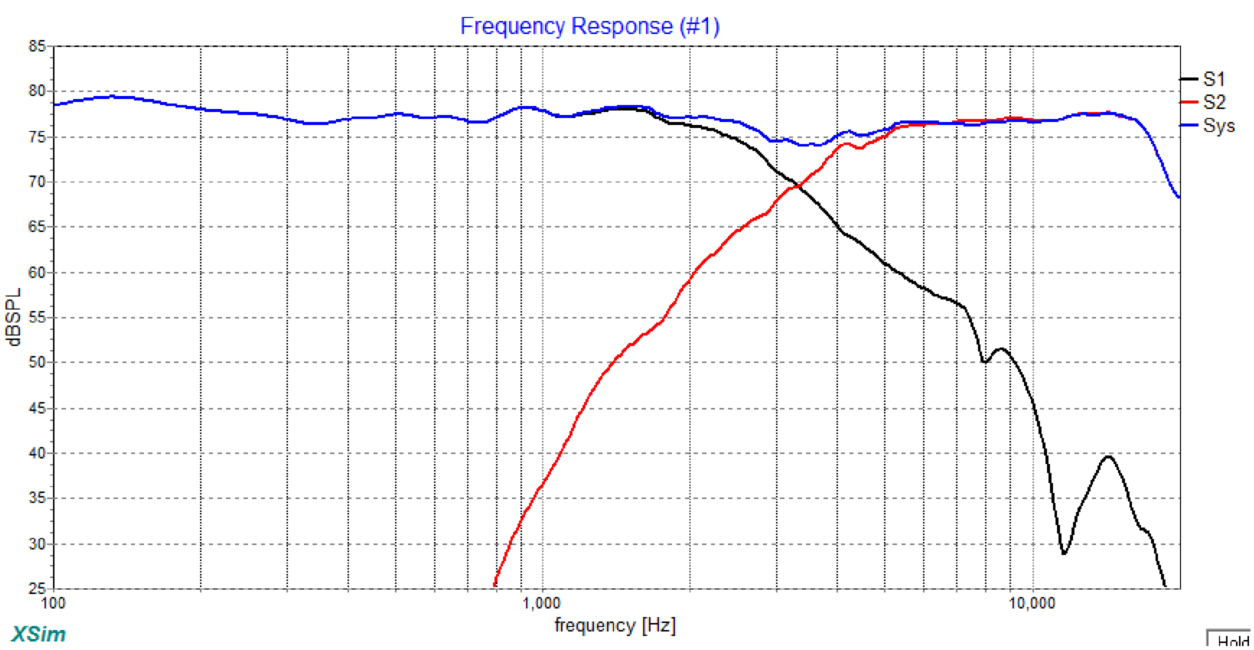
90 Degrees response

This is excellent behaviour with no gaping holes and a smooth downward slope. The tweeter is missing in action > 10 kHz, but this seems to help with tonal balance in a small lively room.



+15 Degrees Vertical (represents “listener standing”)

Standing up while pacing the office (deep thought mode), things stay nice and composed



-15 Degrees Vertical

Included just to show where the null is starting to form.