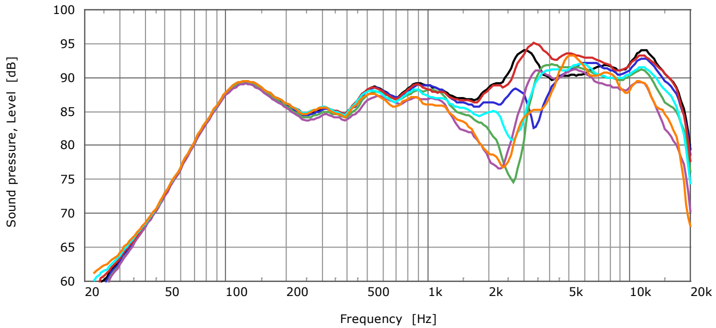
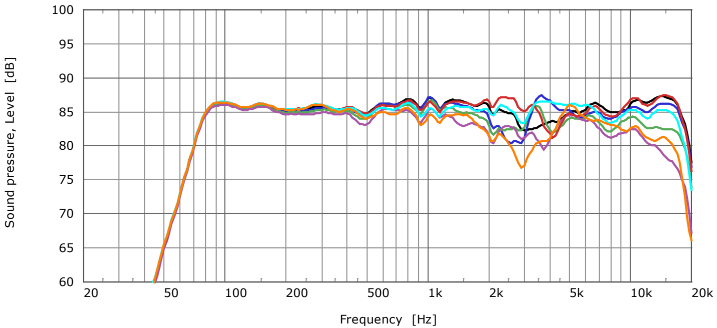
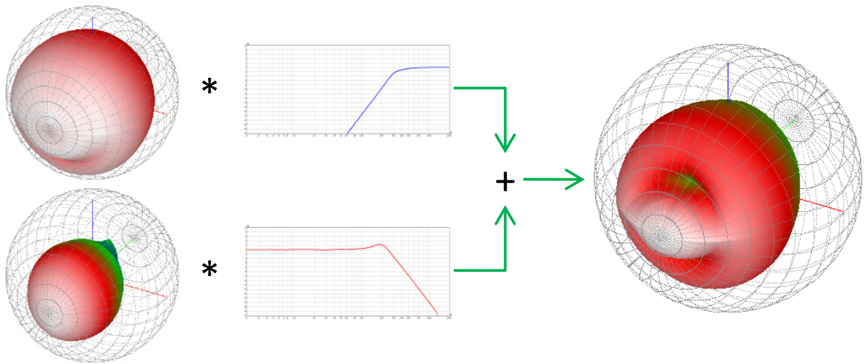
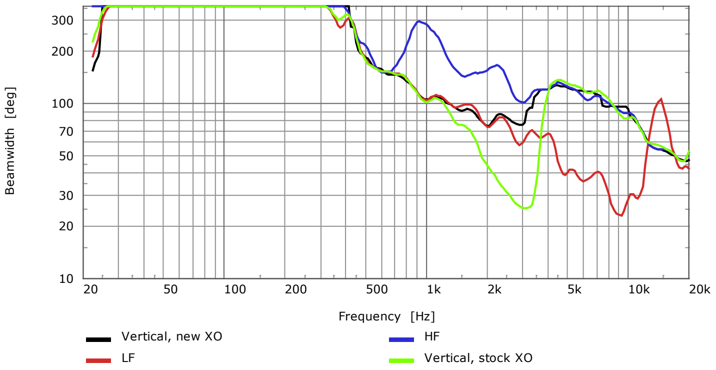
Passive Loudspeaker Directivity Optimization









Topics

1) Application
2) Design considerations
3) Example loudspeaker system
4) Workflow for directivity optimization through the crossover region
5) Passive crossover implementation
6) Response correction with front-end EQ
7) Final results

Passive Loudspeaker Directivity Optimization

Please stop me at any time for questions.

A PDF of all the slides will be available on my website
www.excelsior-audio.com/Publications.html

at the bottom of the page under
AES Papers & Presentations

Applications

1) Home / consumer loudspeakers
2) Studio monitors
3) In-wall / in-ceiling
4) Pro-audio
    a) "Point-source" boxes
    b) Large-scale line array modules

Design Considerations

On-axis frequency response

- small number of listeners

Off-axis frequency response

- typically, much greater number of listeners
- determines the directivity response

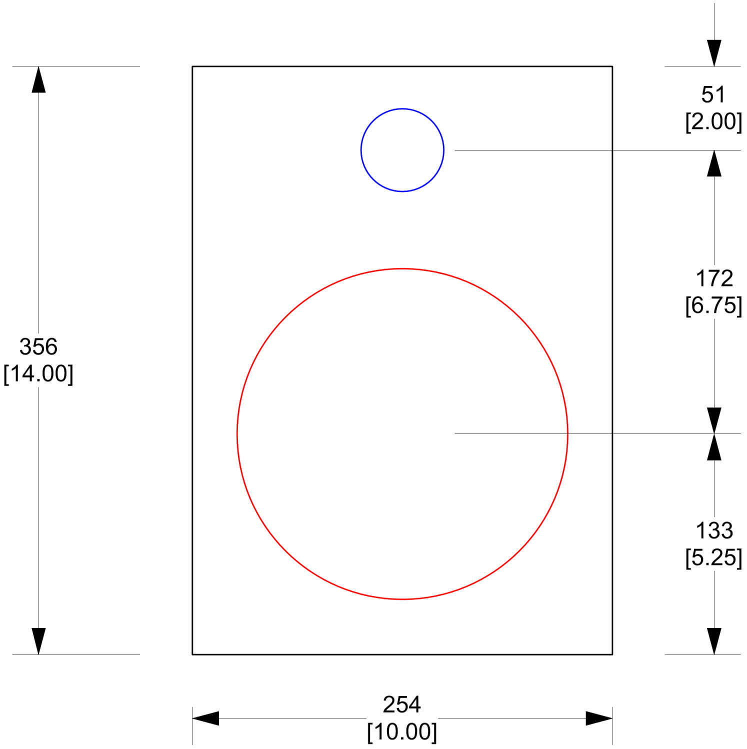
More consistent response from on-axis to off-axis yields more consistent sound quality in different acoustical environments

Sound Reproduction: Loudspeakers and Rooms

Floyd Toole

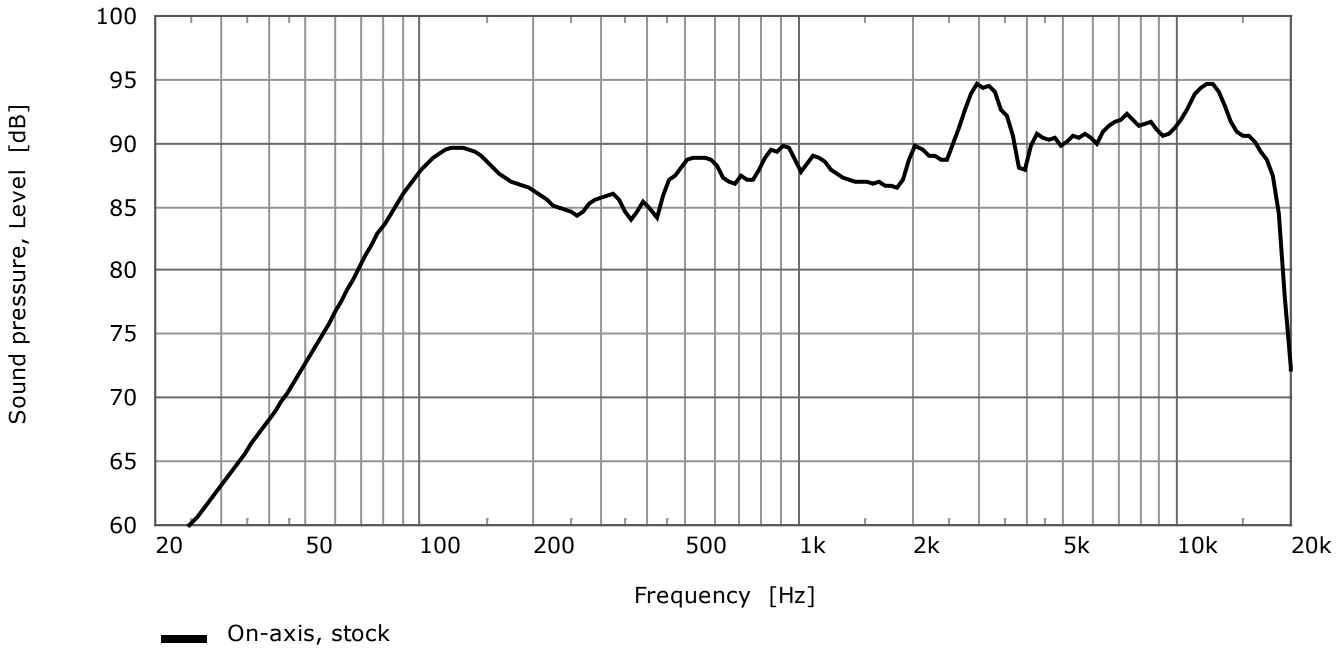
Example Loudspeaker System

Small, two-way loudspeaker system with 200 mm (8 inch) woofer & 25 mm (1 inch) dome tweeter



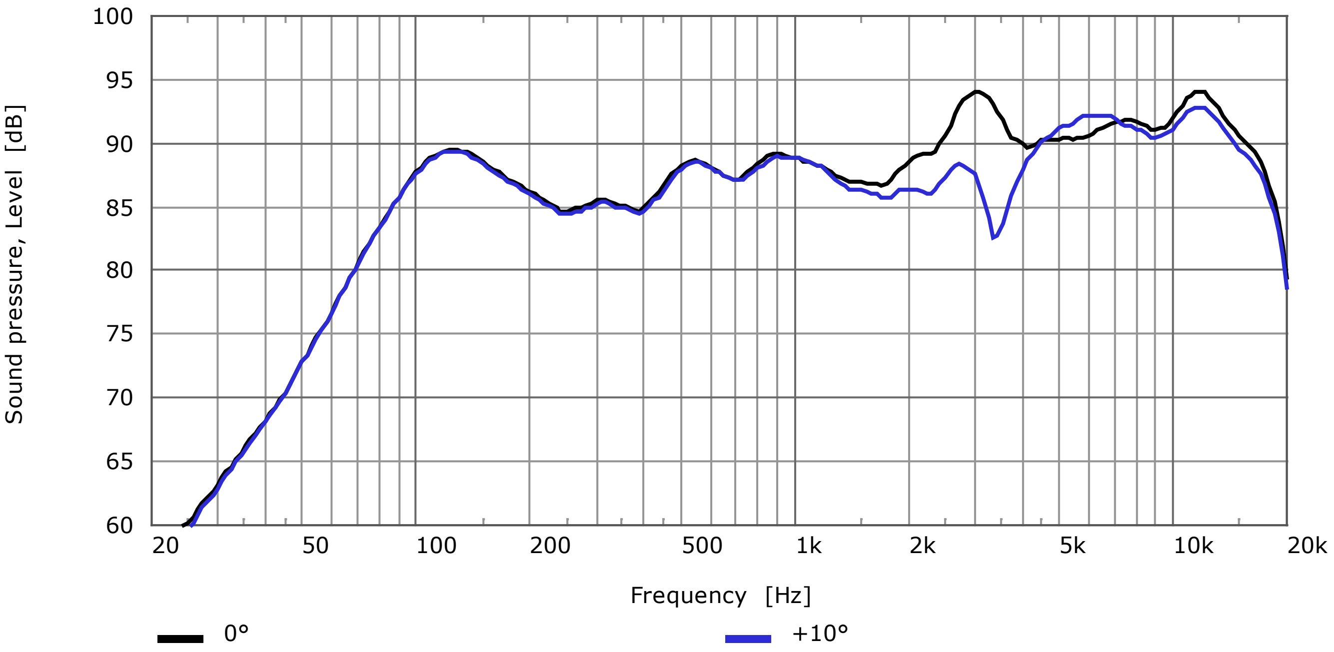
Example Loudspeaker System

On-axis frequency response



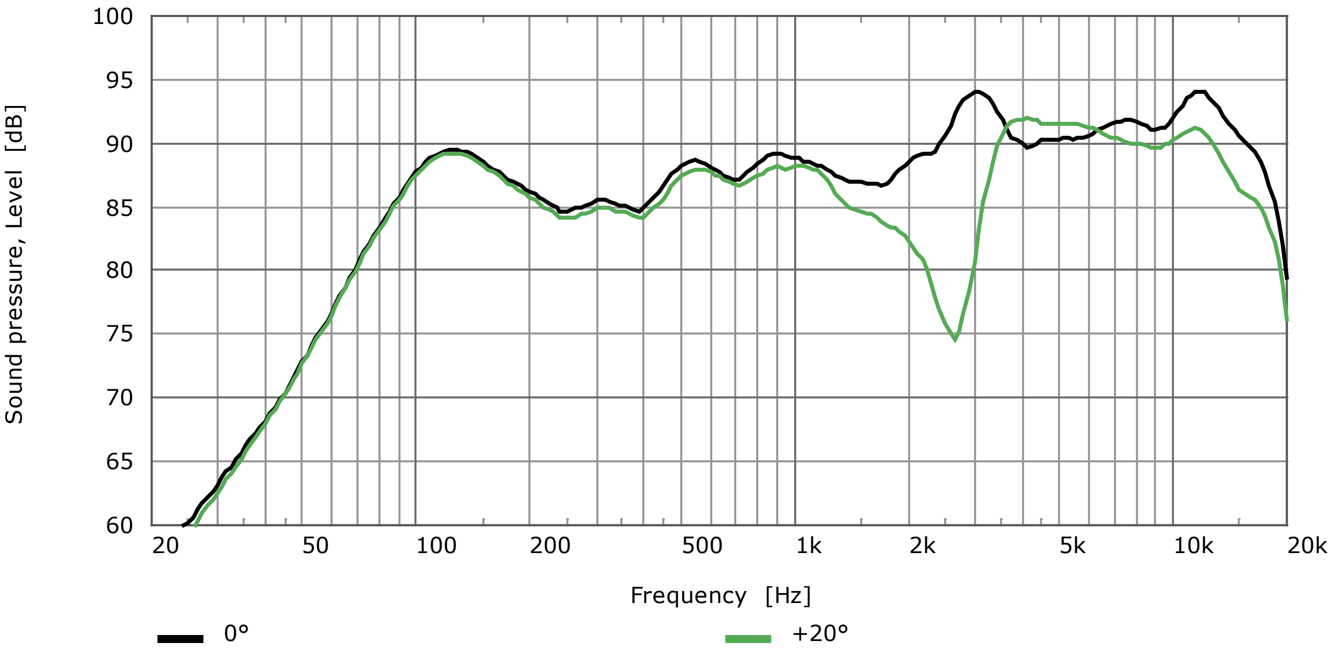
Example Loudspeaker System

Off-axis frequency responses (vertical)



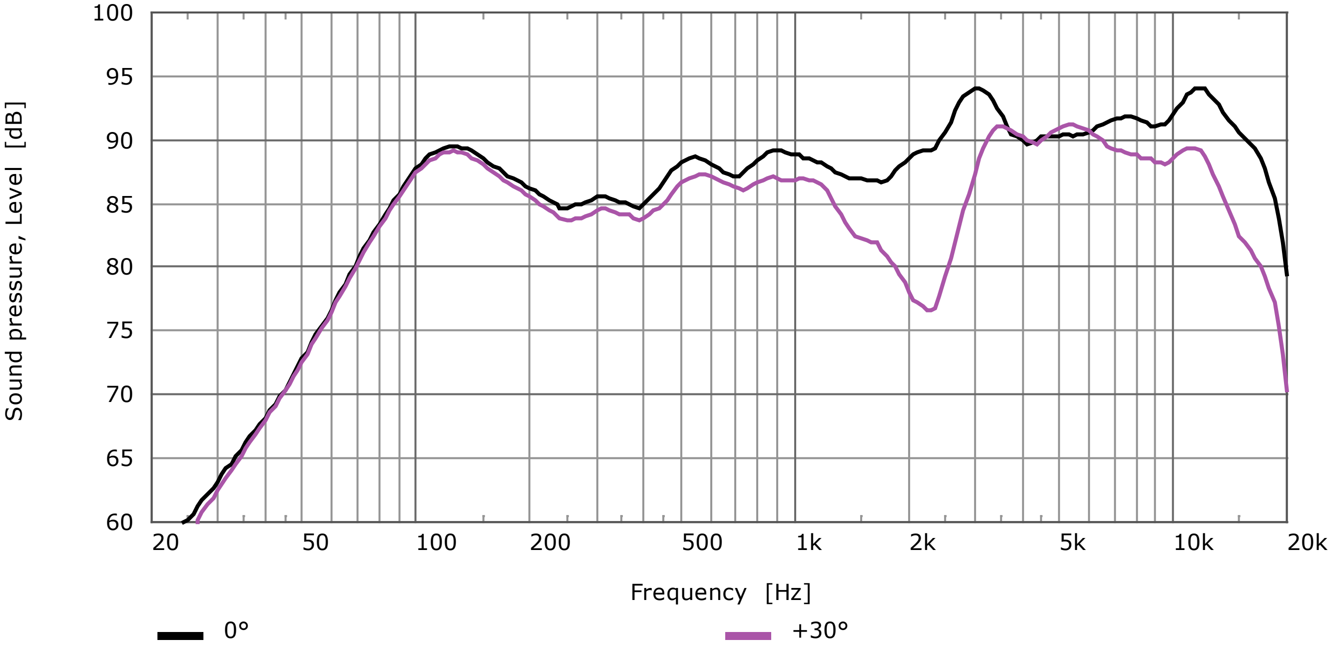
Example Loudspeaker System

Off-axis frequency responses (vertical)



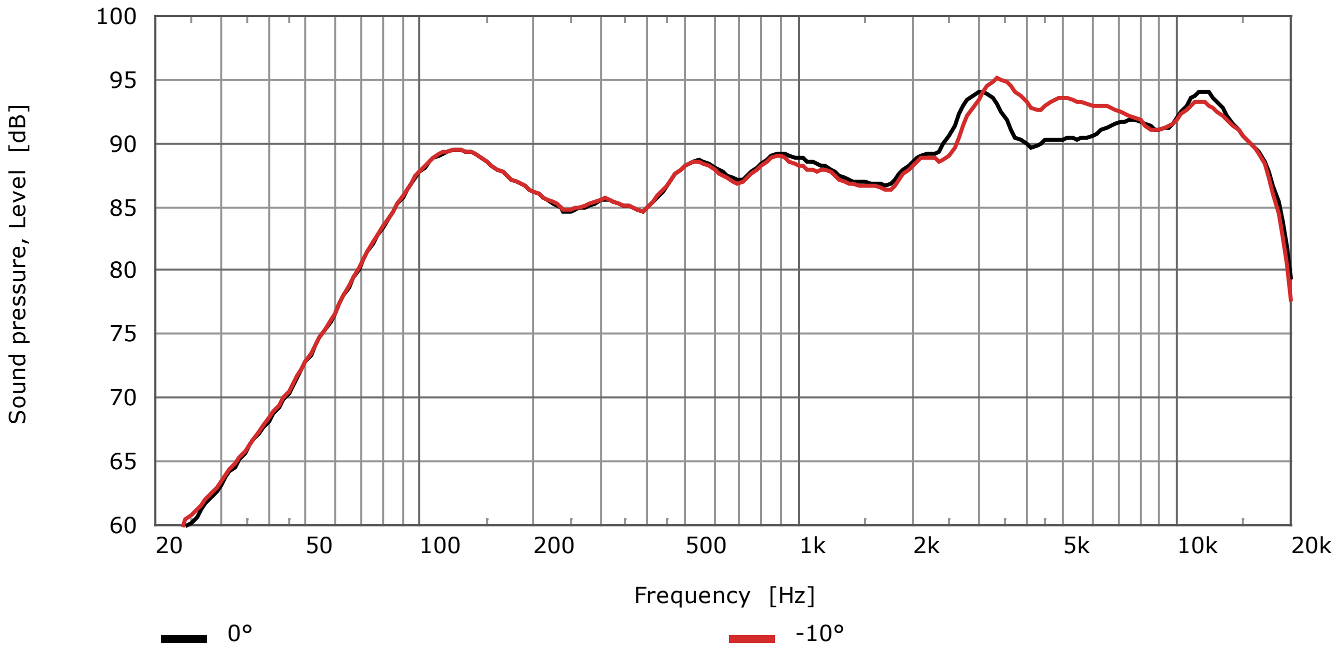
Example Loudspeaker System

Off-axis frequency responses (vertical)



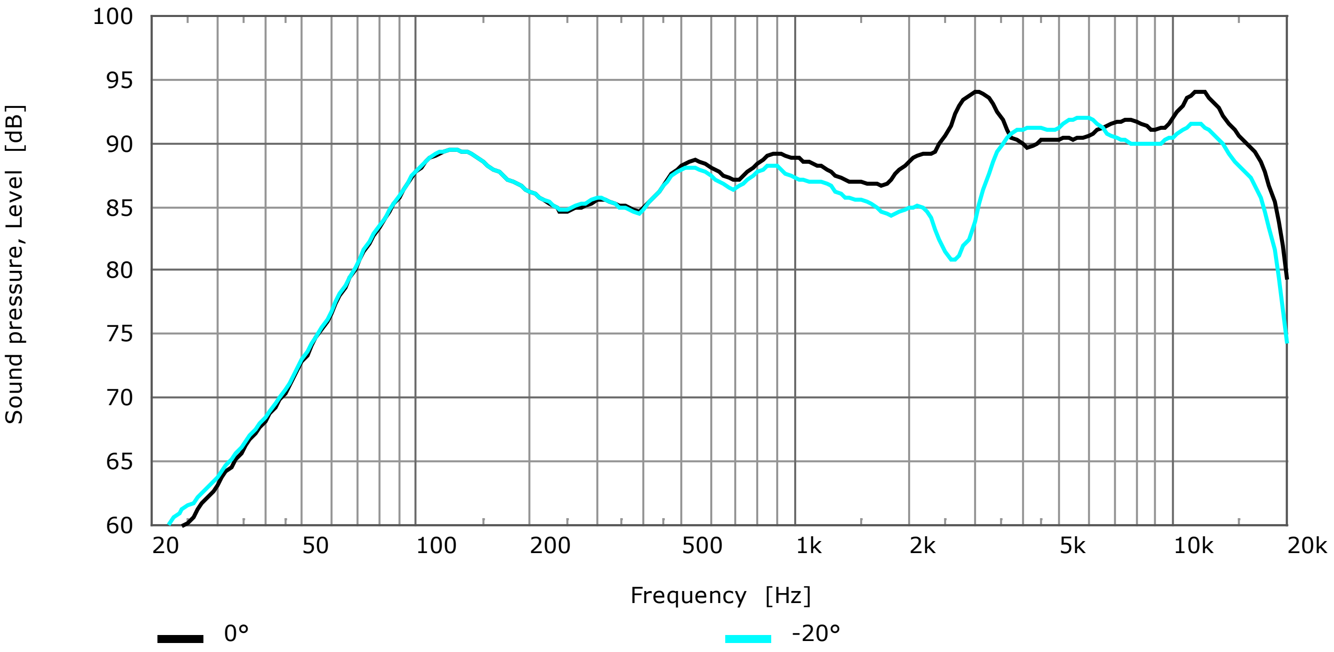
Example Loudspeaker System

Off-axis frequency responses (vertical)



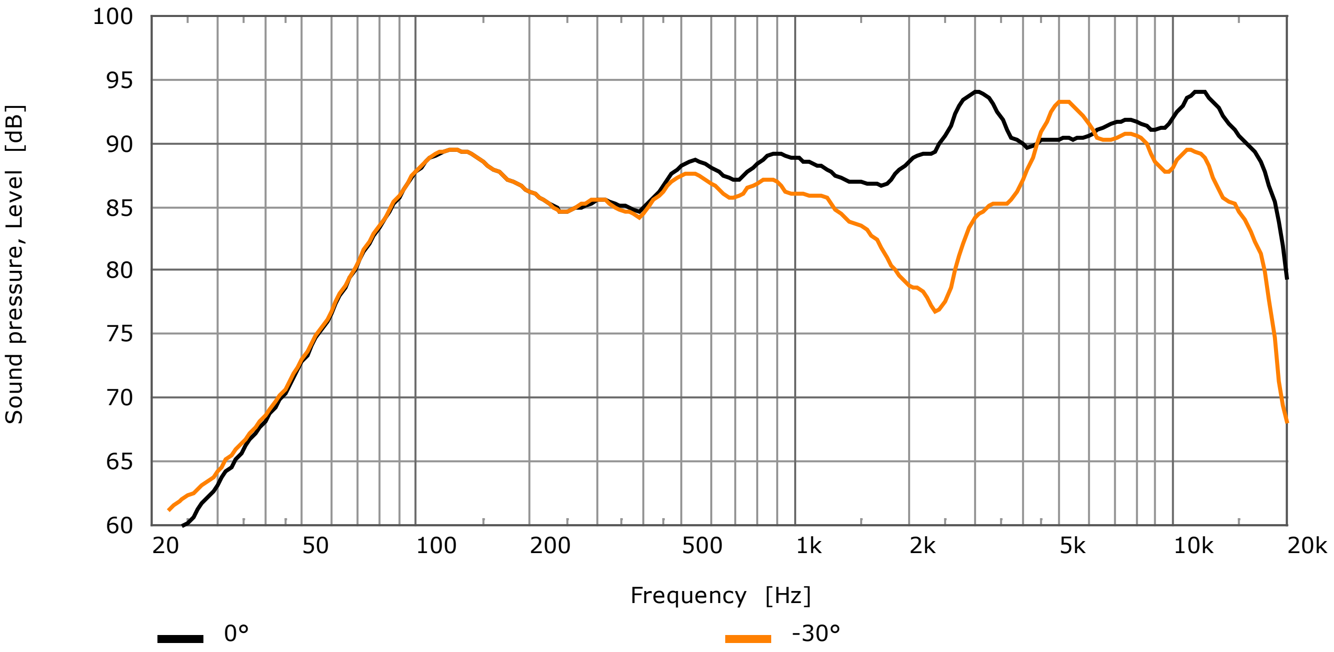
Example Loudspeaker System

Off-axis frequency responses (vertical)



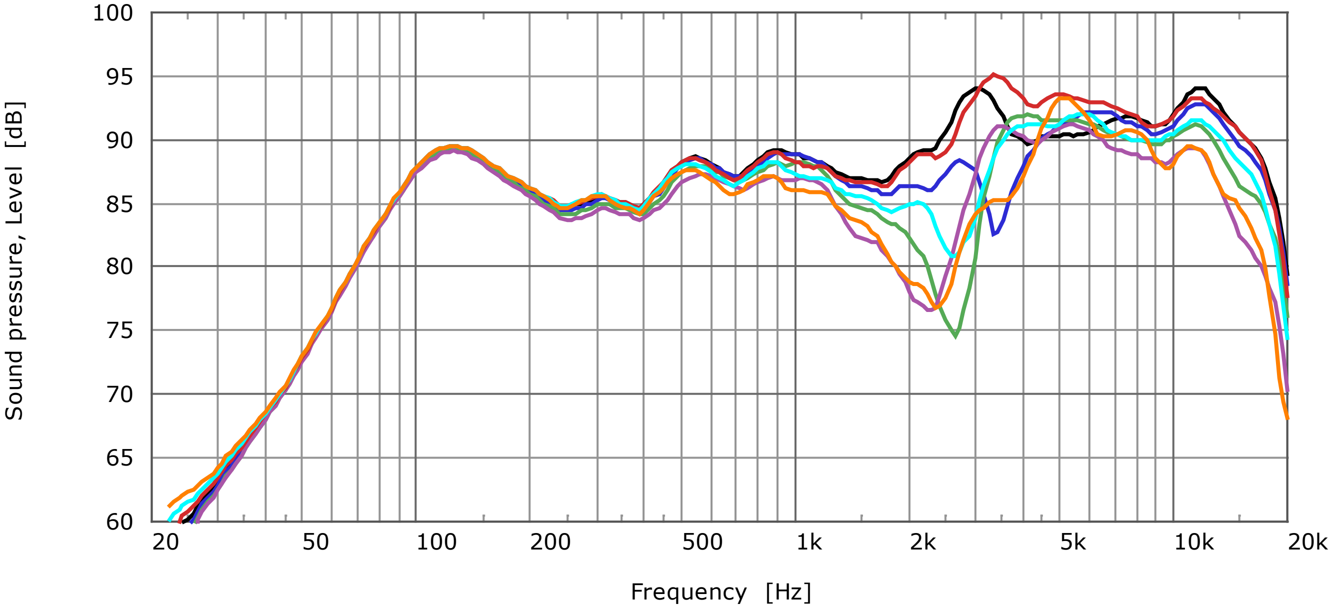
Example Loudspeaker System

Off-axis frequency responses (vertical)



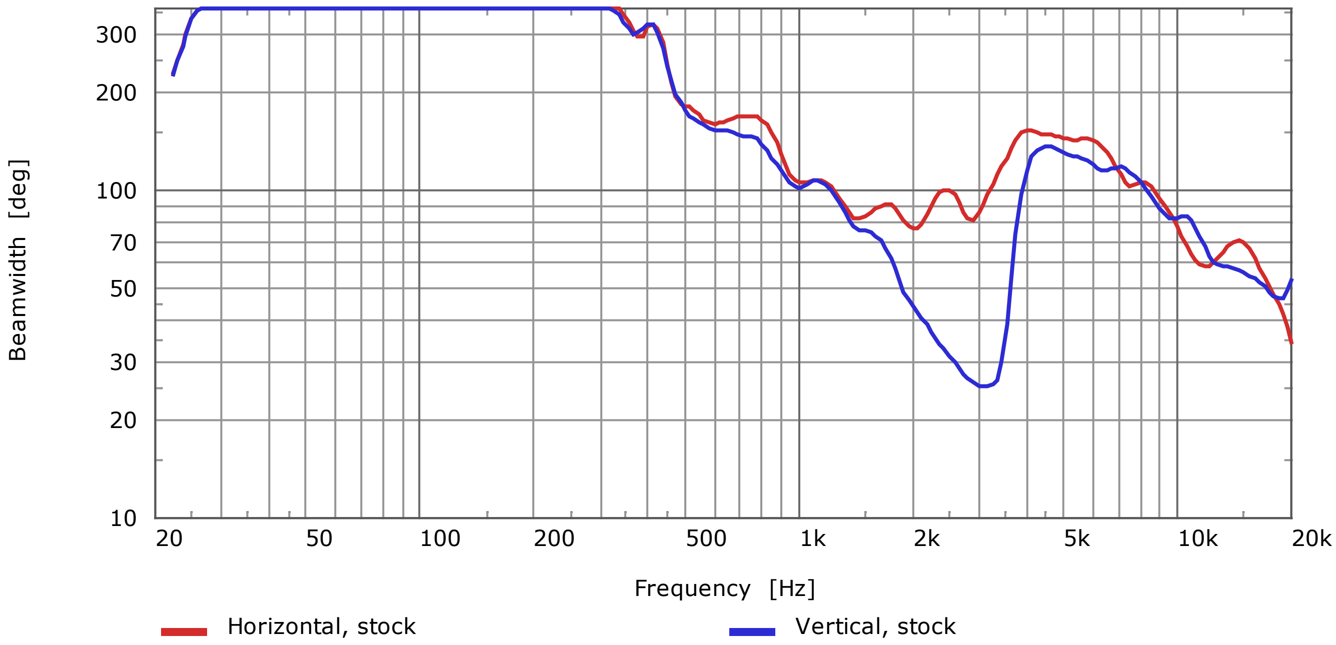
Example Loudspeaker System

Off-axis frequency responses (vertical)



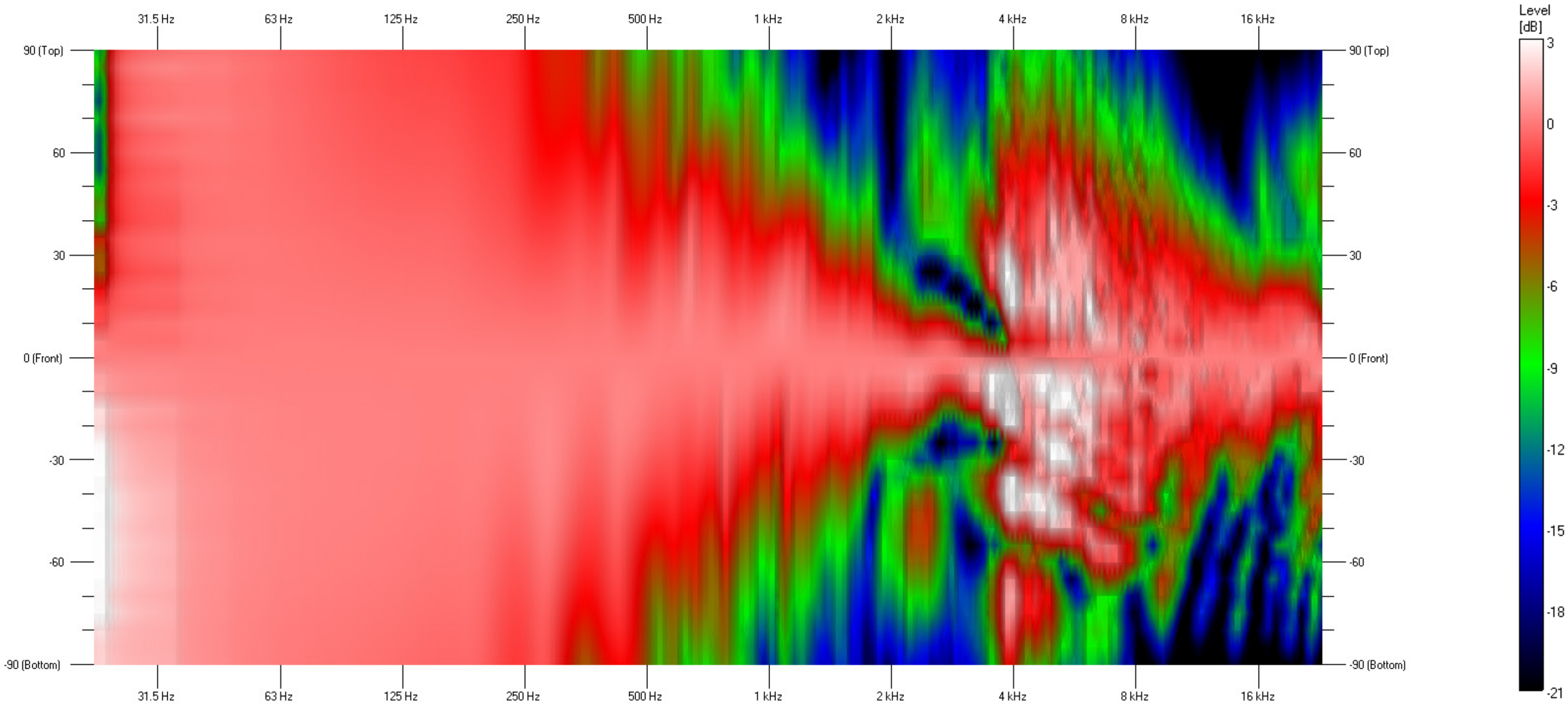
Example Loudspeaker System

Beamwidth (horizontal & vertical)



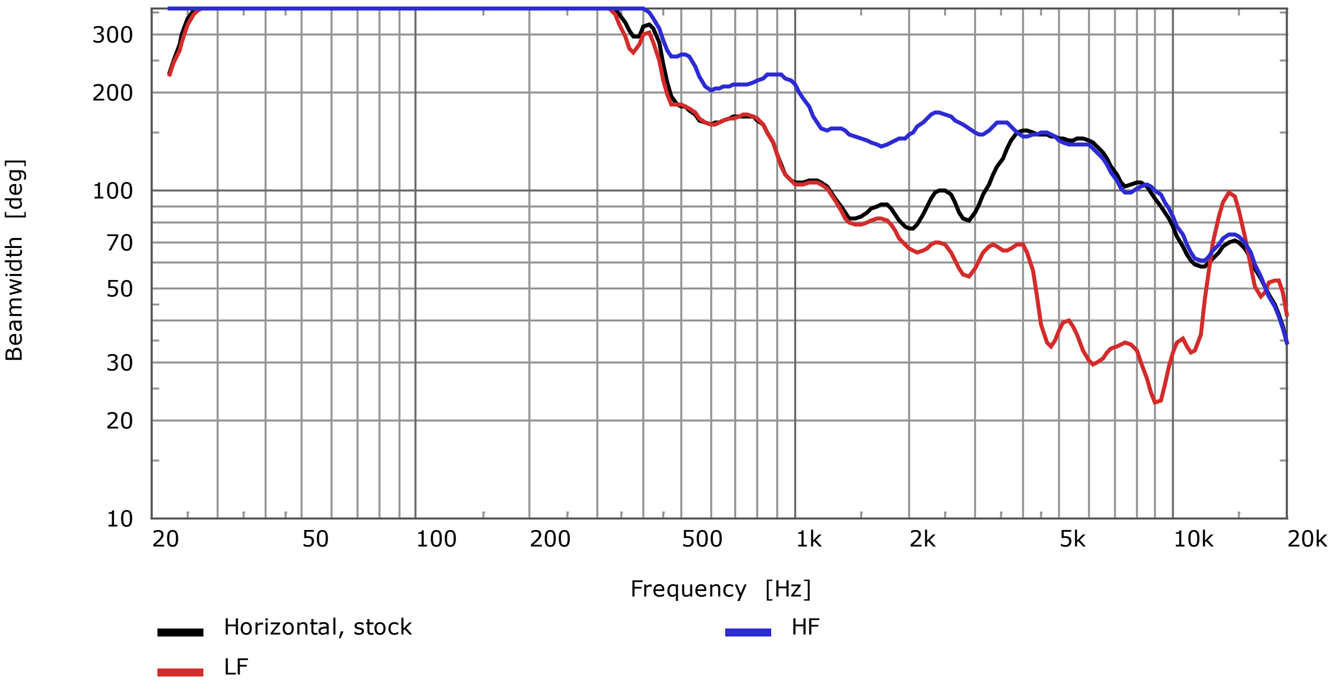
Example Loudspeaker System

Directivity map (vertical)



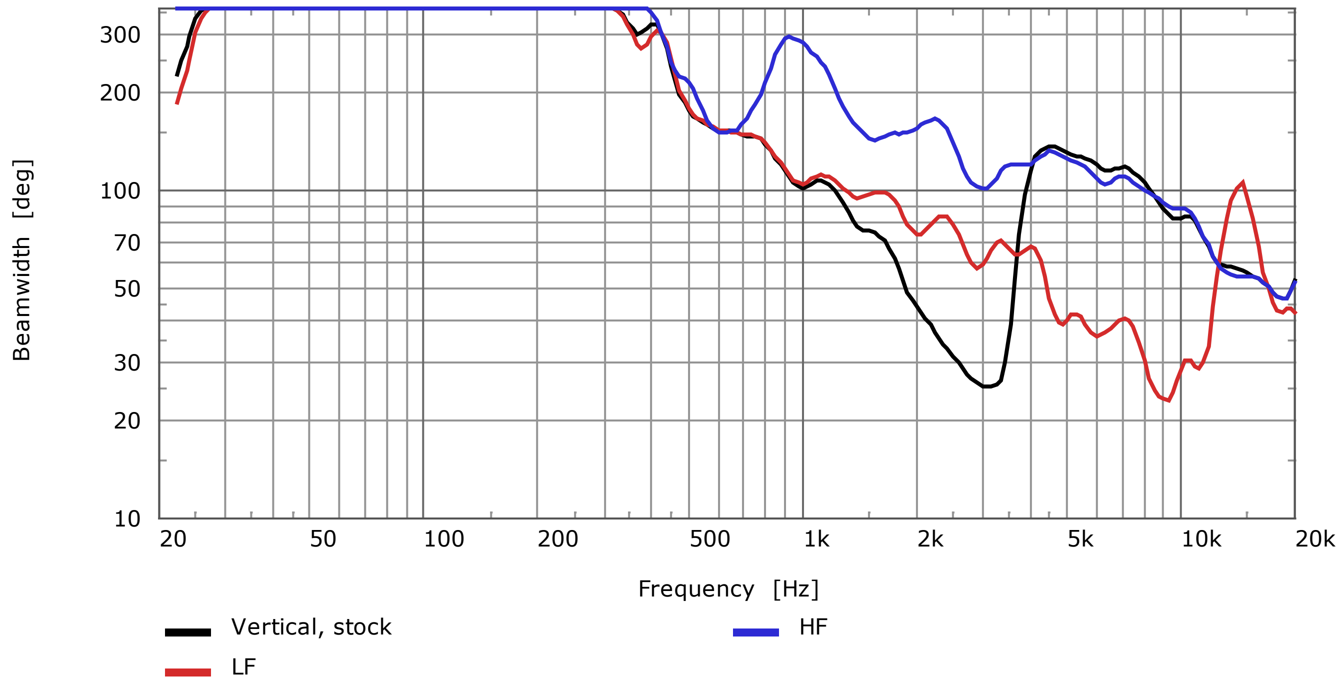
Example Loudspeaker System

Beamwidth of individual components (horizontal)



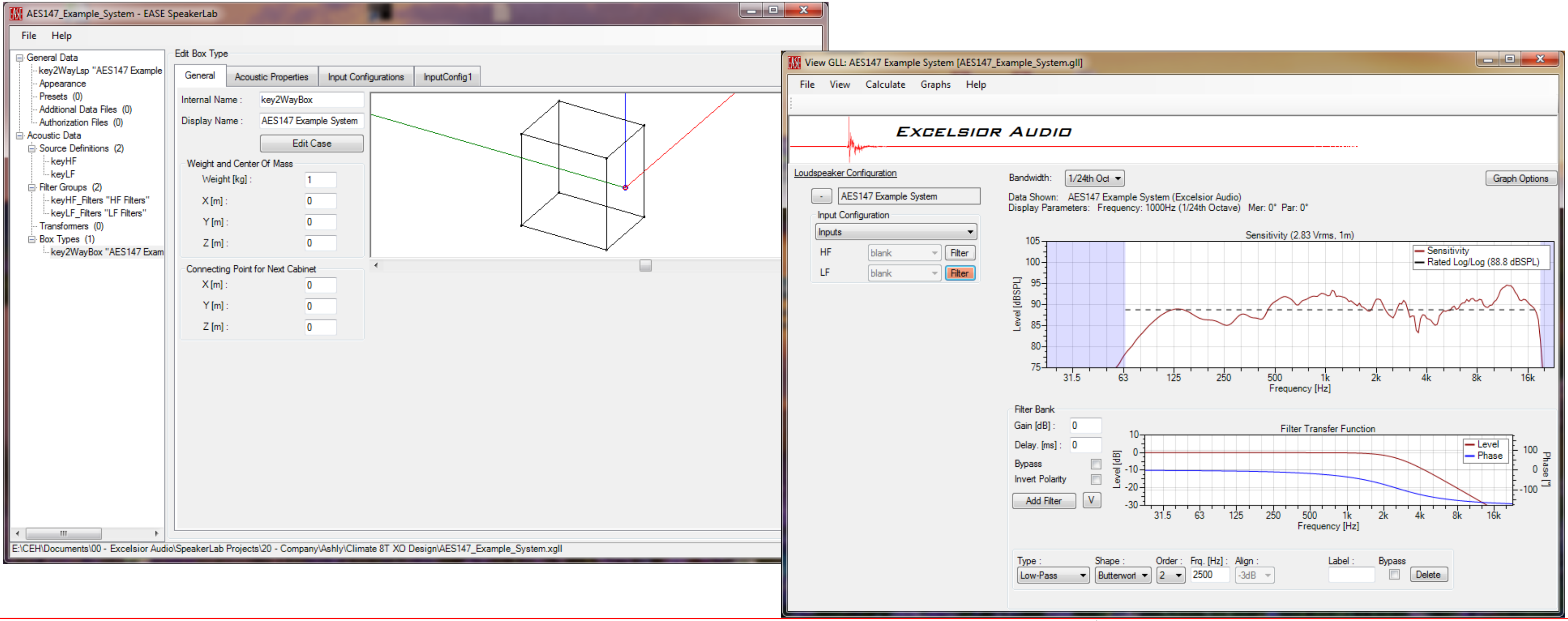
Example Loudspeaker System

Beamwidth of individual components (vertical)



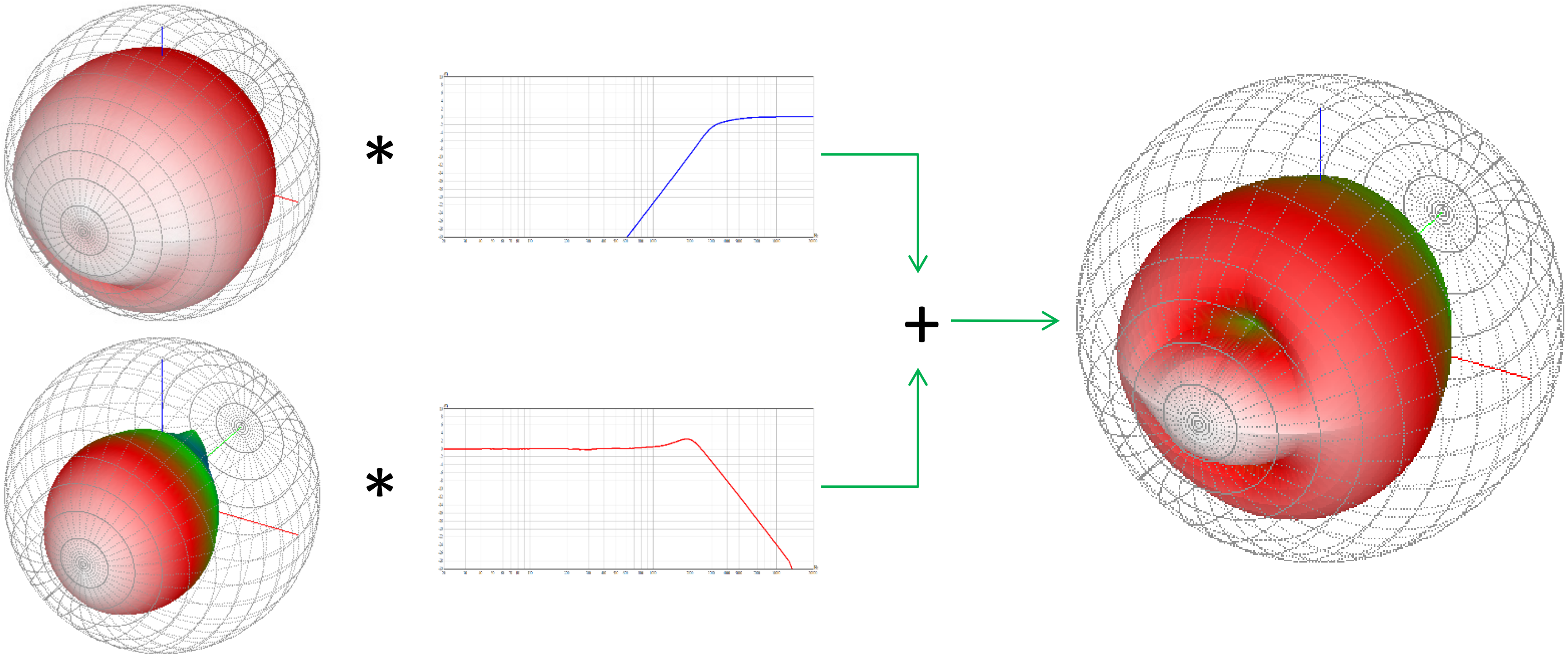
Directivity Optimization

Tools – SpeakerLab (AFMG ease.afmg.eu/index.php/ease_speakerlab.html)



Directivity Optimization

Tools – SpeakerLab



Directivity Optimization

Tools – SpeakerLab

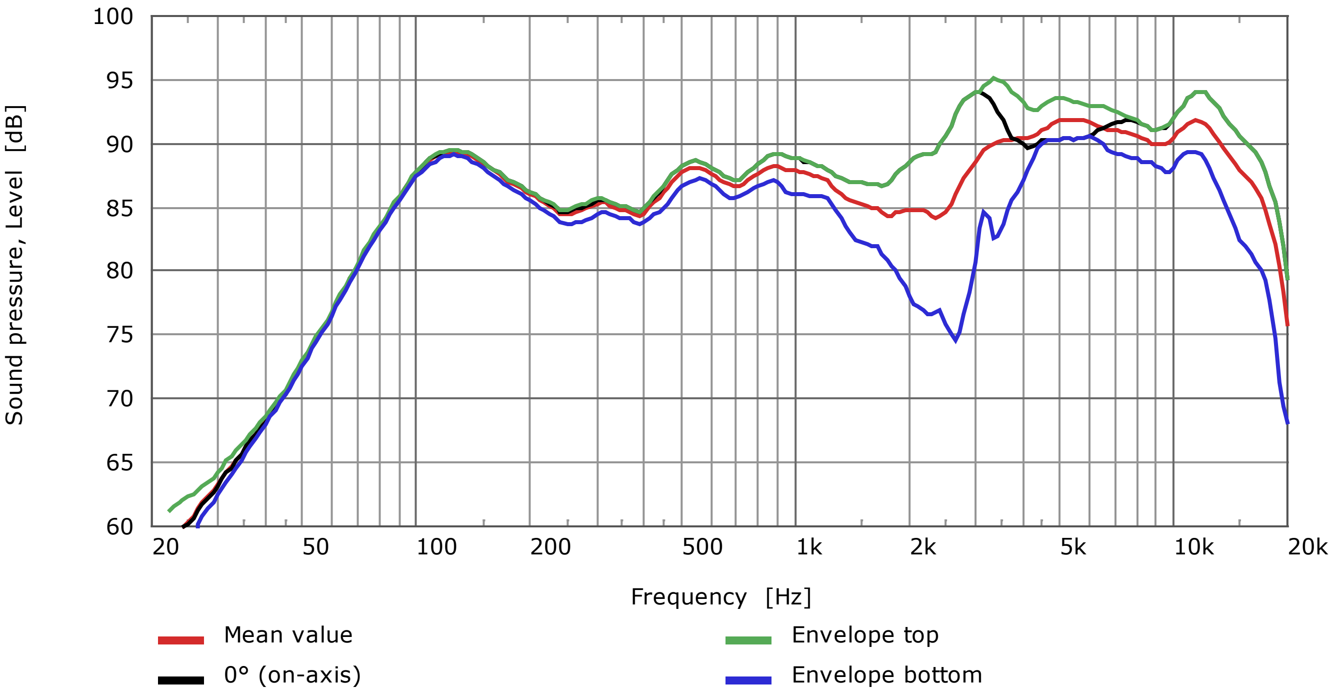
Don't exceed the capabilities of the intended crossover implementation!

Delay & EQ boost are OK for a DSP-based crossover. Not appropriate for a passive crossover.

Directivity Optimization

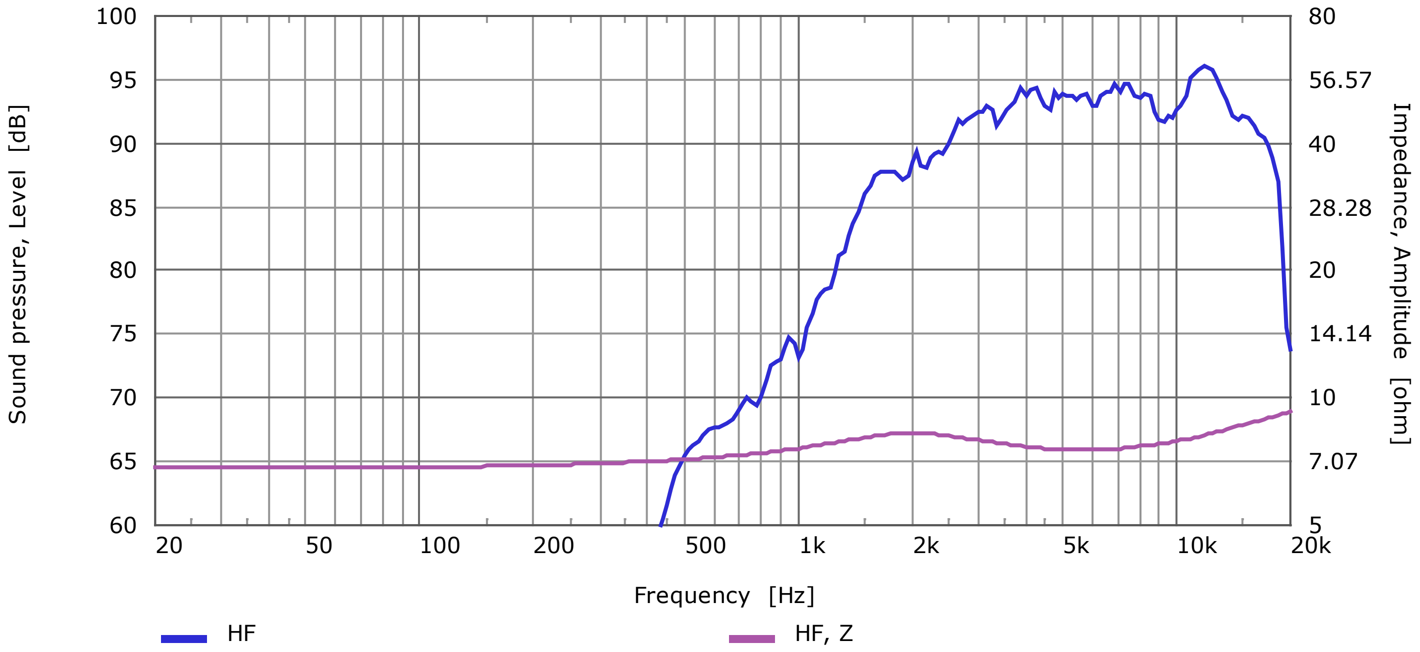
Off-axis response consistency is more important than on-axis

How can a system with this type of a response in the crossover region be equalized to optimize its overall response?



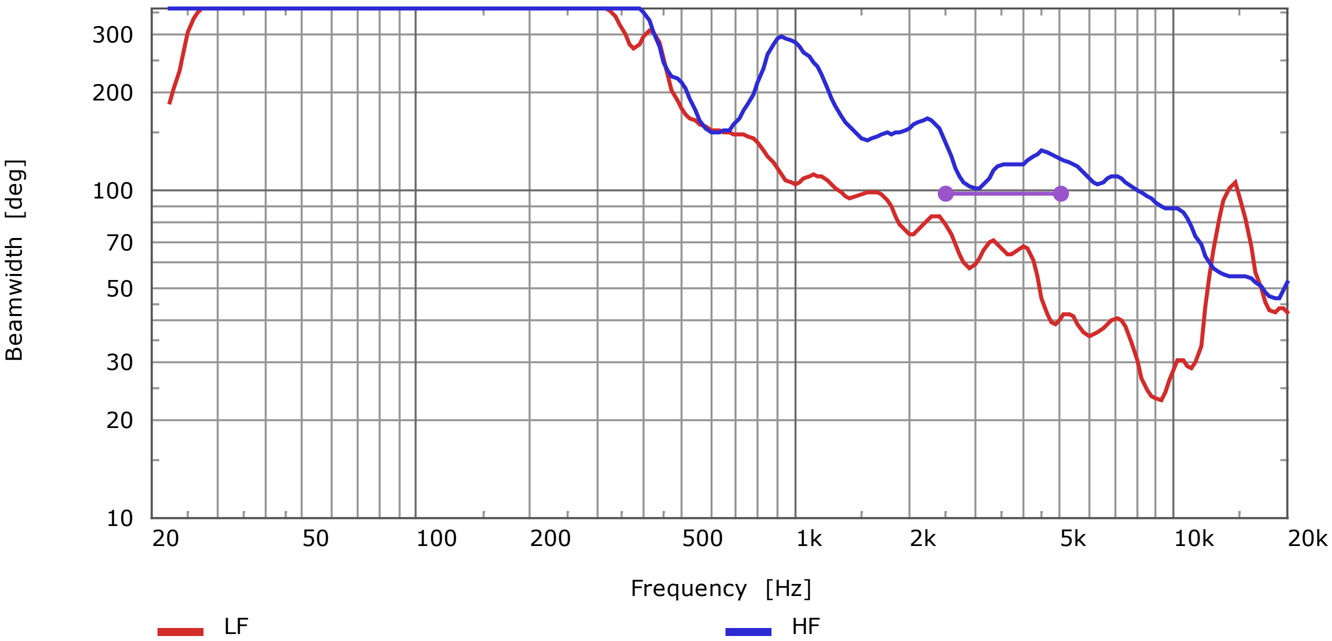
Directivity Optimization

HF driver protection (reliability)



Directivity Optimization

Selecting the XO region



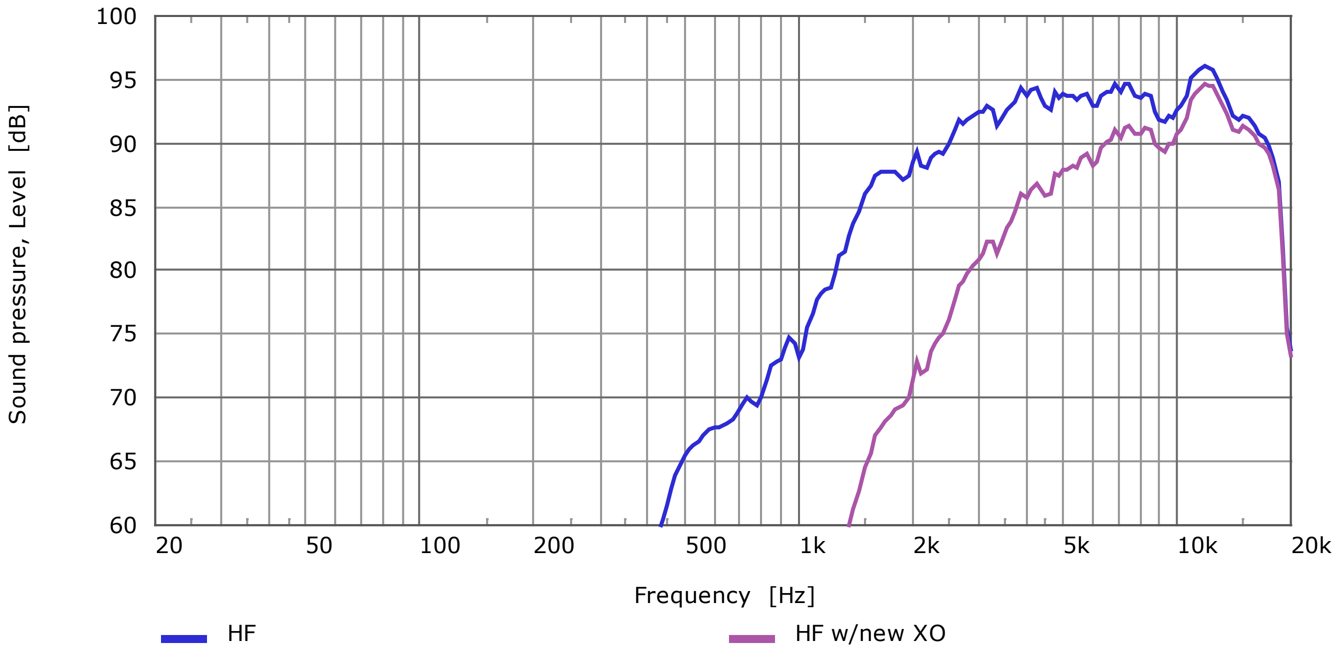
Directivity Optimization

High-pass filter – Intended for passive implementation

2nd order response using staggered poles

Directivity Optimization

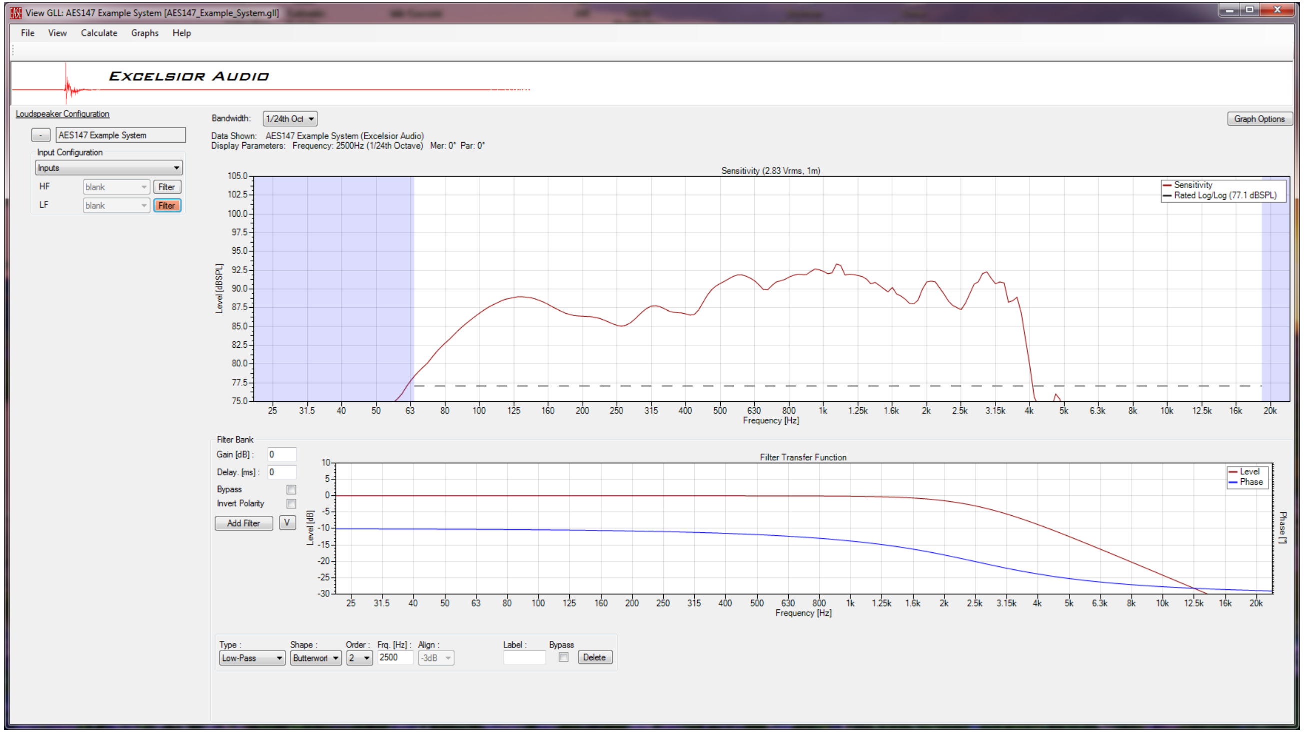
High-pass filter – Intended for passive implementation



Directivity Optimization

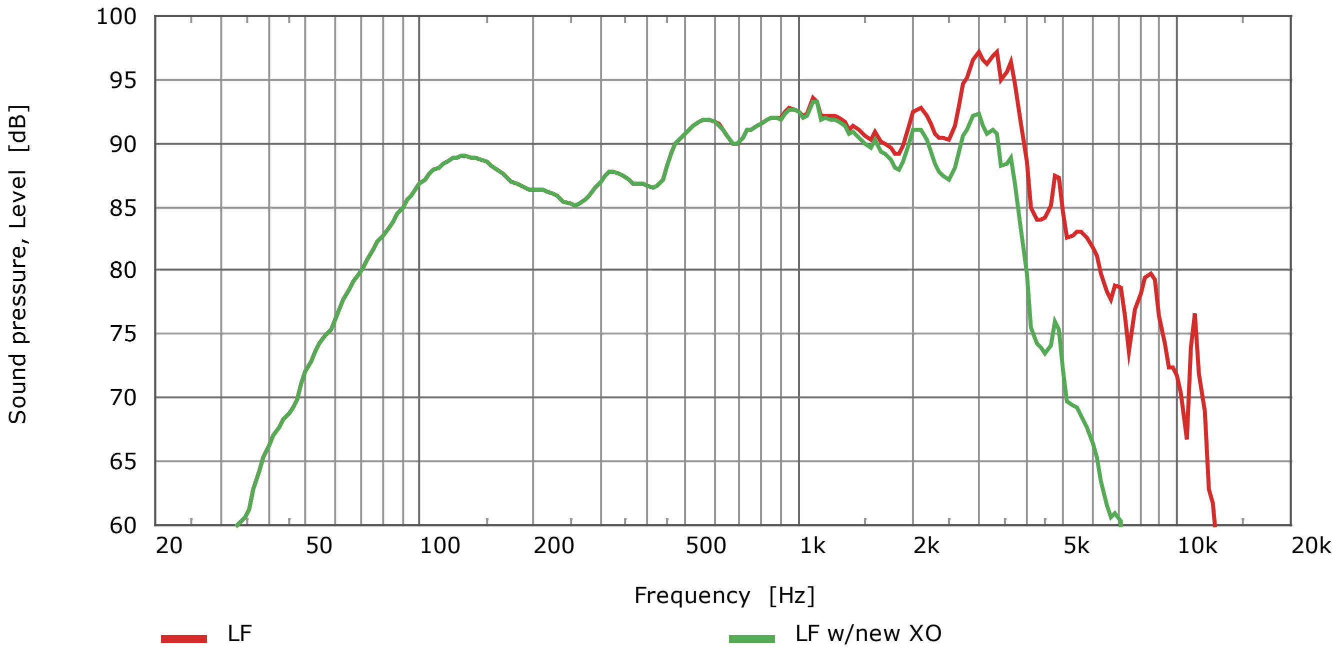
Low-pass filter – Intended for passive implementation

2nd order response



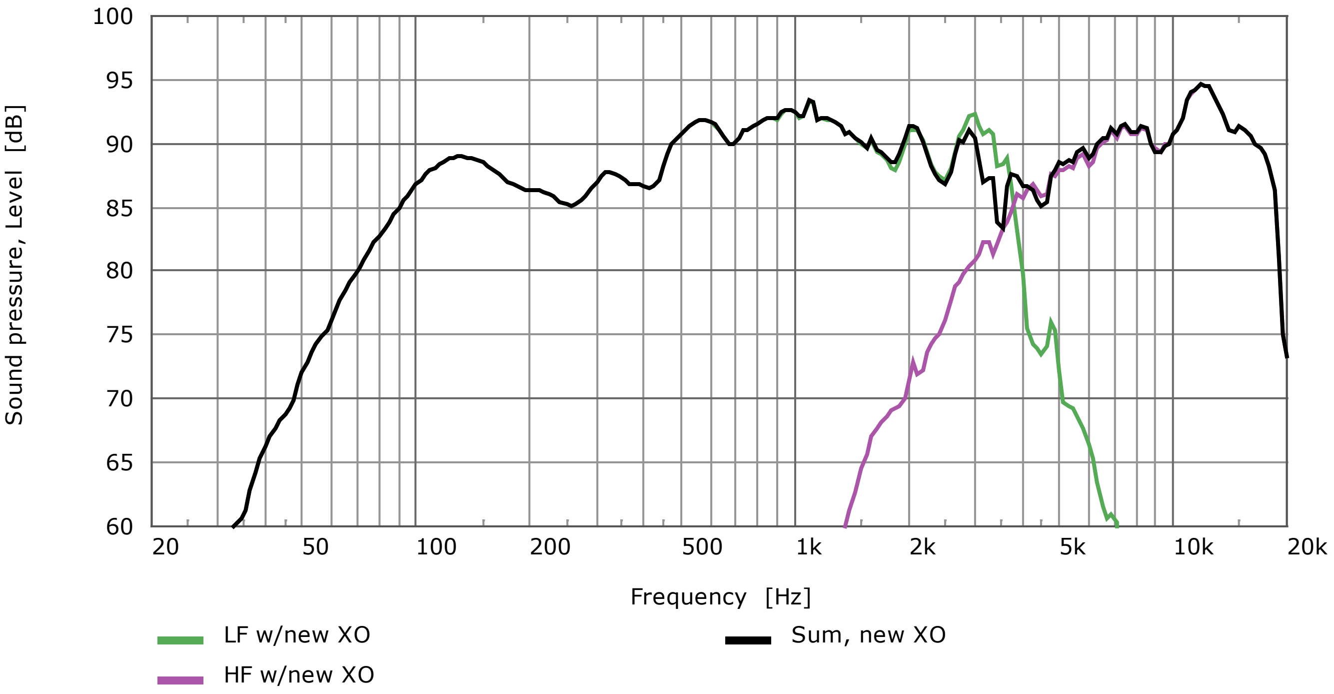
Directivity Optimization

Low-pass filter – Intended for passive implementation



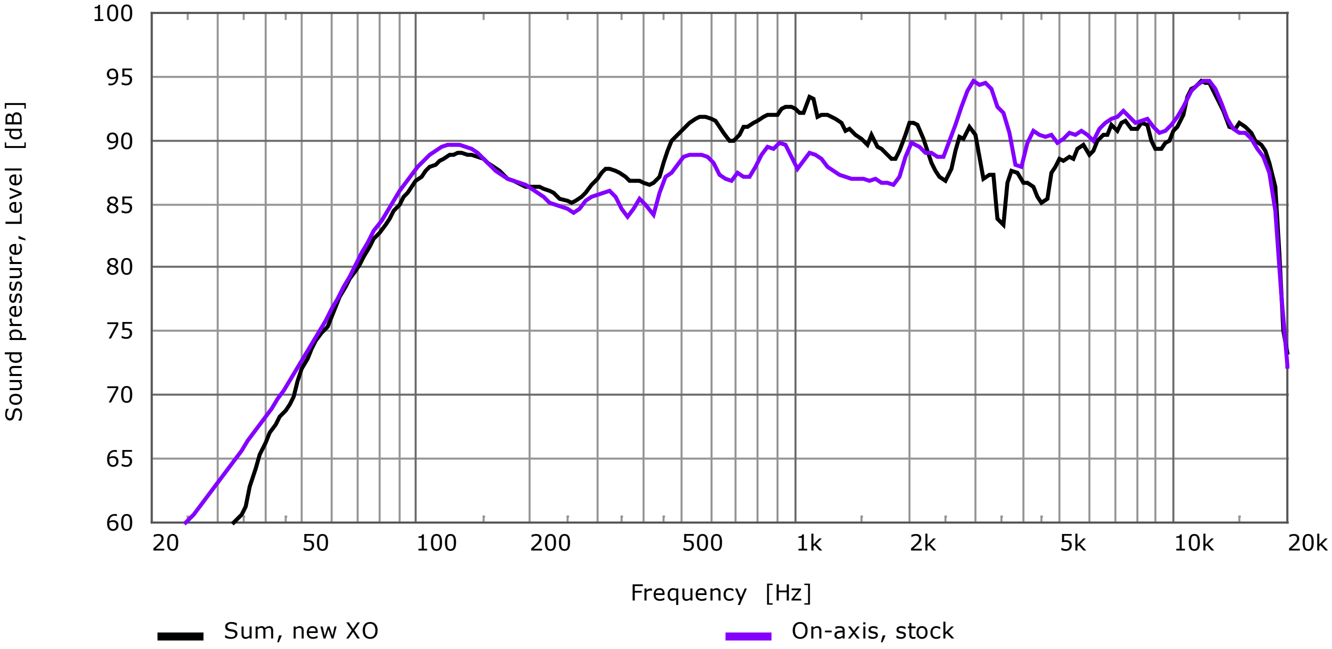
Directivity Optimization

System response, on-axis



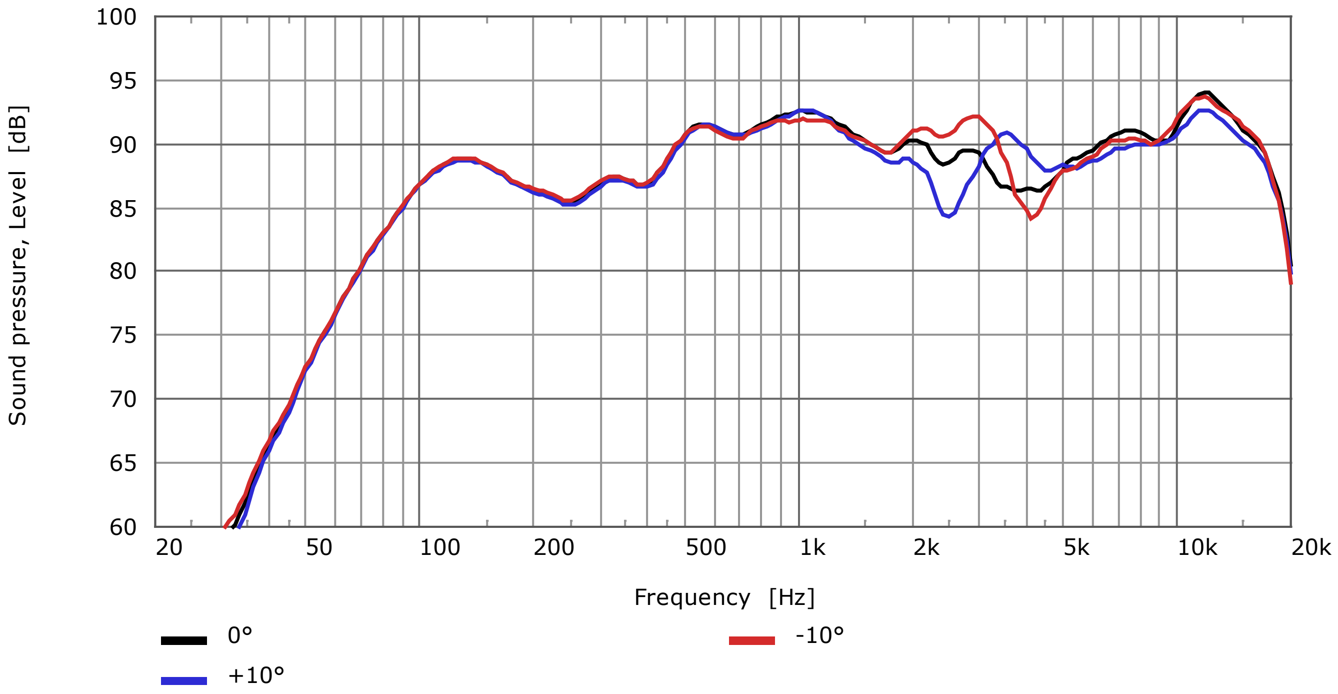
Directivity Optimization

System response, on-axis – compared to stock XO



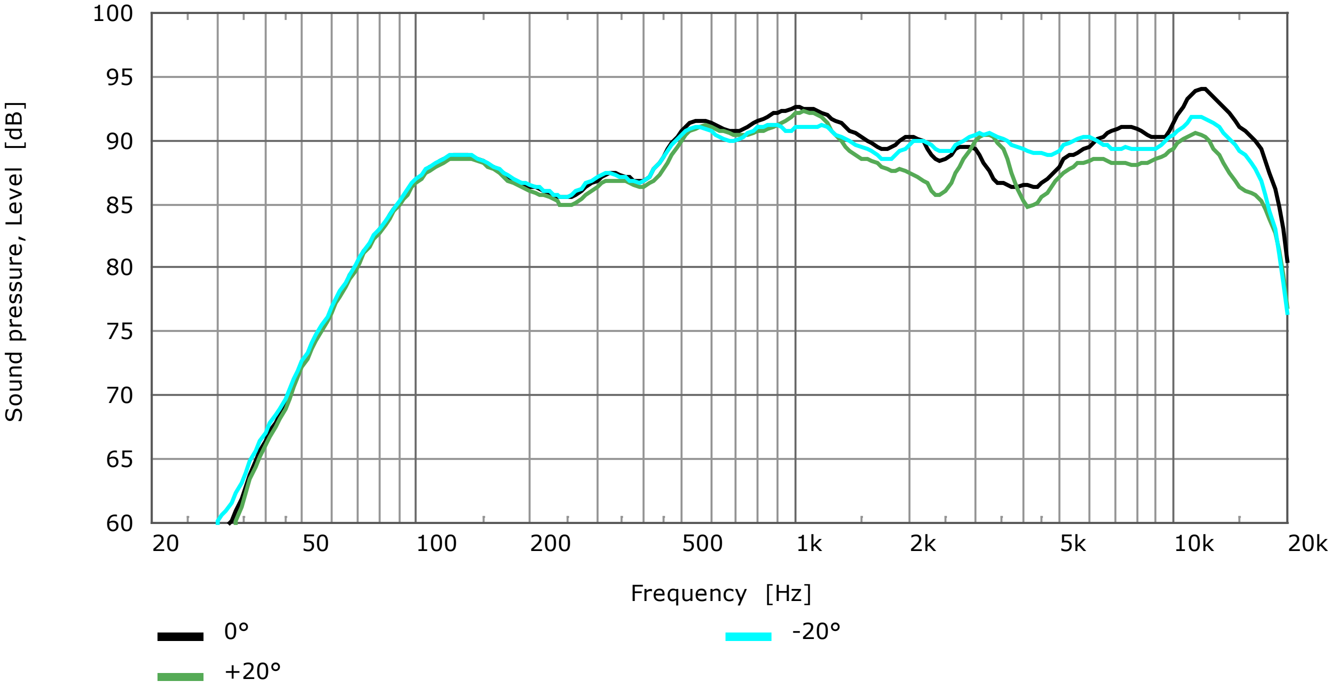
Directivity Optimization

Off-axis frequency responses (vertical)



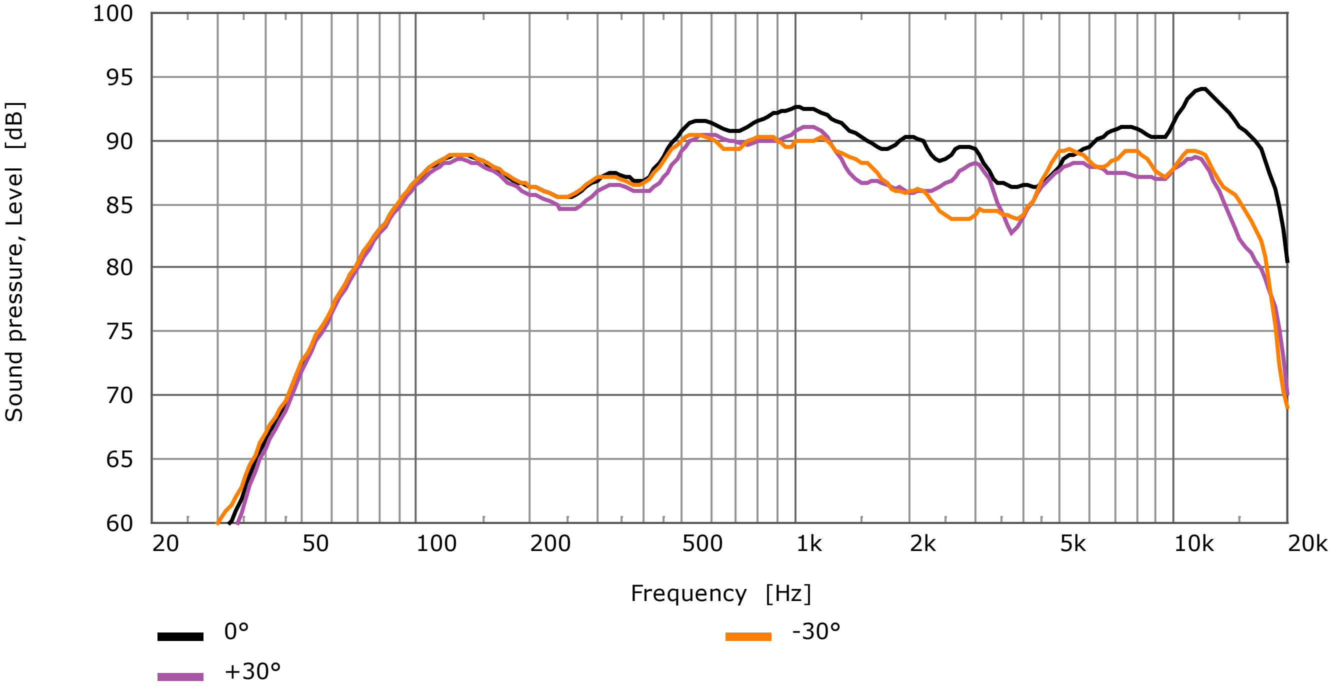
Directivity Optimization

Off-axis frequency responses (vertical)



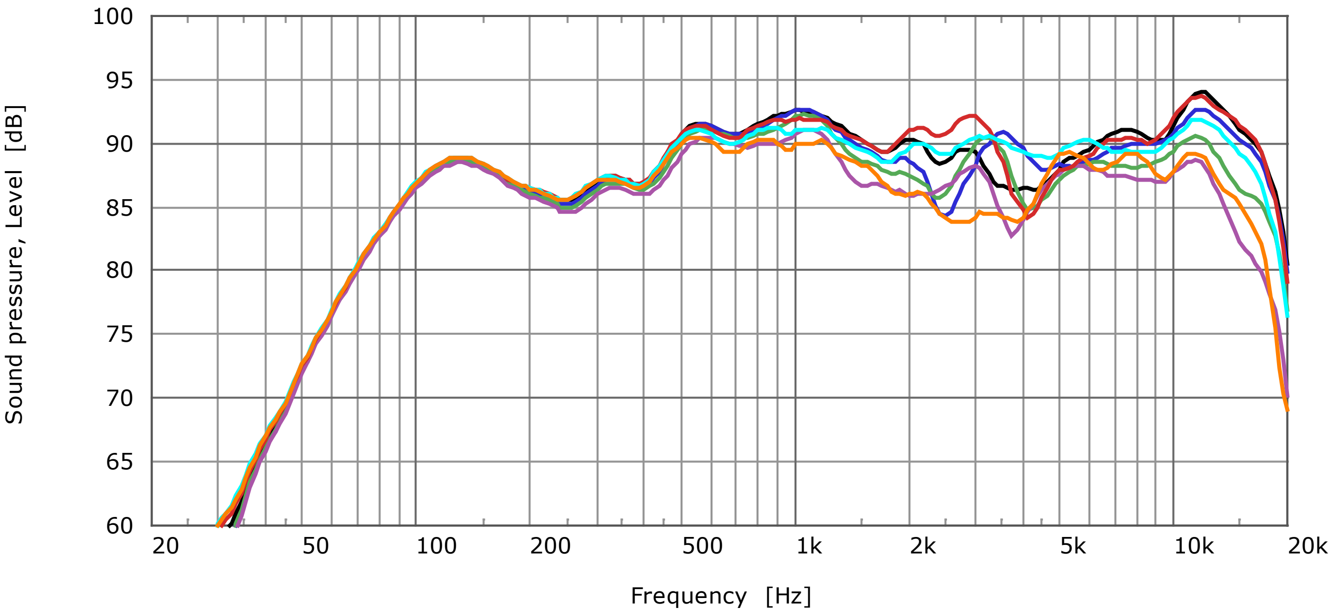
Directivity Optimization

Off-axis frequency responses (vertical)



Directivity Optimization

Off-axis frequency responses (vertical)

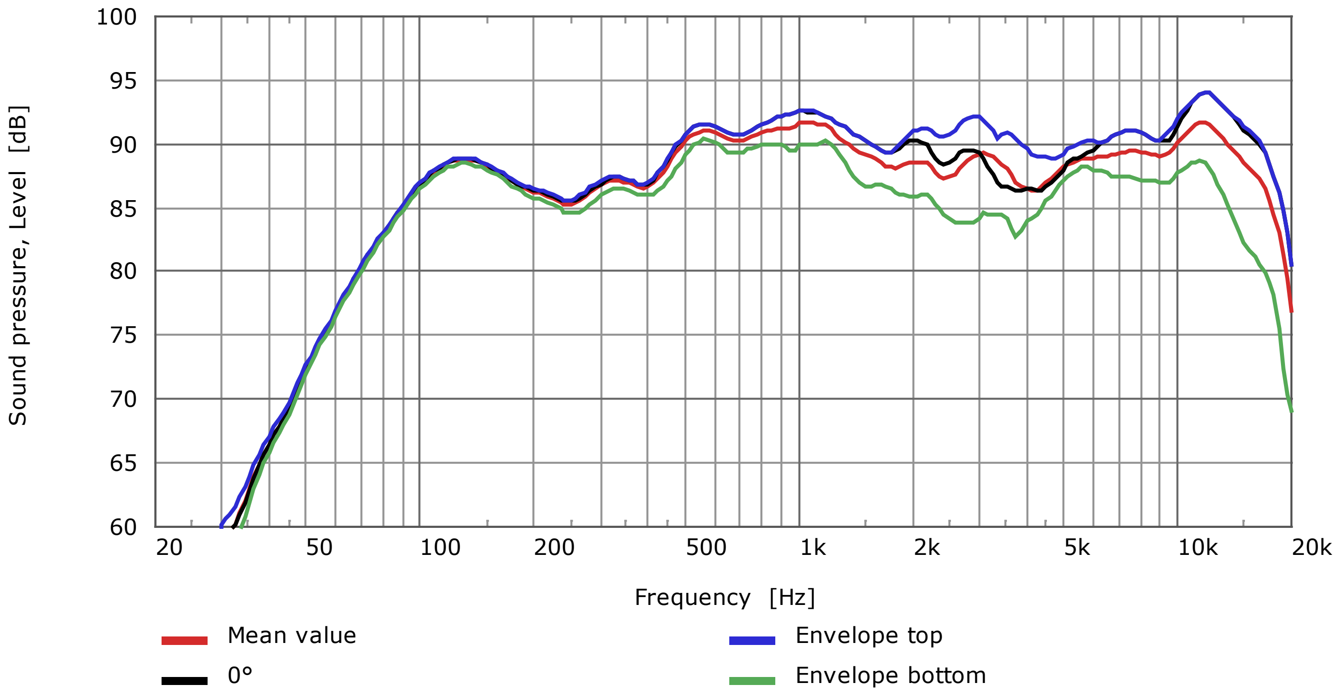


Directivity Optimization

Off-axis response consistency

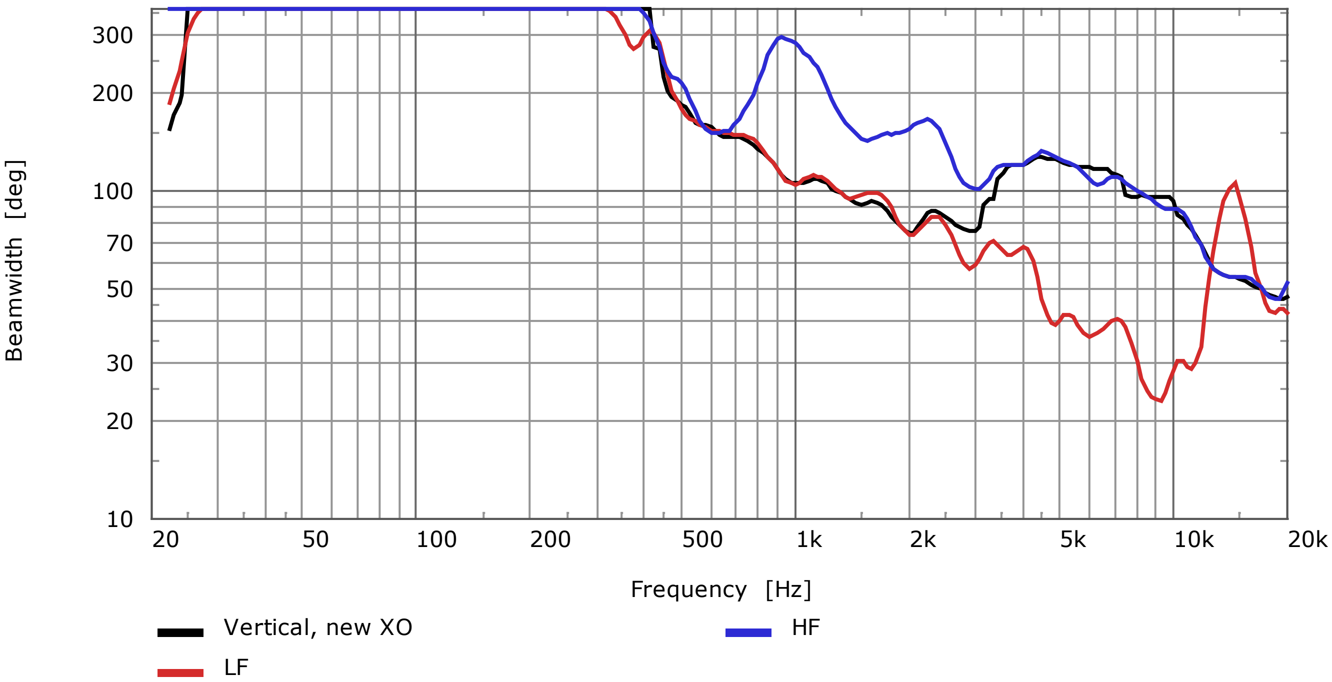
More consistent response in the crossover region

More amenable to equalization in order to optimize its overall response



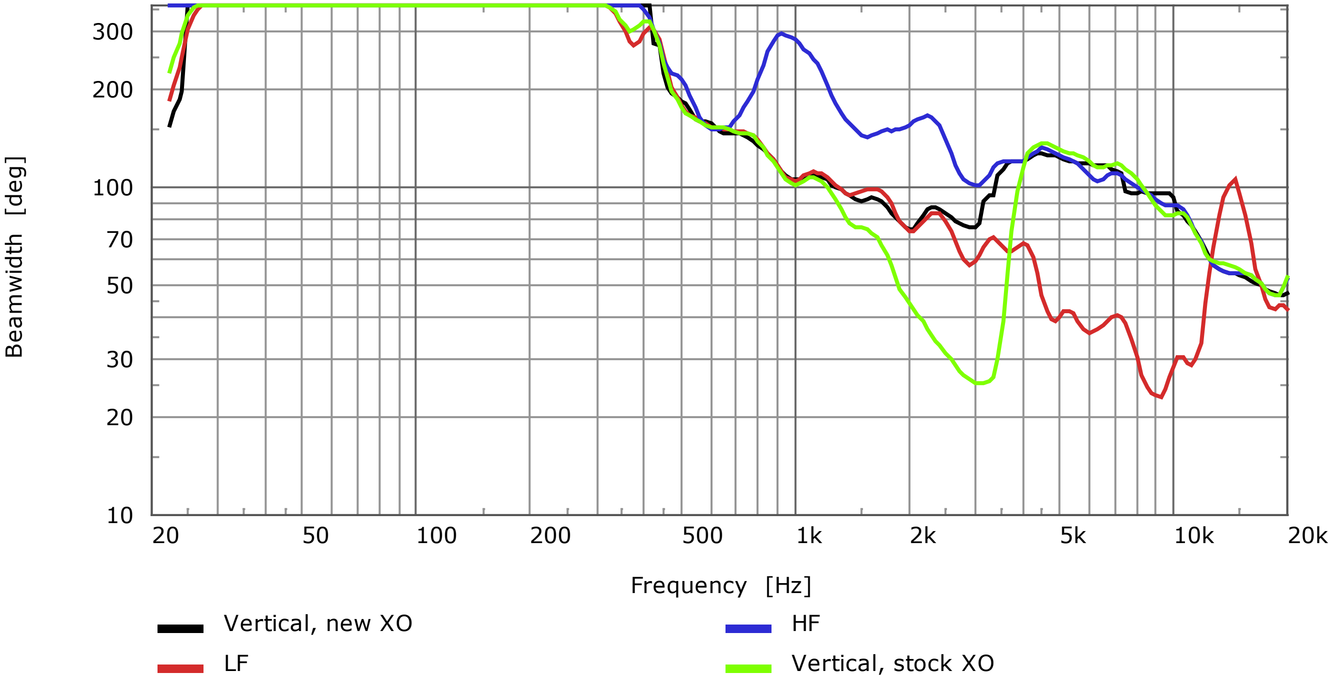
Directivity Optimization

Beamwidth of individual components (vertical)



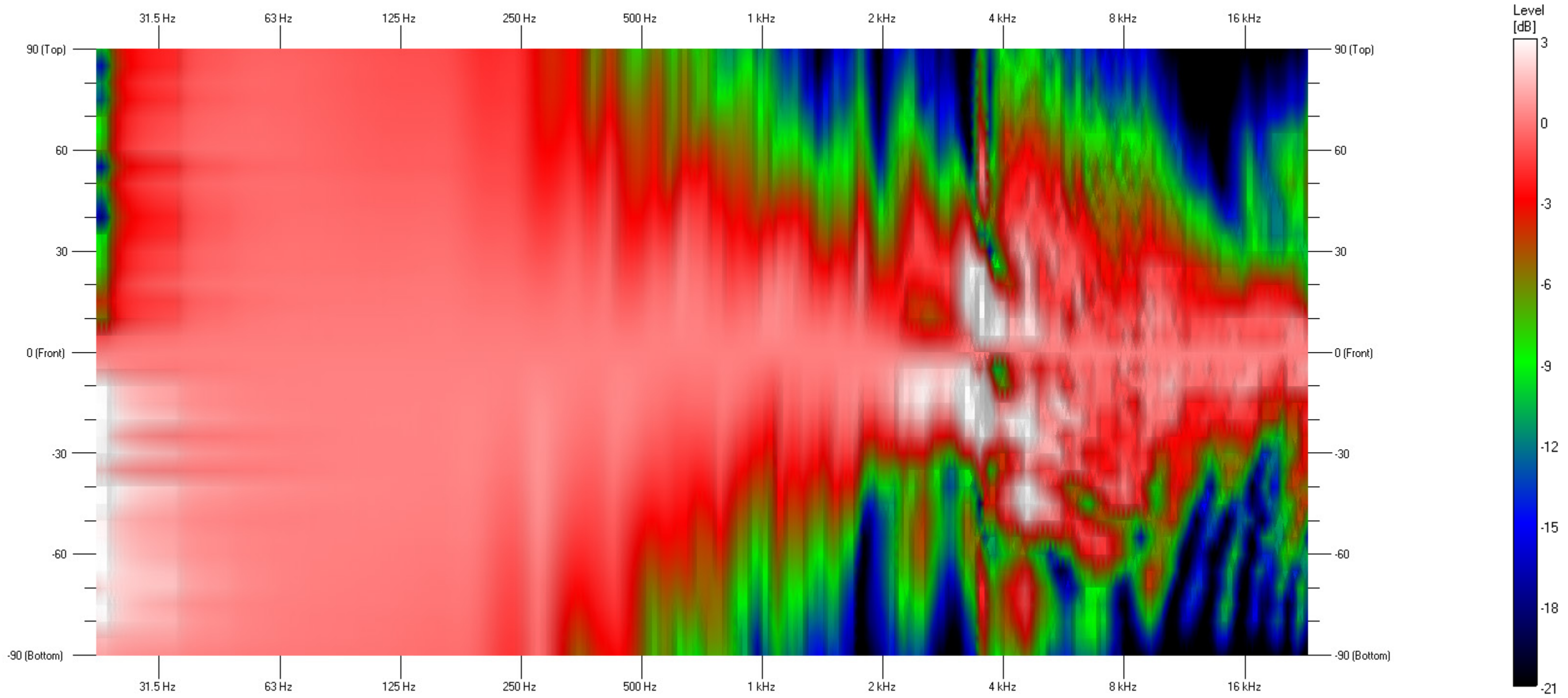
Directivity Optimization

Beamwidth of individual components (vertical)



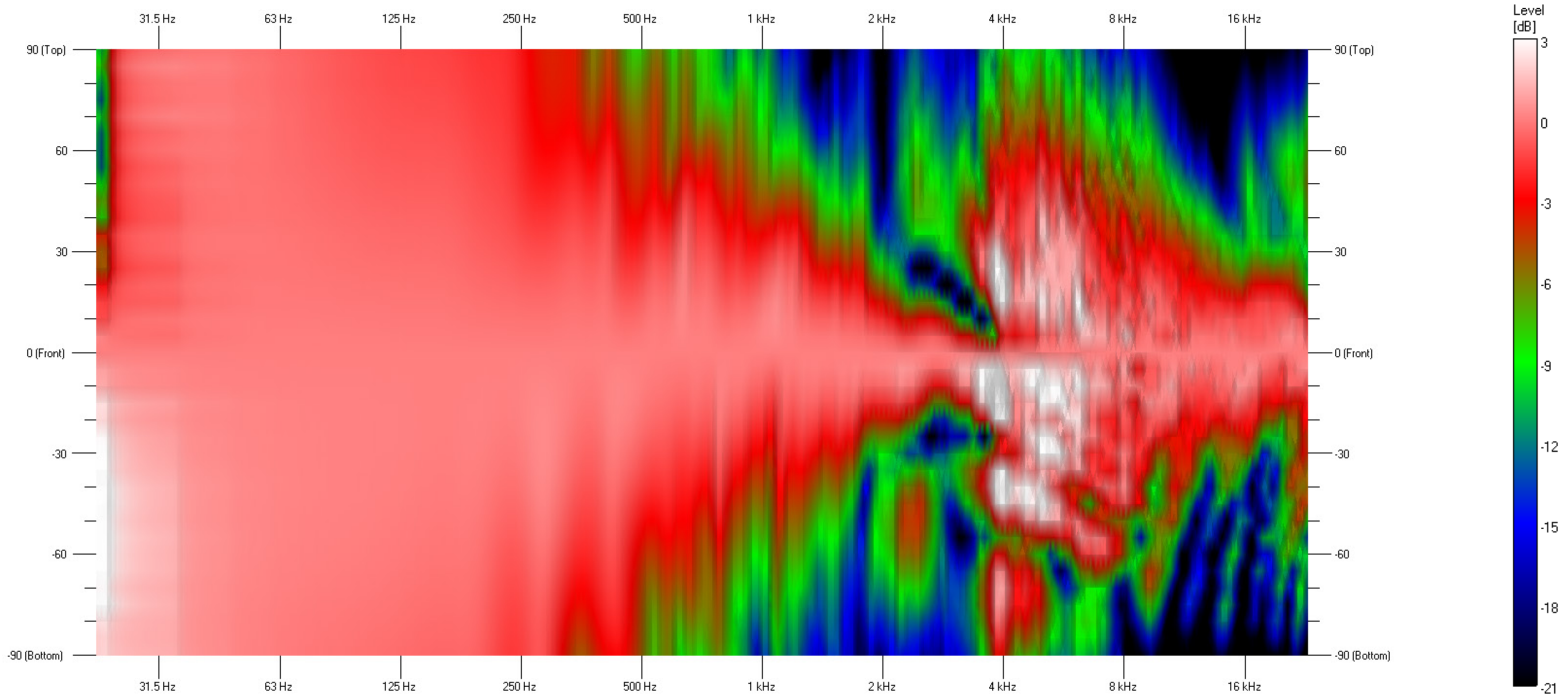
Directivity Optimization

Directivity map (vertical) – New XO



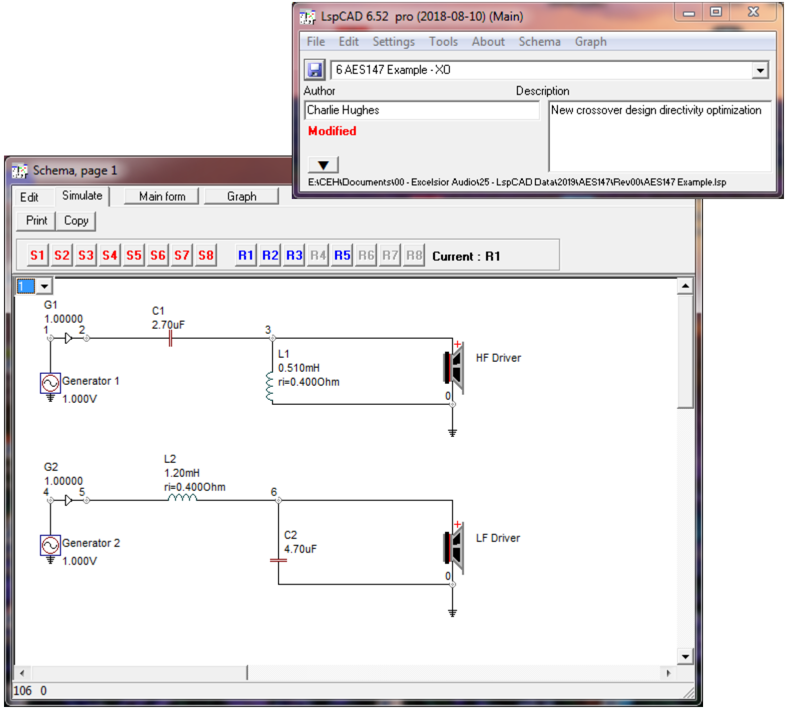
Directivity Optimization

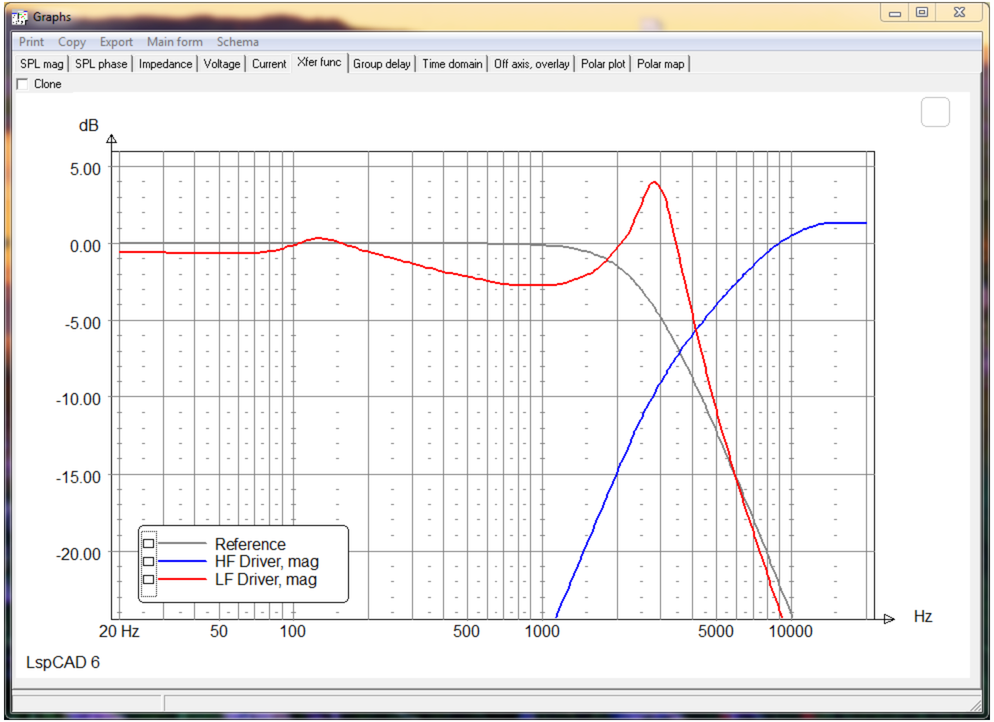
Directivity map (vertical) – Original (stock) XO



Passive Crossover Implementation

Tools – LspCAD (IJData www.ijdata.com)

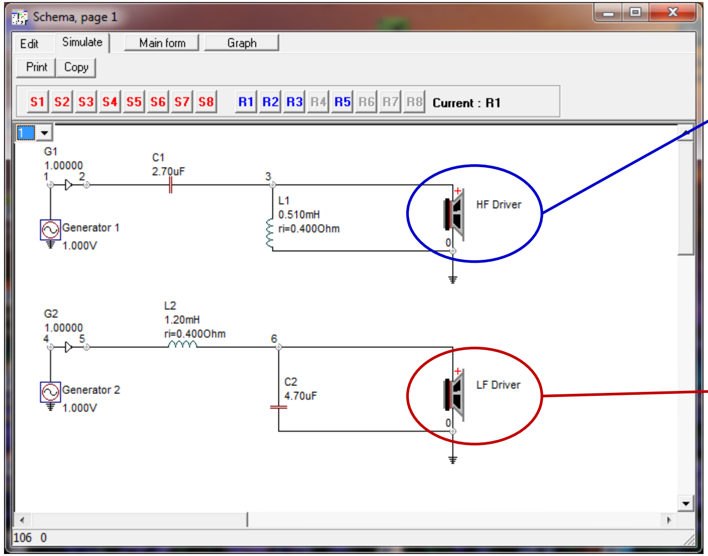


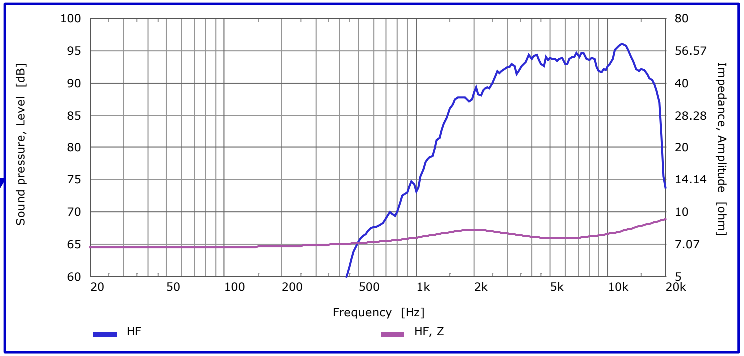


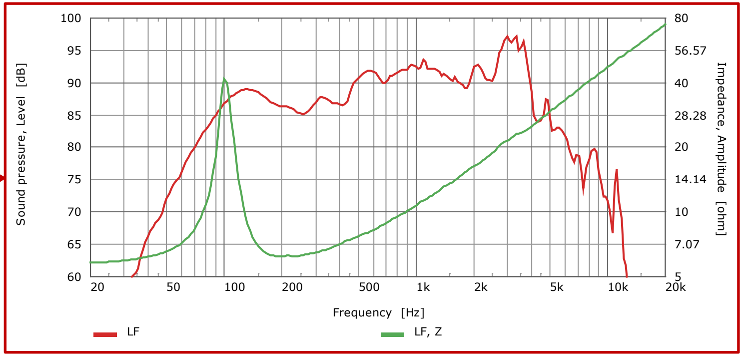
Passive Crossover Implementation

Tools – LspCAD

The drivers' impedance must load the passive network





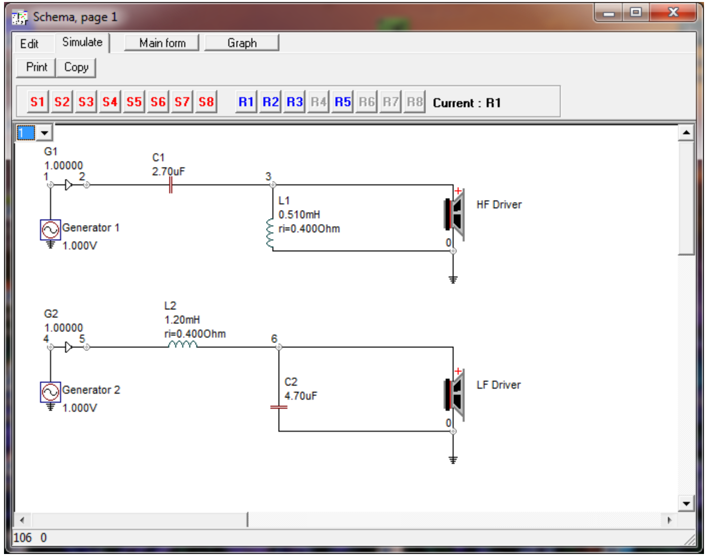


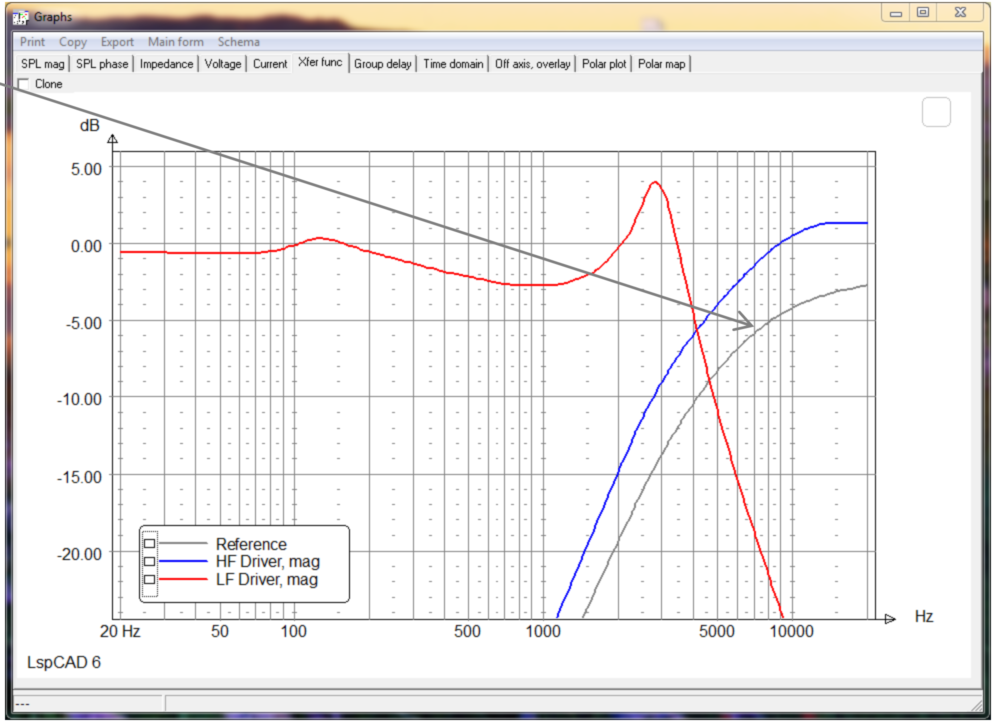
Passive Crossover Implementation

Tools – LspCAD

Reference curve

target transfer function for the filter (exported from SpeakerLab)

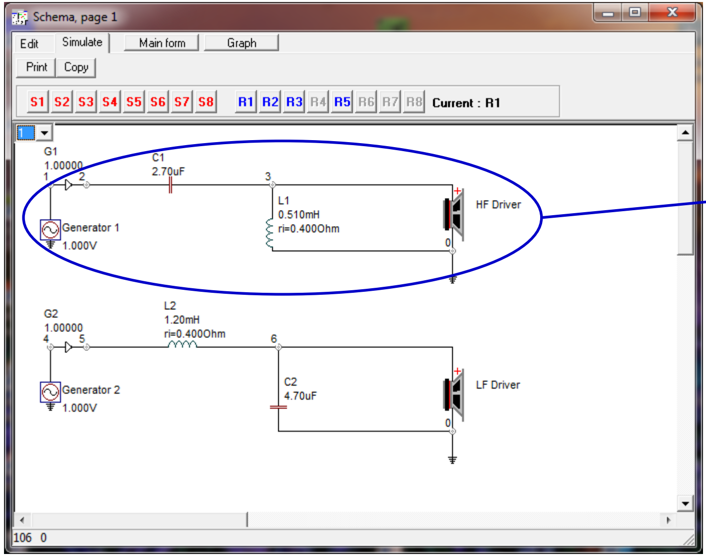


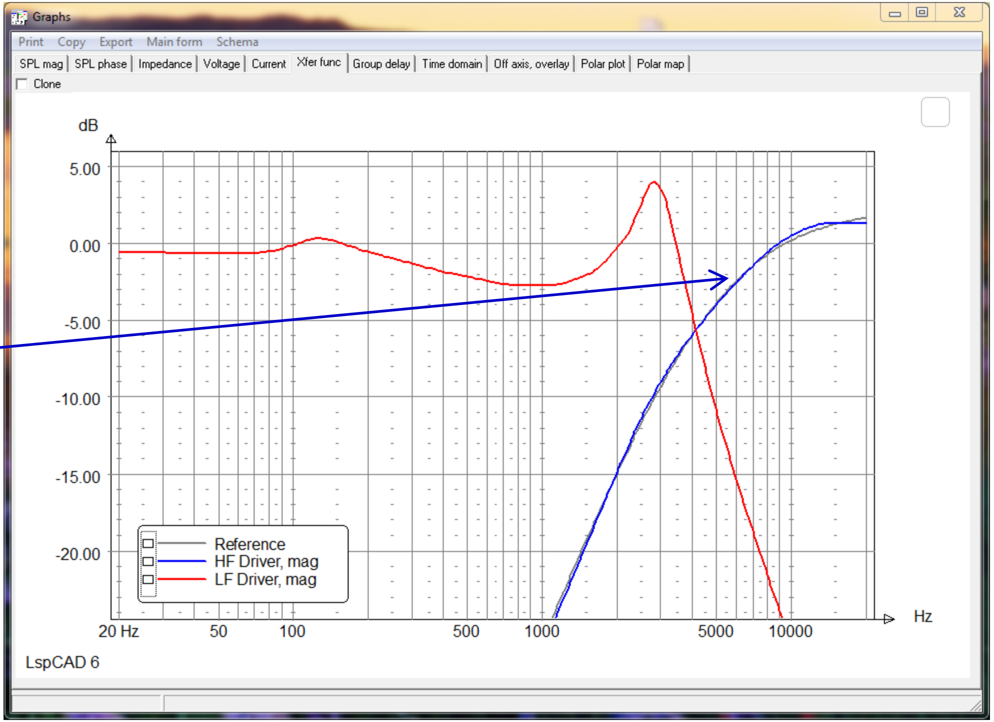


Passive Crossover Implementation

Tools – LspCAD

Match the passive HF filter to the reference curve

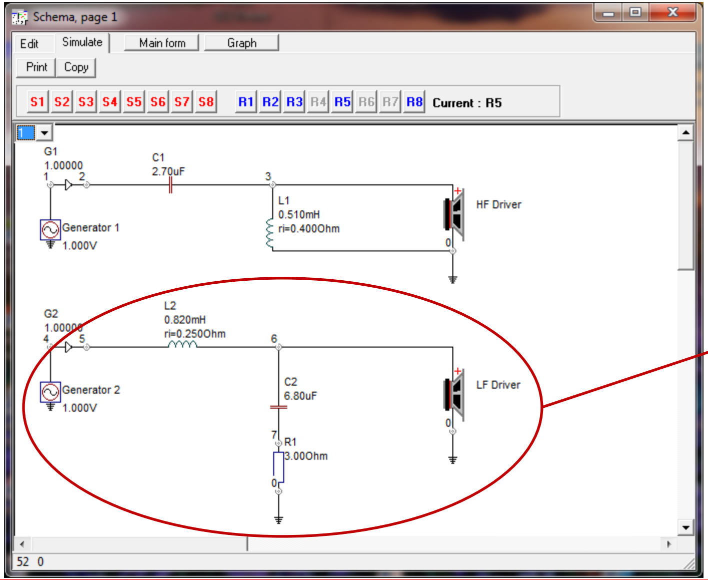


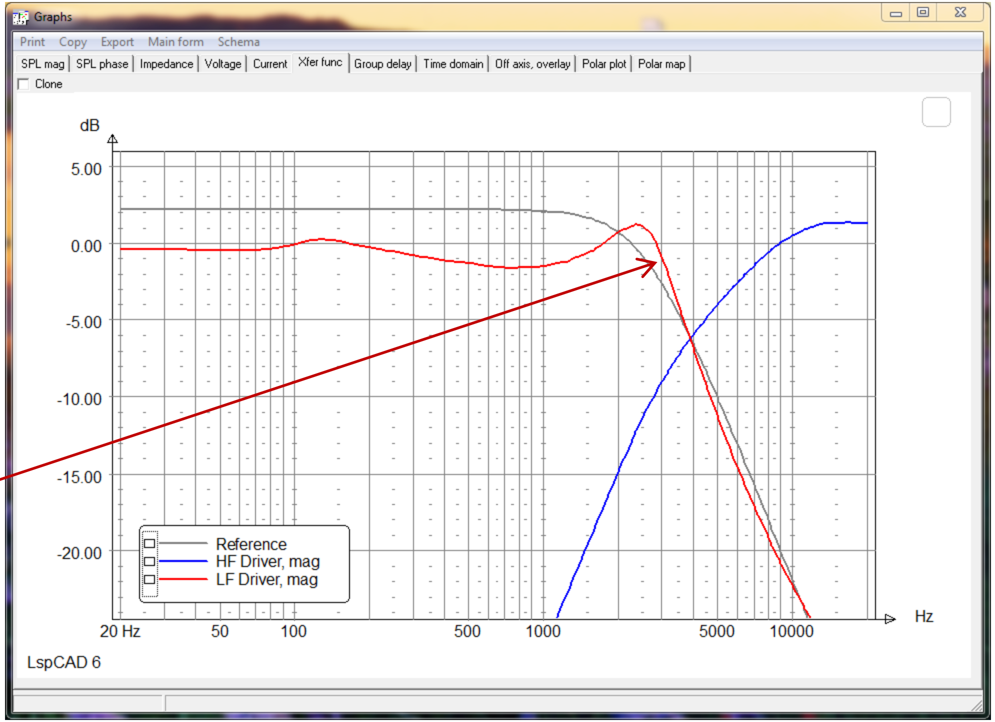


Passive Crossover Implementation

Tools – LspCAD

Match the passive LF filter to the reference curve

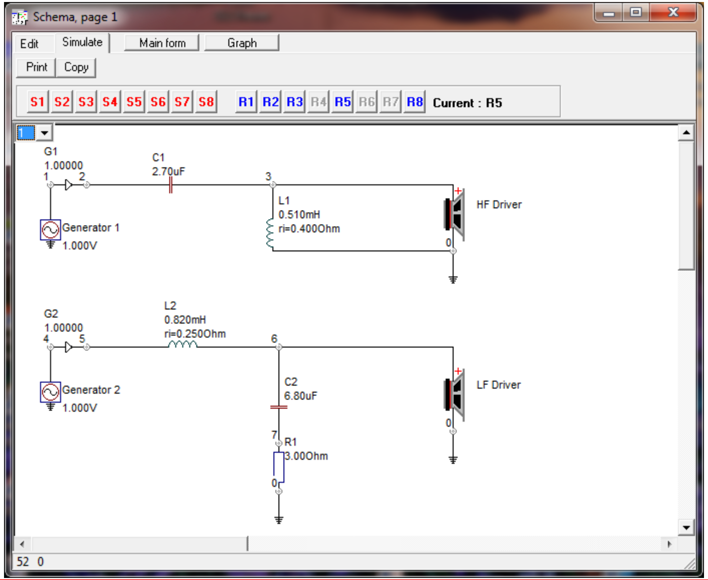


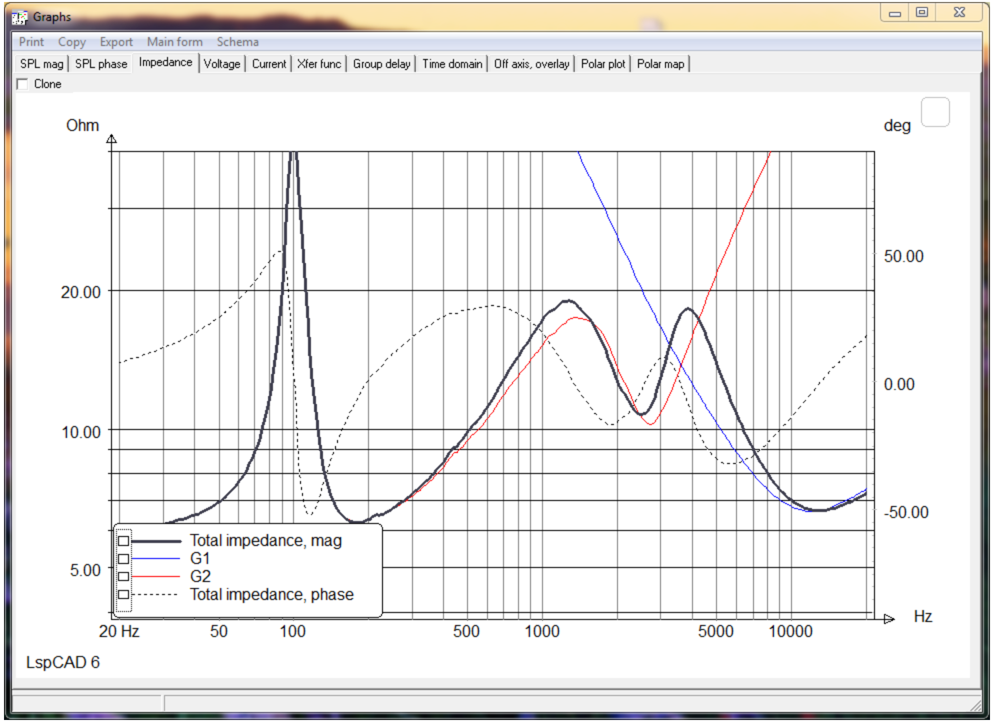


Passive Crossover Implementation

Tools – LspCAD

Inspect the input impedance of the passive crossover!



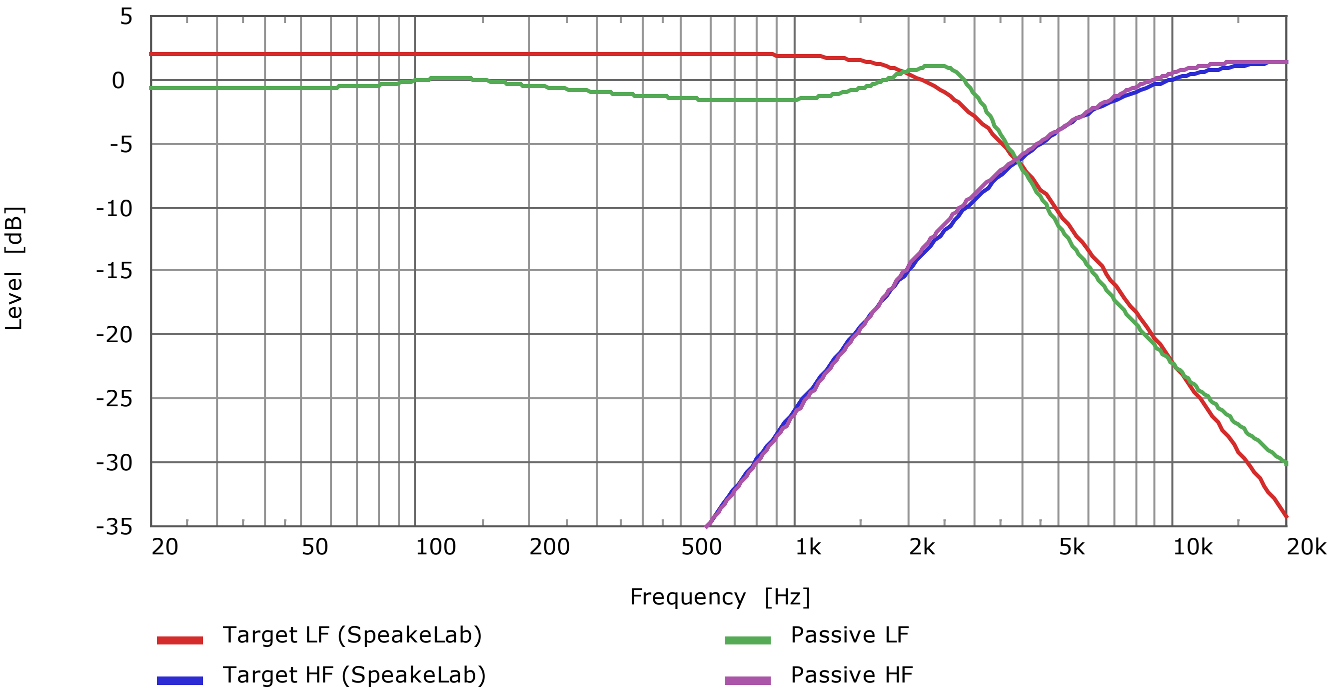


Passive Crossover Implementation

Tools – LspCAD

The passive filters are not an exact match to the target filters.

We need to inspect the system's directivity response using the passive filters.

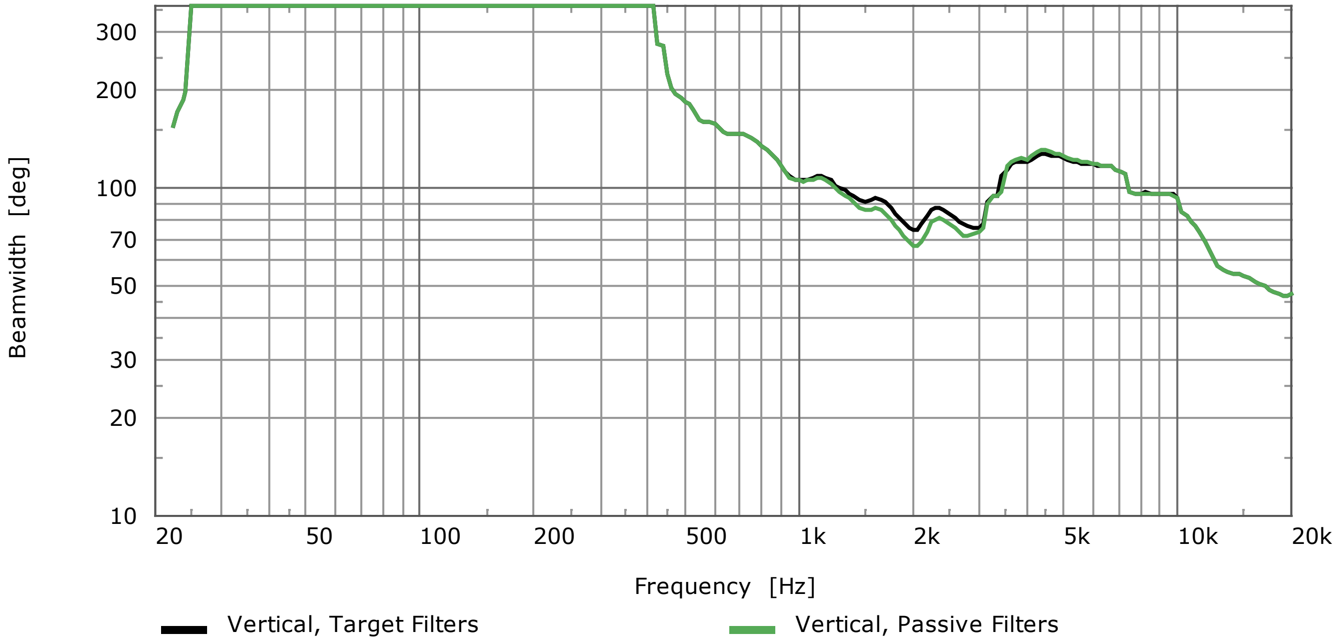


Verify System Directivity with Passive Filters

The passive filter transfer functions exported from LspCAD and imported into SpeakerLab

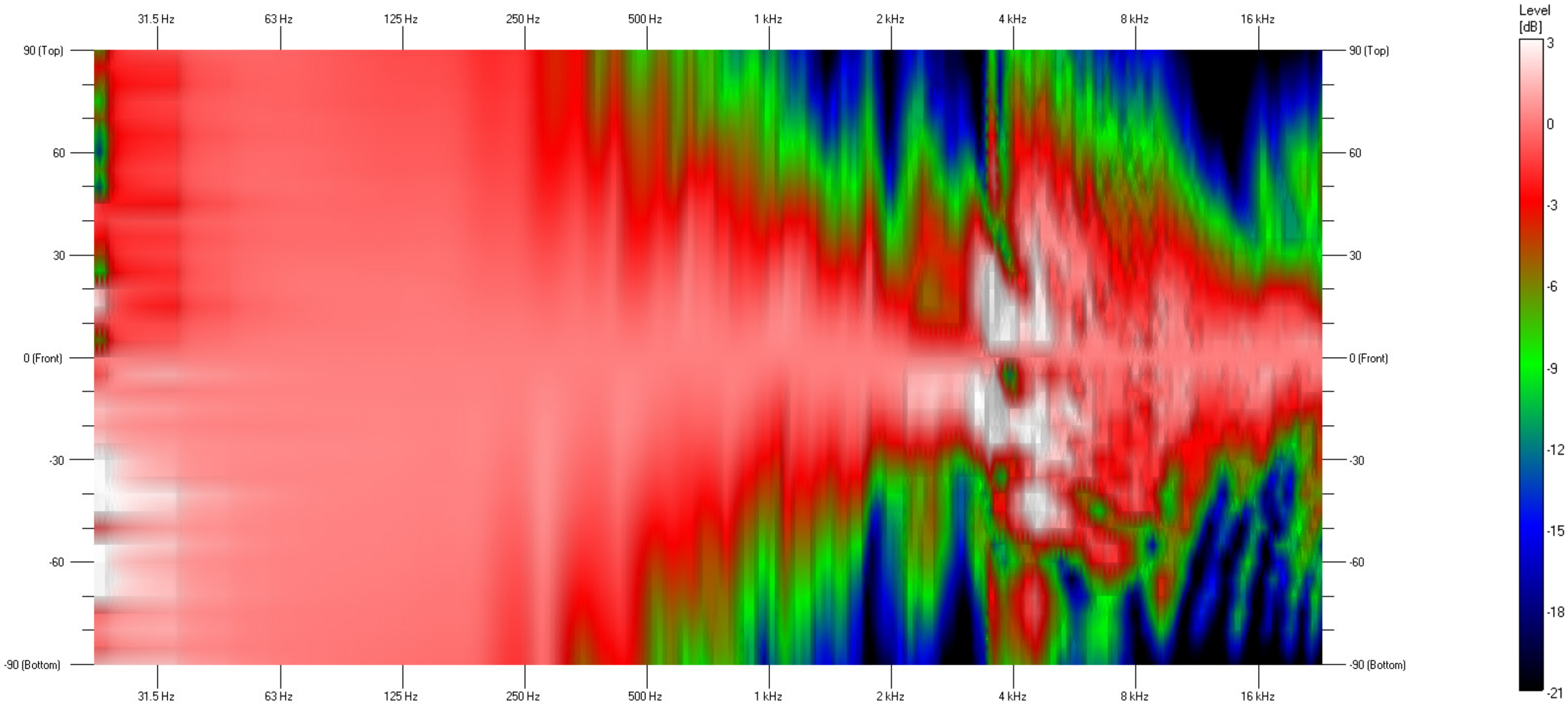
Verify System Directivity with Passive Filters

Beamwidth with target filters & passive filters (vertical)



Verify System Directivity with Passive Filters

Directivity map with passive filters (vertical)



Response Correction with Front-End EQ

Don’t use only the on-axis response for EQ decisions

On-axis frequency response

- small number of listeners

Off-axis frequency response

- typically, much greater number of listeners

EQ based on an ***average response*** can yield better results

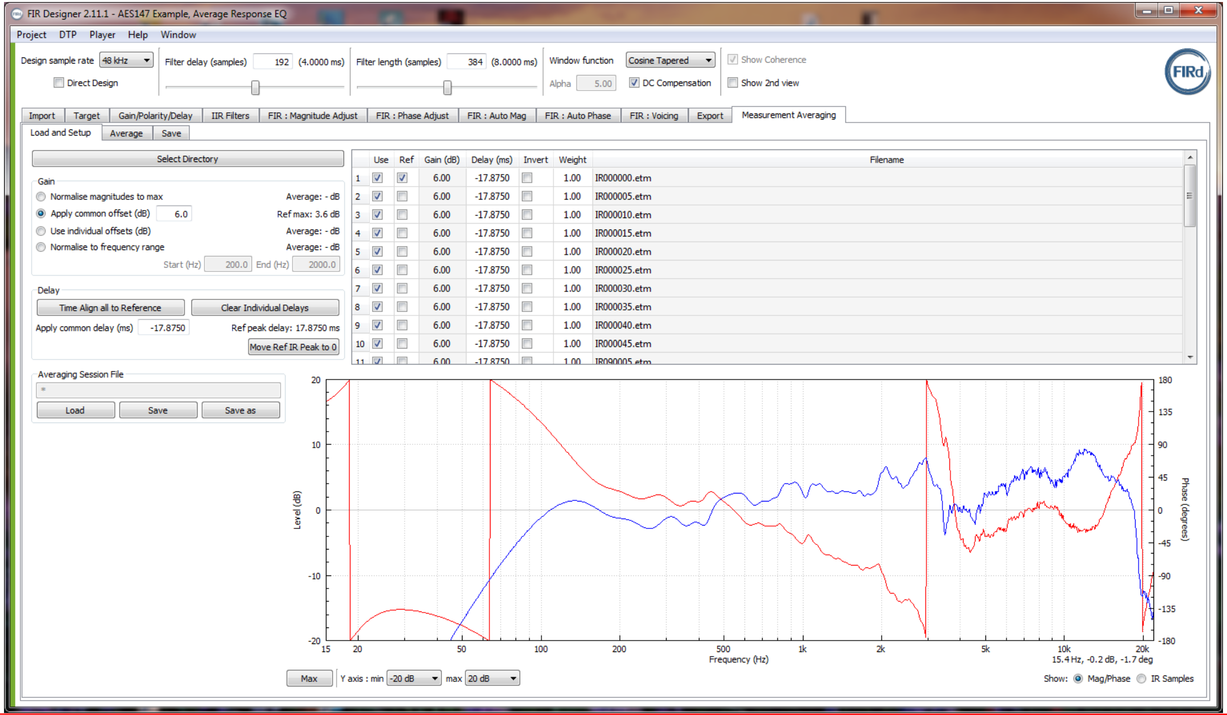
Response Correction with Front-End EQ

Basis for the average response

- Define the intended coverage pattern (included angle) of the loudspeaker system.
- Use the off-axis frequency response measurements within the coverage pattern to calculate an average response.
- Calculate using a *power average*, not a vector (complex) average.

Response Correction with Front-End EQ

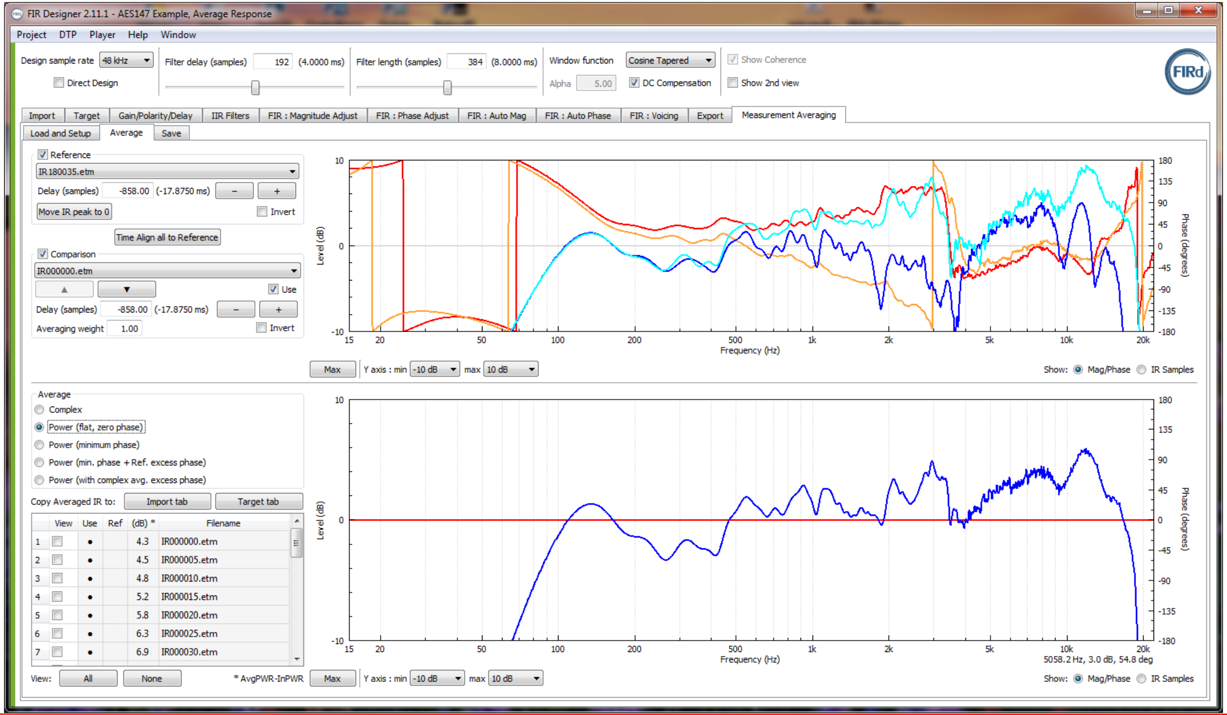
Tools – FIR Designer / Averager (eclipseaudio.com)



	Use	Ref	Gain (dB)	Delay (ms)	Invert	Weight	Filename
1	☑	☑	6.00	-17.8750	☐	1.00	IR000000.etm
2	☑	☐	6.00	-17.8750	☐	1.00	IR000005.etm
3	☑	☐	6.00	-17.8750	☐	1.00	IR000010.etm
4	☑	☐	6.00	-17.8750	☐	1.00	IR000015.etm
5	☑	☐	6.00	-17.8750	☐	1.00	IR000020.etm
6	☑	☐	6.00	-17.8750	☐	1.00	IR000025.etm
7	☑	☐	6.00	-17.8750	☐	1.00	IR000030.etm
8	☑	☐	6.00	-17.8750	☐	1.00	IR000035.etm
9	☑	☐	6.00	-17.8750	☐	1.00	IR000040.etm
10	☑	☐	6.00	-17.8750	☐	1.00	IR000045.etm

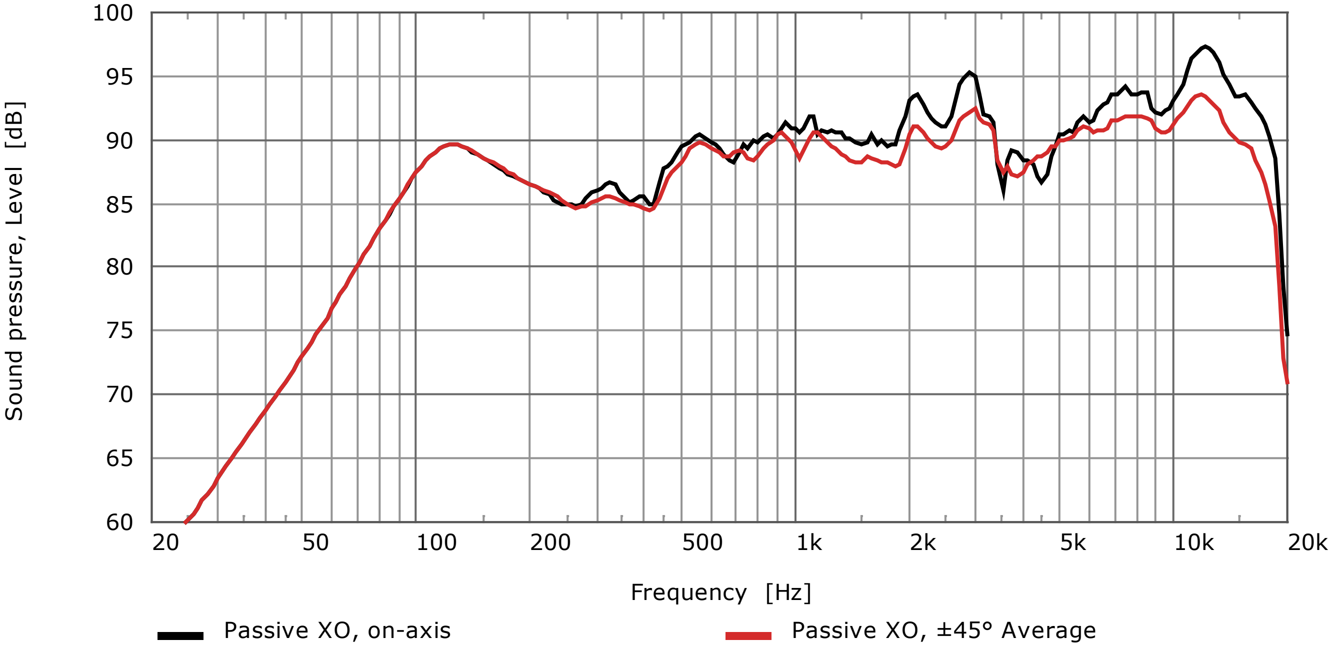
Response Correction with Front-End EQ

Tools – FIR Designer / Averager



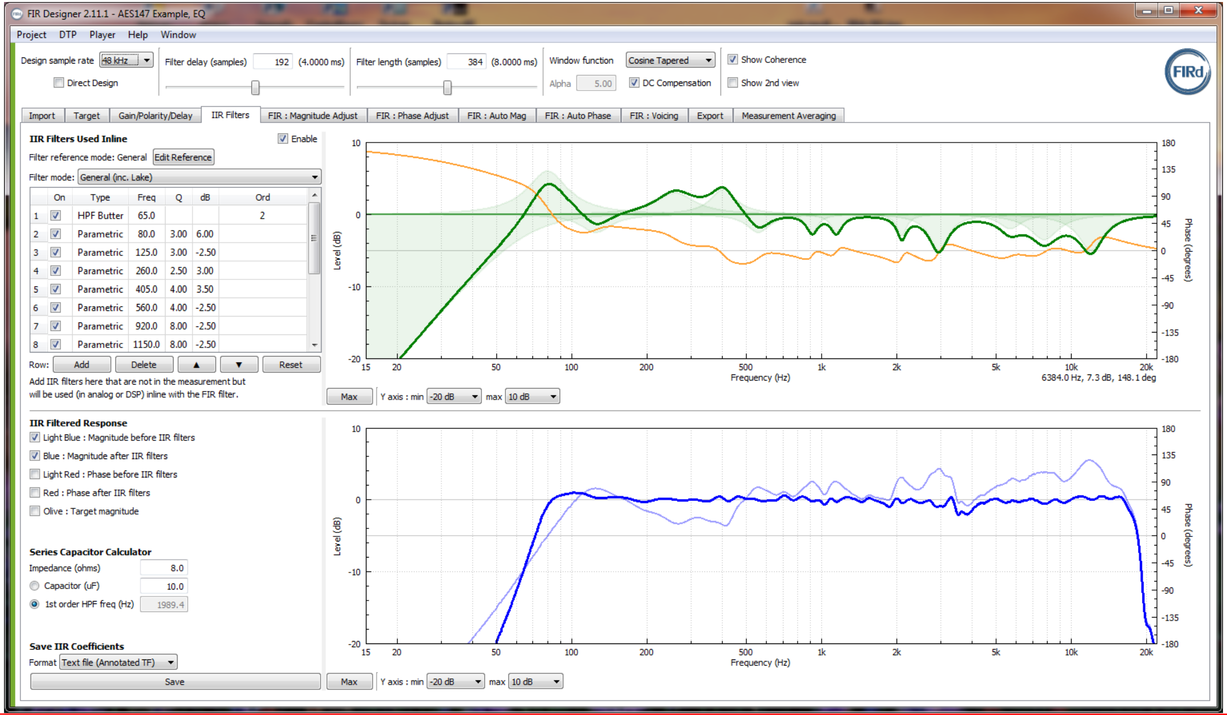
Response Correction with Front-End EQ

Averaged response compared to on-axis



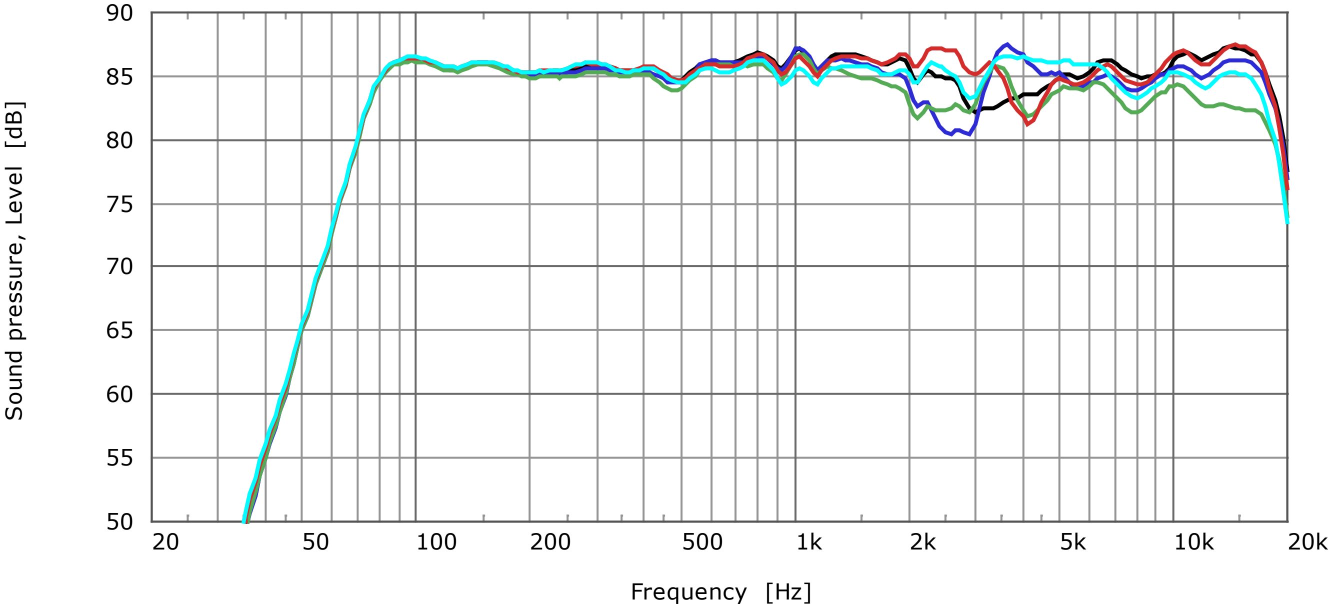
Response Correction with Front-End EQ

Tools – FIR Designer



Final Results

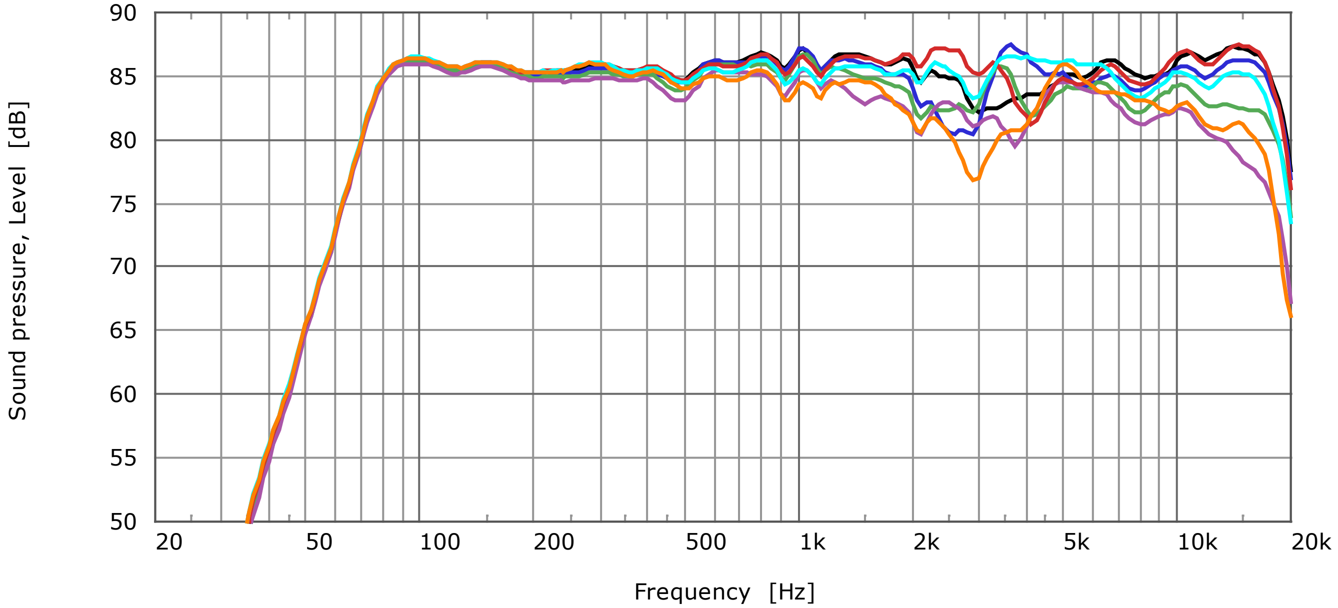
Equalized off-axis frequency responses (vertical)



0°, ±10°, ±20°

Final Results

Equalized off-axis frequency responses (vertical)

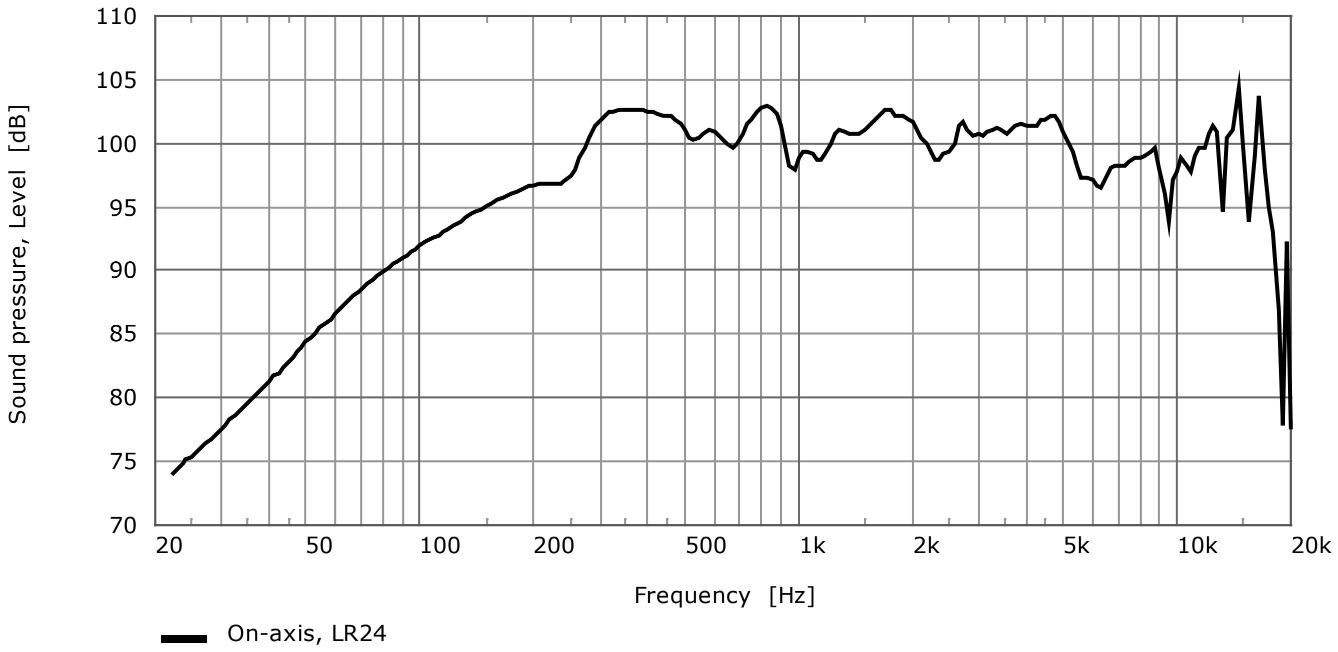


0°, ±10°, ±20°, ±30°

Final Results – Larger Pro-Audio Loudspeaker

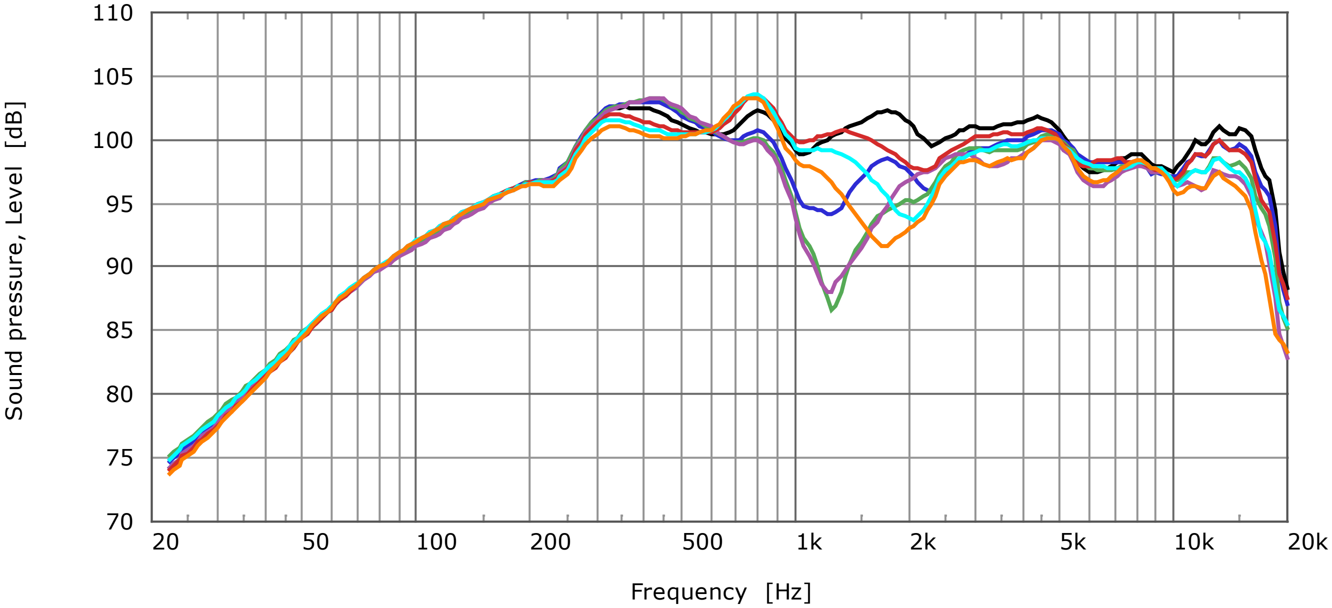
Final Results – Larger Pro-Audio Loudspeaker

On-axis frequency response



Final Results – Larger Pro-Audio Loudspeaker

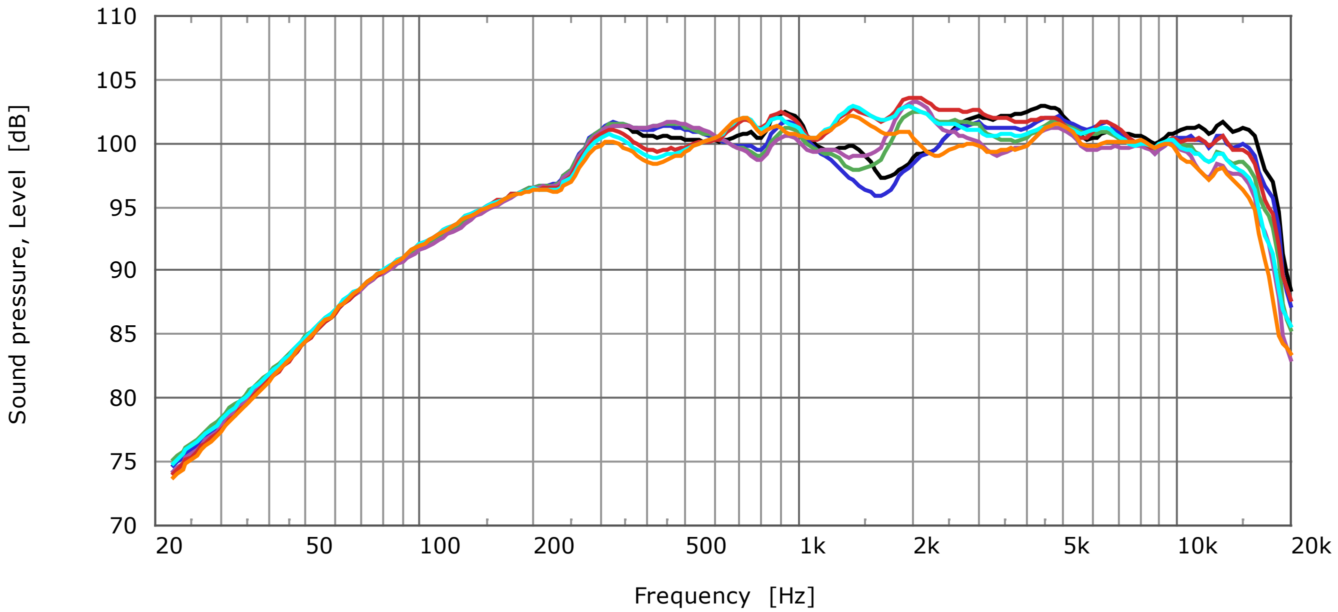
Off-axis frequency responses (vertical), LR24 XO



0°, ±10°, ±15°, ±20°

Final Results – Larger Pro-Audio Loudspeaker

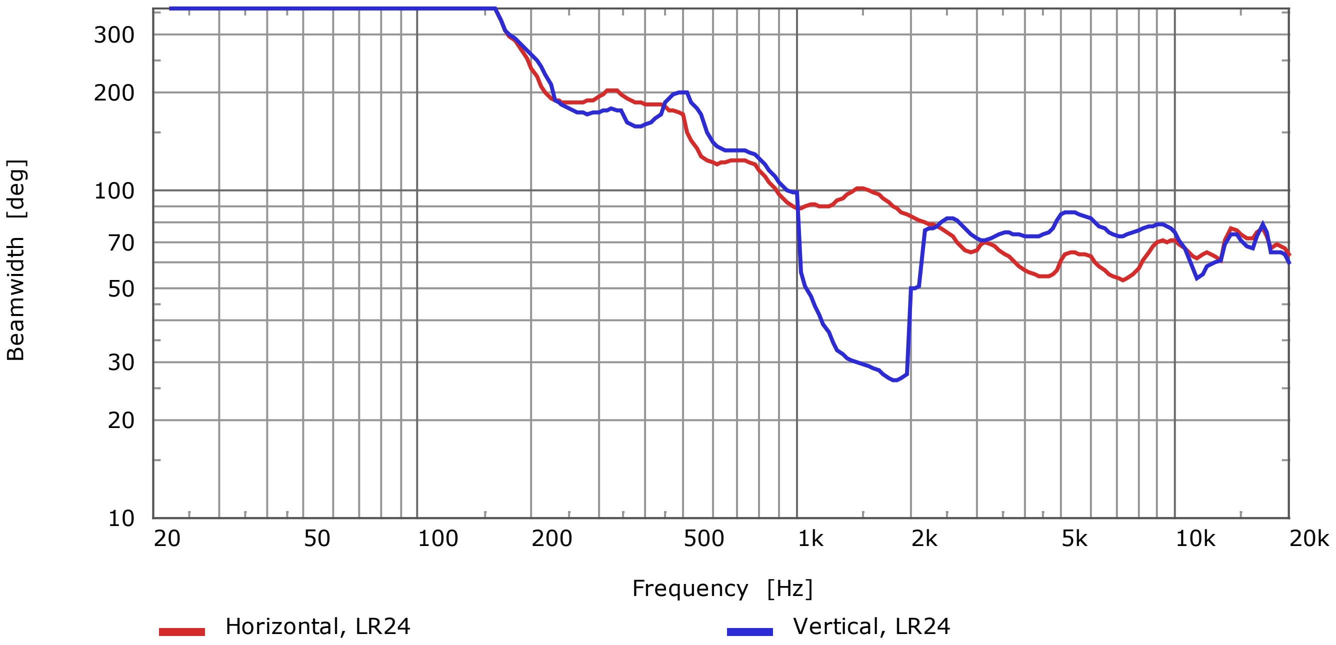
Equalized off-axis frequency responses (vertical), Optimized XO



0°, ±10°, ±15°, ±20°

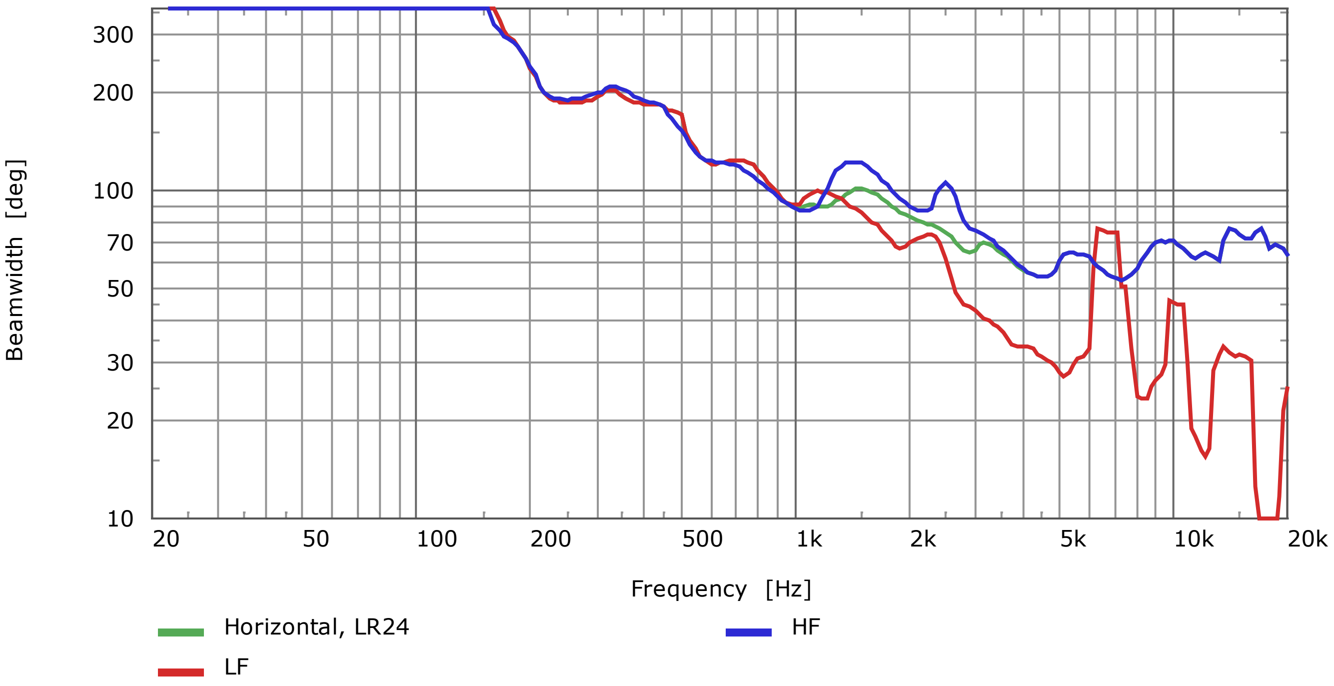
Final Results – Larger Pro-Audio Loudspeaker

Beamwidth (horizontal & vertical), LR24 XO



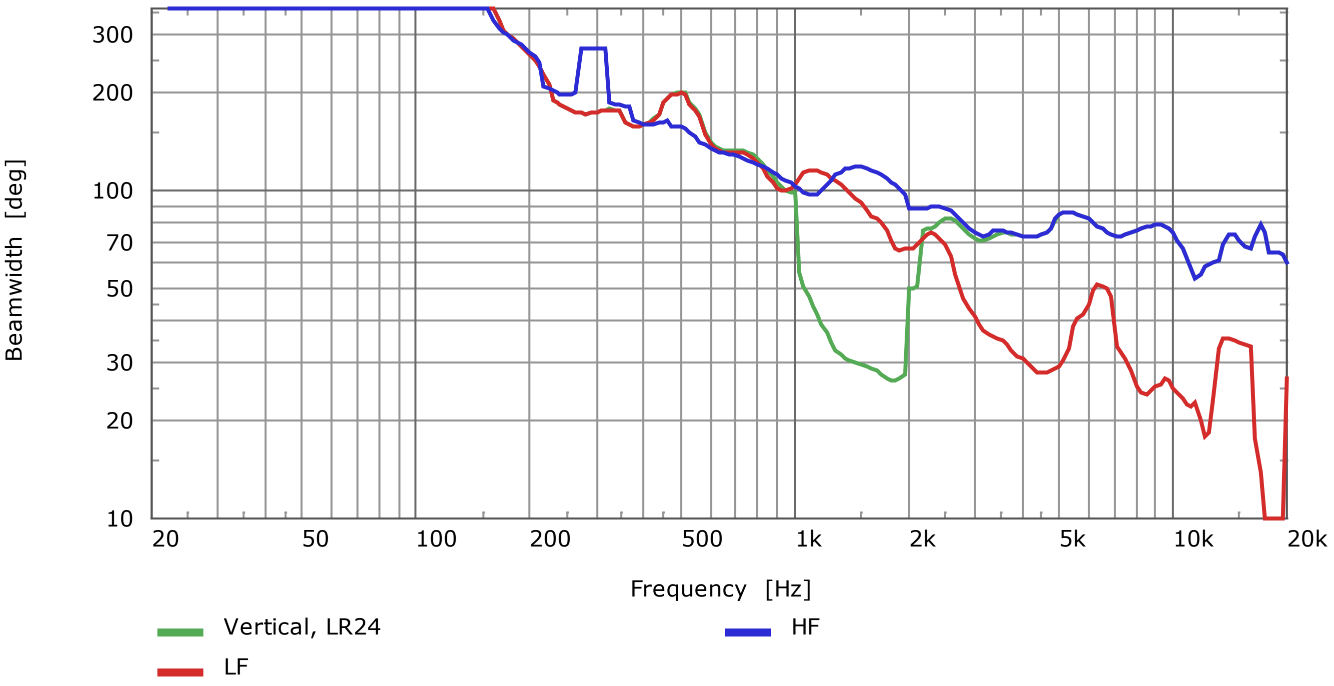
Final Results – Larger Pro-Audio Loudspeaker

Beamwidth of individual components (horizontal), LR24 XO



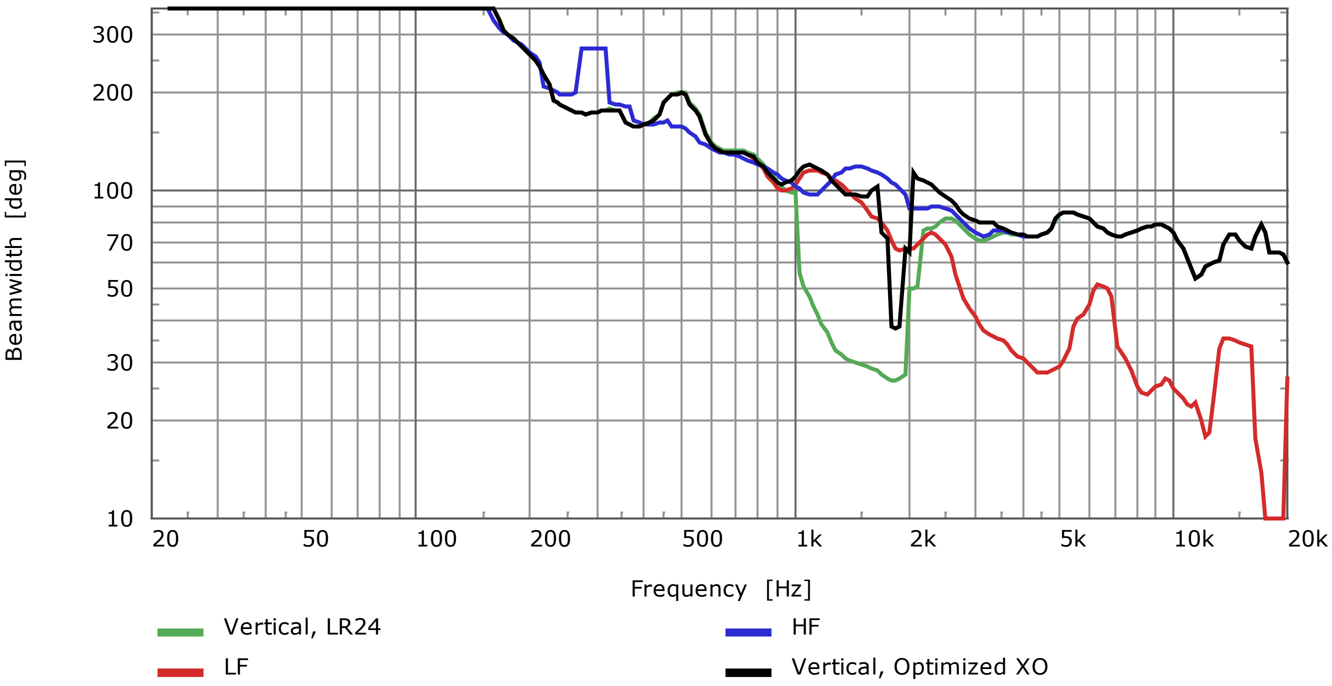
Final Results – Larger Pro-Audio Loudspeaker

Beamwidth of individual components (vertical), LR24 XO



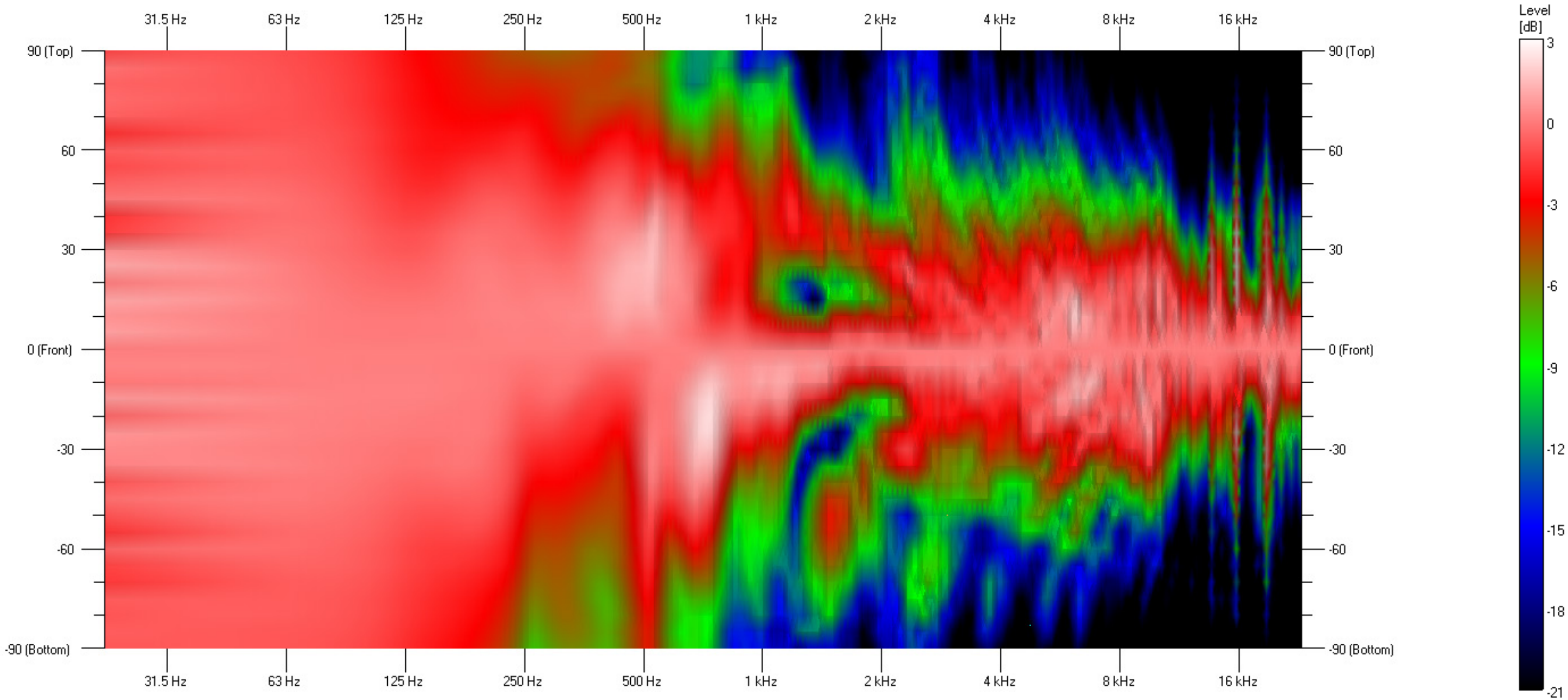
Final Results – Larger Pro-Audio Loudspeaker

Beamwidth of individual components (vertical)



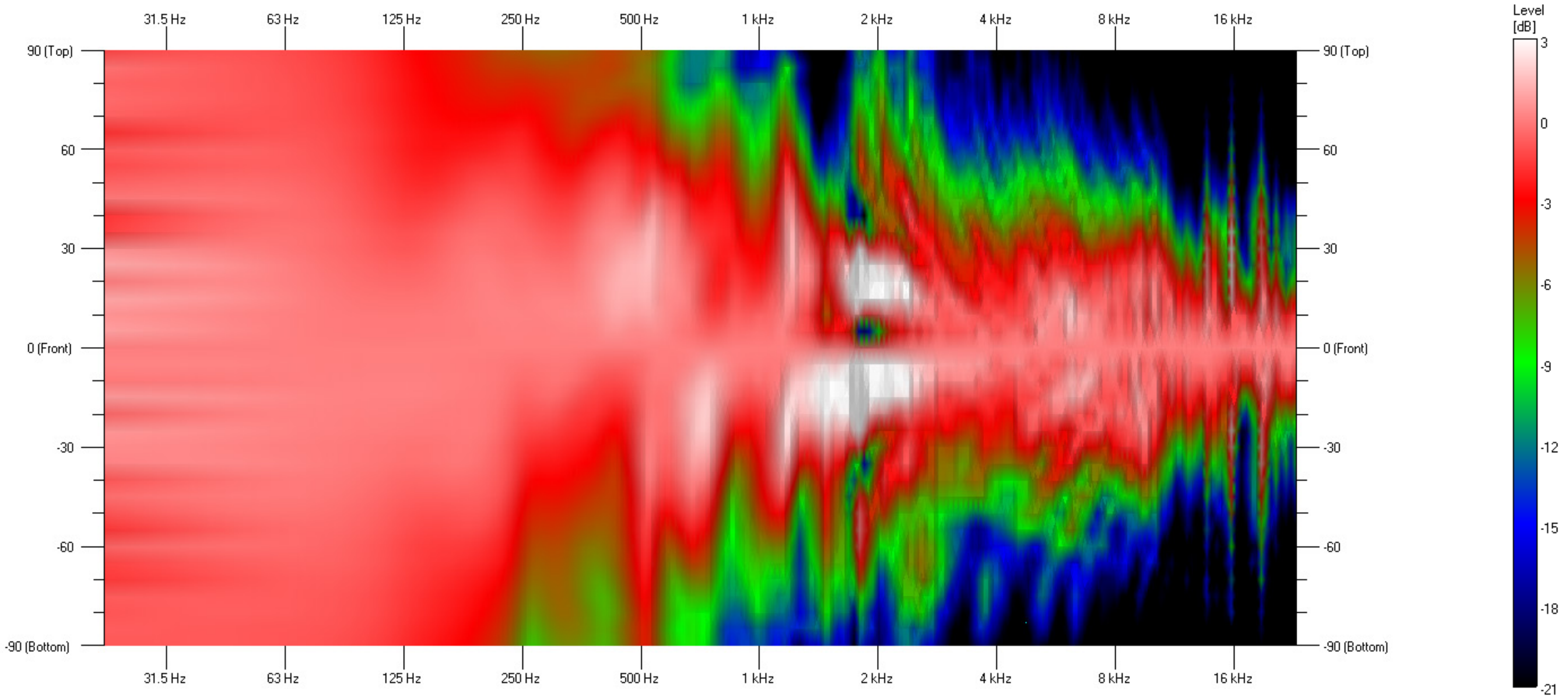
Final Results – Larger Pro-Audio Loudspeaker

Directivity map (vertical) – LR24 XO



Final Results – Larger Pro-Audio Loudspeaker

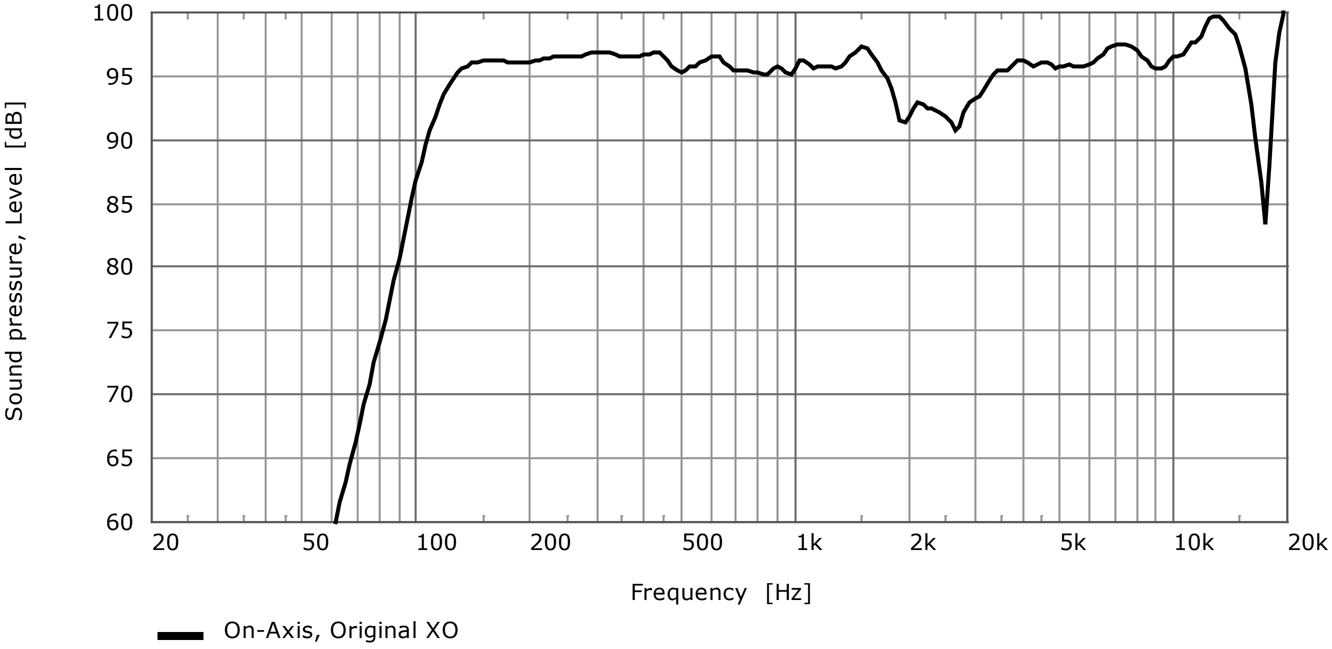
Directivity map (vertical) – Optimized XO



Final Results – Medium-Format Line Array

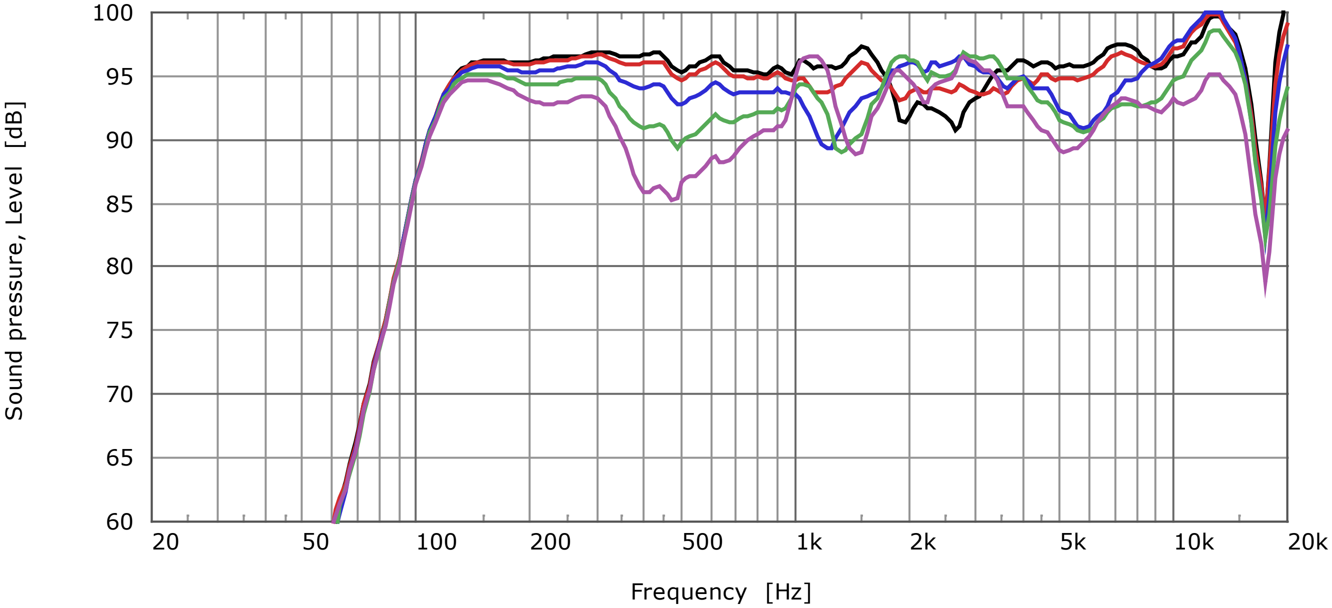
Final Results – Medium-Format Line Array

On-axis frequency response



Final Results – Medium-Format Line Array

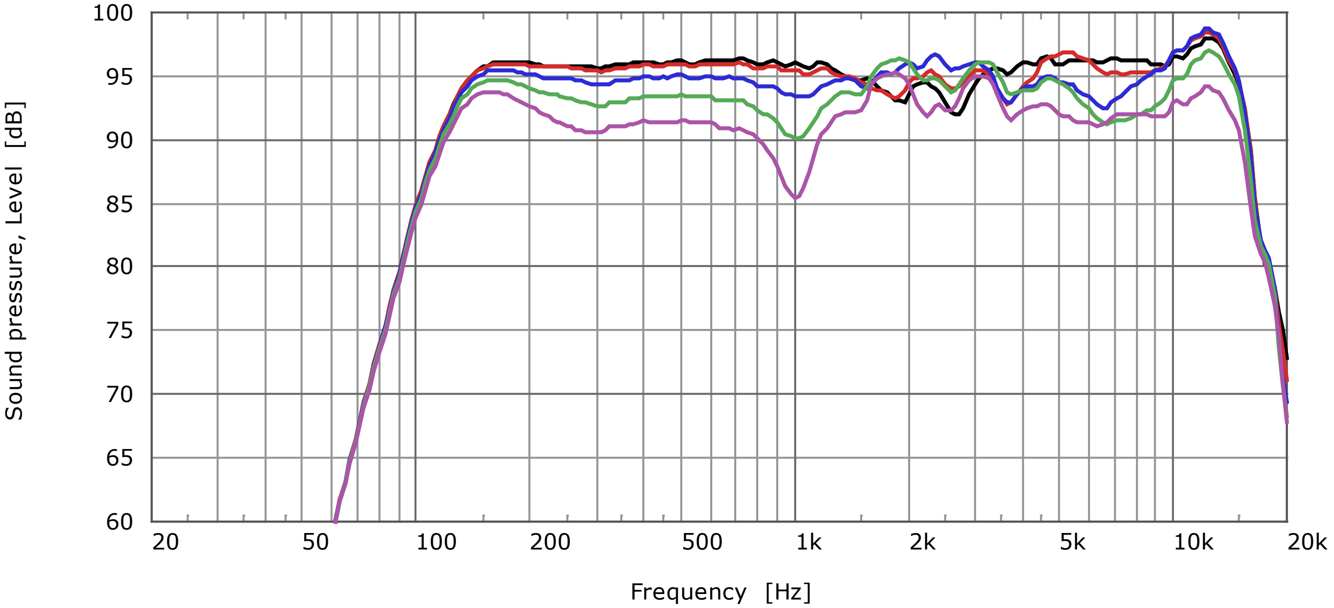
Off-axis frequency responses (horizontal), Original XO



0°, 10°, 20°, 30°, 40°

Final Results – Medium-Format Line Array

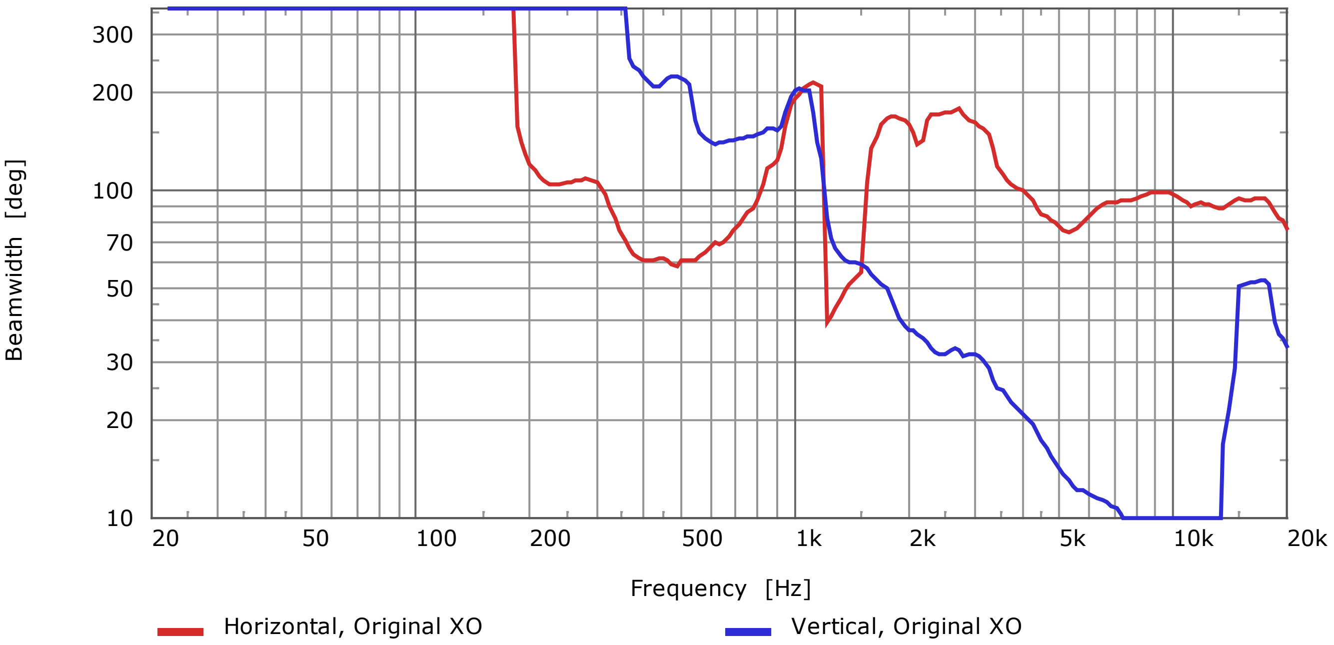
Equalized off-axis frequency responses (horizontal), Optimized XO



0°, 10°, 20°, 30°, 40°

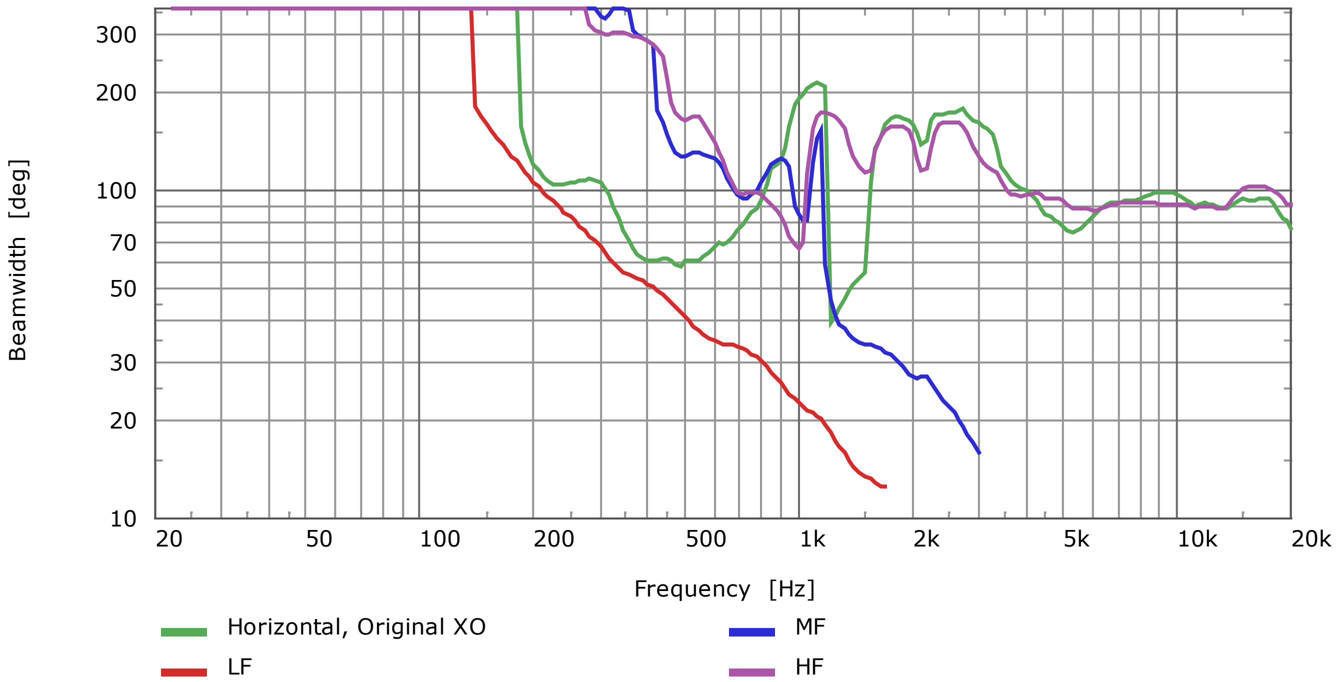
Final Results – Medium-Format Line Array

Beamwidth (horizontal & vertical), Original XO



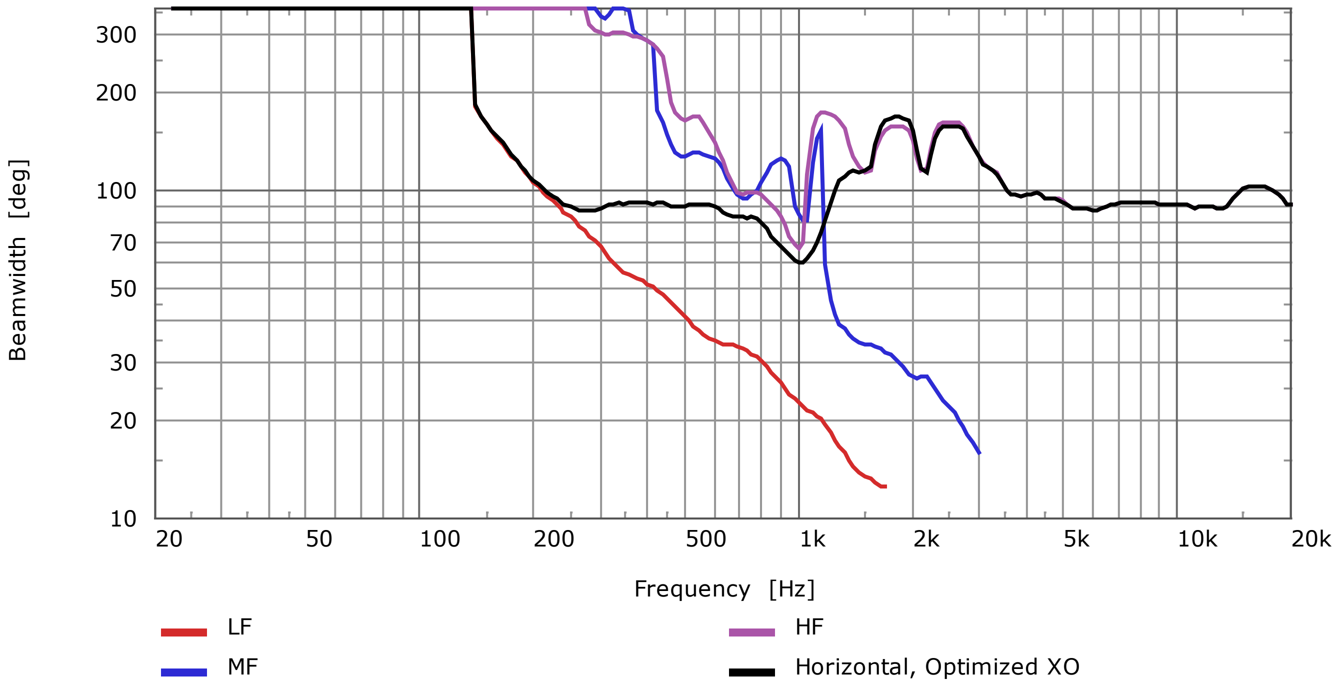
Final Results – Medium-Format Line Array

Beamwidth of individual components (horizontal), Original XO



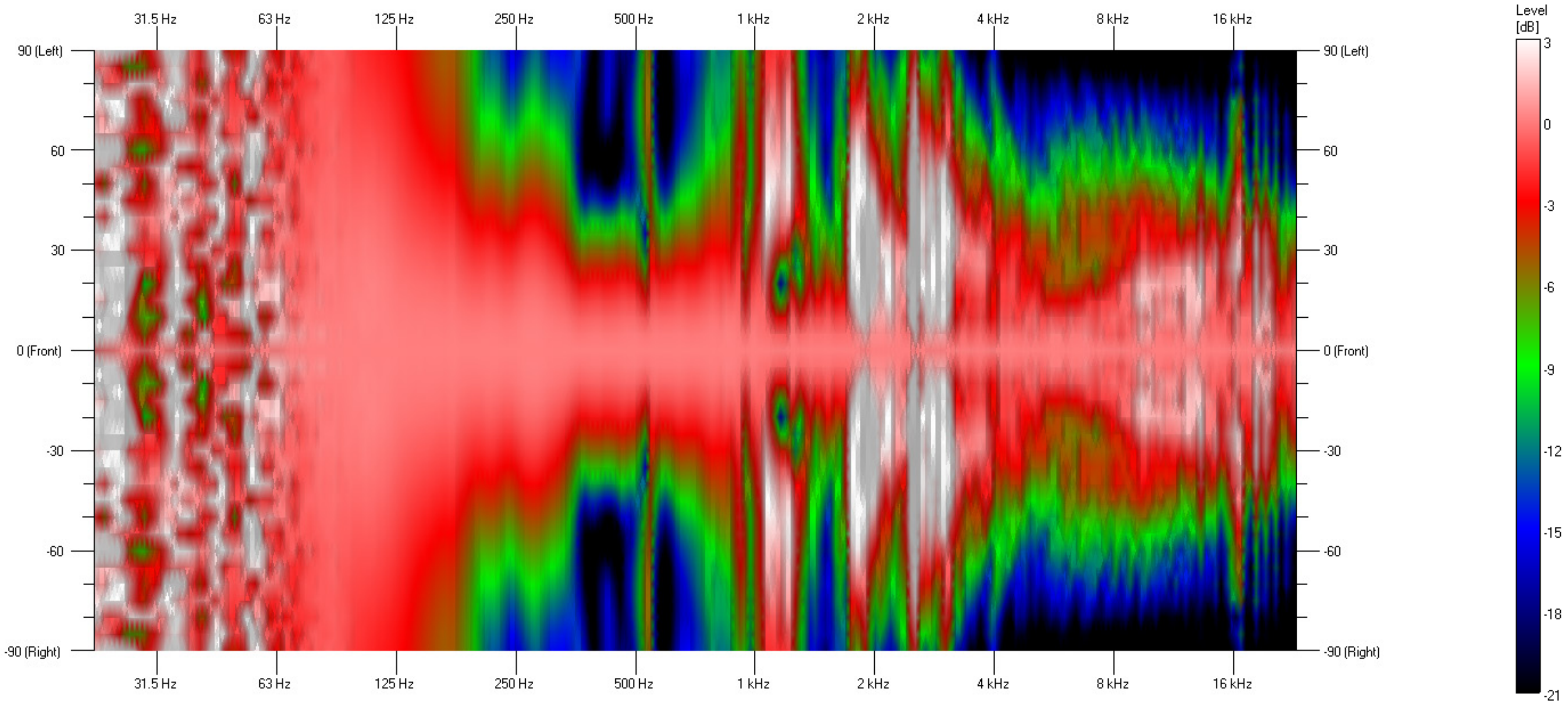
Final Results – Medium-Format Line Array

Beamwidth of individual components (horizontal), Optimized XO



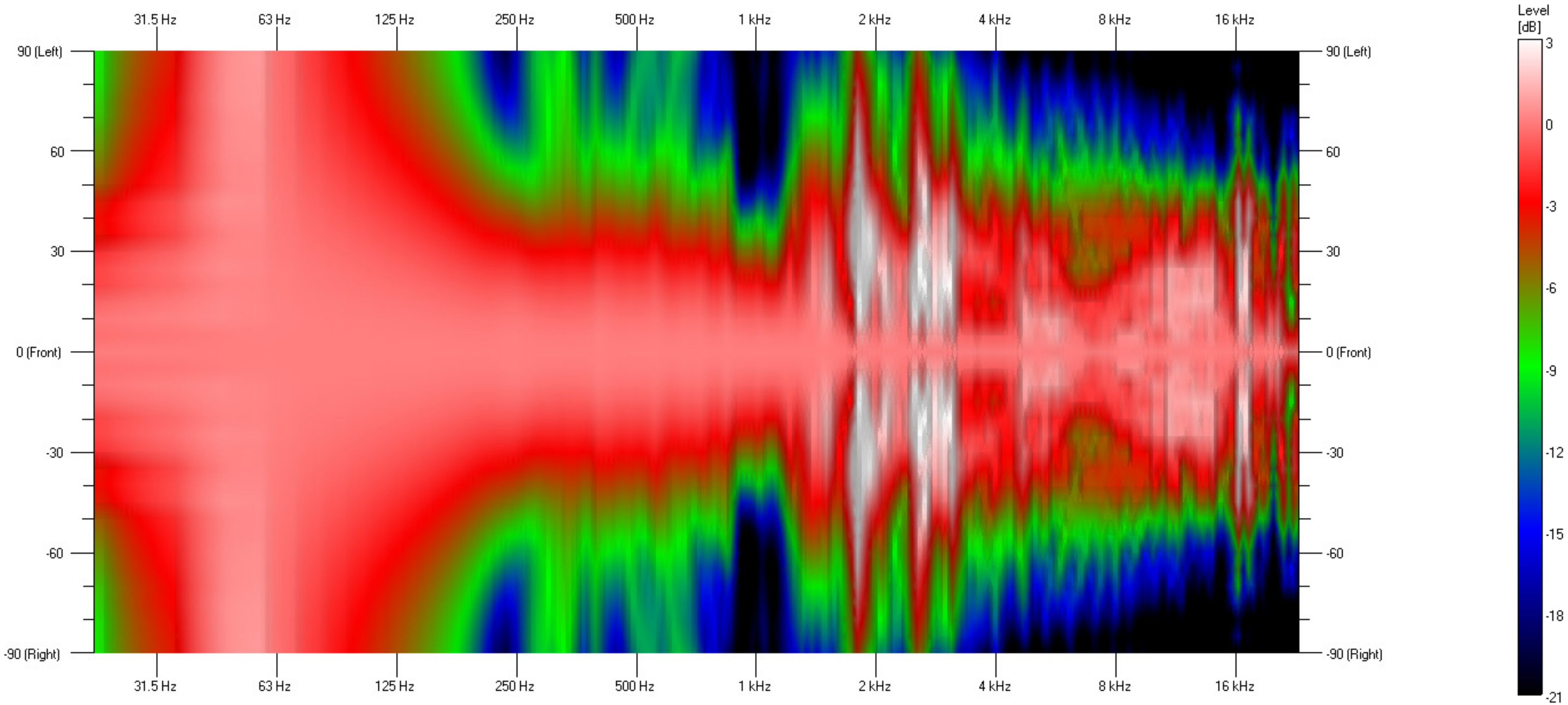
Final Results – Medium-Format Line Array

Directivity map (horizontal) – Original XO



Final Results – Medium-Format Line Array

Directivity map (vertical) – Optimized XO



Further Information

Simulating the Directivity Behavior of Loudspeakers with Crossover Filters; Feistel, Ahnert, Hughes, and Olson
123rd AES Convention, October 2007

http://www.aes.org/e-lib/browse.cfm?elib=14312

Directivity Optimization Through the Crossover Region

Thank you!