Phase Distortions and Time Effects of Audio Systems

Samuel Harsch

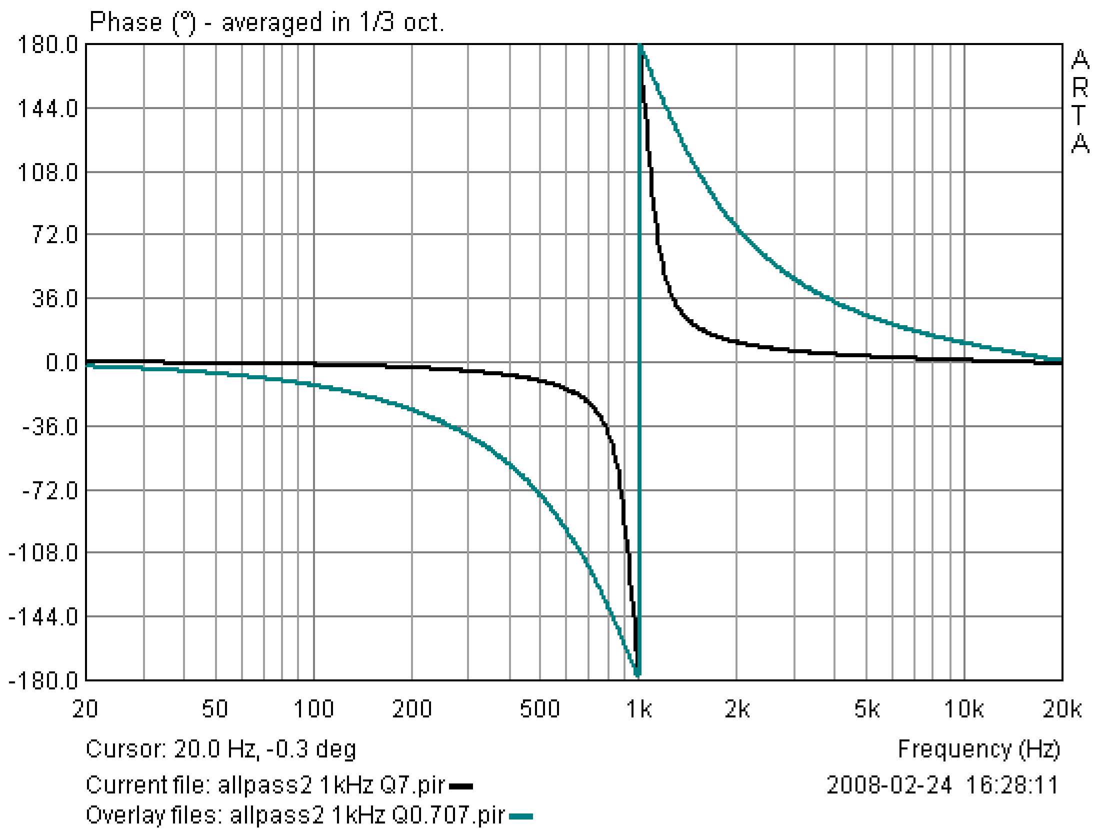
114th meeting AES Swiss section
3 April 2008

Group Phase & Delay

- H (f) is the transfer function of an audio system
  - Phase ph (f) = arg (H(f)) * 180 / ft
  - Group delay tgr (f) = - (1/360) * (dph (f) / df)
- The best way to observe and test the effects of phase is to use an all-pass filter
- An all-pass filter has a constant amplitude, but produces only a phase rotation:
  - A 1st order filter does not produce a phase rotation.
  - A first-order all-pass filter produces a 180 ° phase shift as a 2nd order filter.
  - A second-order all-pass filter produces a 360 ° phase shift as a 4th order filter.

Group Phase & Delay

- All pass 2nd order 1 kHz Q=0.707
- All pass 2nd order 1 kHz Q=0.7



Group Phase & Delay

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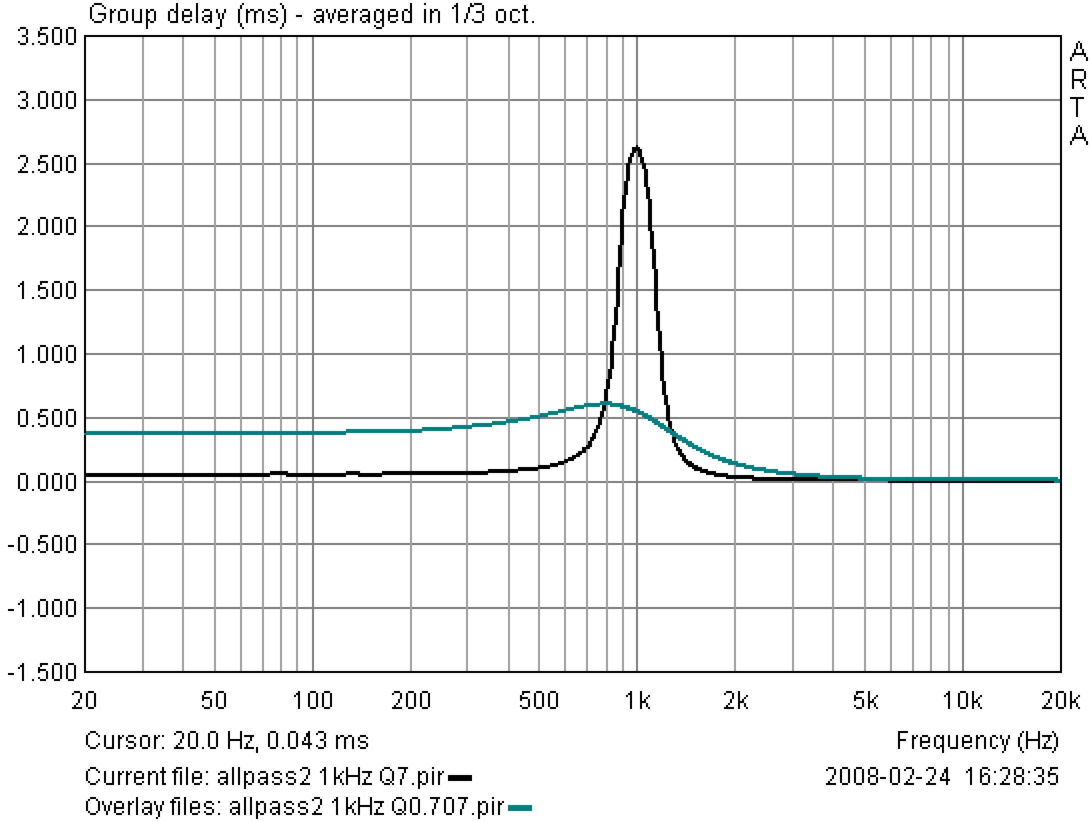


Audibility of phase distortions

- Seem more audible at low frequencies
- The time effect is more pronounced with a high quality (Q) factor
- Perception varies among individuals

Ref:

On the Perception of Phase Distortion
Hideo Suzuki, Shigeru Morita, and Takeo Shindo
JAES, September 1980, Vol 28, No. 9

Sources of phase distortion

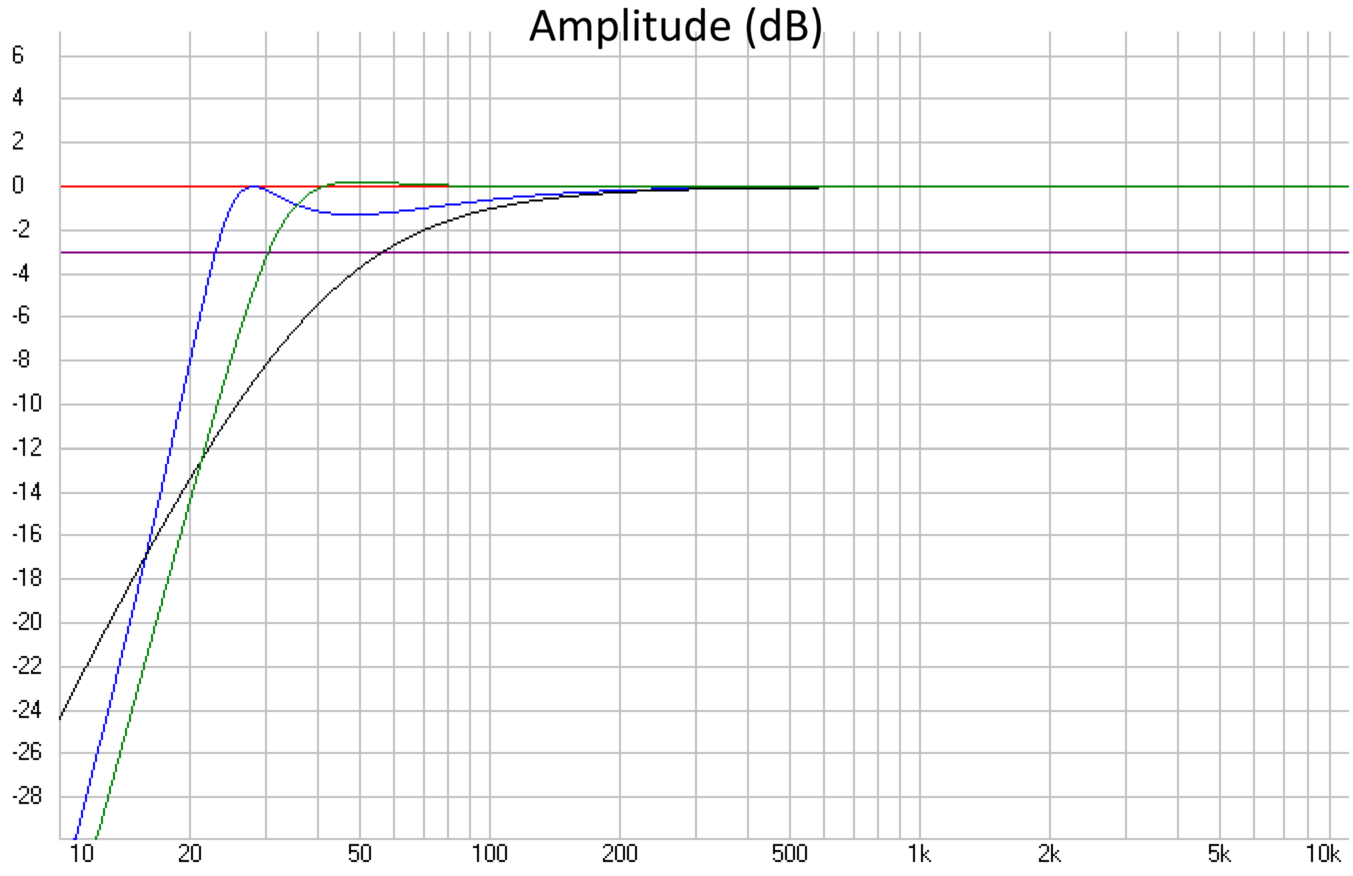
- Low cut of the enclosure
  - Filter
  - Resonances (modes) of the part

Low cut of the enclosure

- The effect is more pronounced with enclosure using a resonator (bass reflex, transmission line, etc.)
- Low frequency cut off is similar to a 2nd order filter for a closed box, and 3rd order for a bass-reflex box

Peerless XXLS10 Loudspeaker in Different Types of Enclosures

- Bass reflex quasi-Butterworth (42 litre, 28Hz)
- Bass reflex low extension (100 litre, 25Hz)
- Closed box (60 litre; 39 Hz, Qtc 0.53)



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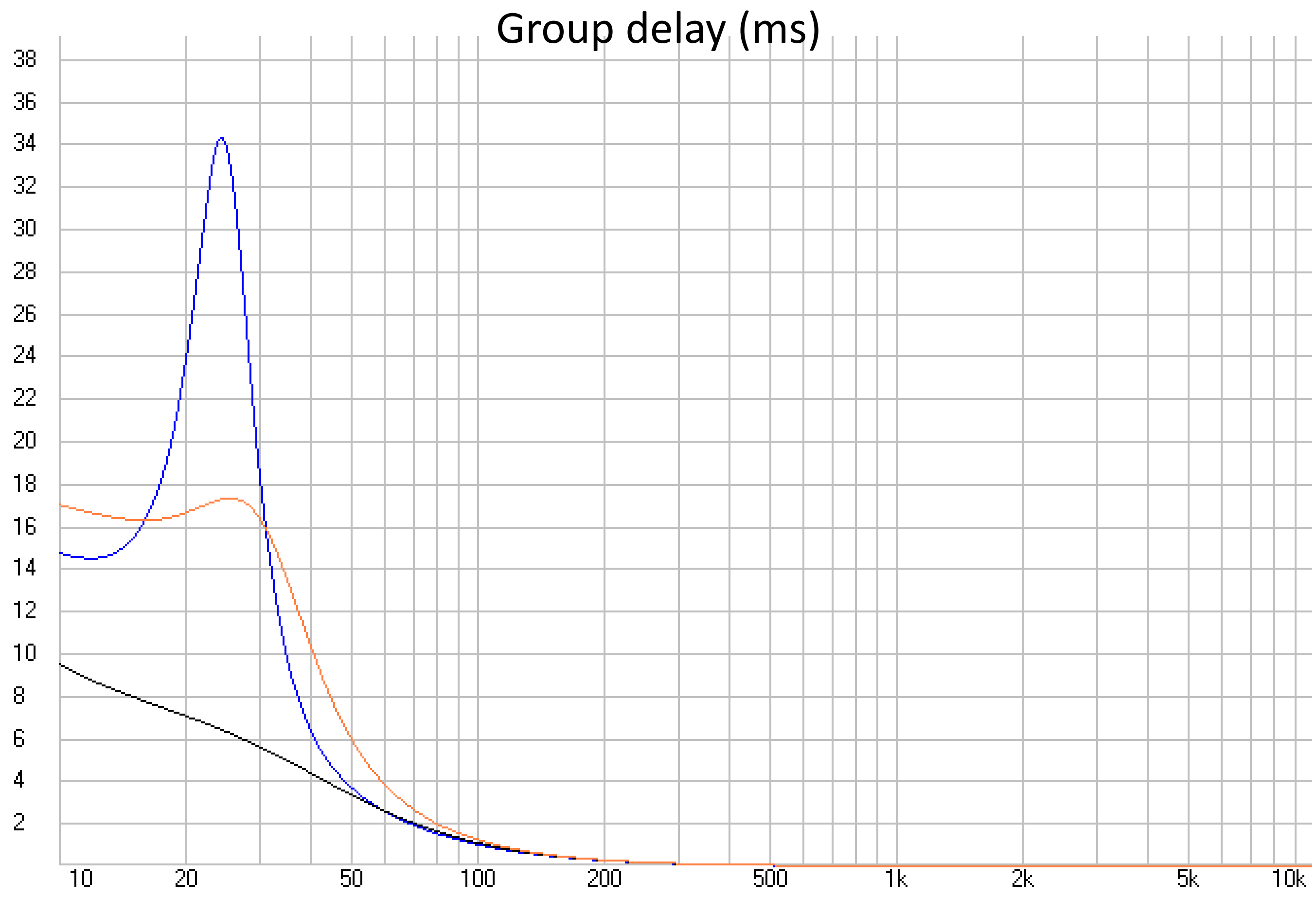
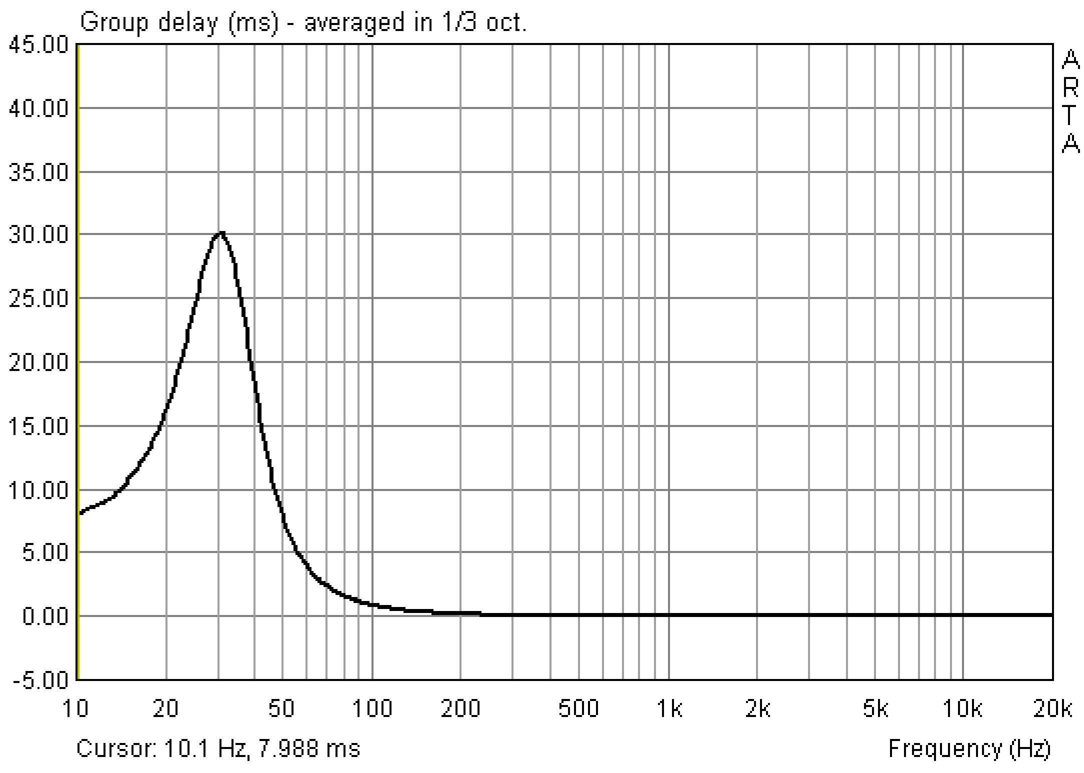


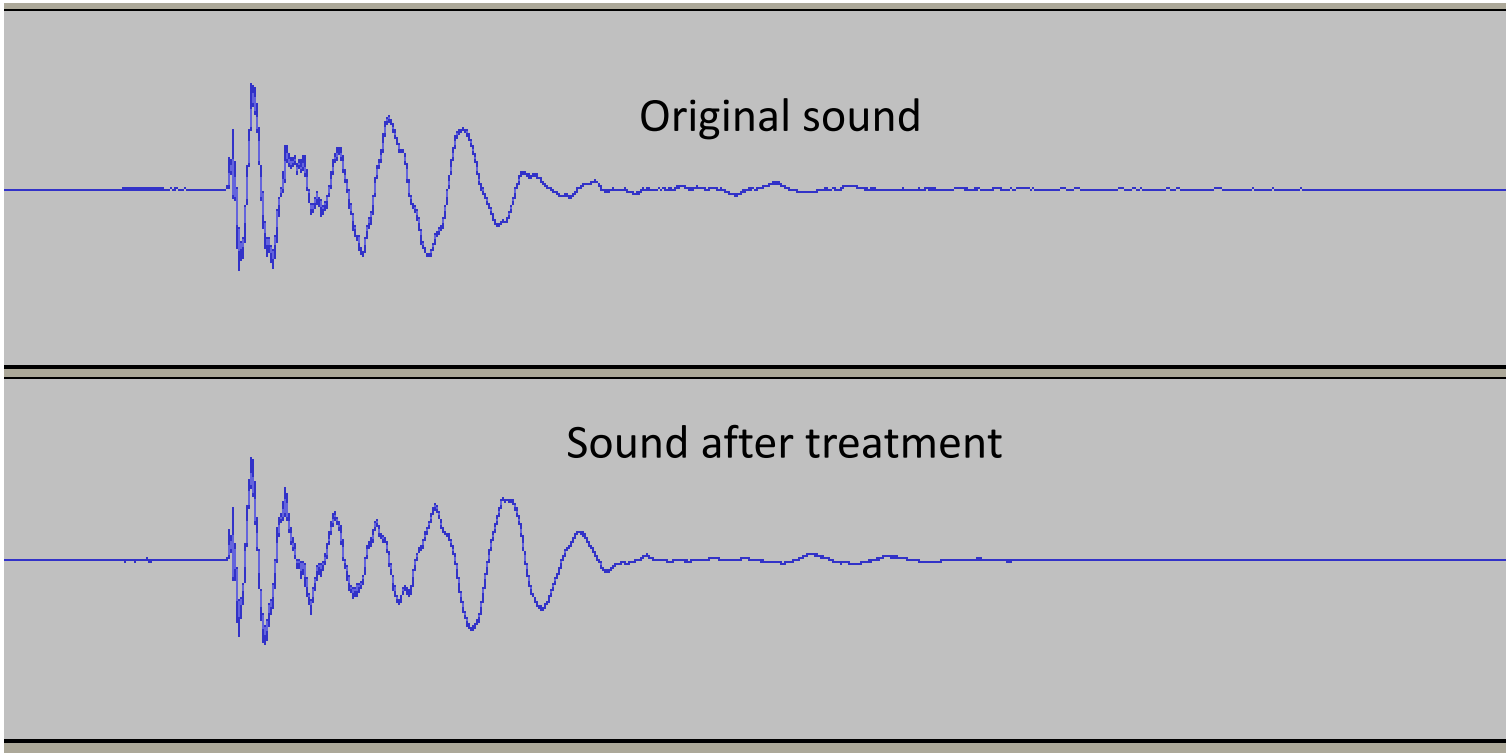
Phase & Group Delay

- Simulation of this effect using an all-pass filter 2nd order 30Hz Q = 1.5



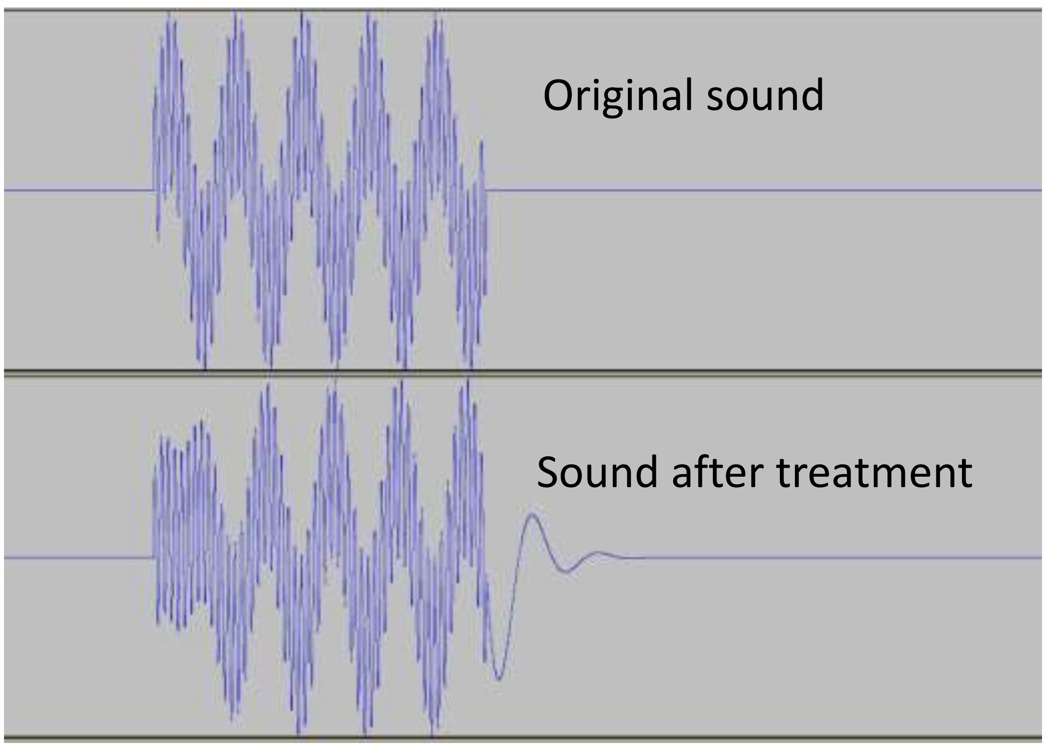
Phase & Group Delay

- Second order all-pass 30Hz Q = 1.5 applied to a recording of a bass drum

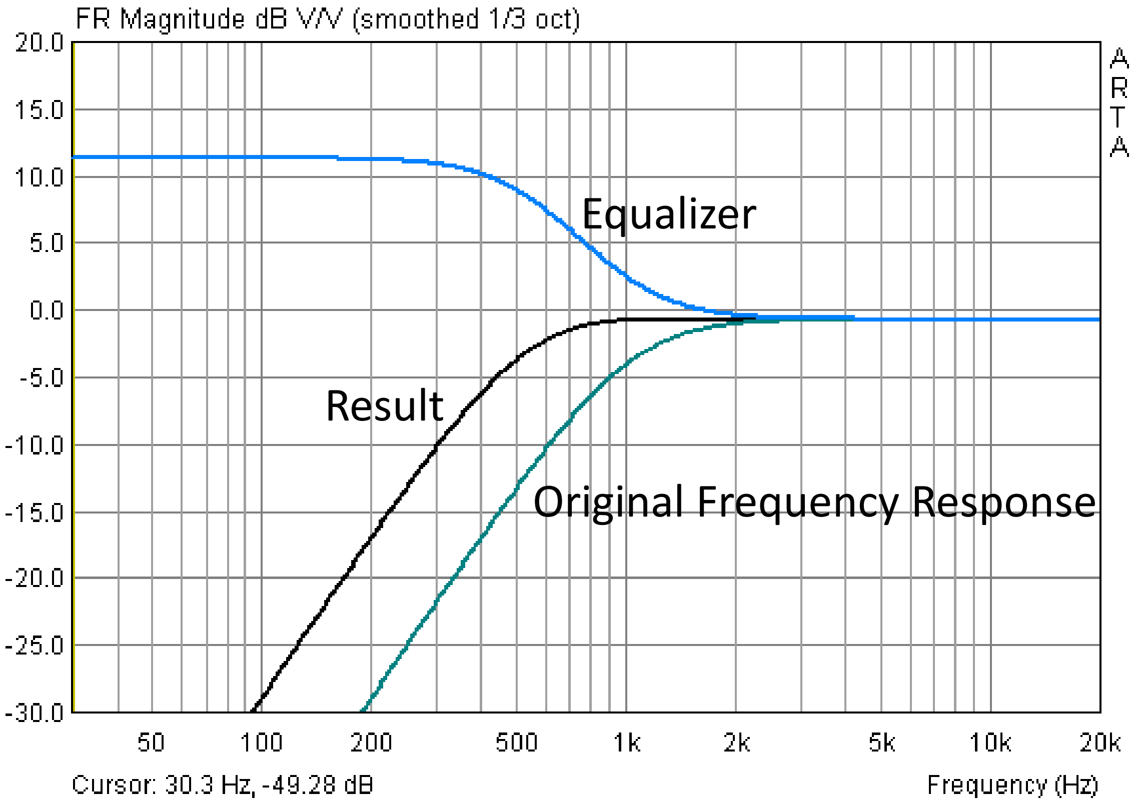


Phase & Group Delay

- Second-order all-pass, 50 Hz, Q = 1.5 applied to a 100ms burst of 50Hz + 500Hz

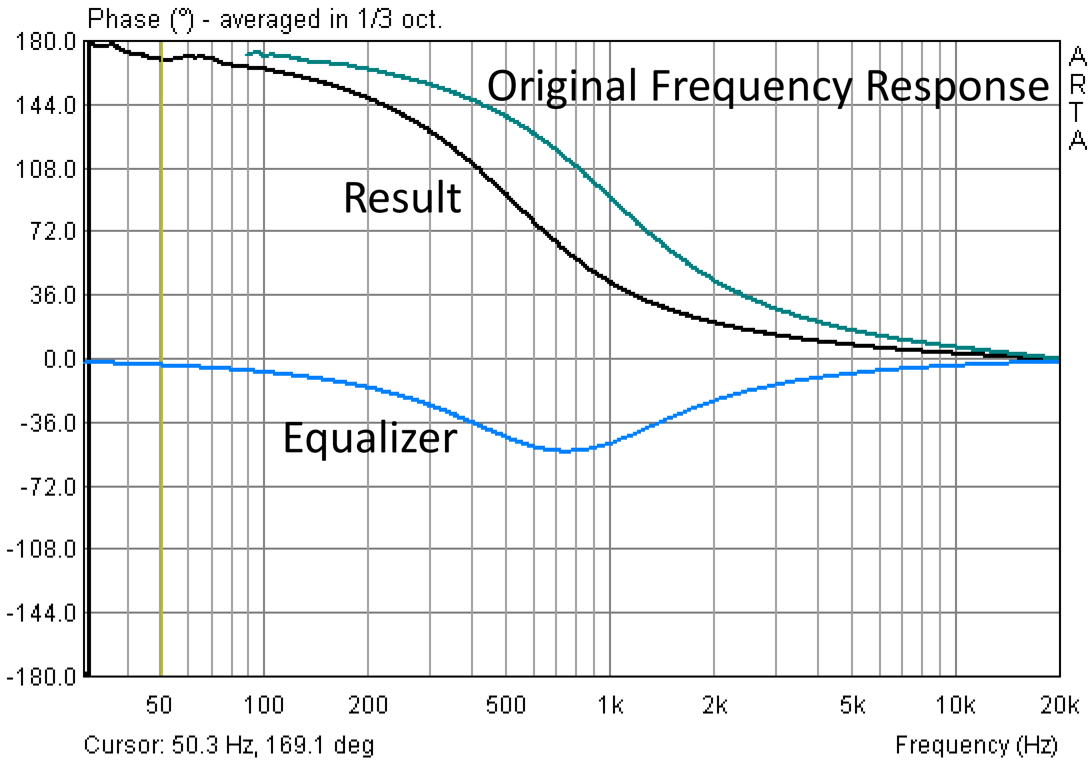


Linkwitz Transform and Equalization of a Closed Box



Here the equalizer is a low-shelf 2nd order

Linkwitz Transform and Equalization of a Closed Box



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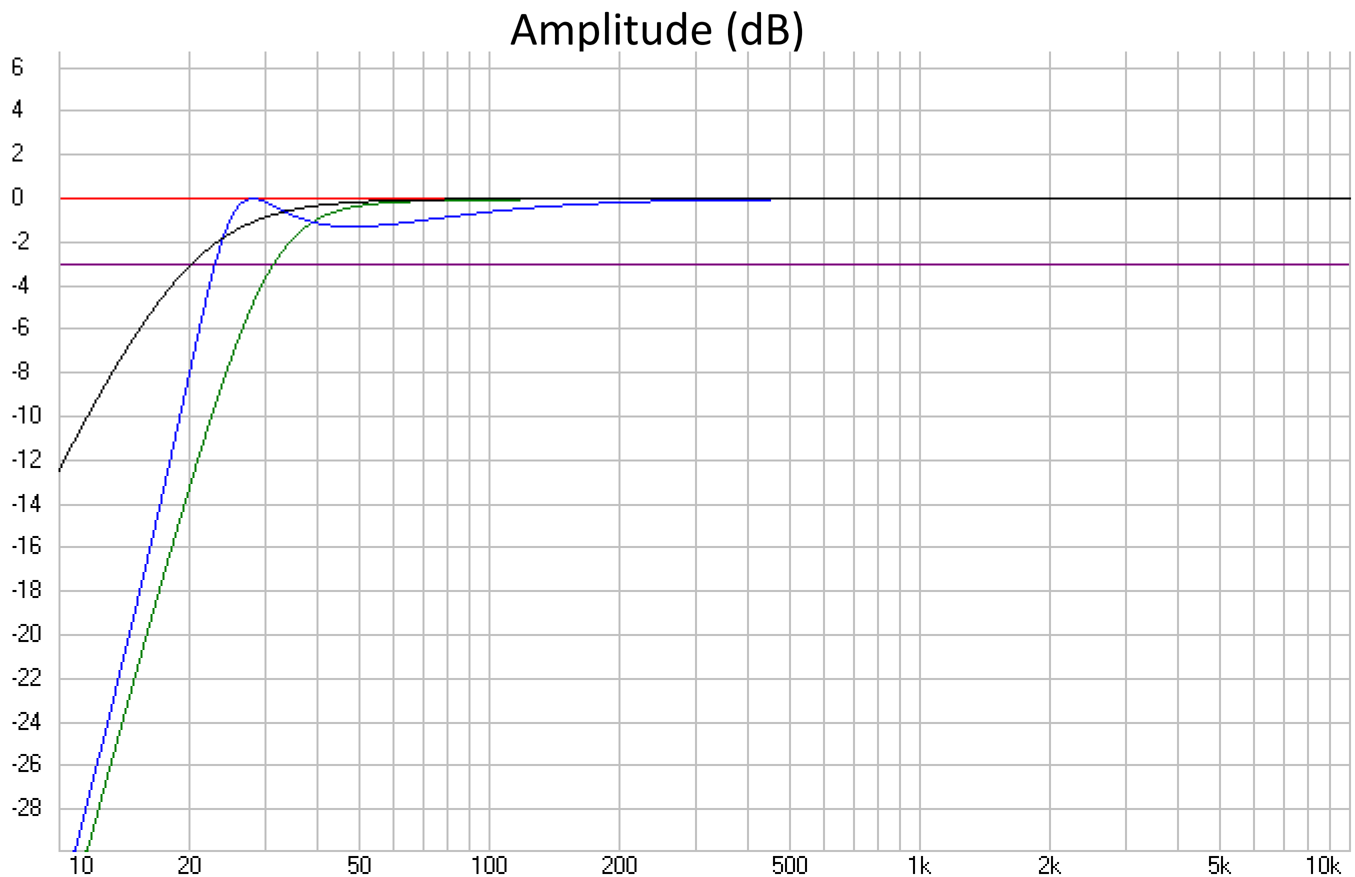

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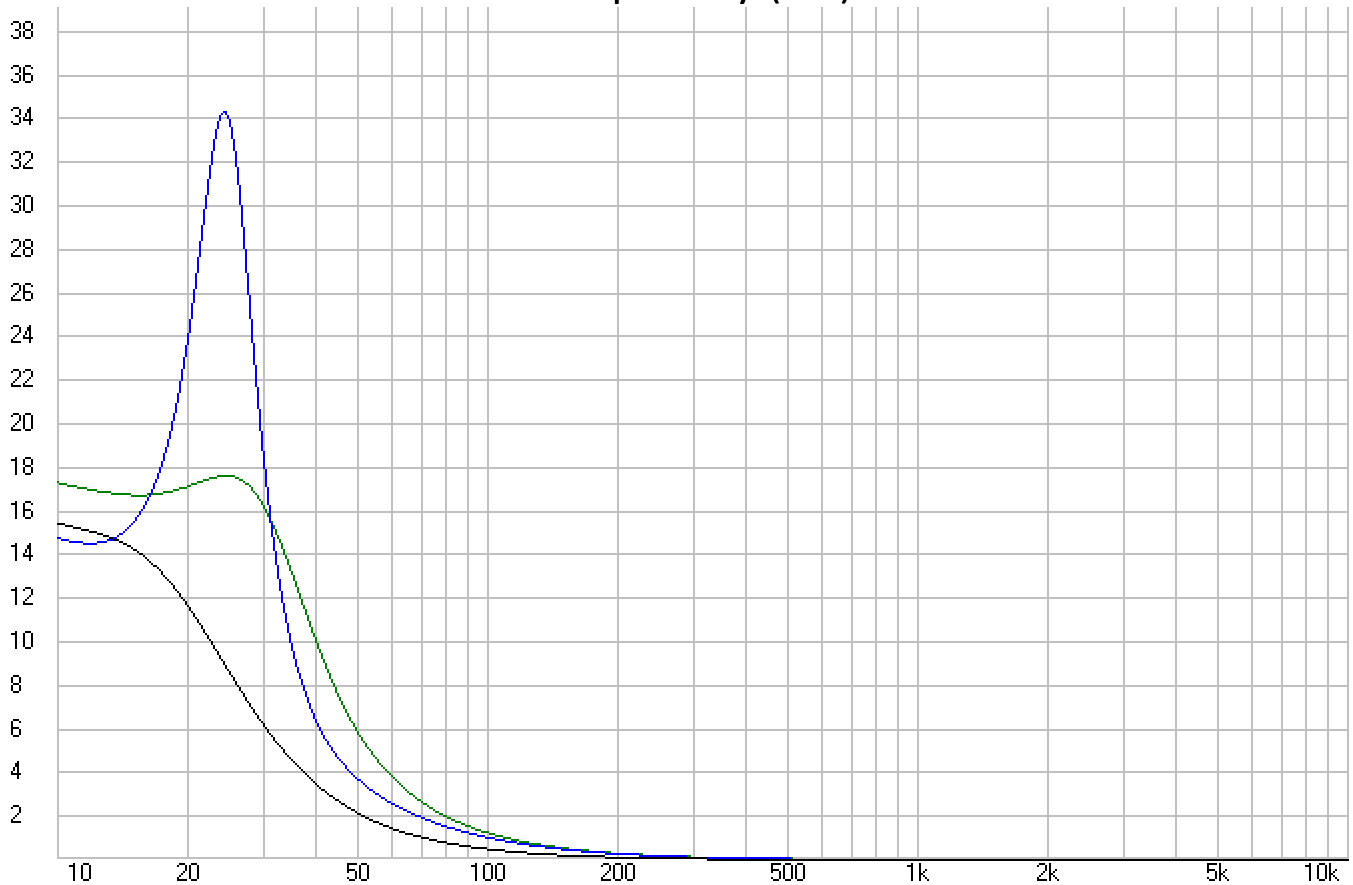
Group Delay (ms)



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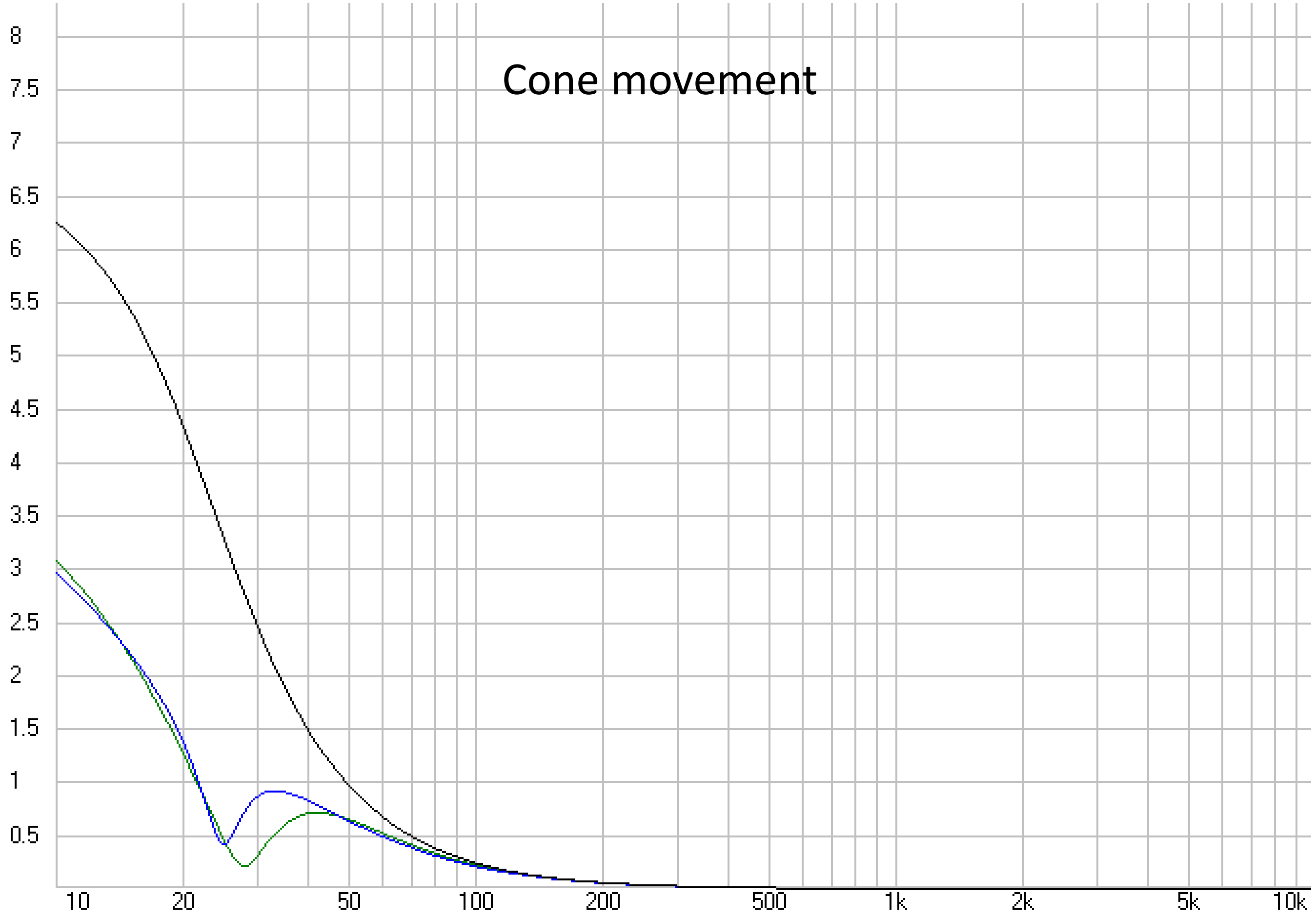
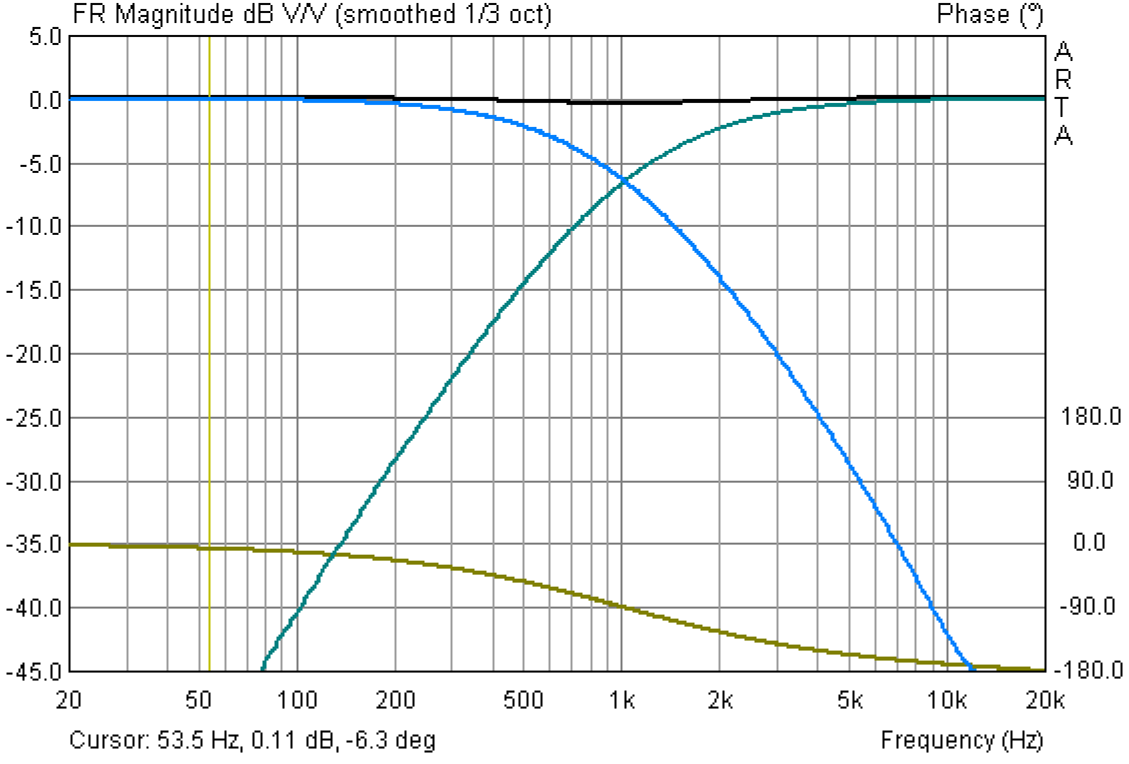


Filter Phase Distortion

- Example with a 2nd order Linkwitz-Riley filter

Polarity reversal



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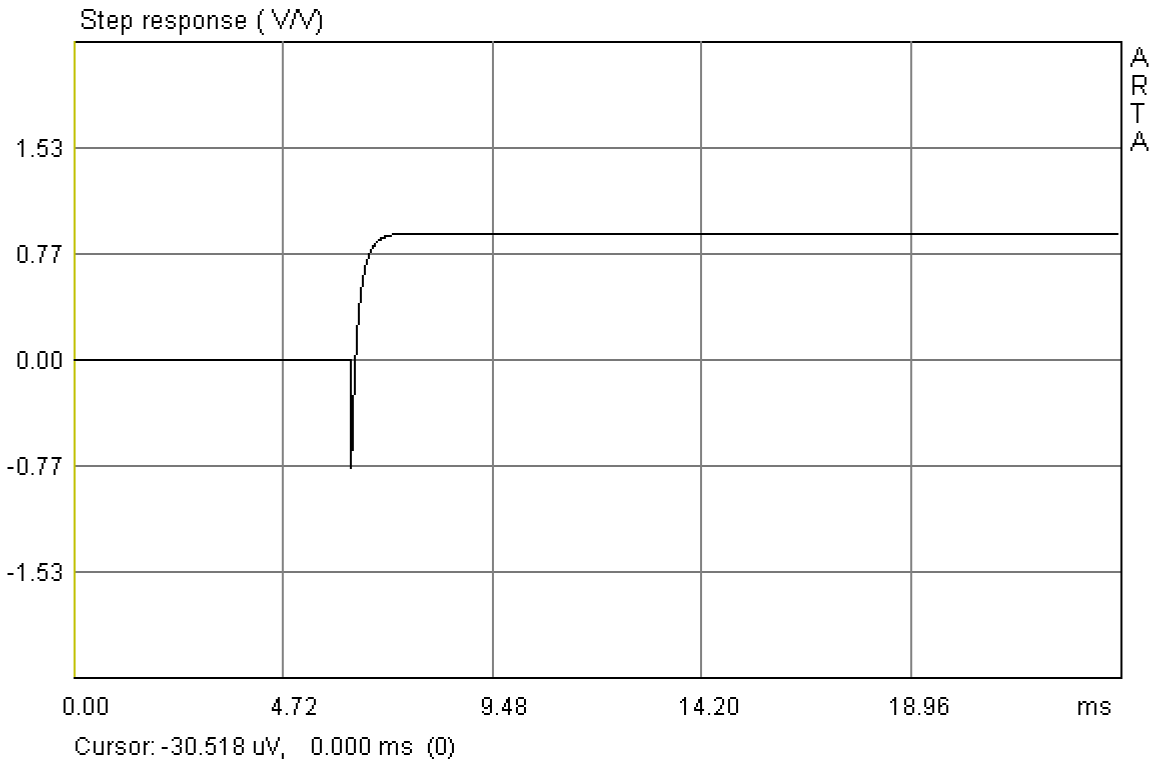
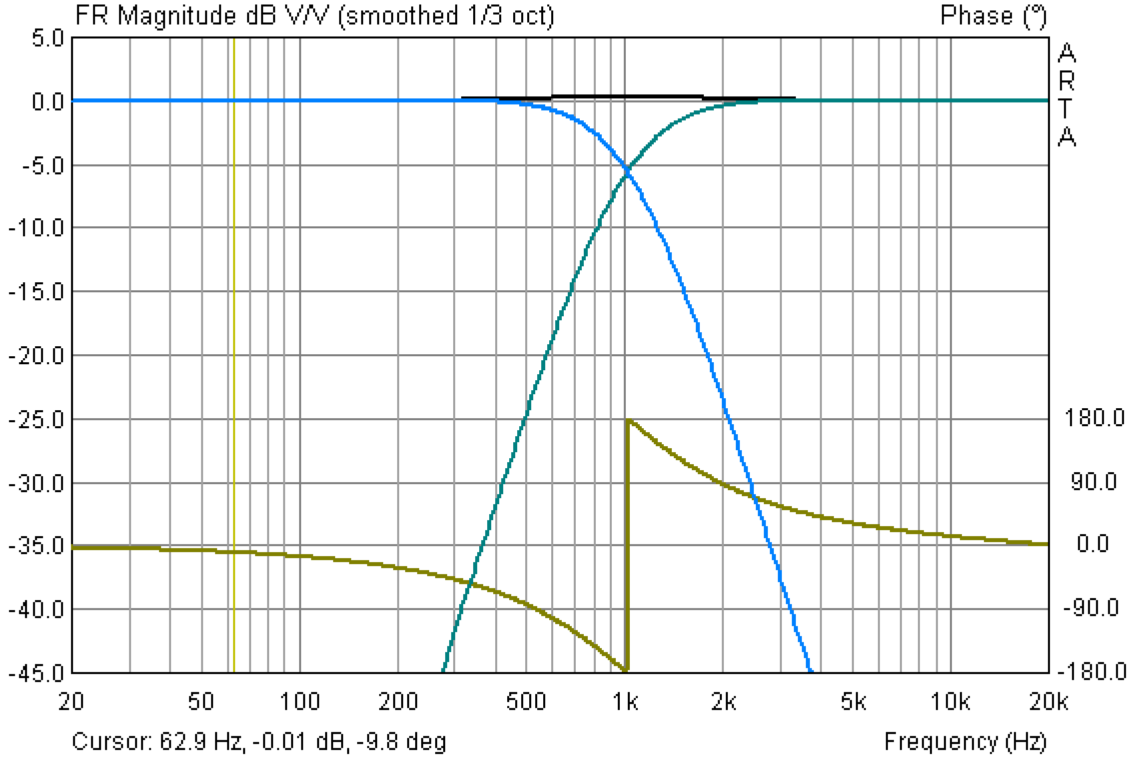


Filter Phase Distortion

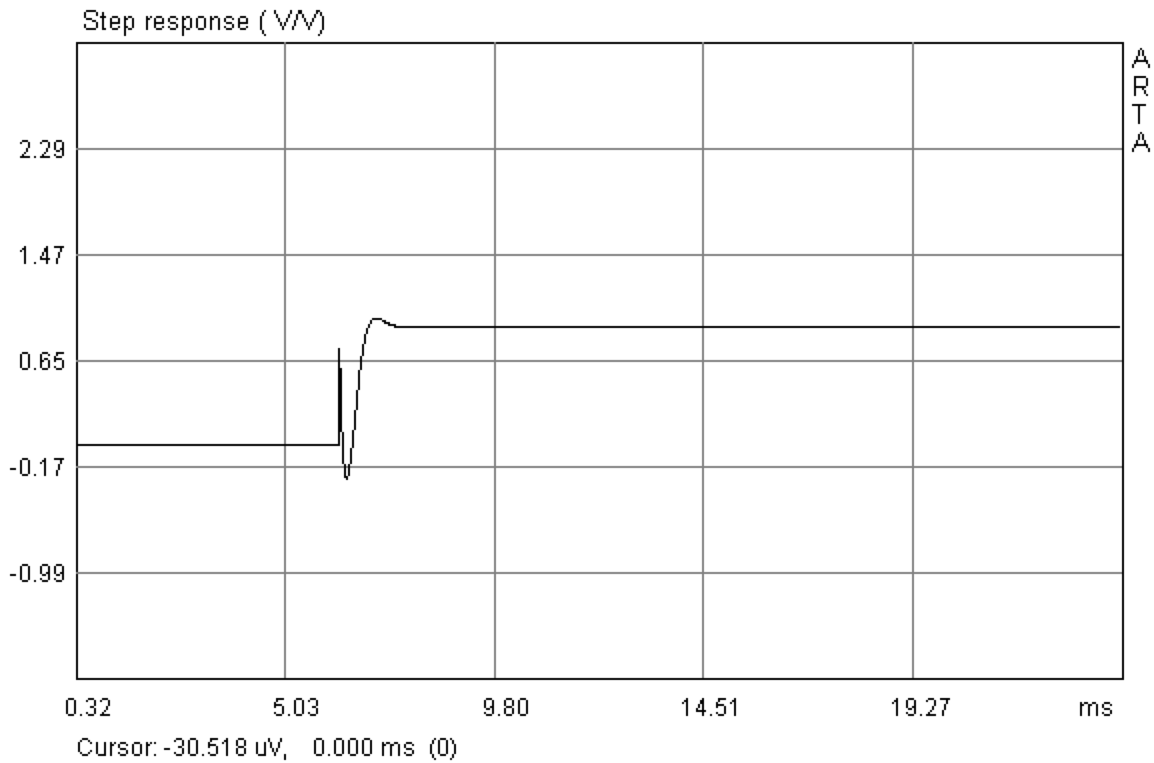
- Example with a 4th order Linkwitz-Riley filter

No inversion of polarity



Filter Phase Distortion

- Example with a 4th order Linkwitz-Riley filter



Filter Phase Distortion

- Linearization of the phase using S. Harsch method:

  1. Select a fc where the phase of the loudspeakers is linear
  2. Low Pass: Butterworth 4th order calculated for fc
  3. High pass: Bessel 2nd order calculated for fc
  4. Insert a constant delay into the high-pass section calculated by: T = (1 / fc) * 0.5
  5. No polarity reversal

- Example for fc = 1kHz:

  Low Pass = Butterworth 4th Order 1kHz
  High pass = Bessel 2nd order 1kHz
  Delay on the high-pass section = (1/1000) * 0.5 = 0.5ms

Filter Phase Distortion

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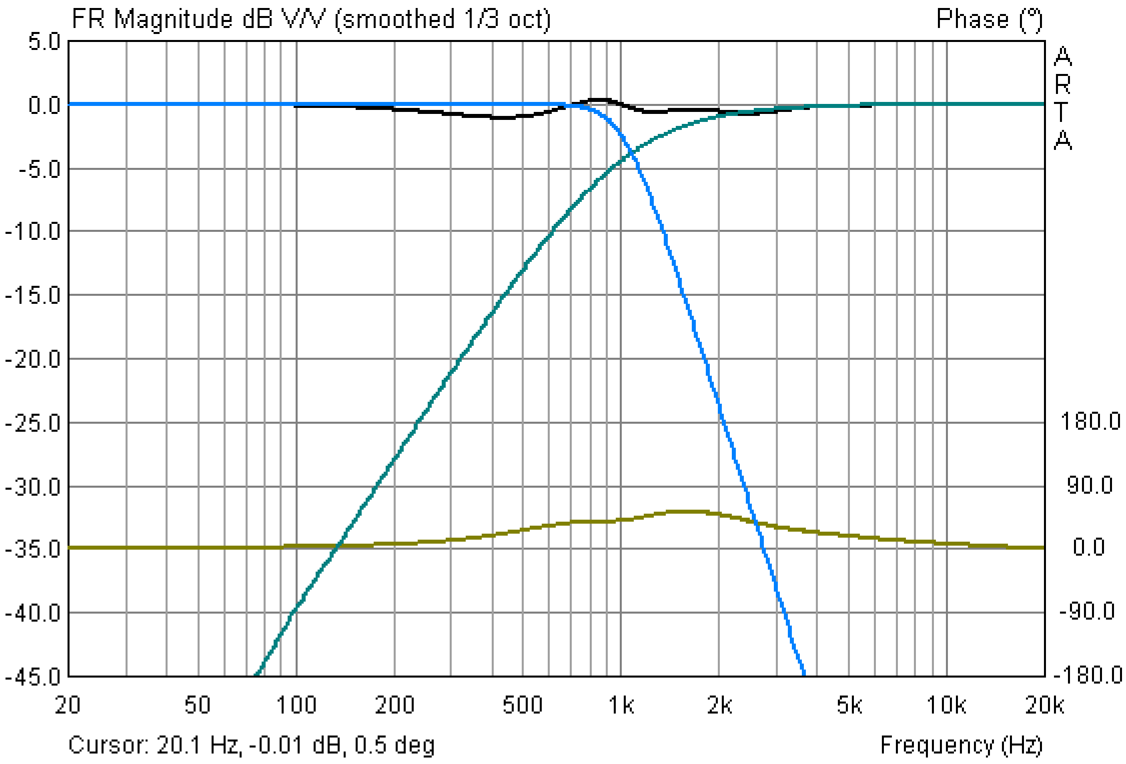

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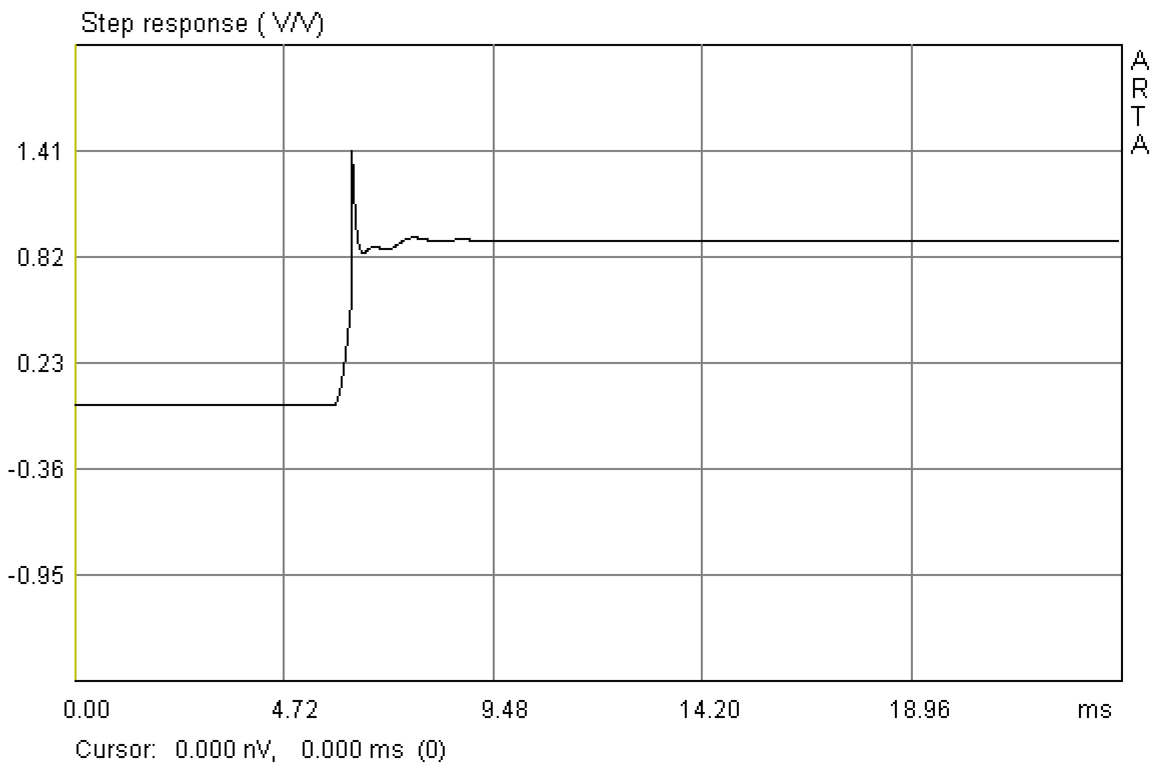
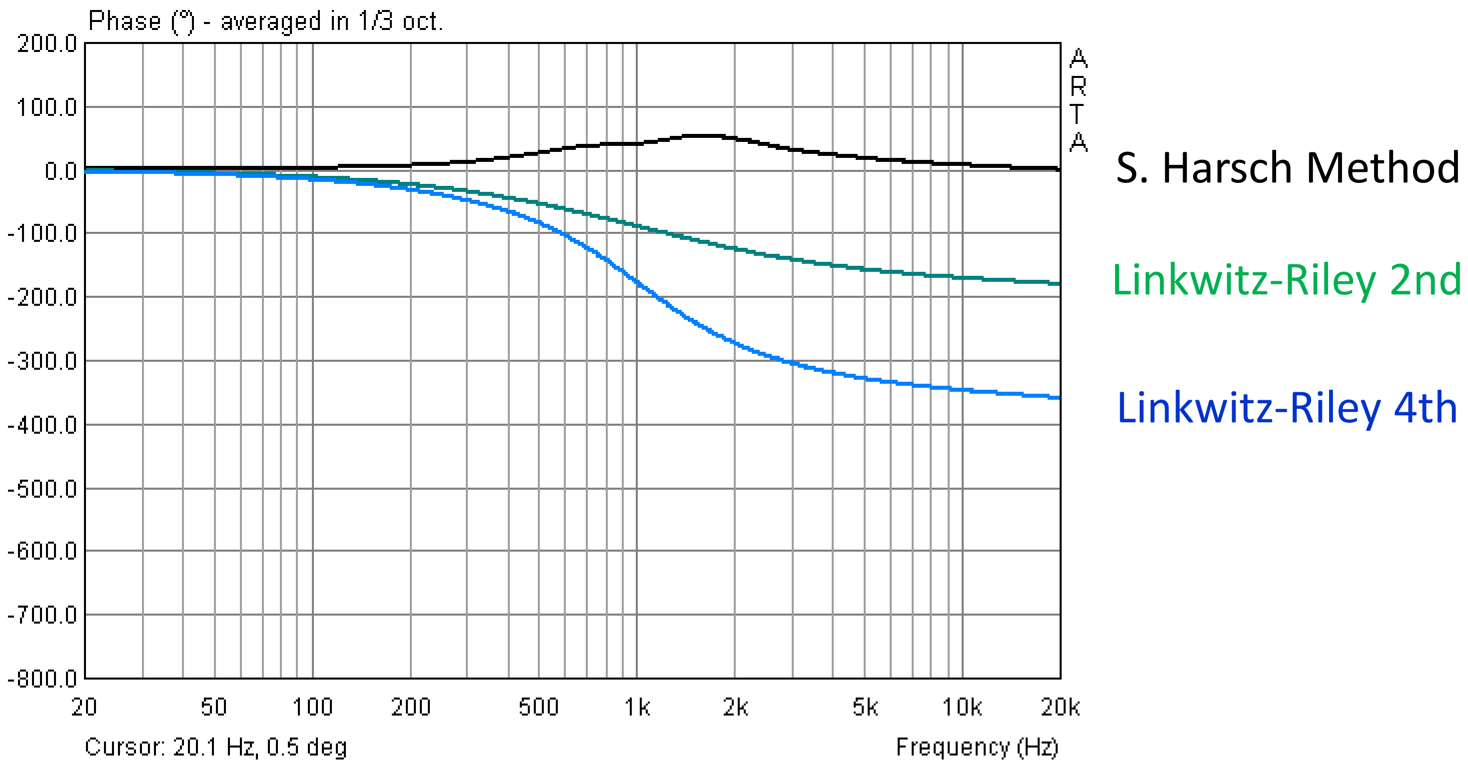


Filter Phase Distortion

- Linearization of the phase using S. Harsch method
- Comparison with 2nd and 4th order Linkwitz-Riley filters



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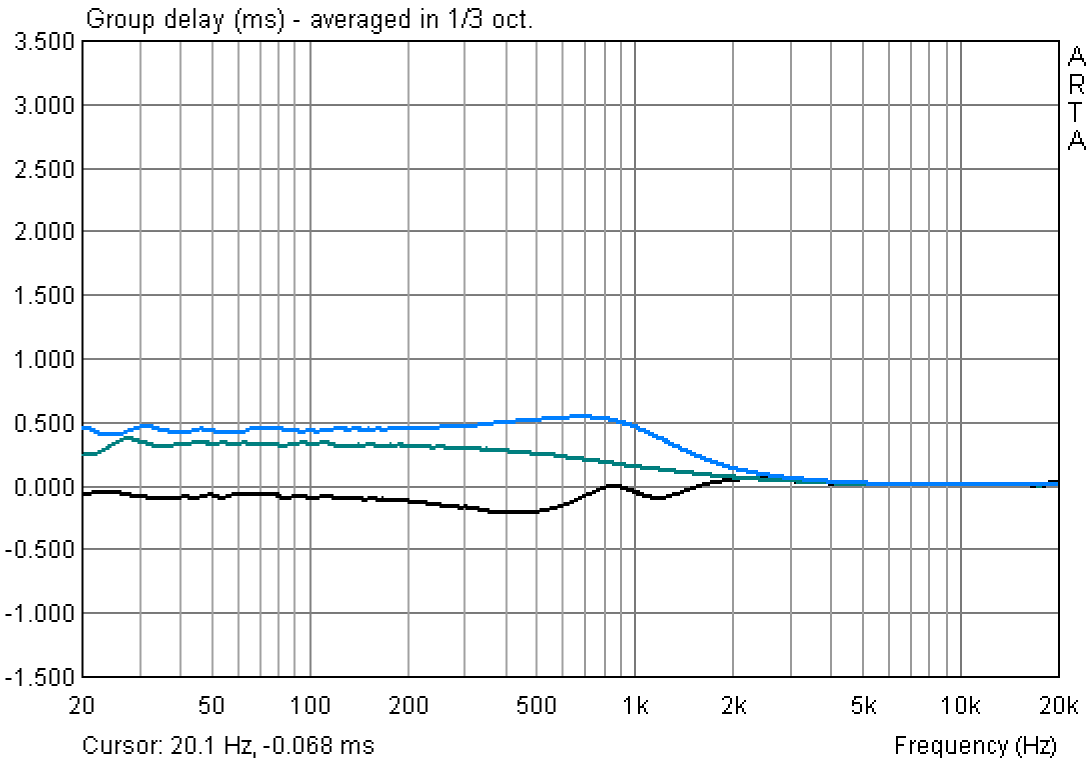


Linkwitz-Riley 4th

Linkwitz-Riley 2nd

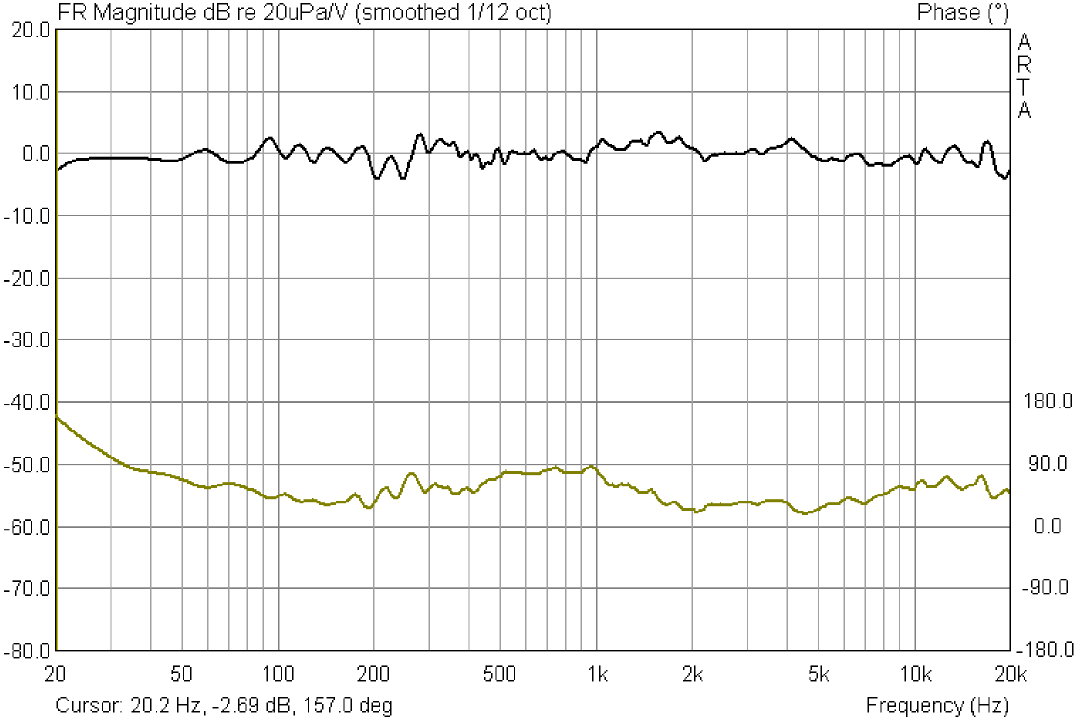
S. Harsch Method

Filter Phase Distortion

- Linearization of the phase using S. Harsch method
  - Advantages:
    - Can be used with any digital filter with the option of configuring of the Butterworth and Bessel filters and to add a constant delay
    - Can be used on existing IIR systems by simple parameterization
    - Can be used with passive filters or analog active filters if the delay can be implemented by physically shifting the loudspeakers.
    - Uses few DSP resources
    - Low latency
  - Disadvantages:
    - Is not a true linear phase filter
    - The polar pattern may have troughs around the frequency of cut at angle

Results

- Example: 2-way enclosure system with low frequency equalization + filter
- S. Harsch @ 400Hz method



Using this Method

- Free use
- If someone wants to use it on a commercial product, I would be happy to put a reference on my website.
- For people interested in hearing phase distortions, I made a plug-in for Audacity which one can introduce an all-pass over an audio file