Lumped-Element vs. Measured System Phase Response

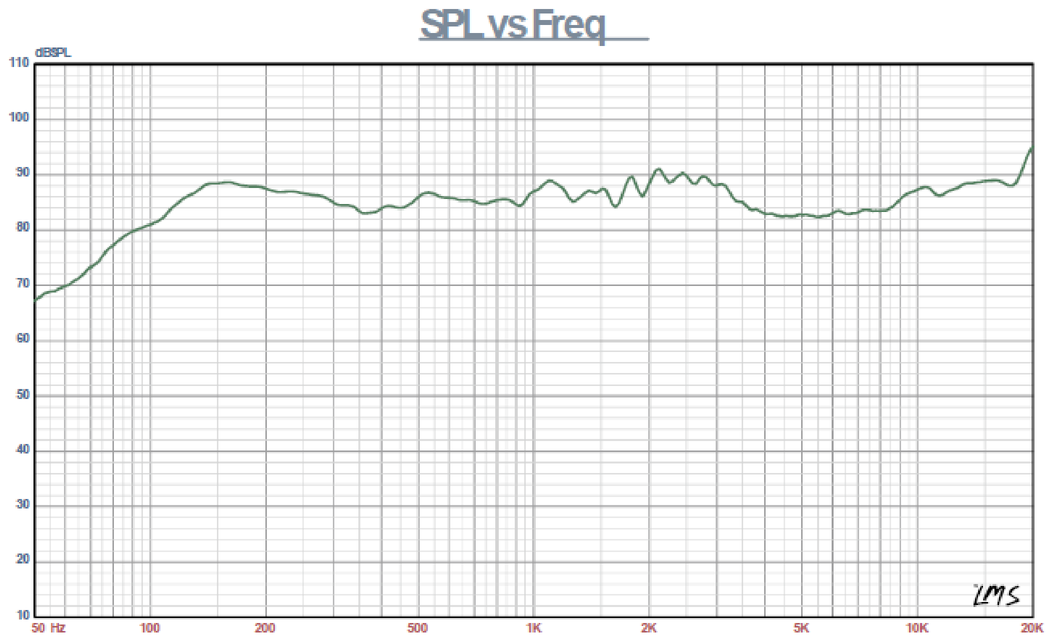
By Bohdan Raczynski
January 2016

A simple, lumped-element model was develop to estimate correctness of published performance of a small, 2-way loudspeaker system described in this thread: http://techtalk.parts-express.com/showthread.php?246377-The-Quarks-M-O-S-D-Computer-Speaker

Woofer

http://www.parts-express.com/fountek-fe83-3-full-range-driver-8-ohm--299-020

Specifications		Magnet System	
Overall Dimensions	D90X43.4mm	Magnet system type	ferrite
Net. Weight	0.47 kgs	Magnetic Gap Height	3.8 mm
Nominal Power Handlng	12 W rms	B Flux Density	1.0T
Nominal Impedance	8 Ohms	Bl Product	3.6Tm
Sensitivity 1W/1M	85.7dB	Max Linear Excursion	3 mm +/-
Frequency Response	100-25,000Hz	**T/S Parameter**	
Resonant frequency	122Hz	Cms	0.77mm/N
Voice Coil		Sd	28.27cm^2
Voice Coil Diameter	20mm	Vas	0.88L
Voice Coil Height	10mm	Mmd	2.1gm
Voice Coil Former	aluminum	Mms	2.2gm
Voice Coil Wire	CCAW round	Qms	2.36
Number of Layers	2	Qes	0.88
DC Resistance	6.5Ohms	Qts	0.64

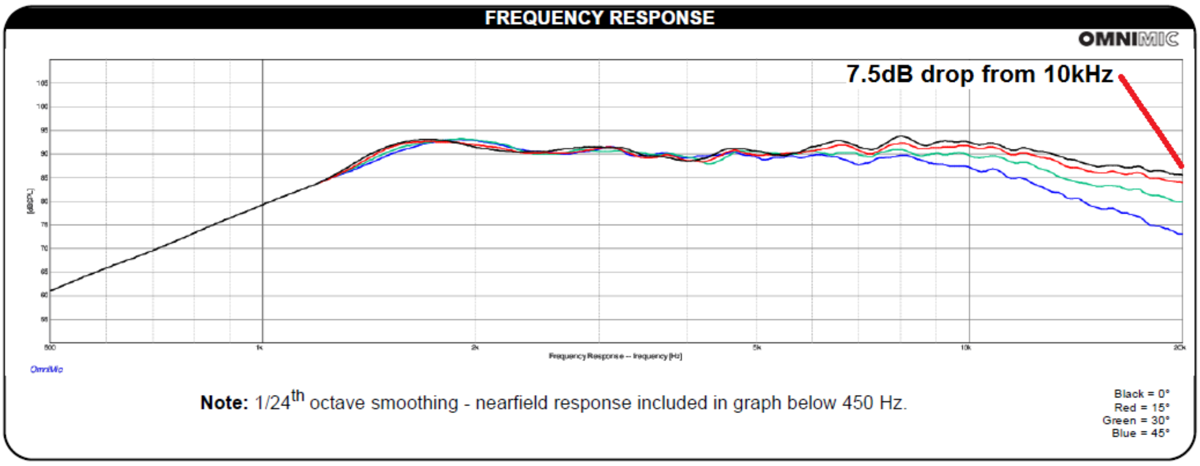


One interesting thing I found was when I measured the T/S parameters on the FE-83 was that even though the manufacturer lists the Fs at 121 Hz my sample measured at 100.3 Hz, and the Qts was a little lower than specified as well. You don't often see drivers measuring with a lower Fs than specified so this was a welcome surprise. This led me to decide to make a vented speaker and see if I could pull a little more bass from the tiny box. I ended up using a press-in port that measured 1" x 4" (PN 260-470). This tuned the enclosure to 102 Hz and gives me good half-space bass into the mid 90's. However, sitting on my desk there is excellent output to about 80Hz.

Tweeter

http://www.parts-express.com/dayton-audio-nd20fa-6-3-4-neodymium-dome-tweeter--275-030

PARAMETERS	
Impedance	6 ohms
Re	5.2 ohms
Le	0.05 mH
Fs	2,005 Hz
Qms	1.50
Qes	2.88
Qts	0.99
Mms	N/A
Cms	N/A
Sd	2.8 cm²
Vd	N/A
BL	N/A
Vas	N/A
Xmax	N/A
VC Diameter	19 mm
SPL	90 dB @ 1W/1m
RMS Power Handling	15 watts
Usable Frequency Range (Hz)	3,500 - 25,000 Hz

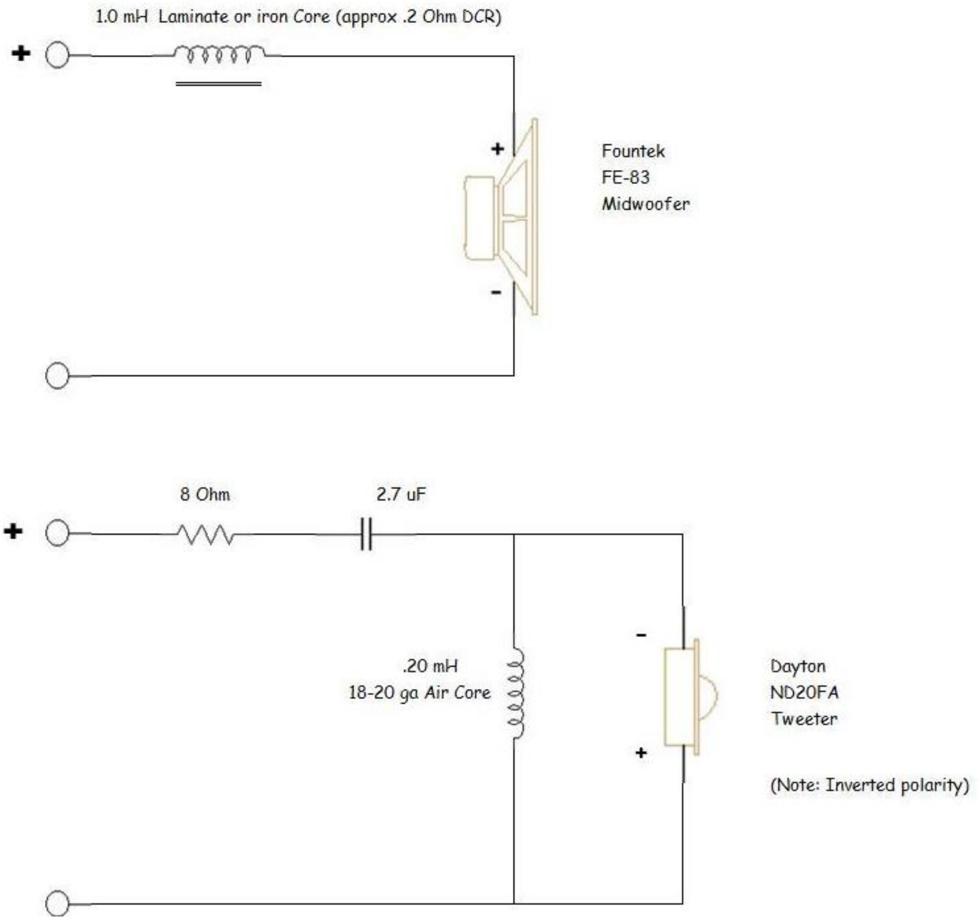


Note: 1/24th octave smoothing - nearfield response included in graph below 450 Hz.

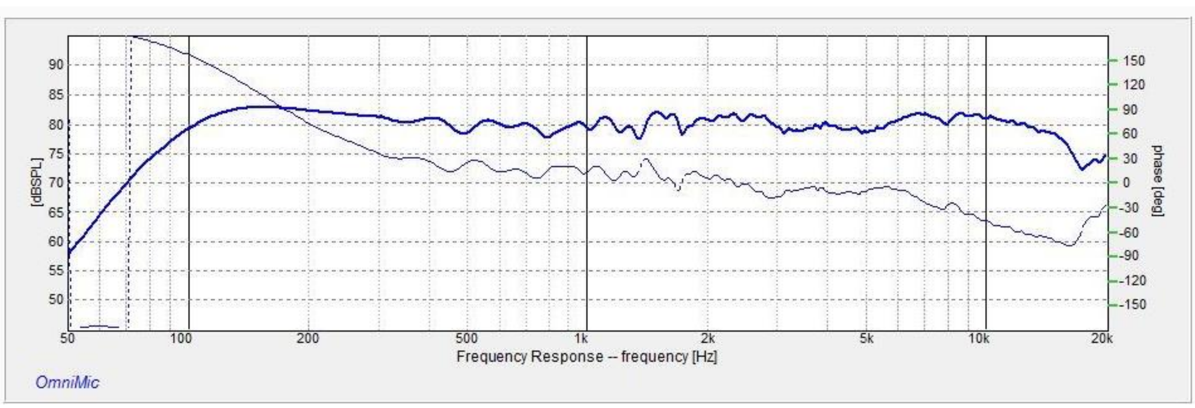
Crossover Network for The Quarks

A micro desktop computer speaker

by Jeff Bagby 3/11/2015



Published SPL and Phase responses

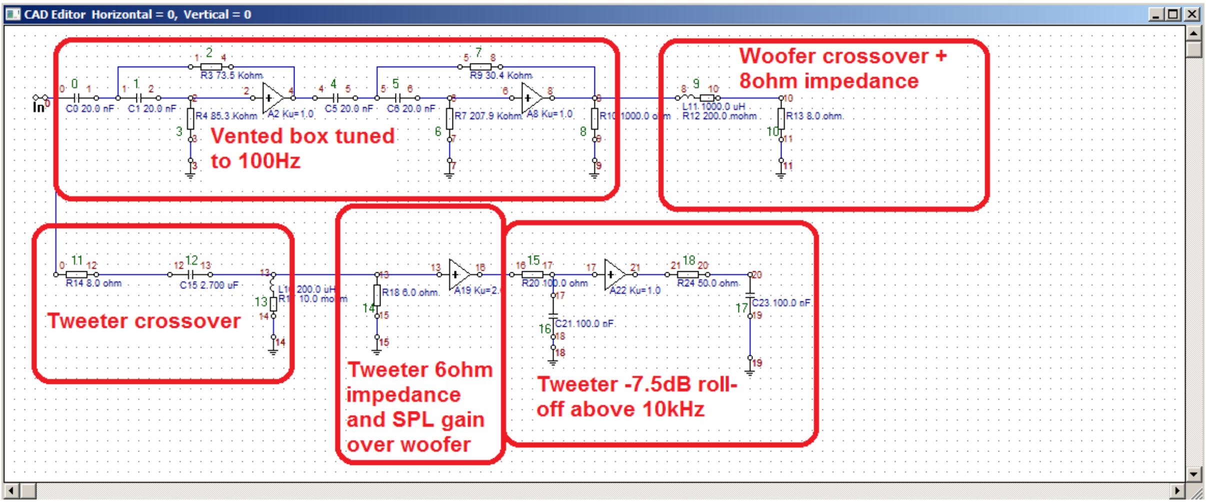


The Analysis

1. Woofer is mounted in vented box, tuned to appr. 100Hz.
2. Woofer's phase unknown, and assumed flat above 1.5kHz.
3. Woofer is 8ohm and has only 1mH inductor (-6dB/oct) for the filter.
4. Woofer is connected with normal polarity.
5. Tweeter is 6ohm, and has -7.5dB drop at 20kHz (see specs above).
6. Tweeter's crossover is +12dB/oct.
7. Tweeter's SPL is about 5-6dB higher then woofer, because it's impedance is lower than woofer and tweeter's efficiency is appr 4.5dB higher than woofer.
8. Tweeter is connected with reversed polarity.

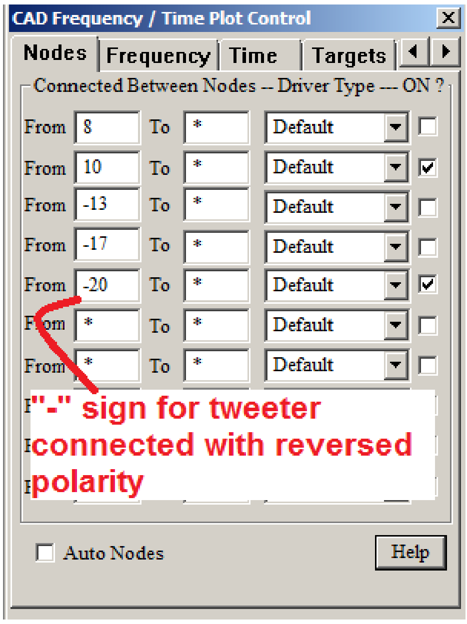
Lumped-Element Modelling circuit

1. Vented box is modelled as +24dB/oct HP filter at 100Hz.
2. Woofer crossover is modelled as per original design (serial inductor and 8ohm shunt resistor).
3. Tweeter crossover is modelled as per original design (+12d/oct and 6ohm resistor).
4. Tweeter roll-off is approximated by two sections of low-pass filters, separated by buffer amplifiers. This is the only circuit representing tweeter's natural SPL/phase roll-off.
5. Tweeter's higher efficiency is approximated by the first OPAMP gain of 2.

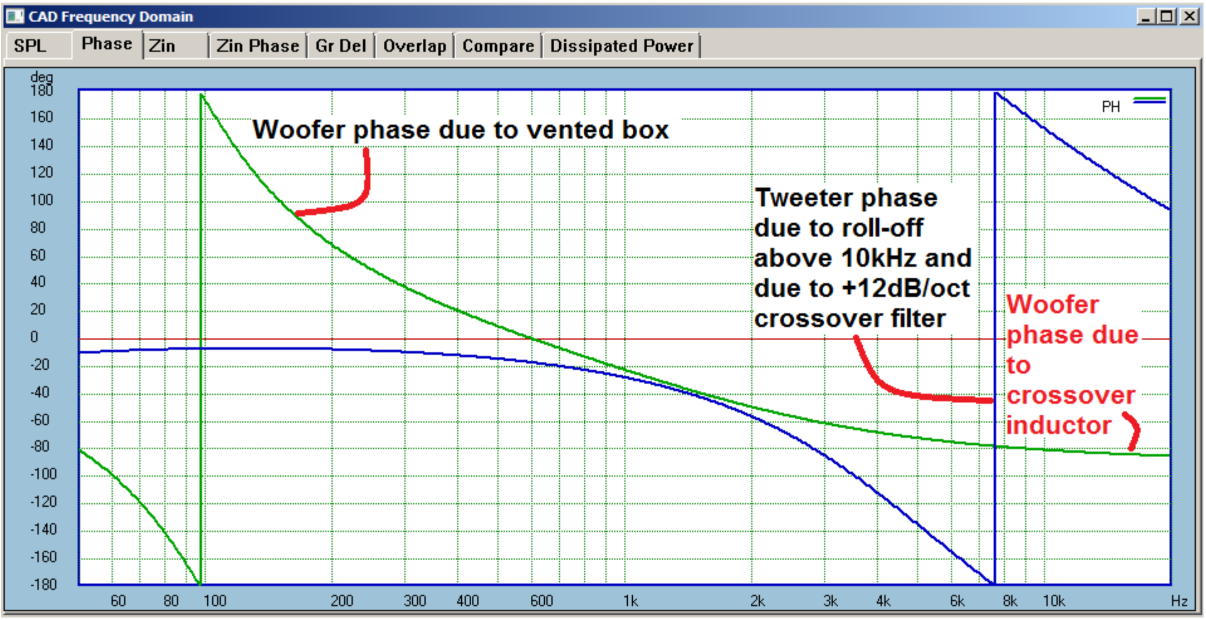


The lumped-element modelling offers good approximation of asymptotic roll-offs for SPL and phase, but obviously does not include normally measurable irregularities in frequency and phase responses. Also, the Zin of both drivers is approximated by fixed resistors of 8ohm and 6ohm. Woofer output is Node 10, tweeter output is Node 20 on the above circuit.

It is observable, that all major lumped-elements affecting SPL/Phase are included in the modelling circuit. They all contribute to the measureable characteristics of the 2-way loudspeaker system under consideration and can not be omitted.

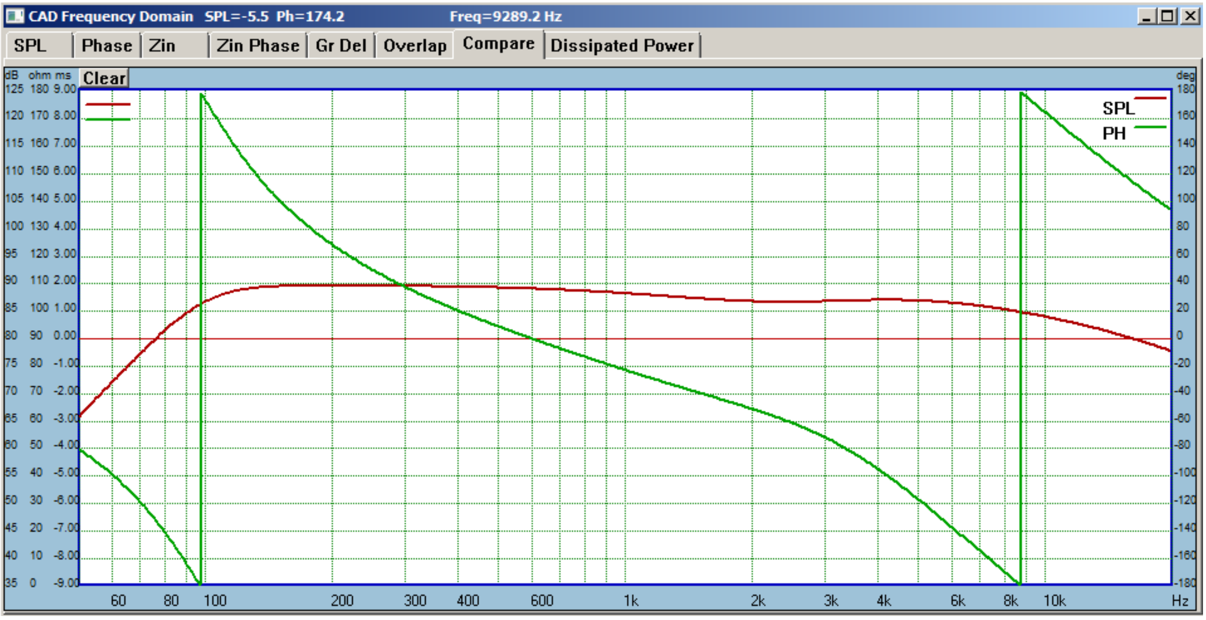


Below 1.5kHz woofer phase dominates (green below 1.5kHz)
Above 1.5kHz tweeters's phase dominates (blue above 1.5kHz).

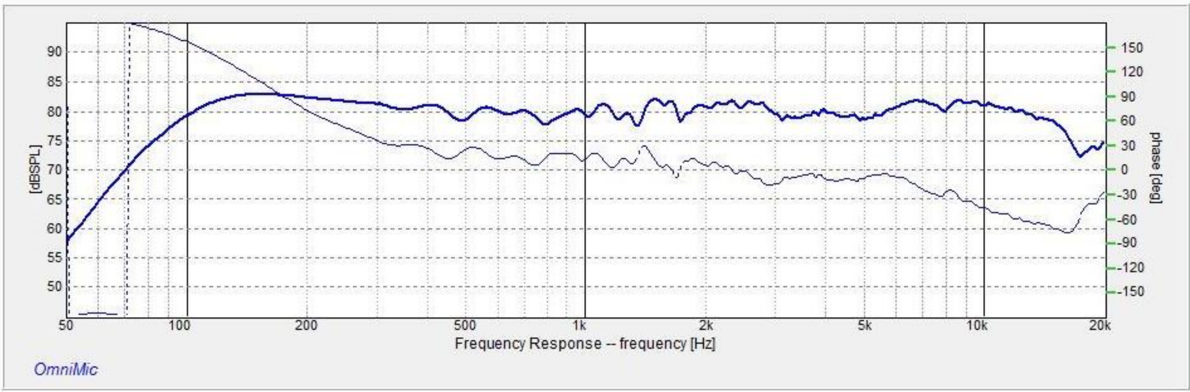


The exclusion of woofer's natural SPL/phase roll-off towards higher frequencies will not affect much phase response above 2.5kHz – this is where tweeter takes over and woofer's SPL contribution fades away.

Modelled SPL and Phase Responses



Published SPL and Phase responses



Summary

The SPL, modelled with such simplistic curcuit, is surprisingly close to the measured and published SPL.

On the other hand, measured and published phase response deviates significantly from the modelled phase response, with the measured phase appearing to be flattening out towards higher frequencies.

It is anticipated, that as a minimum, the +12dB/oct crossover and the 7.5dB drop in tweeter’s SPL would show in the measured phase response.

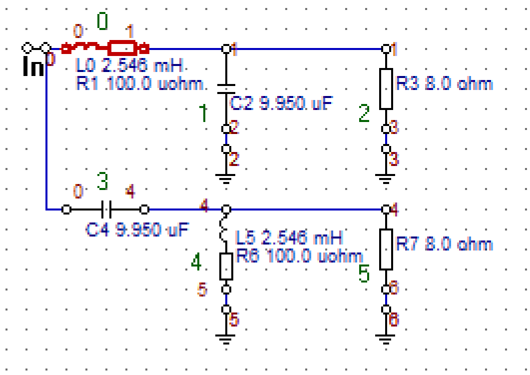
Loudspeaker System Phase Response

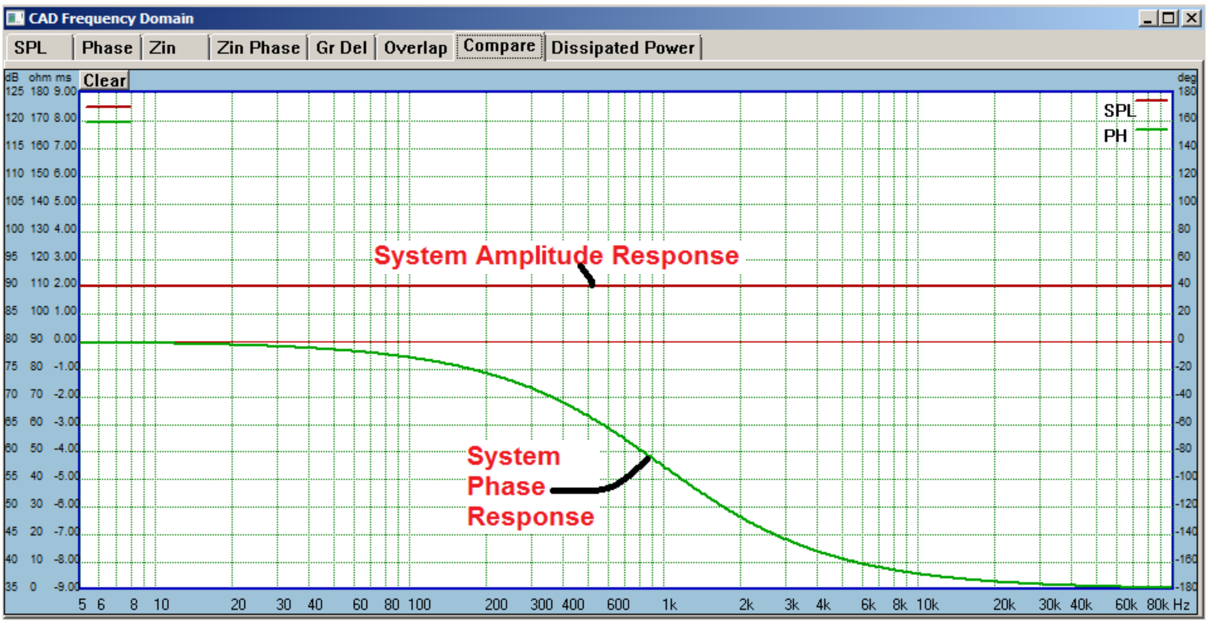
When examining phase response of the loudspeaker system, for the sake of simplification, we consider only the crossover part of the loudspeaker system. Explanations that follow, are equally applicable to loudspeaker drivers, as they are also “minimum-phase” devices.

Each crossover channel filter taken separately, is a “minimum-phase” device. Therefore, its phase response is mathematically related to its magnitude response and vice-versa. Knowing magnitude response we can derive the exact phase response, and knowing phase response, we can derive it’s exact magnitude response.

However, for most crossovers, the minimum-phase relationship breaks down when filters are connected together, to form a loudspeaker system crossover.

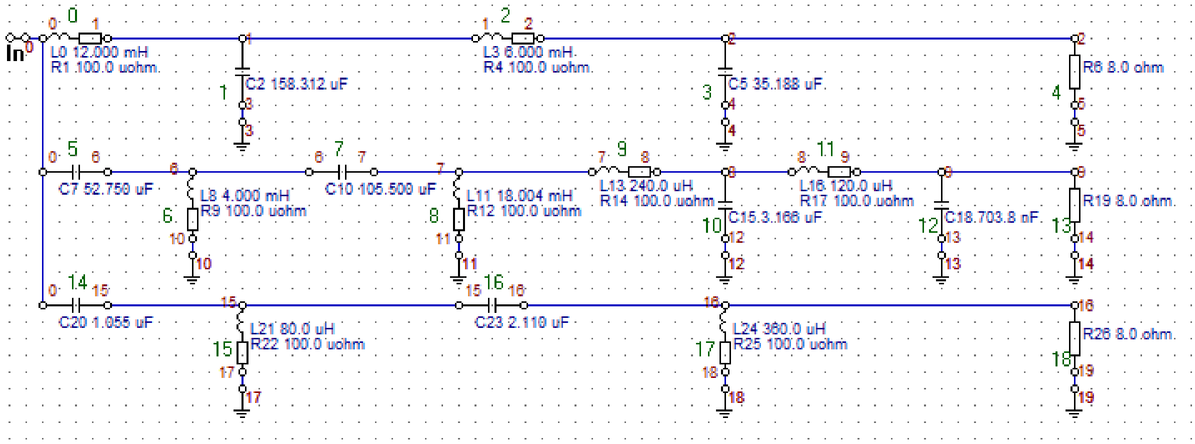
Here is an example of 2-way, LR crossover at 1000Hz. Since magnitude response of the system is a ruler-flat line (see below), the “minimum-phase” system with flat amplitude would have to exhibit flat phase response.

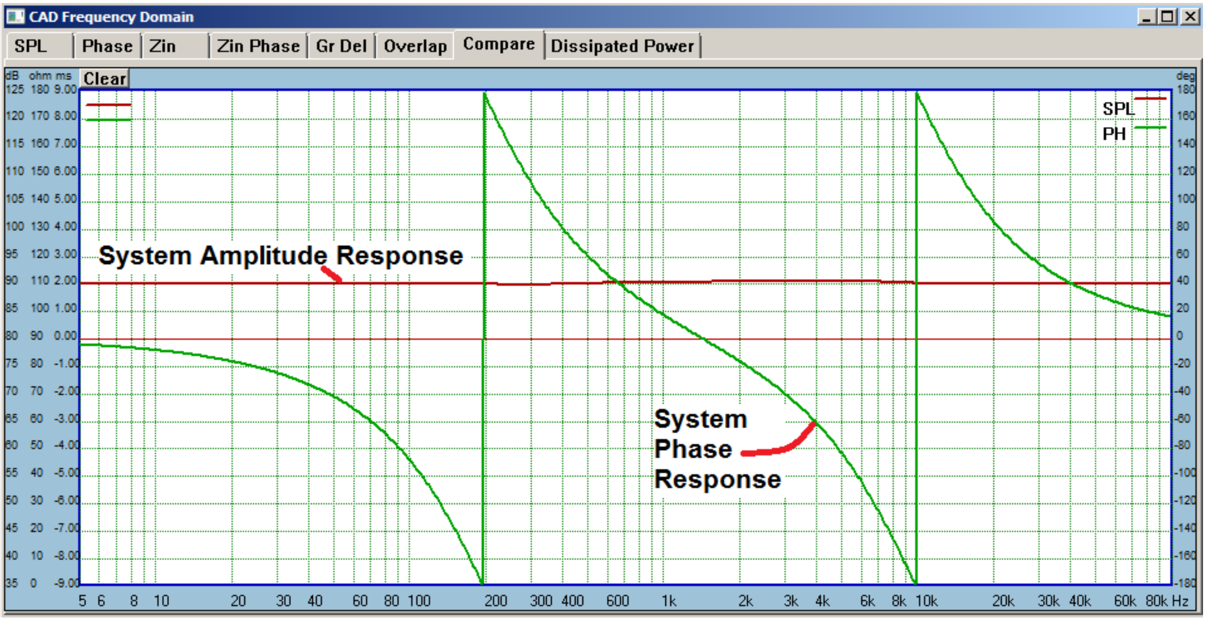




However, the actual system phase response is nothing like a flat line – it has **180deg shift towards higher frequencies**.

Here is another example of 3-way, LR crossover at 200Hz/10kHz. Again, since magnitude response of the system is a ruler-flat line (see below), the “minimum-phase” system with flat amplitude would also exhibit flat phase response.





Again, the actual system phase response is nothing like a flat line – it has **720deg shift towards higher frequencies**.

Including loudspeaker drivers in the above process, would typically exacerbate the phase shift of the system, because drivers would add their own inherent phase lags.

Conclusions

Measuring phase response of a loudspeaker driver can be performed with good degree of accuracy – see http://www.bodziosoftware.com.au/Min_Phase_Appr_Deriveration.pdf

Measuring phase response of a loudspeaker system is more challenging task. Phase response of a loudspeaker system can't be classified as "minimum-phase" in general, therefore, it is not possible to employ HBT as a guiding tool for the reasons explained above.

A great care must be taken when measuring phase response of the loudspeaker system. As always, you will be left with the same decisions regarding placement of the FFT window in front of the impulse response, or subtracting the correct amount the time-of-flight from the measured phase.

One possible option left is to create a lumped-element circuit, as explained above, and incorporate correctly measured amplitude/phase responses of each driver. This approach would yield expected system phase response quite accurately, so it can be used a guidance for the actual measurement process of the phase response.

Thank you for reading

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