Universität Rostock Traditio et Innovatio

Institute of Communications Engineering

Evaluation Strategies for the Optimization of Line Source Arrays

Florian Straube [2], *Frank Schultz* [1], *Michael Makarski* [3], *Sascha Spors* [1] *and Stefan Weinzierl* [2]

[1] Research Group Signal Processing and Virtual Acoustics, University of Rostock

[2] Audio Communication Group, TU Berlin

[3] Four Audio GmbH & Co. KG, Aachen

AES 59th International Conference

on Sound Reinforcement Engineering and Technology

2015-07-16 10:00-10:20 a.m. Session 11, P.2-1

Recent Trends for Line Source Array Applications

Curved LSA

-intensity shading by curving band-zoning/array morphing

e.g. Meyer Sound MAPP XT

e.g. L-ACOUSTICS SoundVision

Curved LSA

-curving and electronic beam forming (FIR/IIR)

e.g. EASE Focus FIR Maker

e.g. Martin Audio Display

e.g. Duran Audio AXYS with Digital Directivity Synthesis (DDS)$\rightarrow$ now with JBL

Straight LSA

-electronic beam forming (FIR)

e.g. EAW Resolution

Version: 0.00 2015-07-19

Optimization Method

Complex-Directivity Point Source Model (CDPS) [Mey84, vB00, Fei09]

$$P(m,f) = \sum_{i=1}^{i=L\,N} \underbrace{D(i,f)}_{\text{FIR-Filter}} \cdot \underbrace{H_{\text{post}}(\beta(m,i),f) \cdot \frac{e^{-j\frac{2\pi f}{c}|x_m - x_{0,i}|}}{4\pi\,|\mathbf{x}_m - \mathbf{x}_{0,i}|} \cdot \frac{\Lambda_{y,\text{LSA}}}{L}}_{G(m,i,f)}.$$

Least Squares Optimization / **Pressure Matching** (DDS like) [vB00, Col14] with

-Tikhonov regularization /

energy constraint on the loudspeaker weights [Bet12]

$$\min_{\mathbf{d}(f)} \|\mathbf{G}(f)\mathbf{d}(f) - \mathbf{p}_{\text{des}}(f)\|_2^2 \qquad \text{subject to:} \quad \|\mathbf{d}(f)\|_2^2 \leq D_{\text{max}}^2$$

Other Optimization Approaches

-active noise control, personal audio, multi-zone sound field synthesis [Cho02, Bai14, Col14]

-find minimum of constrained nonlinear multivariable function, Matlab: `fmincon()` [Tho09]

-solve multiobjective goal attainment problems, Matlab: `fgoalattain()` [Tho11, Fei13]

-near field & far field beam forming (DDC like) [vB00, Bai13]

Evaluation Setup

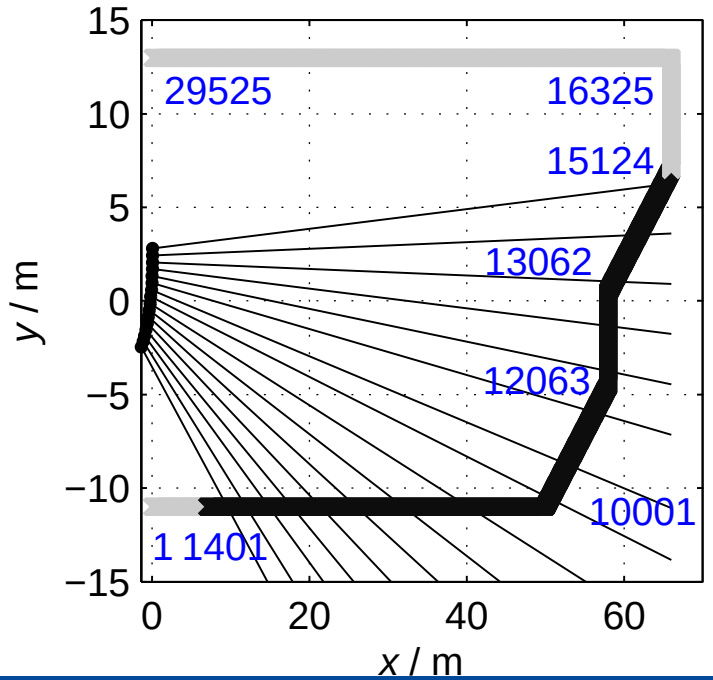
LSA Cabinet Model [Mey84]

height 0.372m, ideal circular / line pistons, ideal X-Over 400 Hz & 1.5 kHz

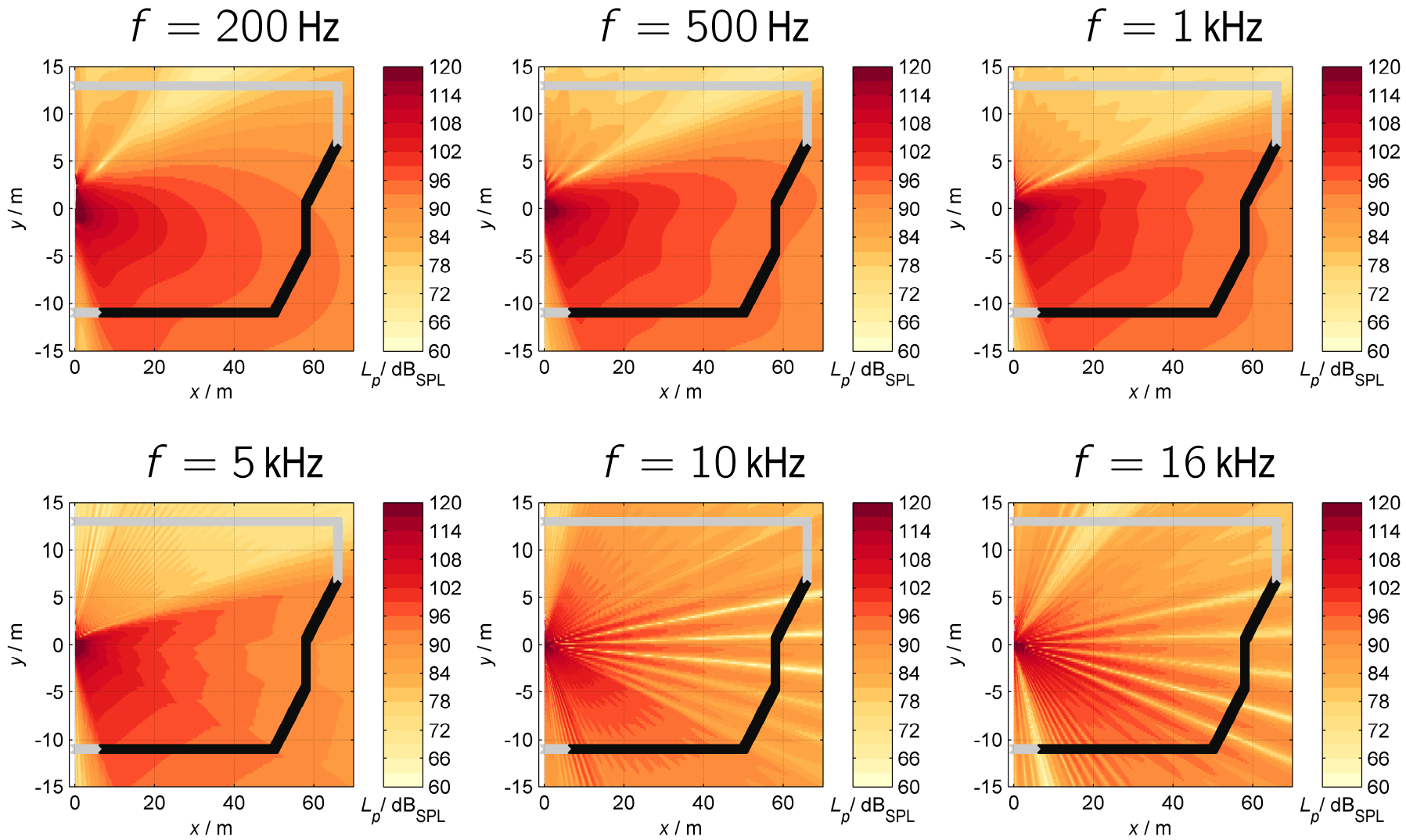
	#	$f_{\text{alias}}/\text{Hz}$	diameter/length in inch	Δy in inch	$\text{dB}_{\text{SPL@1W,1m}}$
LF	1	461	12 (circ)	14.65	96
MF	4	1844	3 (circ)	3.66	86
HF	10	4610	1.2 (line)	1.46	112

LSA Model

16 cabinets, length ≈6m, tilt angle +3°, splay angles top to down: 5x2°, 3°, 2°, 6x3°, 2x4°

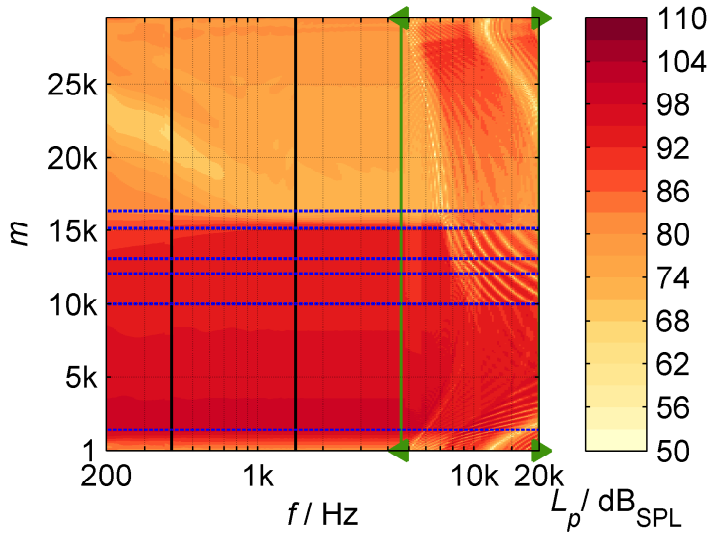


SPL Distribution in xy-Plane

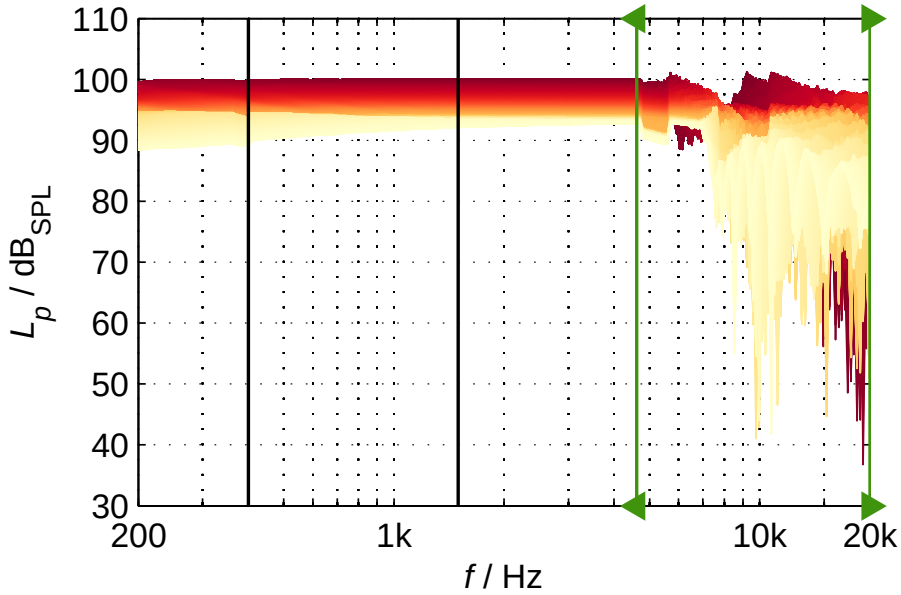


Frequency Responses & Directivity

Position Index Plot [Tho09, Fei13]



Frequency Responses in Audience Zone



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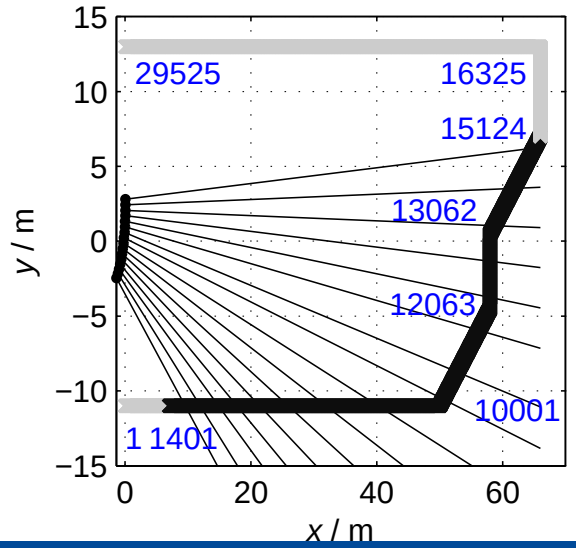
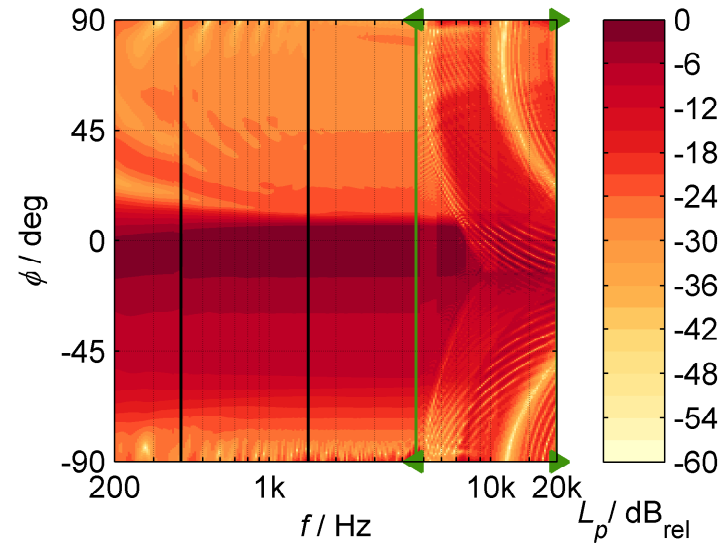


Farfield Radiation Pattern



Technical Quality: Errors

Absolute error

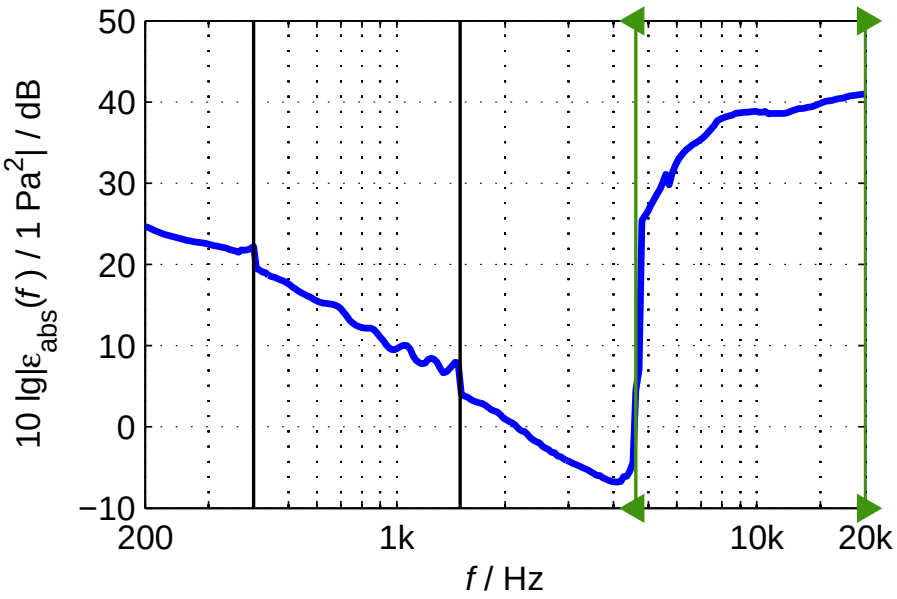
frequency dependent

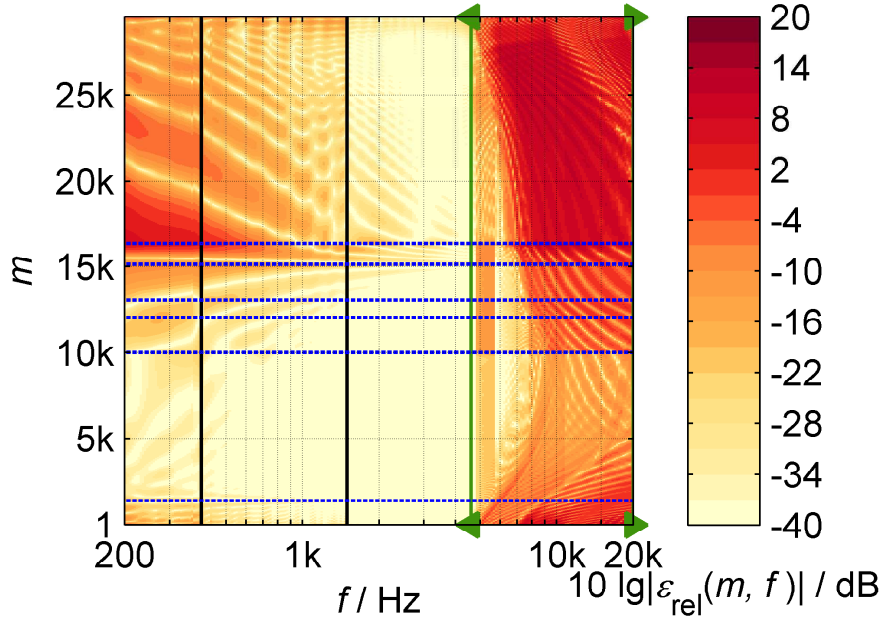
$$\epsilon_{\text{abs}}(f) = \|\mathbf{G}(f)\mathbf{d}(f) - \mathbf{p}_{\text{des}}(f)\|_2^2$$

Relative error

frequency & position dependent

$$\epsilon_{\text{rel}}(m, f) = \left| \frac{P_{\text{des}}(m, f) - P(m, f)}{P_{\text{des}}(m, f)} \right|^2$$





Technical Quality: Acoustic Contrast & Error Distribution

[Cho02, Bai14, Col14]

Acoustic contrast (bright vs. dark zone)

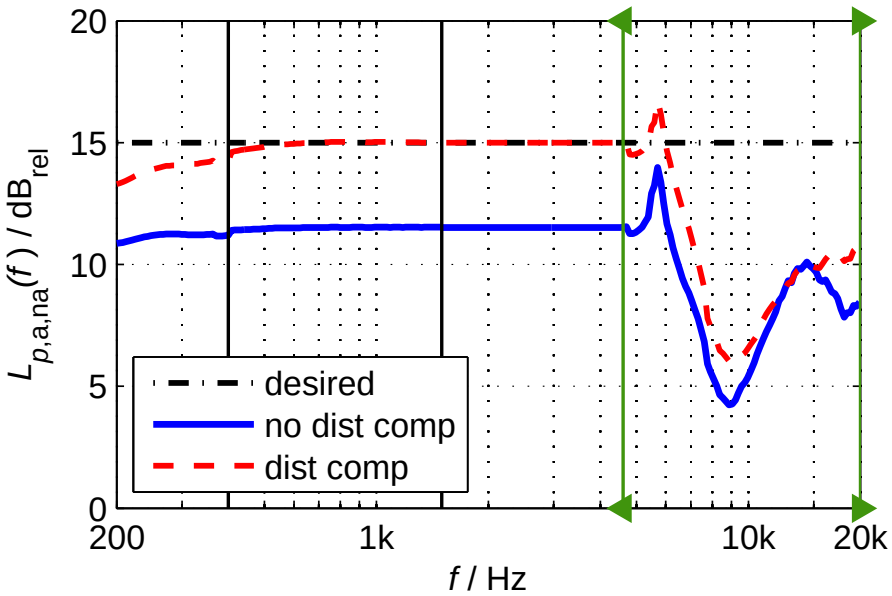
audience vs. non-audience zone

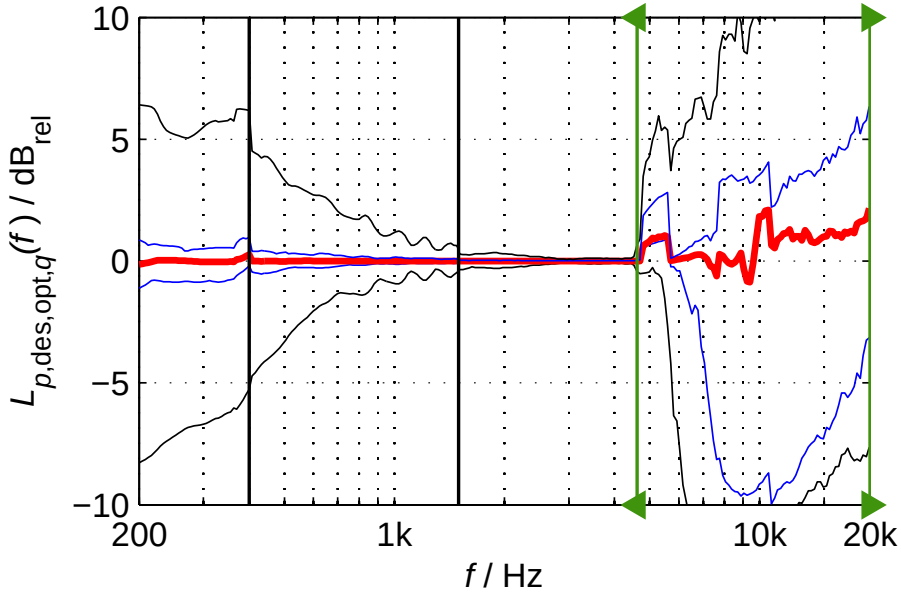
Distribution measure

q ={0.05, 0.25, 0.5, 0.75, 0.95} quantiles

$$L_{p,\mathrm{a,na}}(f) = 10\ \log_{10}\left(\frac{\frac{1}{M_\mathrm{a}}\|\mathbf{p}_{m\in\mathcal{M}_\mathrm{a}}(f)\|_2^2}{\frac{1}{M_\mathrm{na}}\|\mathbf{p}_{m\in\mathcal{M}_\mathrm{na}}(f)\|_2^2}\right)$$

$$L_{p,\mathrm{des,opt},q}(f) = \underset{m}{\mathcal{Q}_q}\left[10\ \log_{10}\left(\frac{|P_\mathrm{des}(m,f)|^2}{|P(m,f)|^2}\right)\right]$$

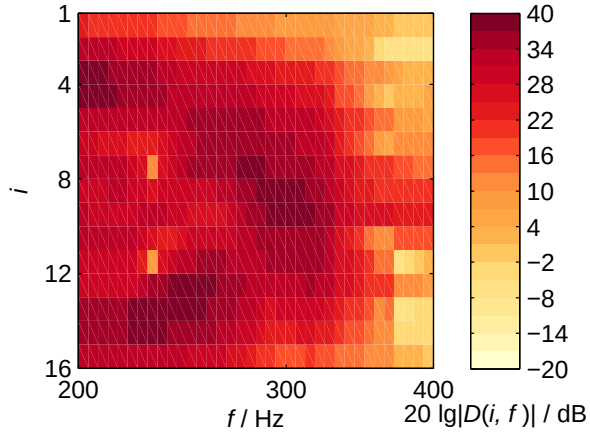




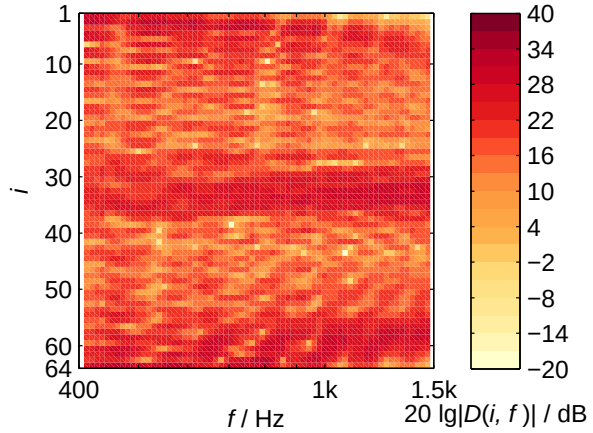
FIR Filters→Driving Function Index Plots [Tho08]

Magnitude in dB

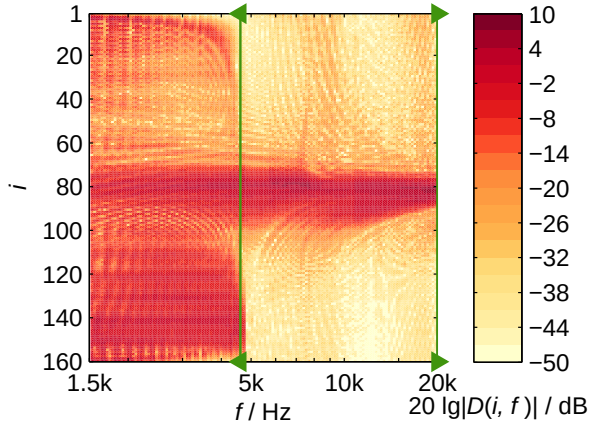
LF



MF

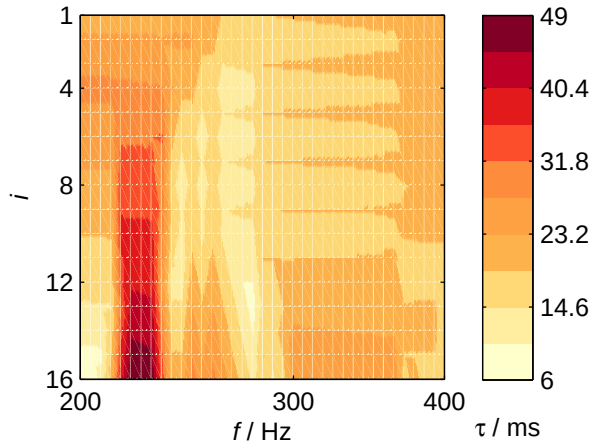


HF



Group Delay in ms

LF



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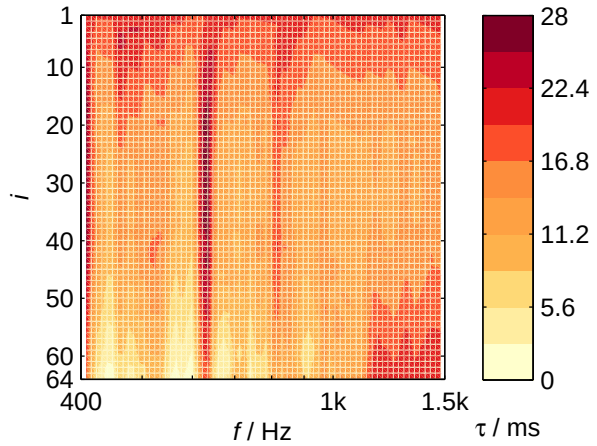

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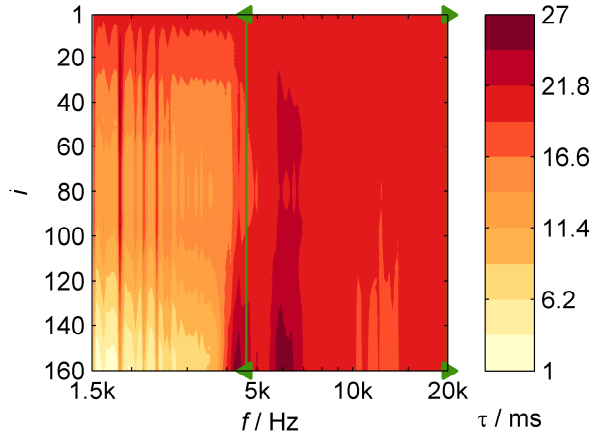
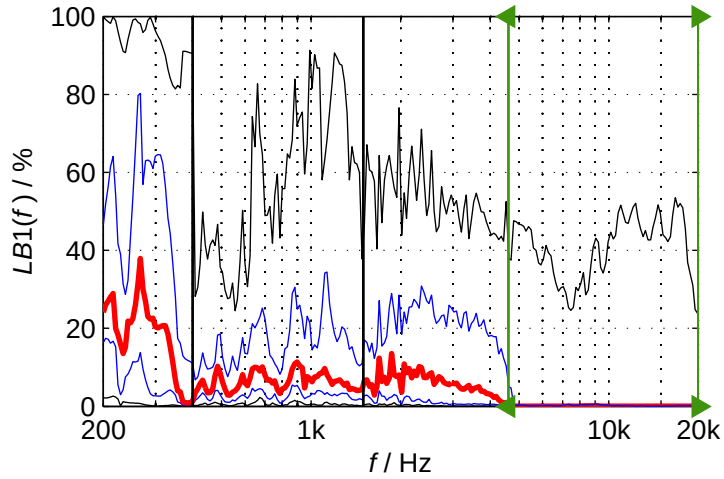


Technical Quality: Array Effort [Cho02, Bai14, Col14]

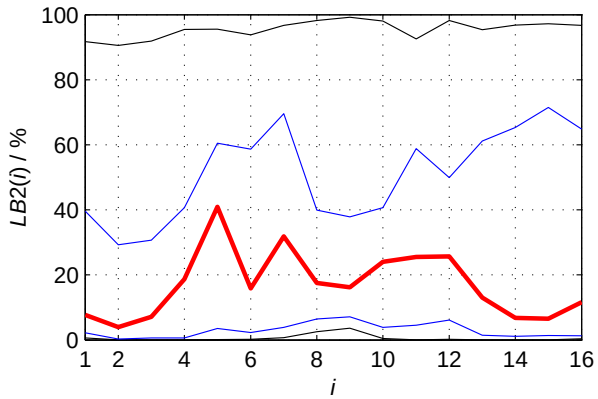
$$LB1(f) = \frac{\underset{i}{\mathcal{Q}_q}\left[|D(i,f)|^2\right]}{\max_i\left[|D(i,f)|^2\right]}$$



q ={0.05, 0.25, 0.5, 0.75, 0.95} quantiles

$$LB2(i) = \frac{\underset{f}{\mathcal{Q}_q}\left[|D(i,f)|^2\right]}{\max_f\left[|D(i,f)|^2\right]}$$

LF



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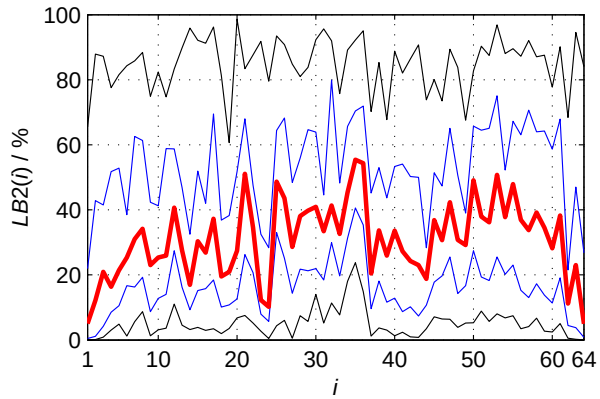

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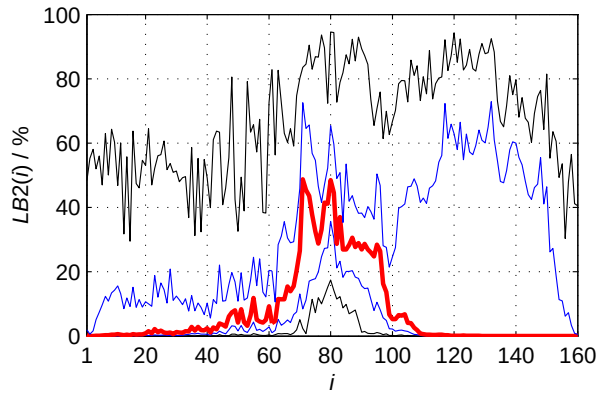

Conclusion

- LS optimization above spatial aliasing frequency?
- technical error measures give further hints on R&D and optimization algorithm requirements
- usage of smaller waveguides$\rightarrow$ spatial aliasing shifted to higher frequencies
- phase of optimized sound field?
- what sound fields are needed in terms of perception?

slides @ `http://spatialaudio.net`

References

[Bai13, Bai14, Bet12, Cho02, Col14, Fei09, Fei13, Mey84, Tho08, Tho09, Tho11, Tho13, vB00]

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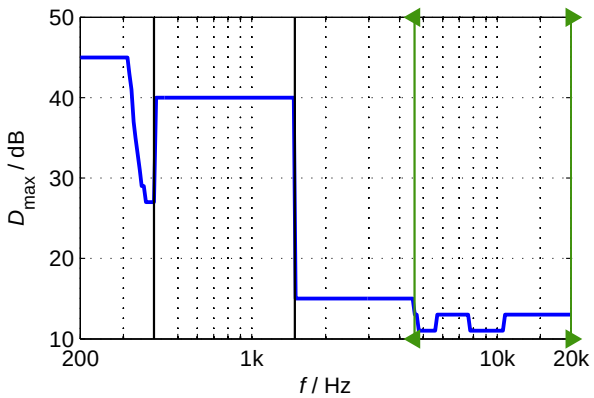
[Tho13] Thompson, A.; Luzarraga, J. (2013): "Drive granularity for straight and curved loudspeaker arrays." In: *Proc. of the Institute of Acoustics*, 35(2).

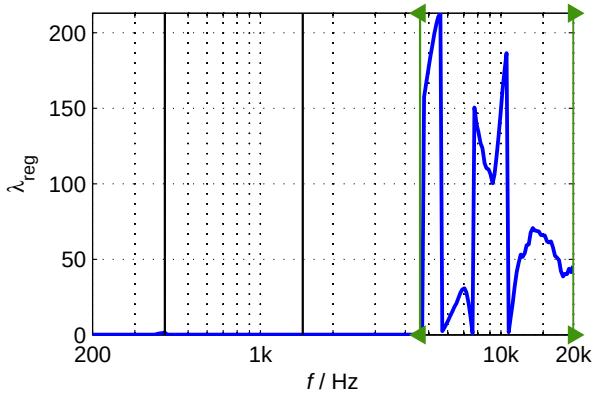
[vB00] van Beuningen, G.W.J.; Start, E.W. (2000): "Optimizing directivity properties of DSP controlled loudspeaker arrays." In: *Proc. of the Institute of Acoustics*, 22(6).

Optimization Parameters

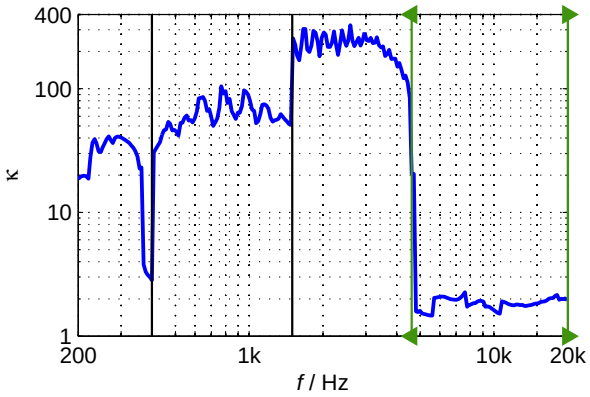
D^2_{max}



regularization value λ_{reg}



condition number κ



$$\mathbf{d}(f, \lambda_{\text{reg}}) = \left[\mathbf{G}(f)^{\text{H}}\mathbf{G}(f) + \lambda_{\text{reg}}\mathbf{I}_{L\,N}\right]^{-1} \mathbf{G}(f)^{\text{H}}\mathbf{p}_{\text{des}}(f)$$

Evaluation Setup LSA1

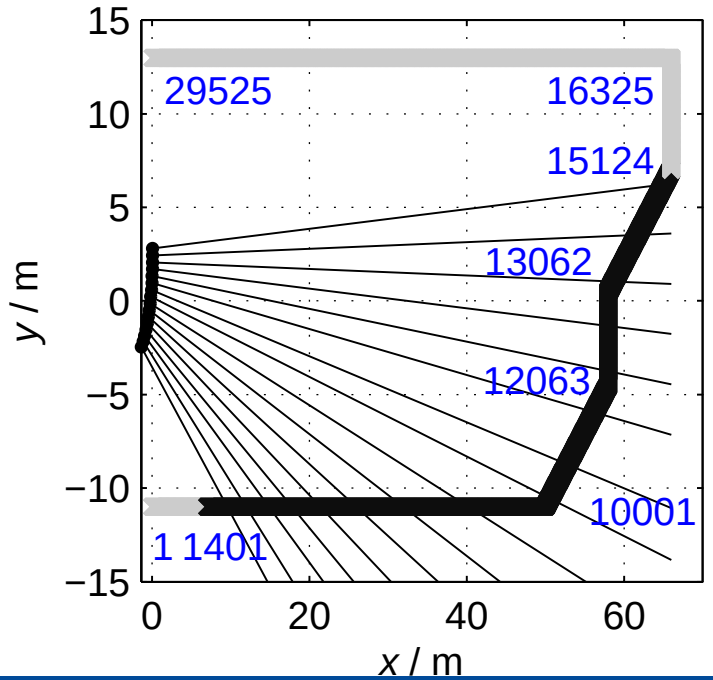
LSA1 Cabinet Model [Mey84]

height 0.372m, ideal circular / line pistons, ideal X-Over 400 Hz & 1.5 kHz

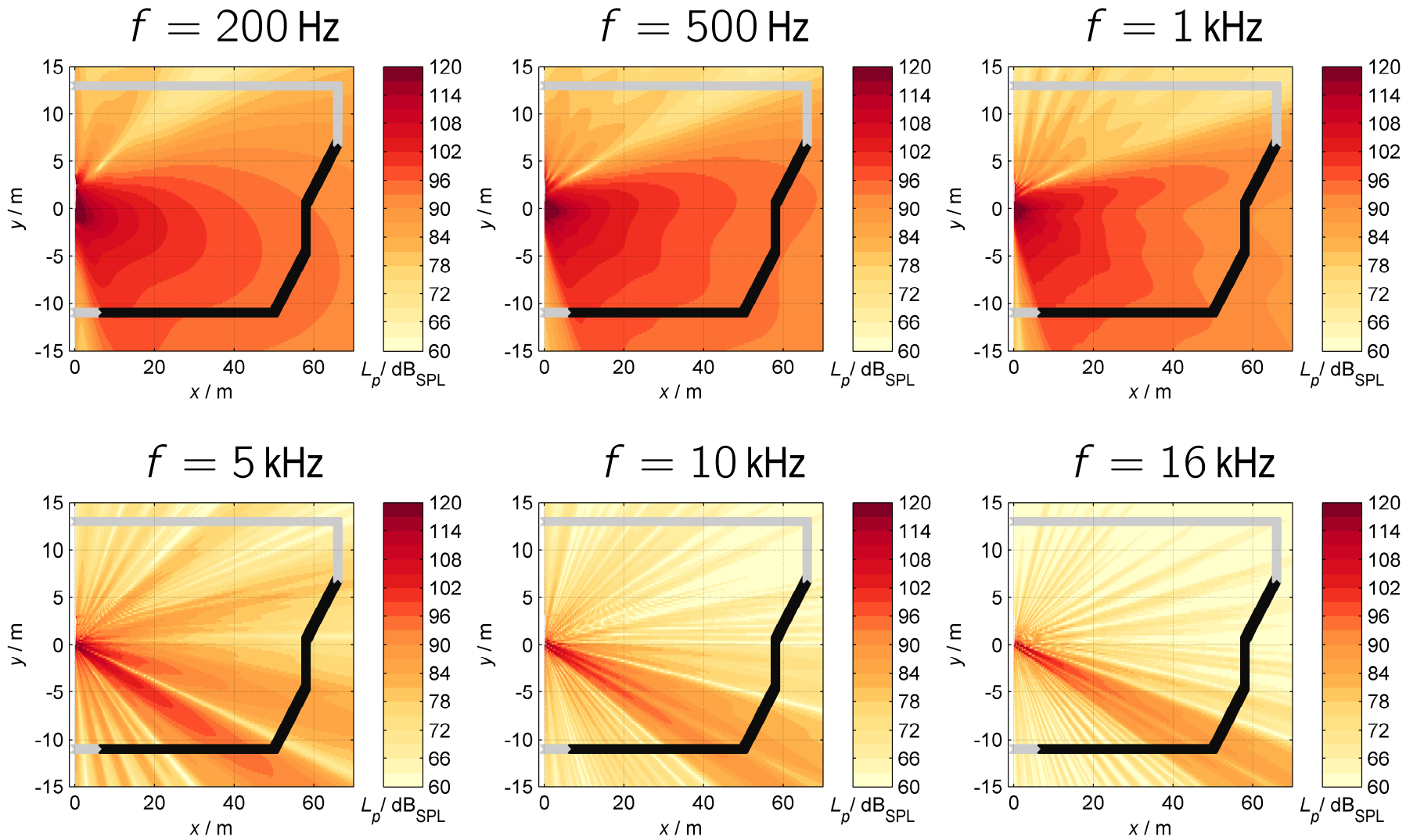
	#	$f_{\text{alias}}/\text{Hz}$	diameter/length in inch	Δy in inch	$\text{dB}_{\text{SPL@1W,1m}}$
LF	1	461	12 (circ)	14.65	96
MF	2	922	6 (circ)	7.32	94
HF	1	461	12 (line)	14.65	112

LSA Model

16 cabinets, length ≈6m, tilt angle +3°, splay angles top/down: 5x2°, 3°, 2°, 6x3°, 2x4°

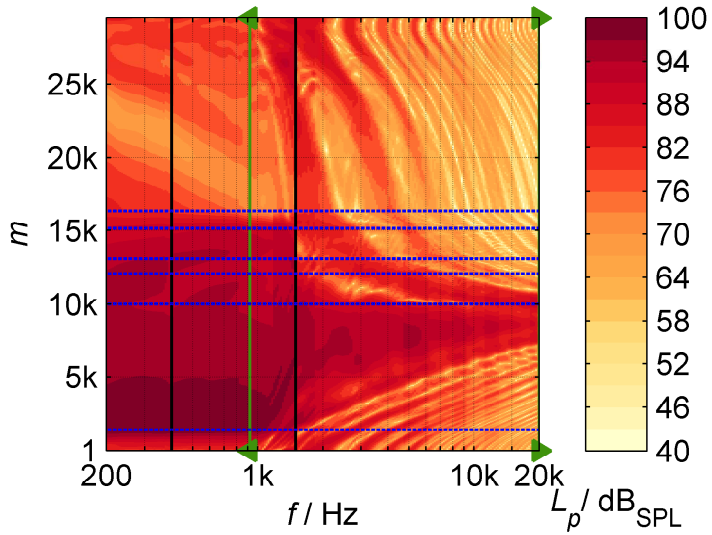


SPL Distribution in xy-Plane

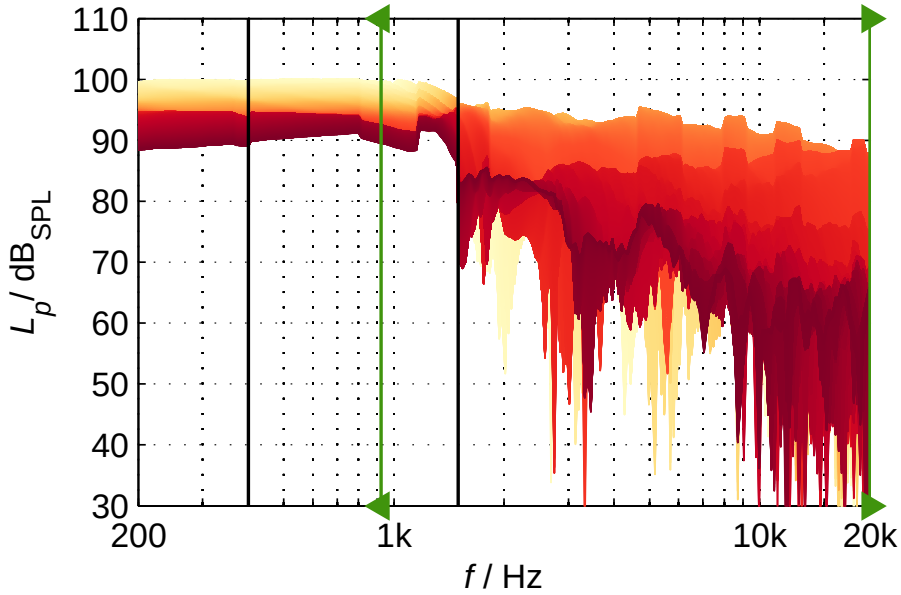


Frequency Responses & Directivity

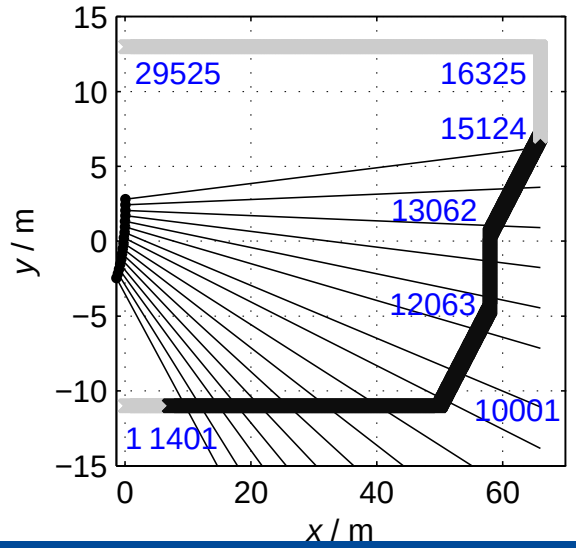
Position Index Plot [Tho09]



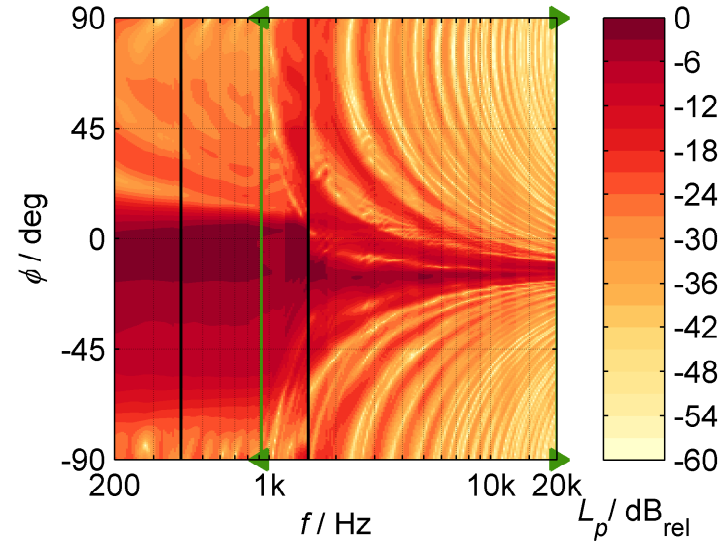
Frequency Responses in Audience Zone



Venue Setup



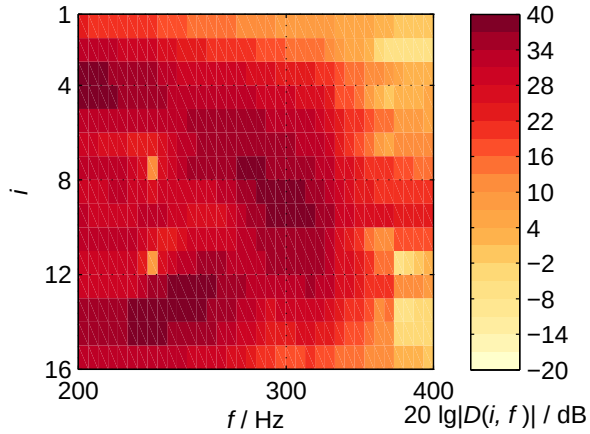
Farfield Radiation Pattern



FIR Filters→Driving Function Index Plots

Magnitude in dB

LF



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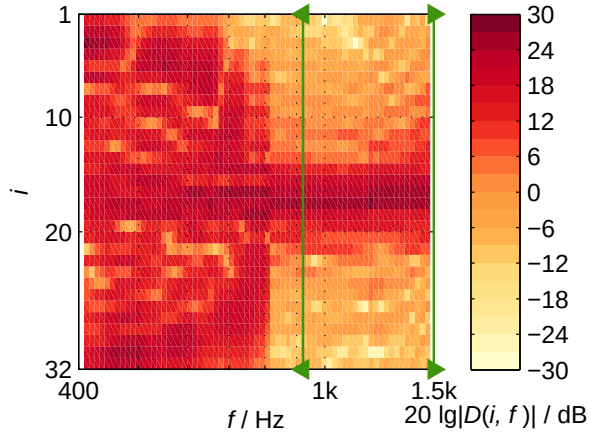
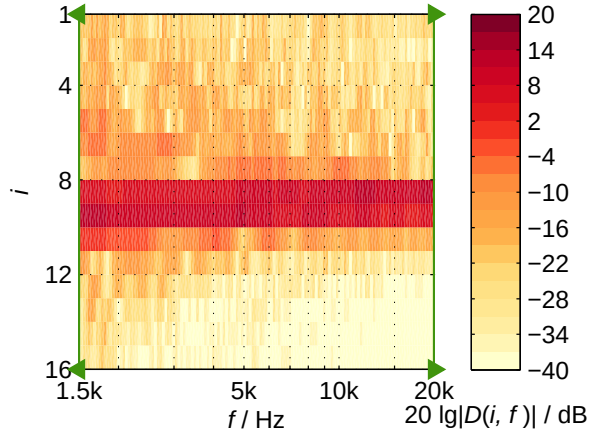
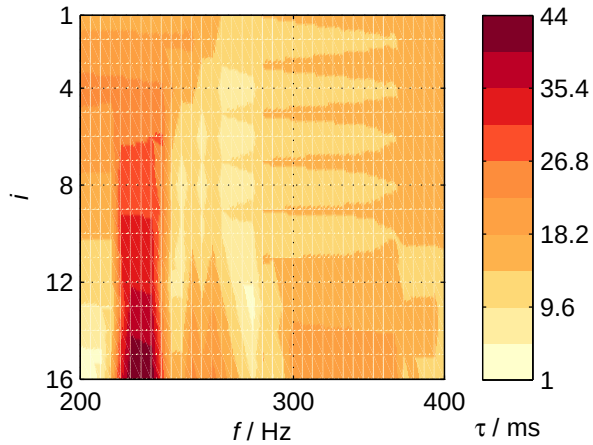


HF



Group Delay in ms

LF



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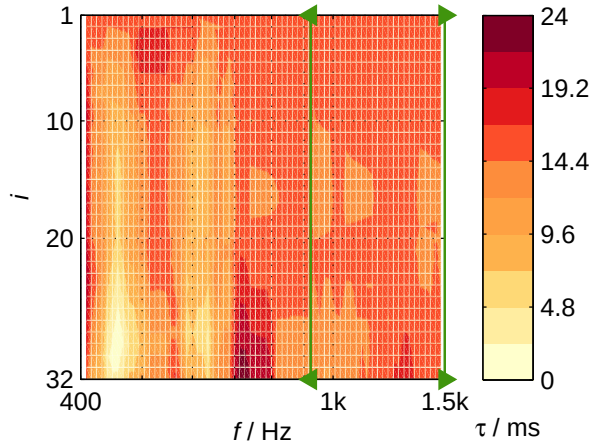
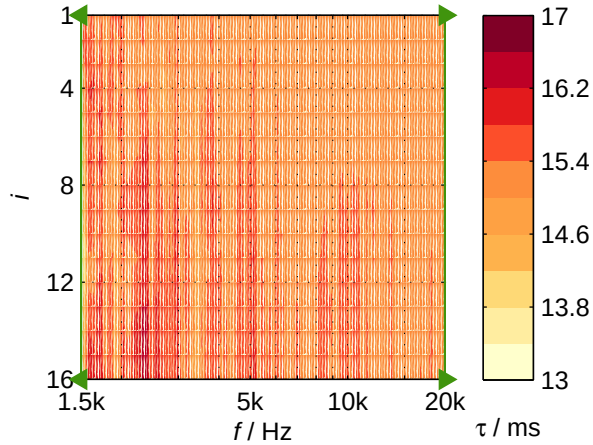


HF



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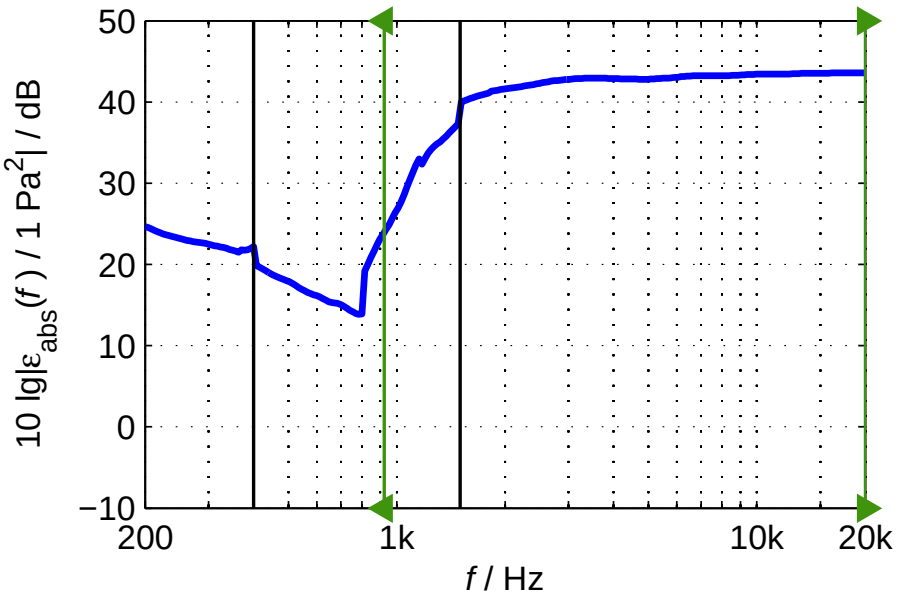

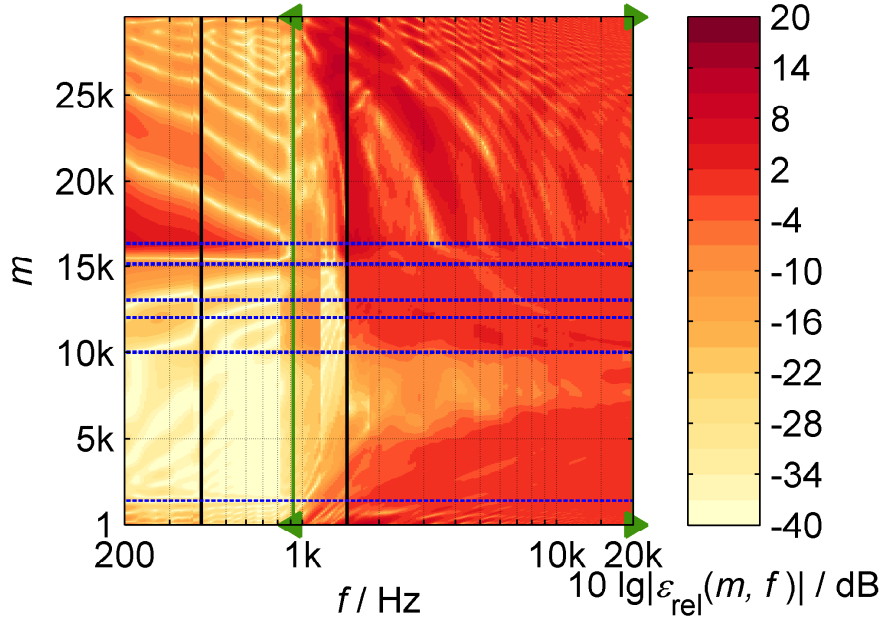

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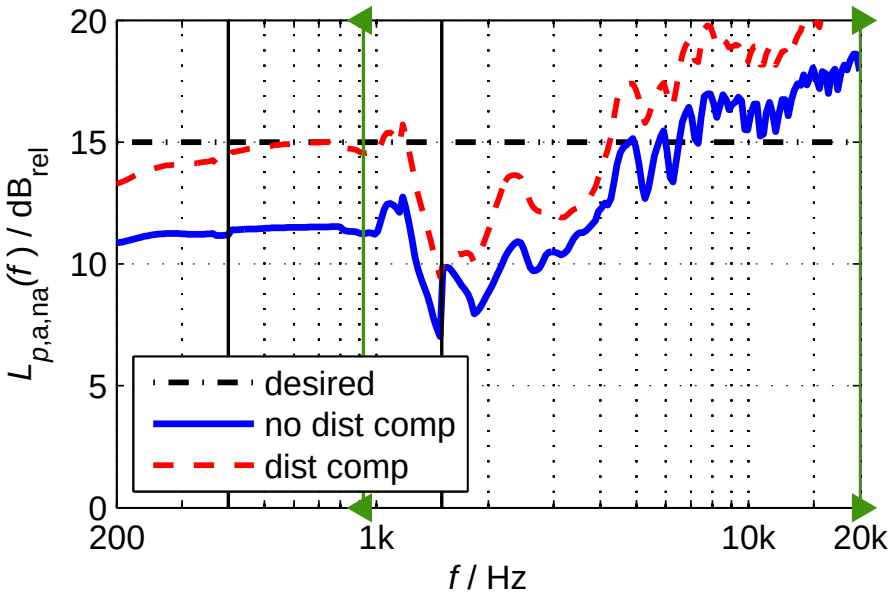
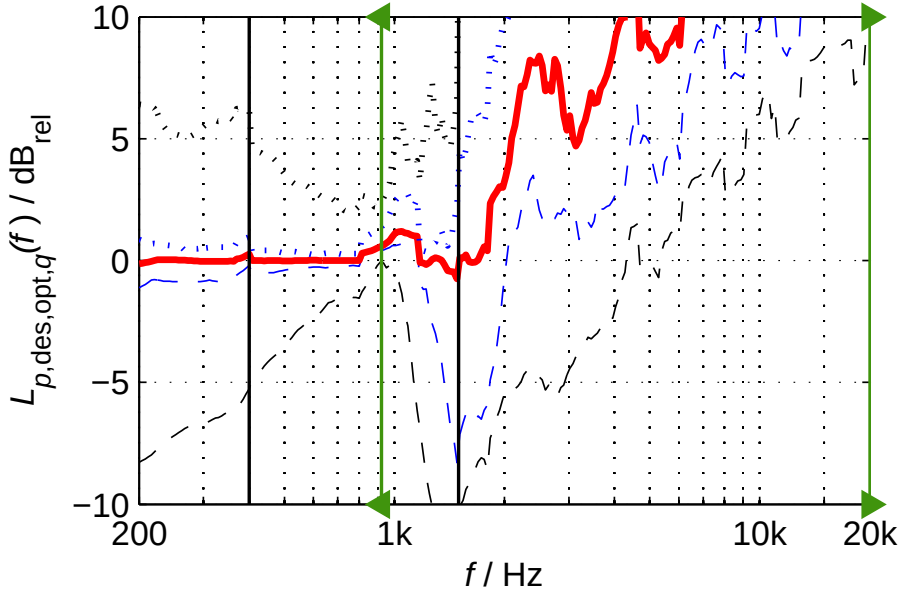
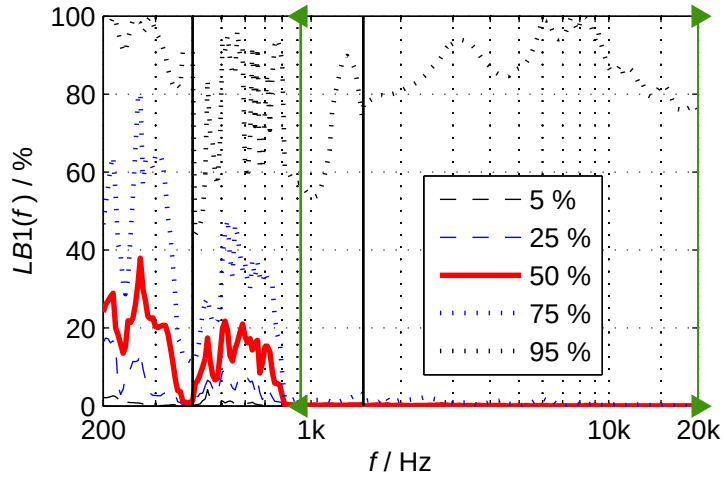
$$L_{p,\mathrm{des,opt},q}(f) = \underset{m}{\mathcal{Q}_q}\left[10\log_{10}\left(\frac{|P_\mathrm{des}(m,f)|^2}{|P(m,f)|^2}\right)\right]$$





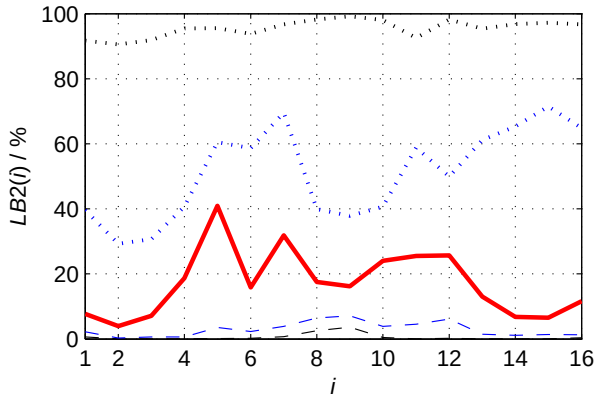
Technical quality: Array Effort [Cho02, Bai14, Col14]

$$LB1(f) = \frac{\underset{i}{\mathcal{Q}_q}\left[|D(i,f)|^2\right]}{\max\limits_{i}\left[|D(i,f)|^2\right]}$$

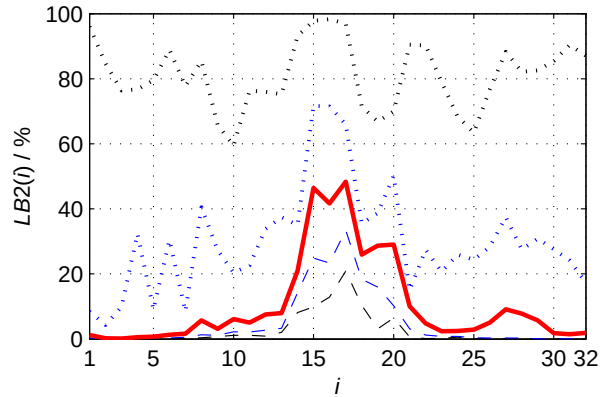


$$LB2(i) = \frac{\underset{f}{\mathcal{Q}_q}\left[|D(i,f)|^2\right]}{\max\limits_{f}\left[|D(i,f)|^2\right]}$$

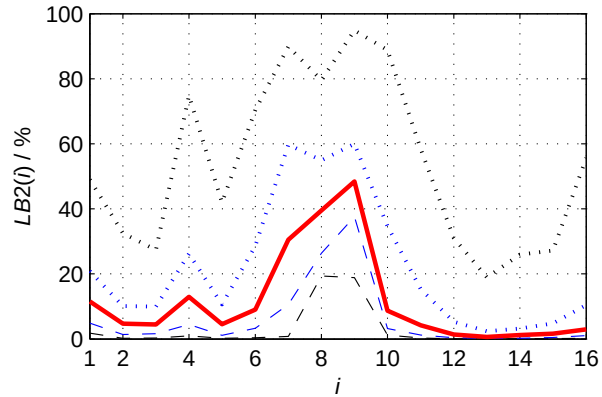
LF



MF

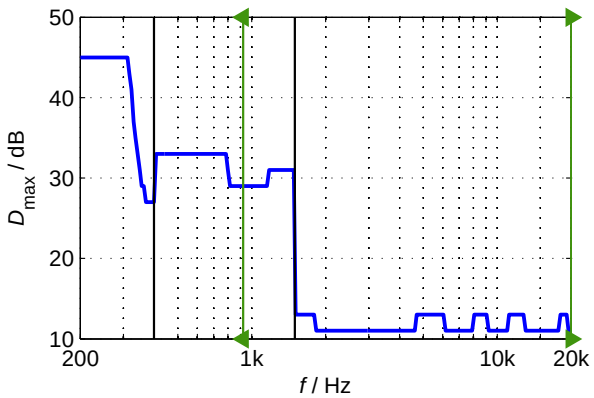


HF

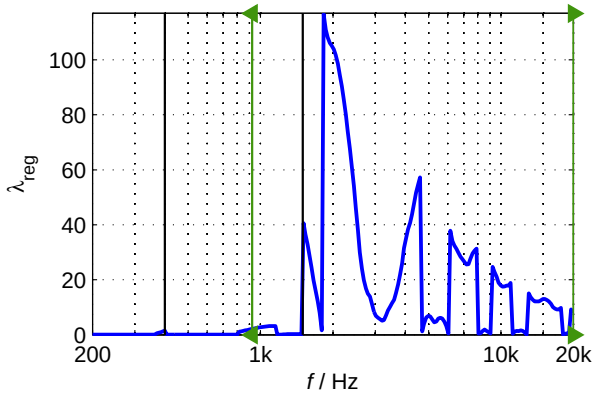


Optimization Parameters

D^2_{max}



regularization value λ_{reg}



condition number κ