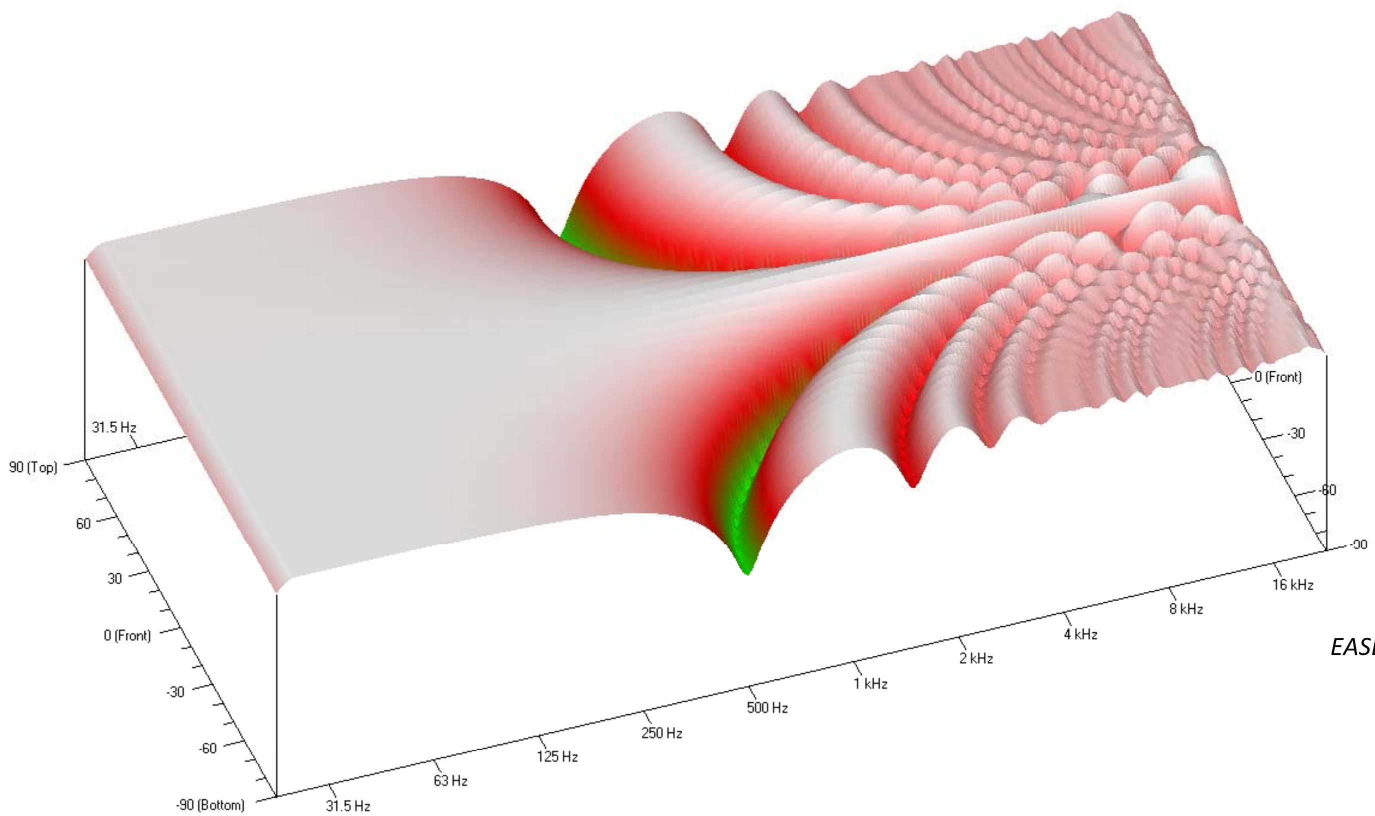
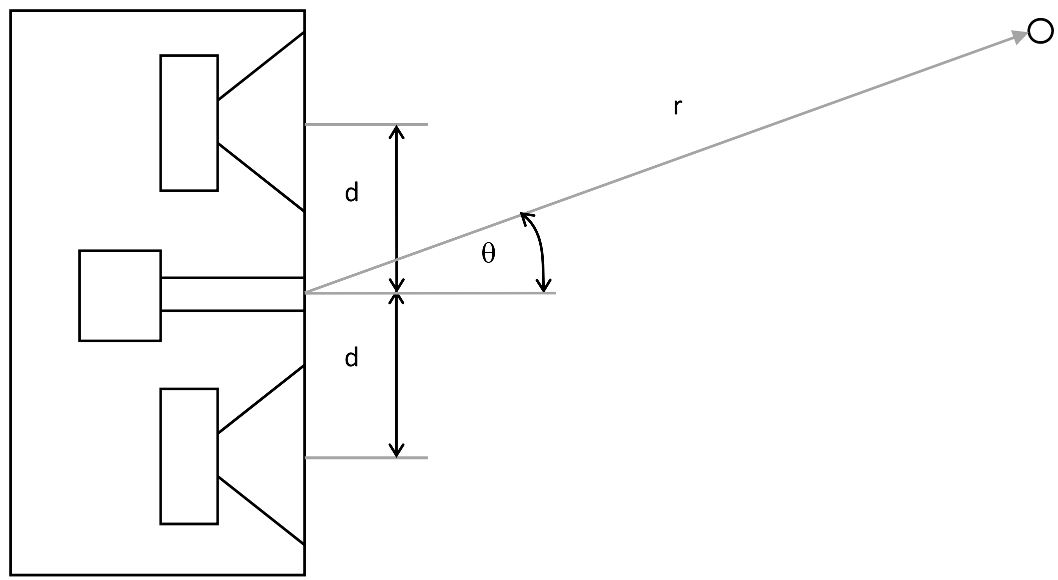
Loudspeaker Directivity Improvement Using Low Pass and All Pass Filters



EASE SpeakerLab

Example Loudspeaker System



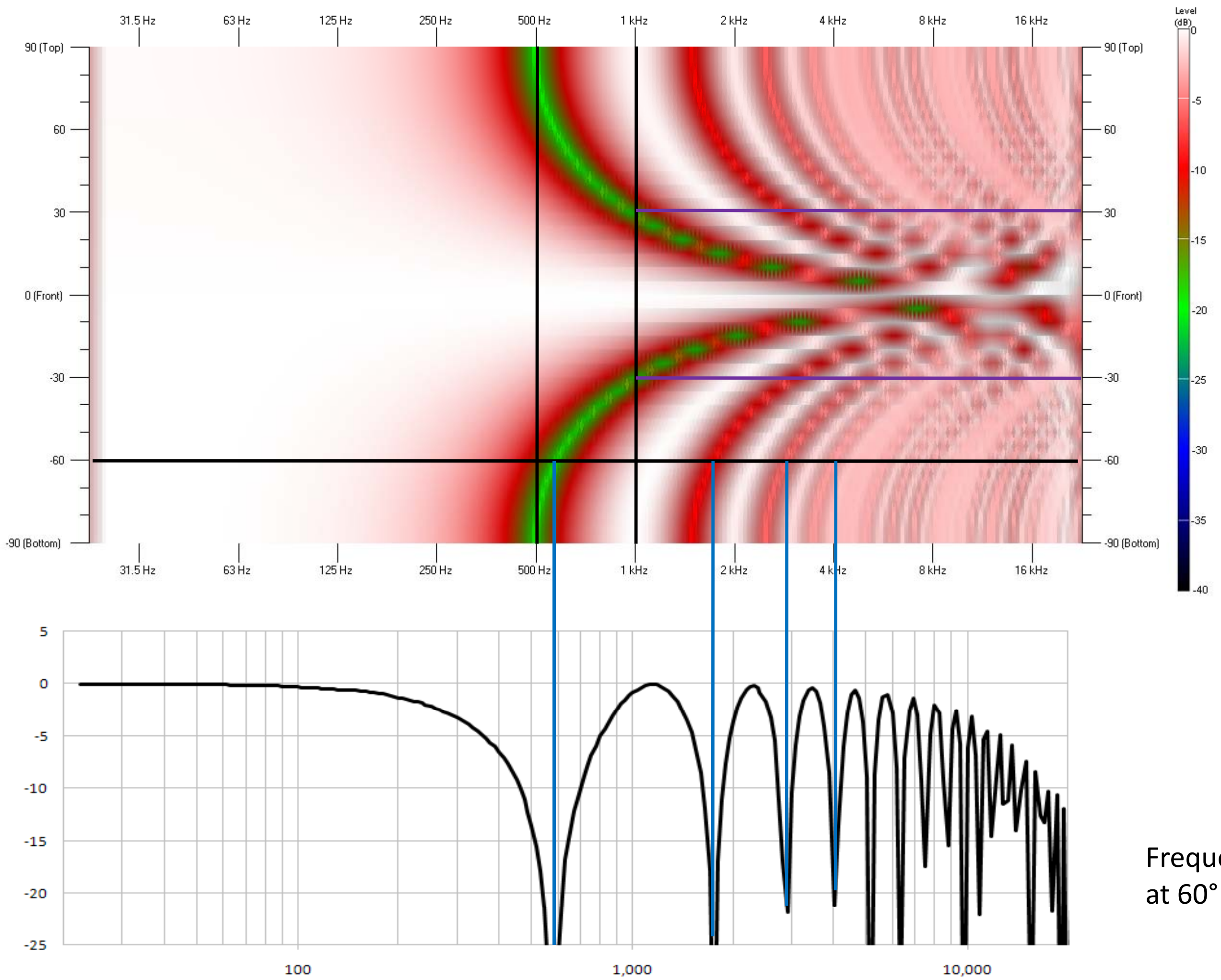
For models and graphs

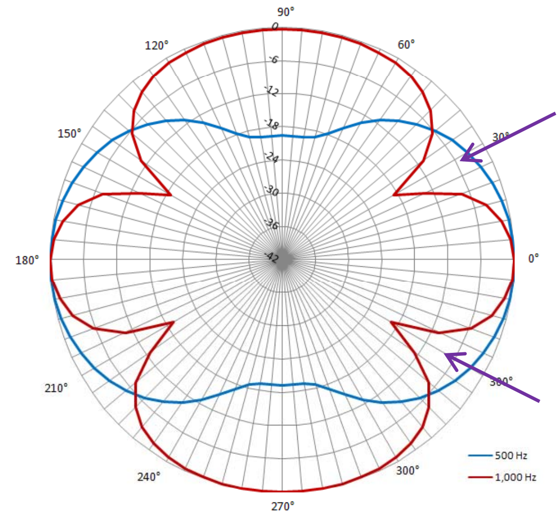
LF drivers: 250 mm (10 inches) HF horn dimension: 64 mm (2.5 inches)

d = 170 mm (6.75 inches), r = 20 m (65.5 feet)

Omni-directional point sources are used in the models

Vertical Directivity Map – Two LF Drivers



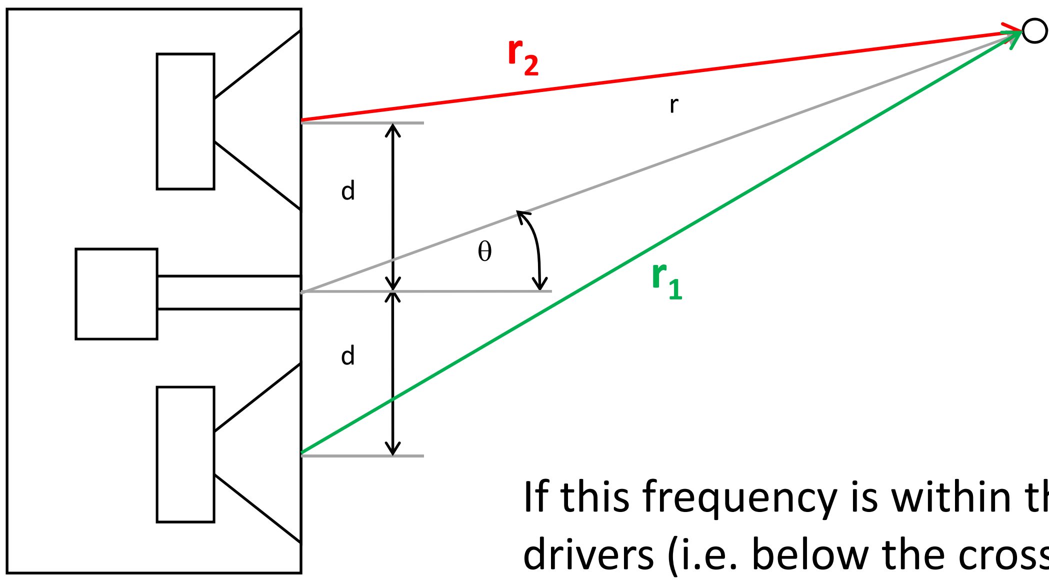


Polar graph – 1/3 octave
500 Hz and 1,000 Hz

Frequency response
at 60° off-axis

Lowest frequency null at a given angle

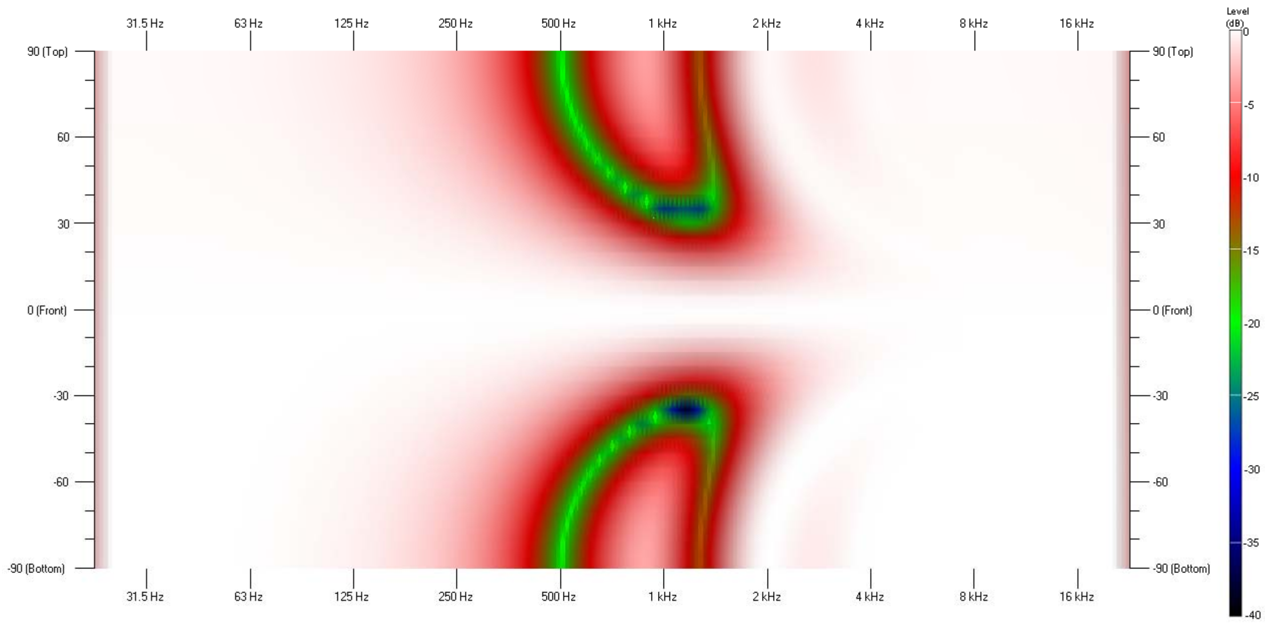
$$f_x = \frac{1}{2} c * \left| \left\{ \left[(r\cos\theta)^2 + (d + r\sin\theta)^2 \right]^{\frac{1}{2}} - \left[(r\cos\theta)^2 + (d - r\sin\theta)^2 \right]^{\frac{1}{2}} \right\}^{-1} \right|$$

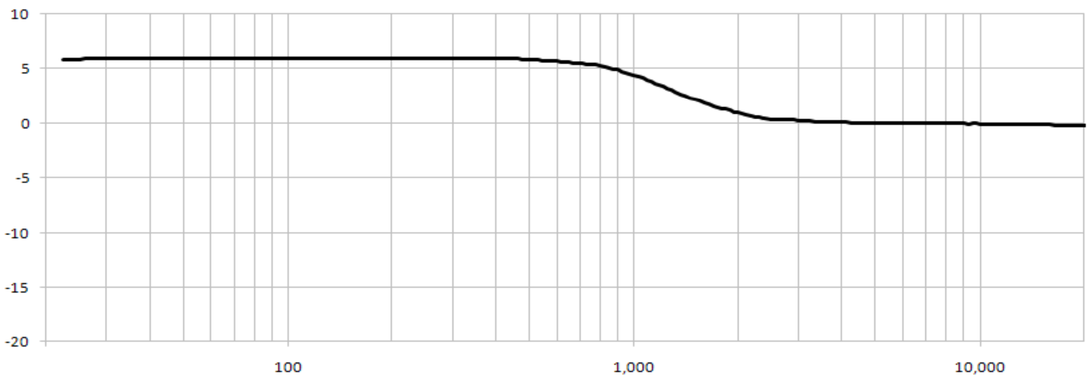


If this frequency is within the pass band of the LF drivers (i.e. below the crossover frequency), the output from one of the drivers must be attenuated in order to minimize the comb filtering.

A low pass filter may be used to accomplish this.

Example Loudspeaker System

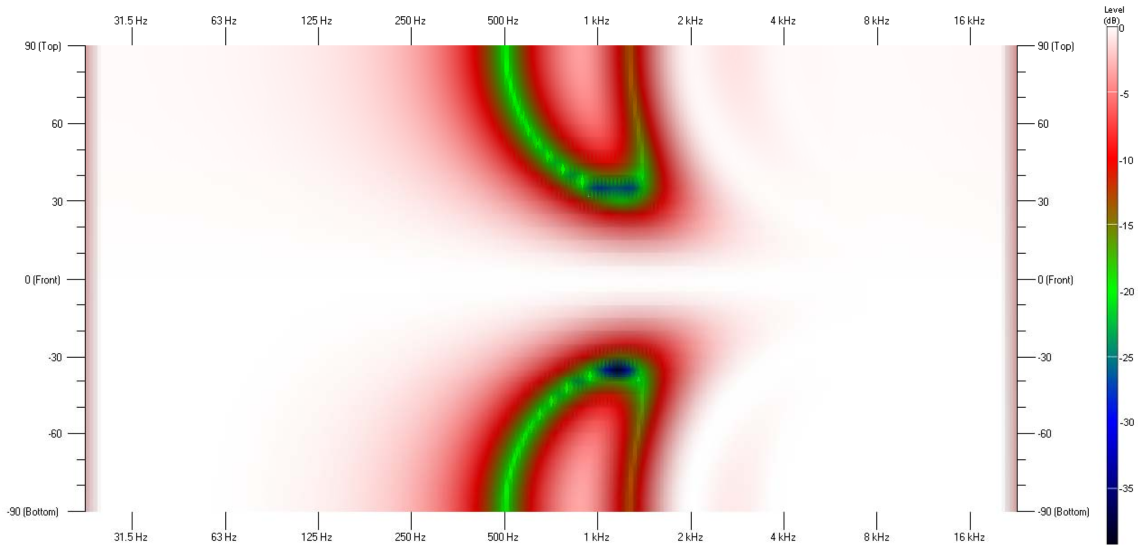




Frequency response on-axis

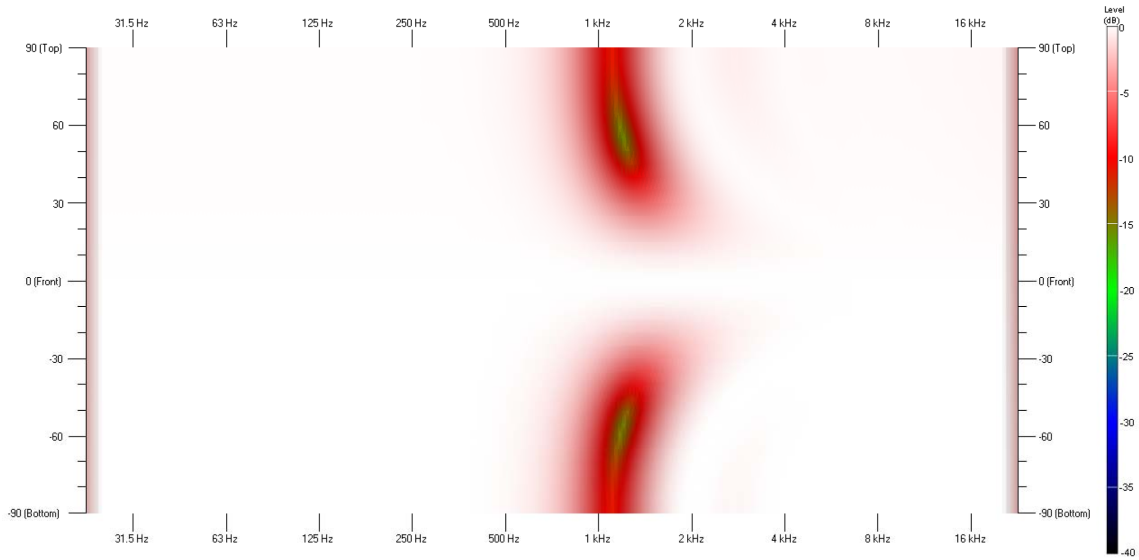
Crossover: 1.2 kHz
4th order Linkwitz-Riley

Example Loudspeaker System



Both LF drivers active

Crossover: 1.2 kHz
4th order Linkwitz-Riley



One LF driver active
(one muted)

Determining Low Pass Filter Parameters

$$f_{\varphi} = \frac{\varphi}{360} * \frac{c}{|r_1 - r_2|}$$

$$r_1 = \left[(r\cos\theta)^2 + (d + r\sin\theta)^2\right]^{\frac{1}{2}} \qquad r_2 = \left[(r\cos\theta)^2 + (d - r\sin\theta)^2\right]^{\frac{1}{2}}$$

Used to determine the frequency of any arbitrary phase difference between the two LF drivers for a given driver spacing, off-axis angle and observation distance

Below $f_{120°}$ there is only constructive interference
Above $f_{120°}$ there is both constructive & destructive interference (comb filtering)

At $f_{180°}$ there is maximum cancellation

Determining Low Pass Filter Parameters

$$\frac{P_1}{P_2} = \frac{1 + P_{Roff-axis}}{1 - P_{Roff-axis}}$$

Required pressure ratio of the individual LF drivers given the desired off-axis pressure ratio

$$P_{Roff-axis} = \frac{P_{T180^\circ}}{P_{T0^\circ}}$$

Ratio of the off-axis pressure where there is maximum cancellation to the on-axis pressure

Performance Criterion

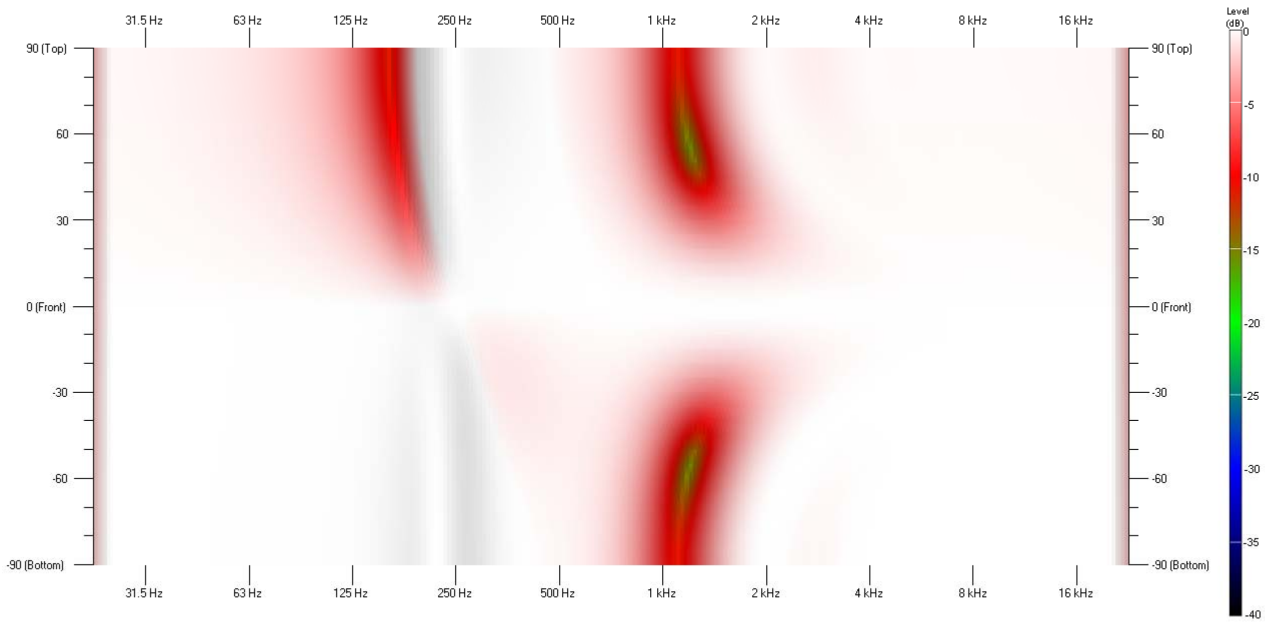
Level of $P_{Roff\text{-}axis}$ should be no greater than -1 dB $\quad$ $P_{Roff\text{-}axis}$ = 10^(-1/20) = 0.8913

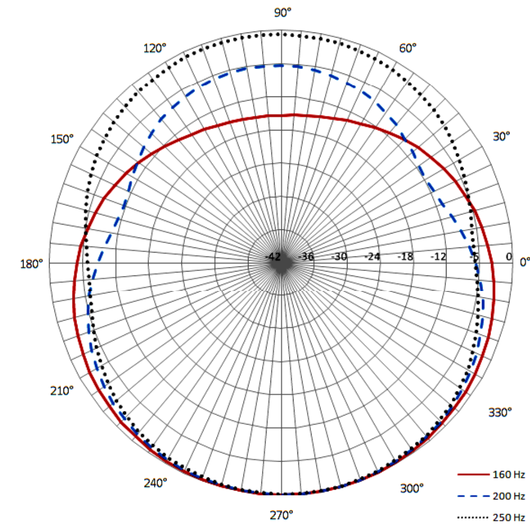
P_1/P_2 = 17.39 $\quad$ 20*log(17.39) = 24.8 dB

The level difference between the two LF drivers at f_{180° should be 24.8 dB

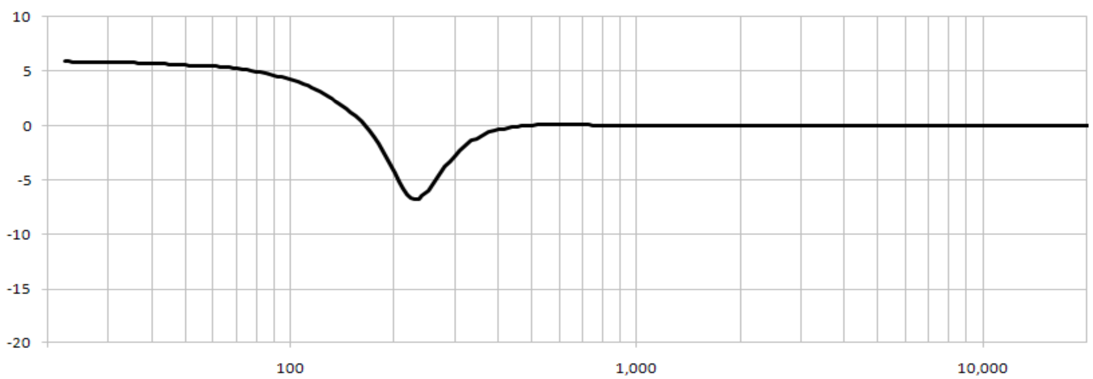
A 4th order low pass filter with a cut-off frequency of approximately f_{90°, one octave below f_{180°, may be used to yield this attenuation

Example Loudspeaker System





Polar graph – 1/3 octave
160, 200 and 250 Hz

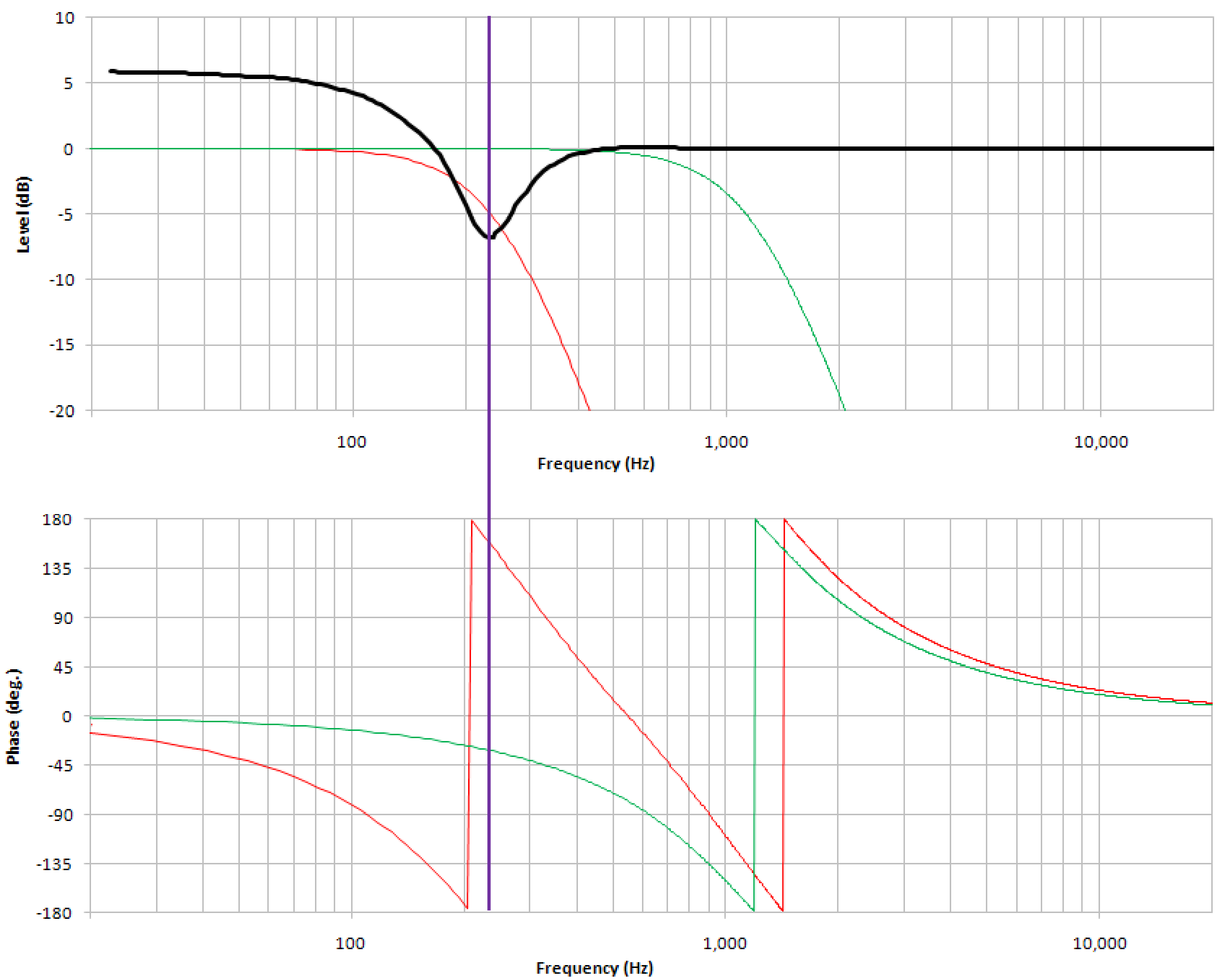


Frequency response on-axis

Crossover: 1.2 kHz
4th order Linkwitz-Riley

LPF on one LF driver: 250 Hz
4th order Linkwitz-Riley

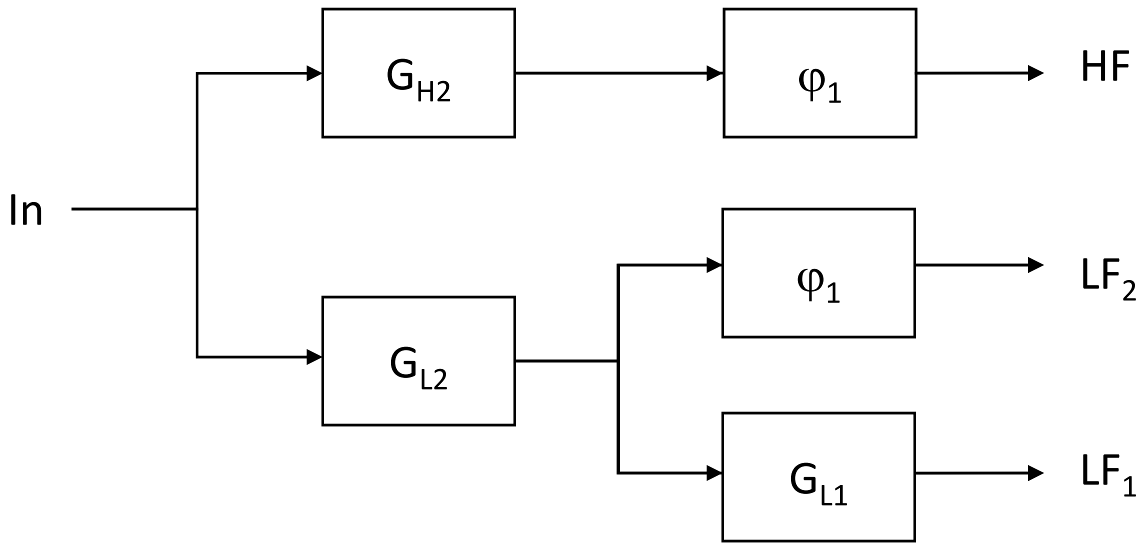
Example Loudspeaker System



Crossover: 1.2 kHz
4th order Linkwitz-Riley

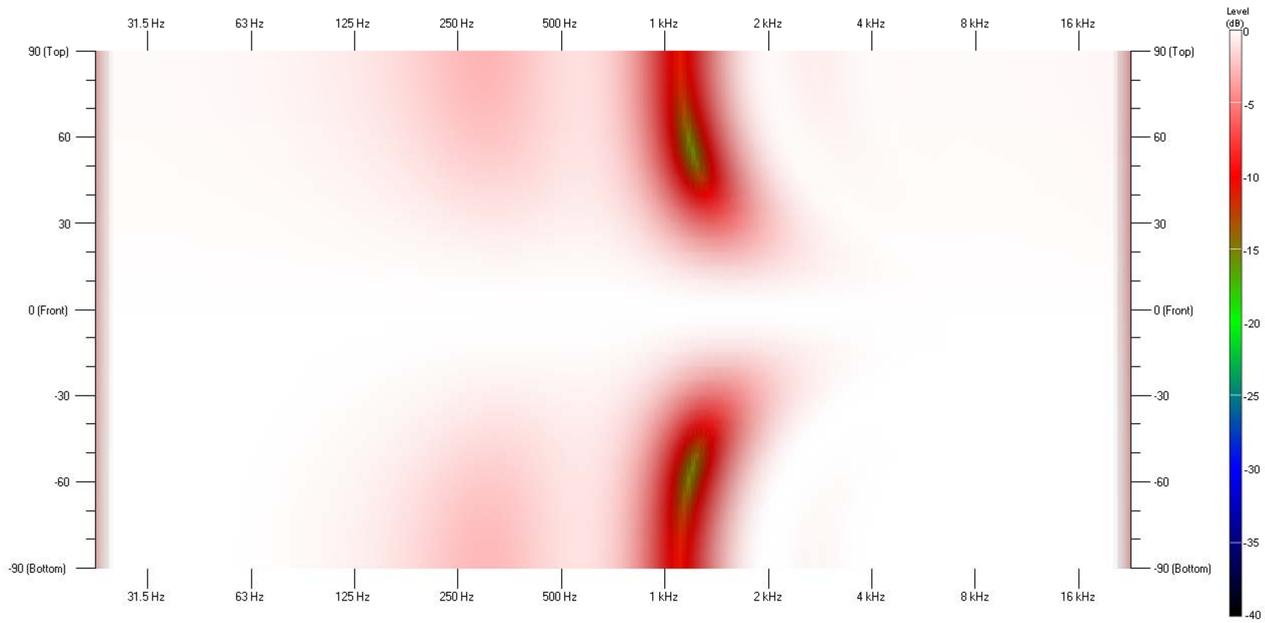
LPF on one LF driver: 250 Hz
4th order Linkwitz-Riley

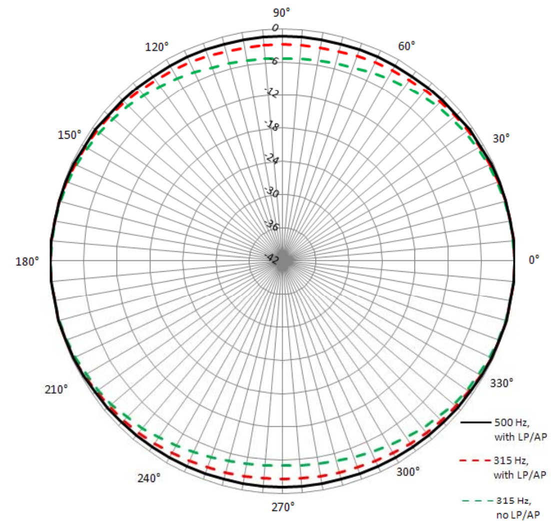
Phase Compensation



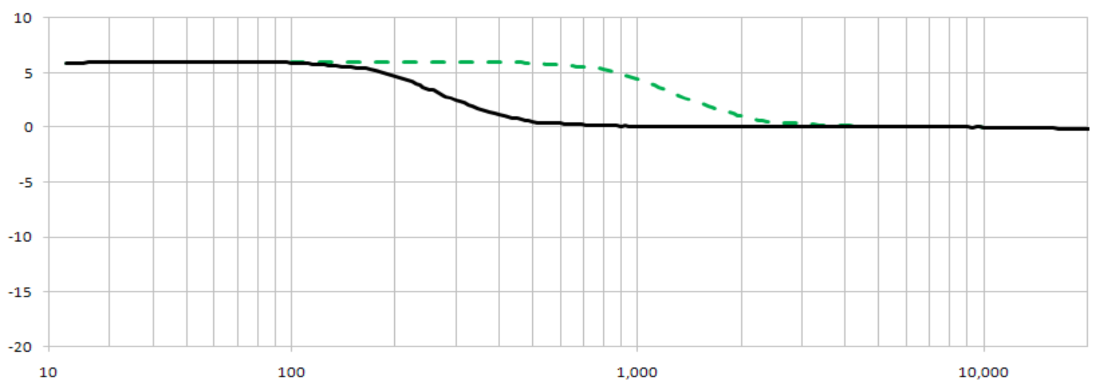
φ_1 is an All Pass filter with the same phase response as G_{L1}
(Phase shift but with flat magnitude response)

Example Loudspeaker System





Polar graph – 1/3 octave
500 Hz and 315 Hz (with & w/o filtering)



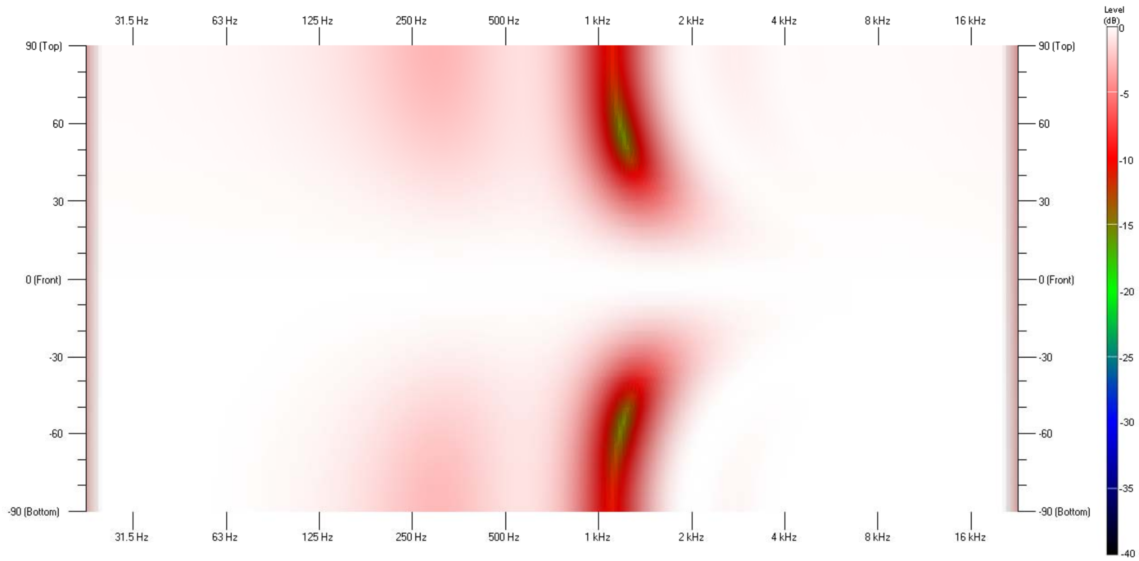
Frequency response on-axis

Crossover: 1.2 kHz
4th order Linkwitz-Riley

LPF on one LF driver: 250 Hz
4th order Linkwitz-Riley

APF on other LF driver: 250 Hz
2nd order Butterworth

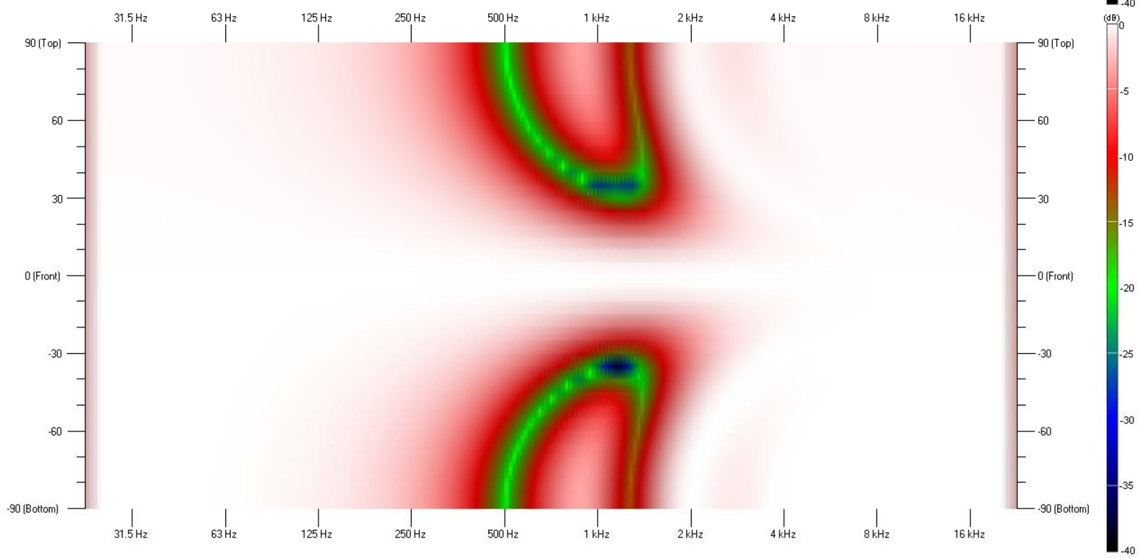
Example Loudspeaker System



Crossover: 1.2 kHz
4^{th} order Linkwitz-Riley

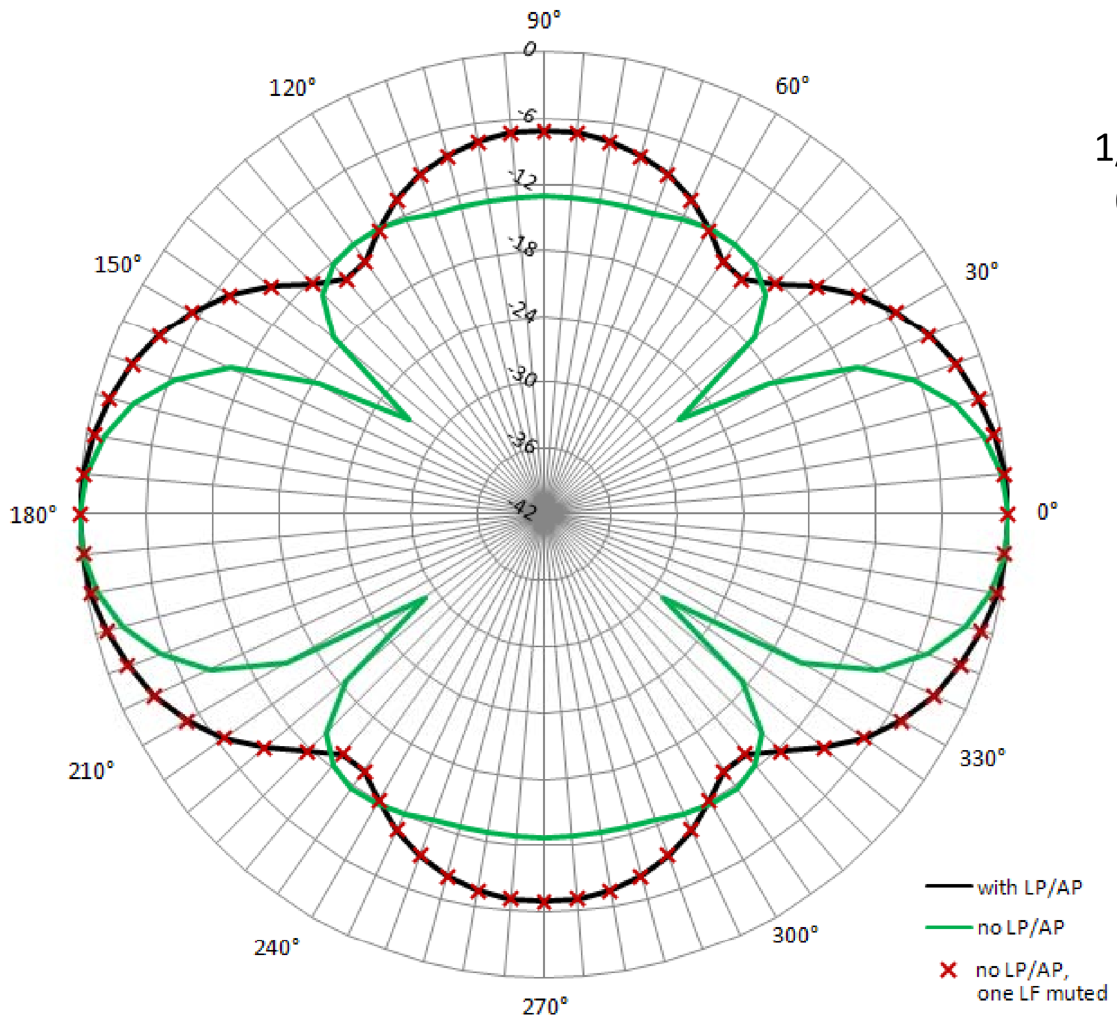
LPF on one LF driver: 250 Hz
4^{th} order Linkwitz-Riley

APF on other LF driver: 250 Hz
2^{nd} order Butterworth



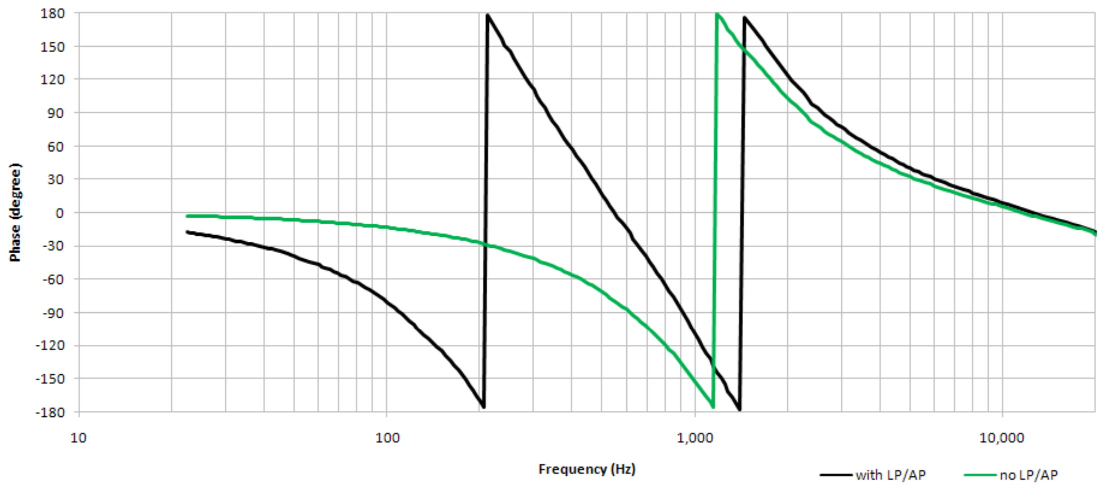
Crossover: 1.2 kHz
4^{th} order Linkwitz-Riley

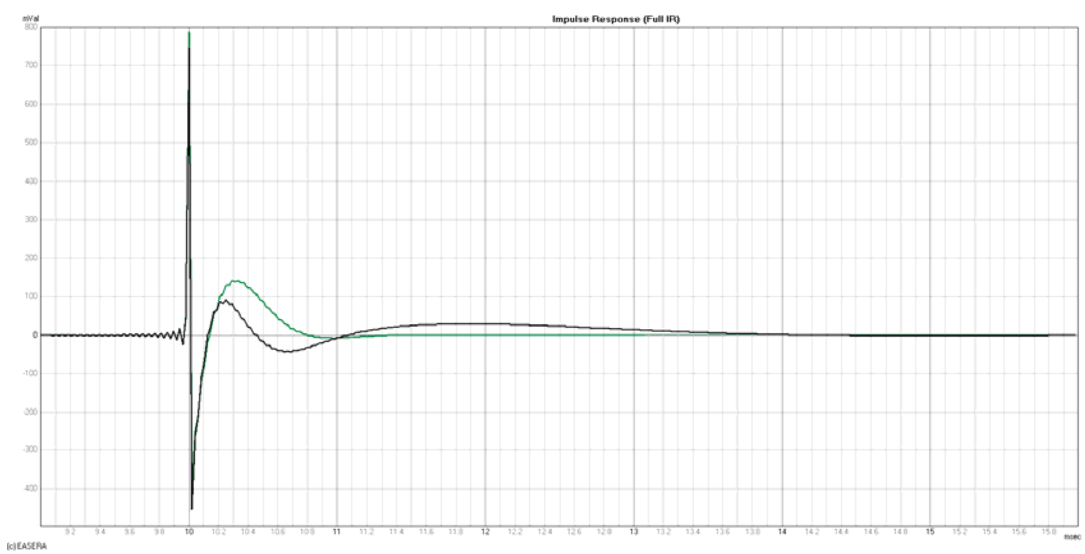
Example Loudspeaker System



Polar graph
1/3 octave, 1.25 kHz
(crossover region)

Example Loudspeaker System





Detrimental Effects

Phase response

Crossover and Low Pass / All Pass Filters

Crossover Only

Impulse response

Real Loudspeaker System

Desirable to have the directivity response of the LF pass band match that of the HF pass band.

Careful spacing of the LF drivers and choice of the LP/AP filter frequency can help extend directivity control below the crossover frequency.

$$\frac{P_1}{P_2} = \frac{1 + P_{Roff-axis}}{1 - P_{Roff-axis}}$$

$$P_{Roff-axis} = \frac{P_{T180^\circ}}{P_{T0^\circ}} = 0.5 \quad \text{(-6 dB)}$$

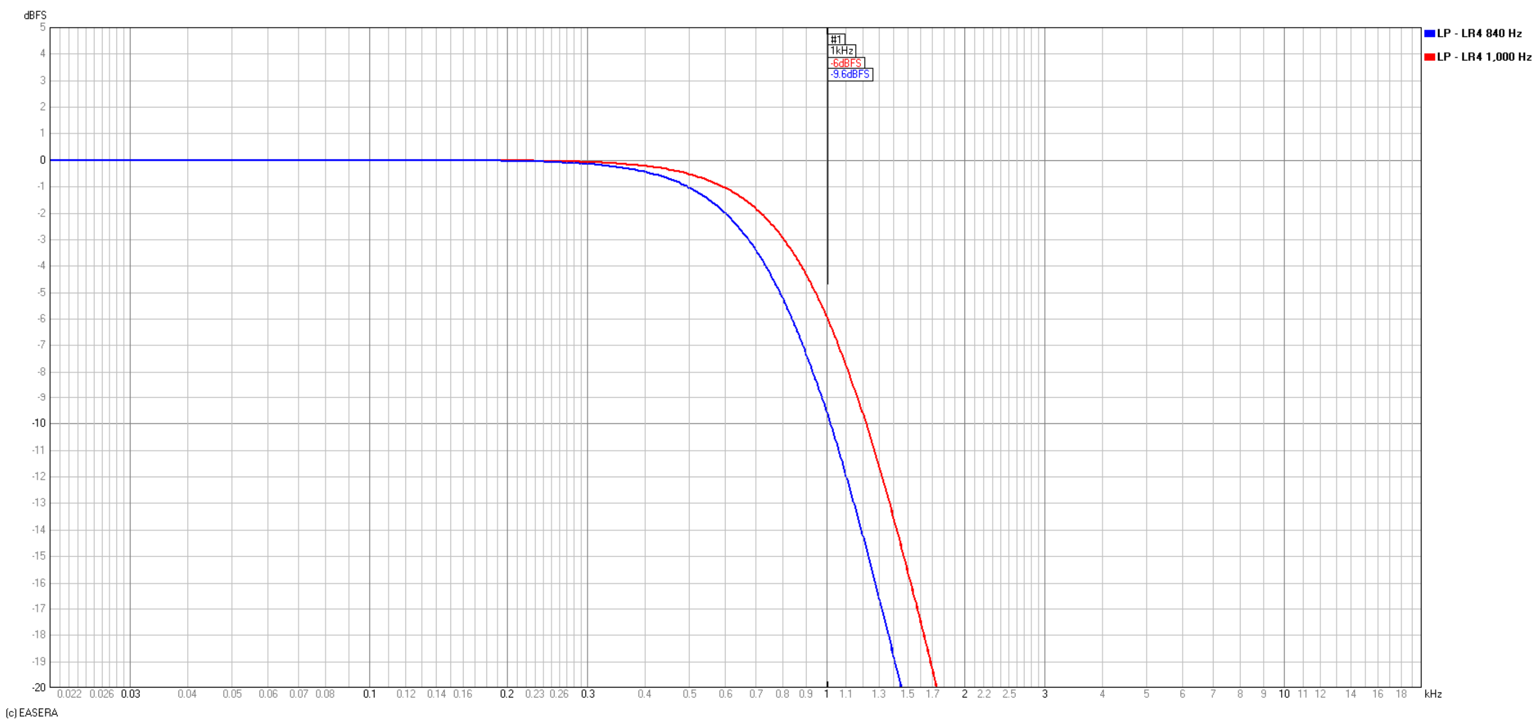
P1/P2 = 3.01 20*log(3.01) = 9.6 dB

The level difference between the two LF drivers at f_{180° should be 9.6 dB

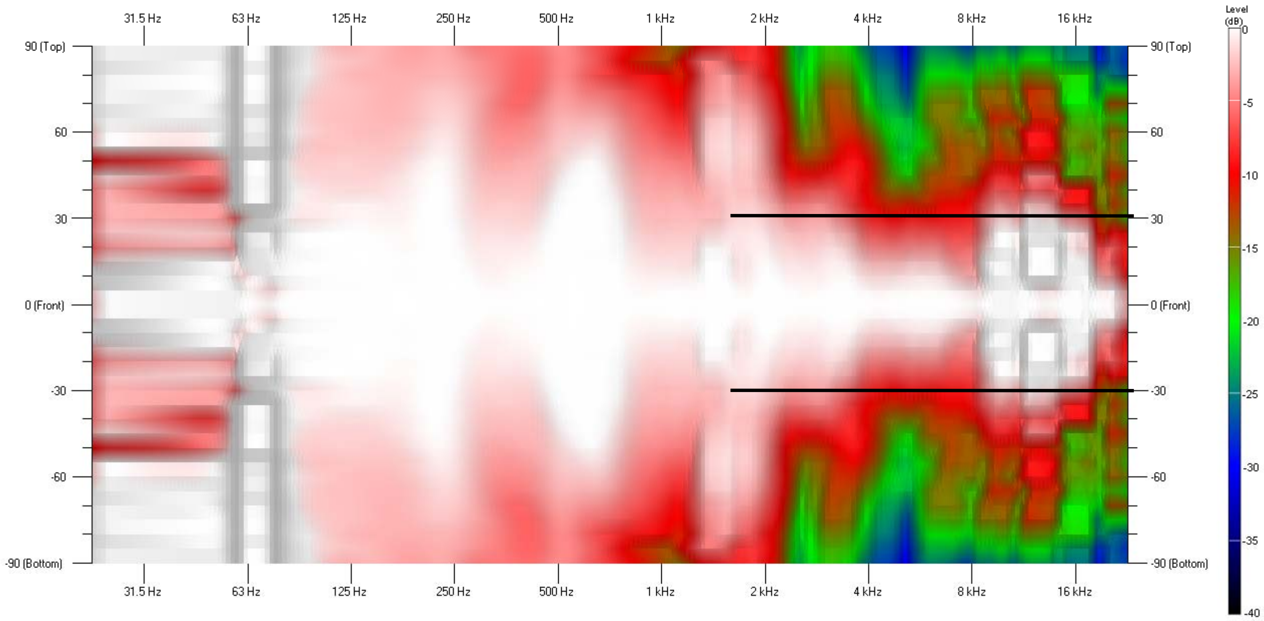
Real Loudspeaker System

A 4th order Linkwitz-Riley low pass filter has an attenuation of 9.6 dB at a frequency approximately 1.19 times its cut-off frequency, f_c.

Reduce the LP/AP filters f_c by a reciprocal amount , 0.84. The original f_c will now have an attenuation of 9.6 dB.



Real Loudspeaker System



Vertical Directivity Map
HF horn only

Beamwidth
(-6 dB angles)
60°
ranges from
50° - 70°

$$f_\varphi = \frac{\varphi}{360} * \frac{c}{|r_1 - r_2|}$$

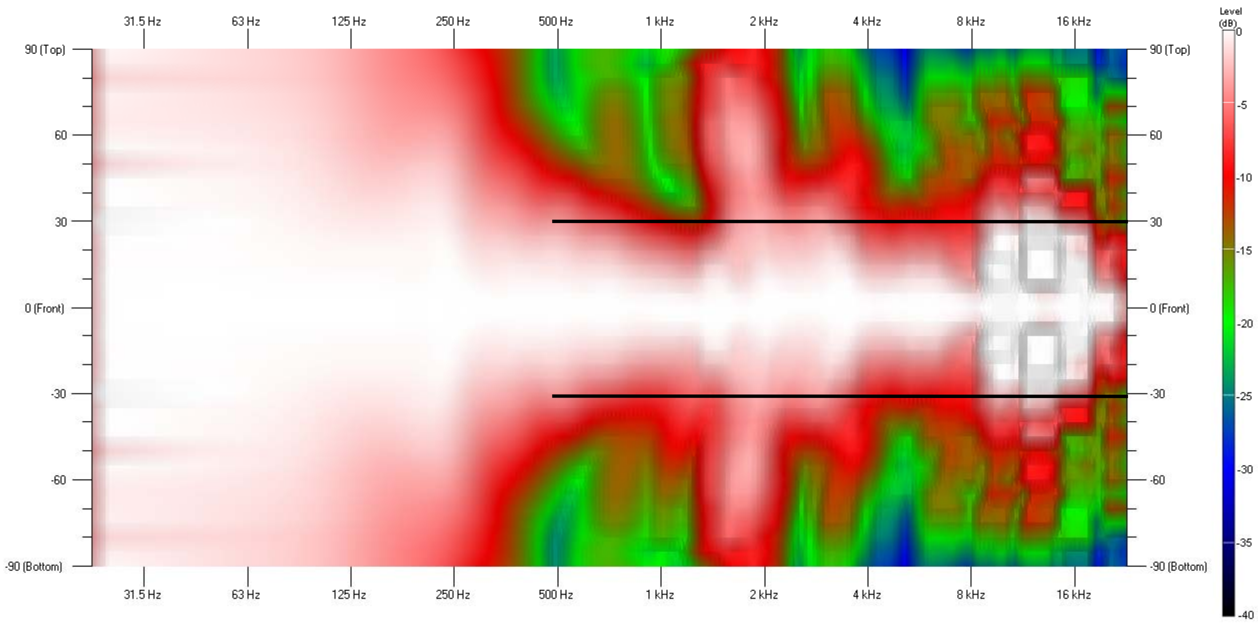
$$r_1 = \left[(r\cos\theta)^2 + (d + r\sin\theta)^2\right]^{\frac{1}{2}}$$

$$r_2 = \left[(r\cos\theta)^2 + (d - r\sin\theta)^2\right]^{\frac{1}{2}}$$

For θ = 30° and φ = 180° $f_{180°}$ = 1,000 Hz f_c = 840 Hz

Lowered 1/6 octave f_c = 750 Hz

Real Loudspeaker System

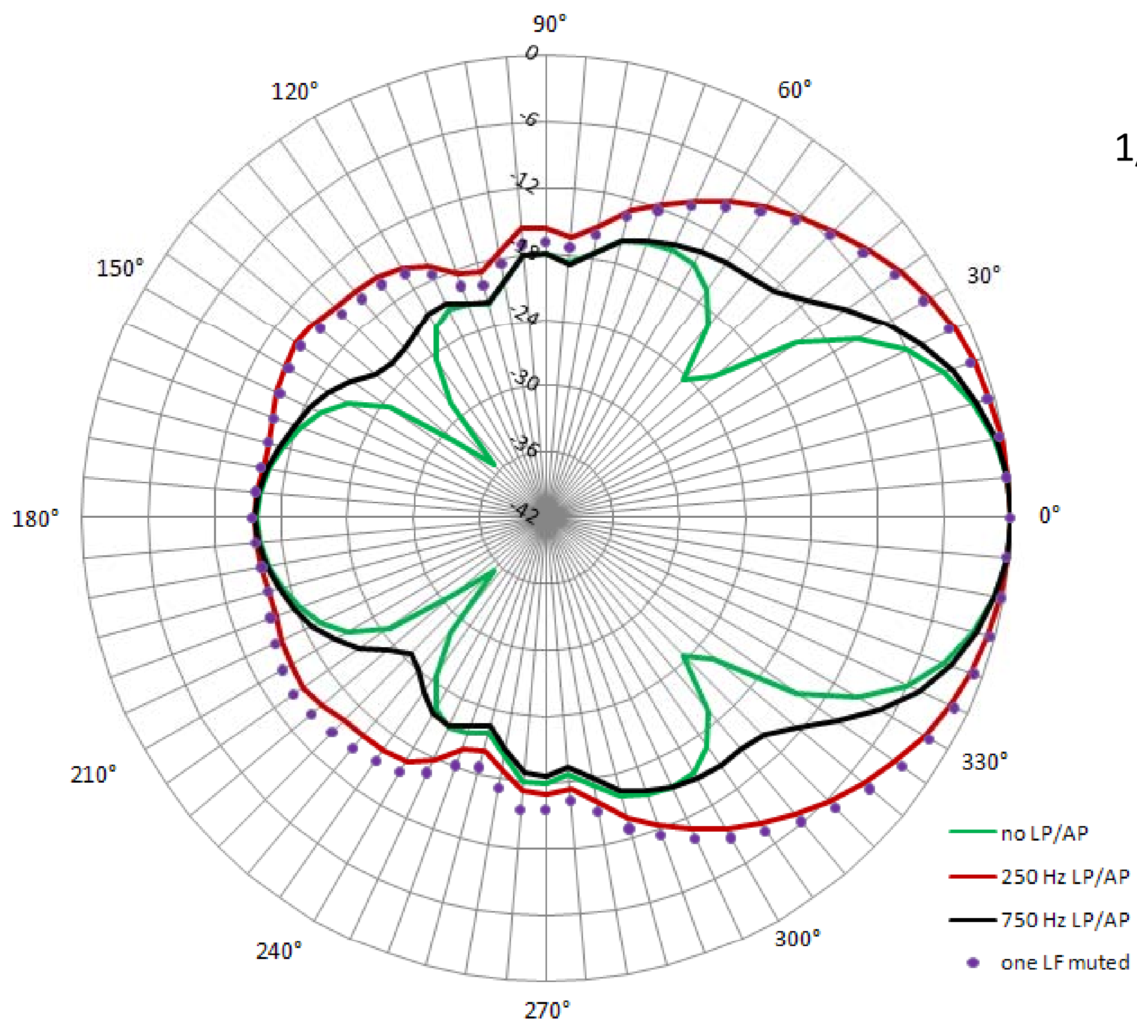


Crossover: 1.2 kHz
4th order Linkwitz-Riley

LPF on one LF driver: 750 Hz
4th order Linkwitz-Riley

APF on other LF driver: 750 Hz
2nd order Butterworth

Real Loudspeaker System



Polar graph
1/3 octave, 800 Hz