Passive Loudspeaker Directivity Optimization

- **Graph 1:**
  - **Frequency [Hz]**: 20, 50, 100, 200, 500, 1k, 2k, 5k, 10k, 20k
  - **Sound pressure, Level [dB]**: 60, 65, 70, 75, 80, 85, 90, 95, 100

- **Graph 2:**
  - **Beamwidth [deg]**: 10, 20, 30, 40, 50, 60, 70, 80, 90, 100

- **Legend:**
  - Vertical, new XO
  - Vertical, stock XO
  - LF
  - HF

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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

On-axis, stock
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

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Example Loudspeaker System

Off-axis frequency responses (vertical)
Example Loudspeaker System

Off-axis frequency responses (vertical)
Example Loudspeaker System

Beamwidth (horizontal & vertical)

![Graph showing beamwidth over frequency for horizontal and vertical orientations.](image-url)
Example Loudspeaker System

Directivity map (vertical)
Example Loudspeaker System

Beamwidth of individual components (horizontal)
Example Loudspeaker System

Beamwidth of individual components (vertical)

![Beamwidth graph](image)
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)

Sound pressure, Level [dB]

Frequency [Hz]

Impedance, Amplitude [ohm]
Directivity Optimization

Selecting the XO region

![Graph showing beamwidth vs. frequency for LF and HF regions]
Directivity Optimization

High-pass filter – Intended for passive implementation

2\textsuperscript{nd} order response using staggered poles
Directivity Optimization

High-pass filter – Intended for passive implementation

![Graph showing sound pressure level vs. frequency for HF and HF w/new XO]
Directivity Optimization

Low-pass filter – Intended for passive implementation

2\textsuperscript{nd} order response
Directivity Optimization

Low-pass filter – Intended for passive implementation

![Graph showing sound pressure level for different frequencies with and without new crossover](image-url)
Directivity Optimization

System response, on-axis
Directivity Optimization

System response, on-axis – compared to stock XO

![Graph showing system response comparison between new XO and stock XO. The graph plots frequency [Hz] on the x-axis and sound pressure level [dB] on the y-axis. The new XO line is shown in black, and the stock XO line is shown in purple. The graph highlights the differences in response across different frequency bands.]
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)

![Graph showing beamwidth of individual components (vertical)]
Directivity Optimization

Beamwidth of individual components (vertical)

![Graph showing 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)
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

![Graph showing on-axis frequency response for LR24 speaker. The graph plots sound pressure level in dB against frequency in Hz. The response is smooth and stable across the frequency range, with peaks and valleys indicating the speaker's performance characteristics.](image-url)
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

![Graph showing beamwidth vs frequency for horizontal, LF, and HF components of 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

![Graph showing on-axis frequency response with frequency on the x-axis and sound pressure level on the y-axis.](graph.png)
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

![Graph showing beamwidth comparison](image-url)
Final Results – Medium-Format Line Array

Beamwidth of individual components (horizontal), Original XO

[Graph showing beamwidth vs frequency for different frequency bands (HF, MF, LF)].
Final Results – Medium-Format Line Array

Beamwidth of individual components (horizontal), Optimized XO

[Graph showing beamwidth vs. frequency for different frequency bands (LF, MF, HF) and 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

[Graph showing the directivity map with frequency levels and directional level changes.]
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!