MULTI-CHANNEL LOW-FREQUENCY ROOM EQUALIZATION USING PERCEPTUALLY MOTIVATED CONSTRAINED OPTIMIZATION

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Problem description

- Multi-channel equalization (use of multiple loudspeakers)
  - Main loudspeaker (being equalized)
  - Auxiliary loudspeakers (helpers)
- Multi-point (equalization in N control points covering an extended listening area)
- Focus on strong low-frequency resonances

Optimization problem description

- Loudspeaker equalization filters of length N_h

$$\mathbf{h}_i = [h_i[0] \ \ldots \ h_i[N_h-1]]^T$$
$$\mathbf{h} = [\mathbf{h}_1^T \ \ldots \ \mathbf{h}_L^T]^T$$

- Equalization filters' frequency responses

$$\mathbf{H}(f_i) = \mathbf{V}(f_i)\,\mathbf{h}$$

- Room impulse response matrix $\mathbf{G}(\omega_i)$
- Equalized RIRs in control points

$$\mathbf{Y}(f_i) = \mathbf{G}(f_i)\,\mathbf{H}(f_i)$$
$$\mathbf{Y} = [\mathbf{Y}^T(f_0) \ \ldots \ \mathbf{Y}^T(f_{N_f-1})]^T$$

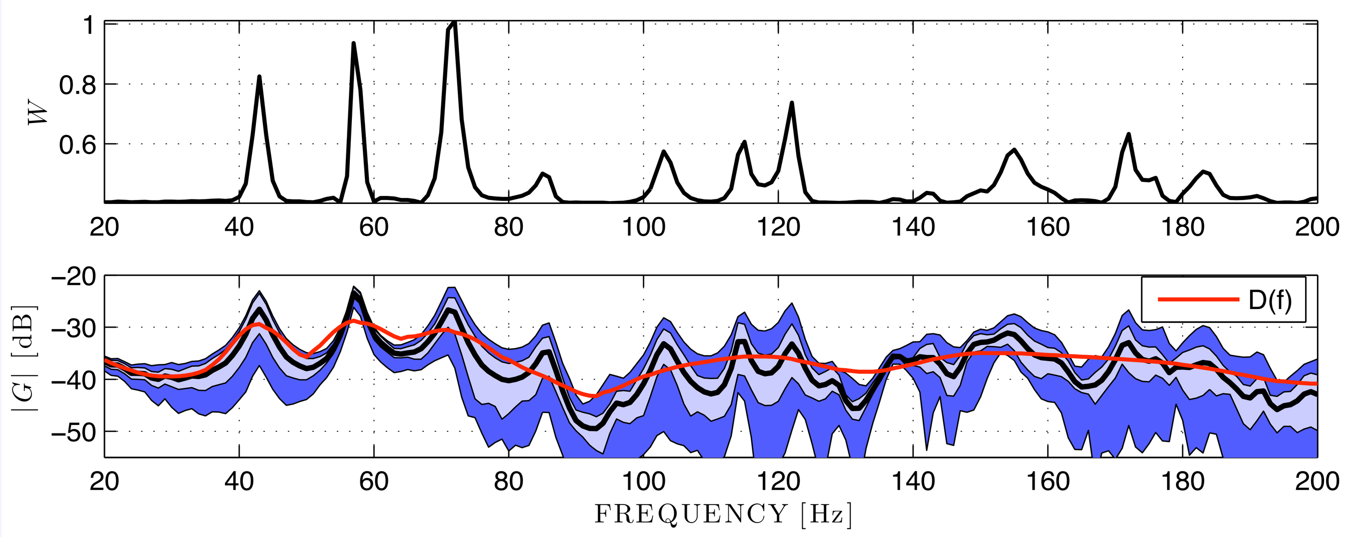
Desired response and cost function

- Desired response: fractional-octave smoothing and averaging along space of the RIRs magnitude frequency characteristics

$$D(f_i) = \sqrt{1/N \sum_{m=1}^{N} (\tilde{G}_{m1}(f_i))^2}$$

- Cost function: weighted magnitude error with resonance penalization

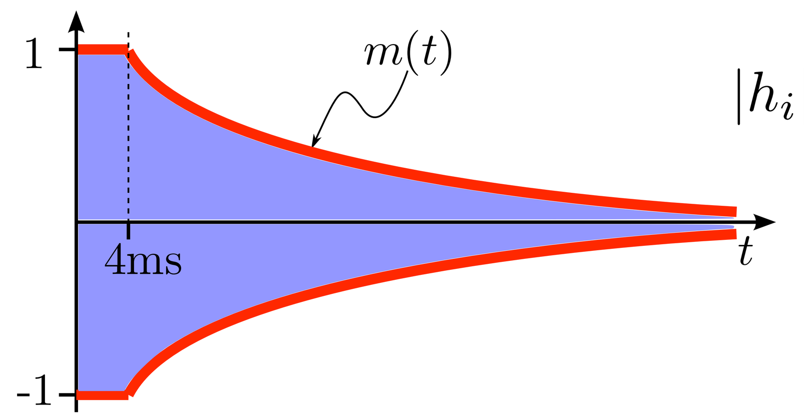
$$J = \|\,\mathbf{W}\,(|\mathbf{Y}| - |\,\mathbf{D}|)\,\|_2$$



Equalization filter constraints

Temporal masking constraint

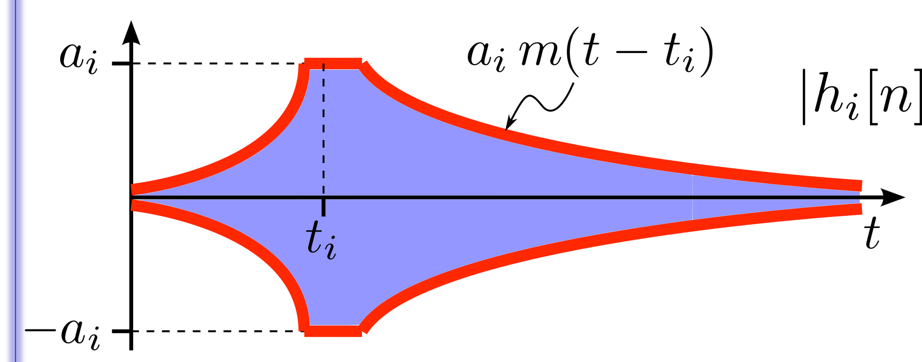
- Use short and well-localized filters (avoid temporal distortions due to spatial sensitivities)



$$|h_i[n]| \le m[n]$$

Auxiliary filter constraints

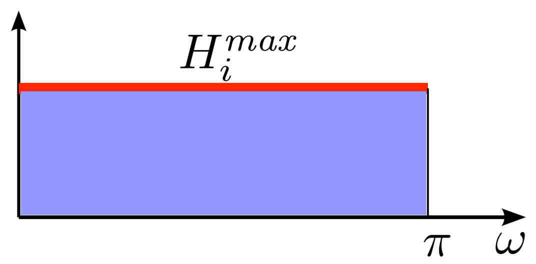
- Delay the signals from auxiliary loudspeakers to keep the precedence effect active and preserve the original localization



$$|h_i[n]| \le a_i\, m[n - n_0]$$

Maximum-gain constraint

- Avoid location sensitivity and insure well-behaved filters



$$|\mathbf{V}(f_i)\,\mathbf{h}| \preceq \mathbf{H}^{max}$$

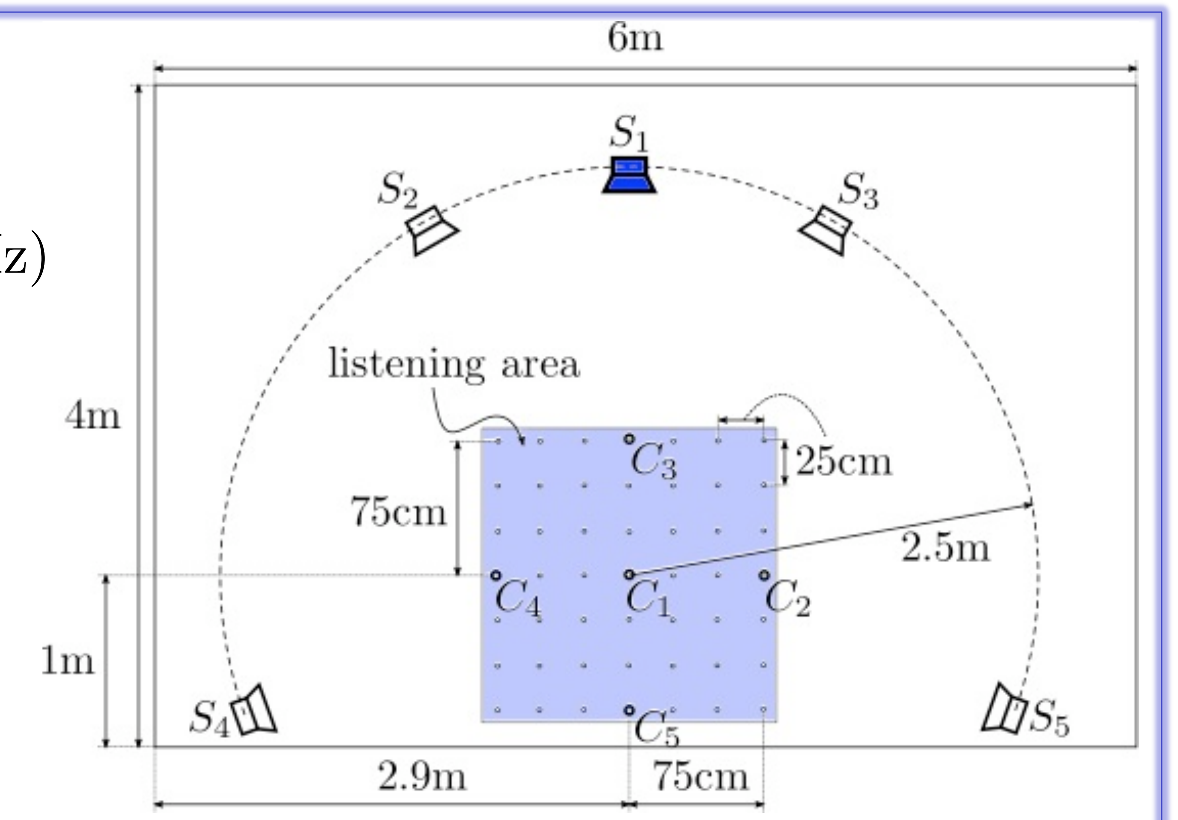
Solution

- Iteratively solving a non-convex program

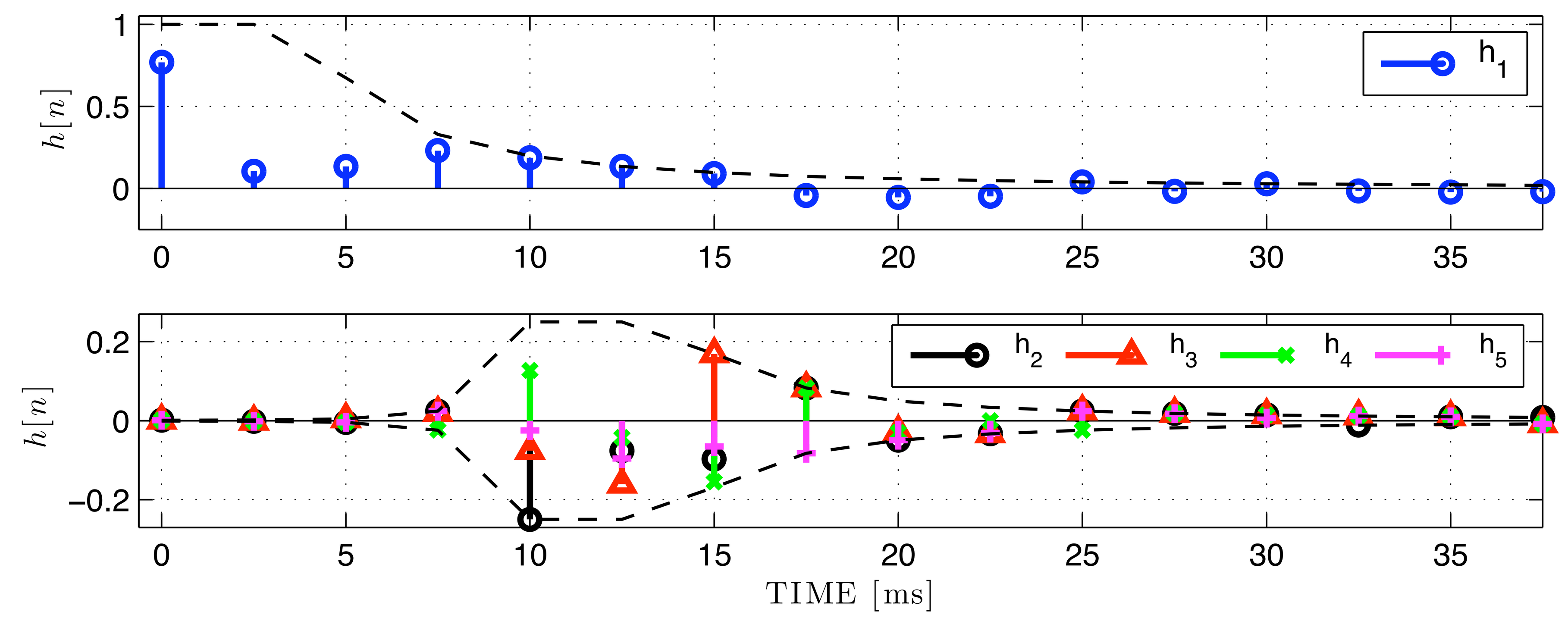
$$\begin{aligned} \text{minimize} \quad & \|\,\mathbf{W}\,(|\mathbf{Y}| - |\,\mathbf{D}|)\,\|_2 \\ \text{subject to} \quad & |\mathbf{h}| \preceq \mathbf{m} \\ & |\mathbf{V}(f_j)\,\mathbf{h}| \preceq \mathbf{H}^{max}, \quad \forall f_j \end{aligned}$$

Simulations

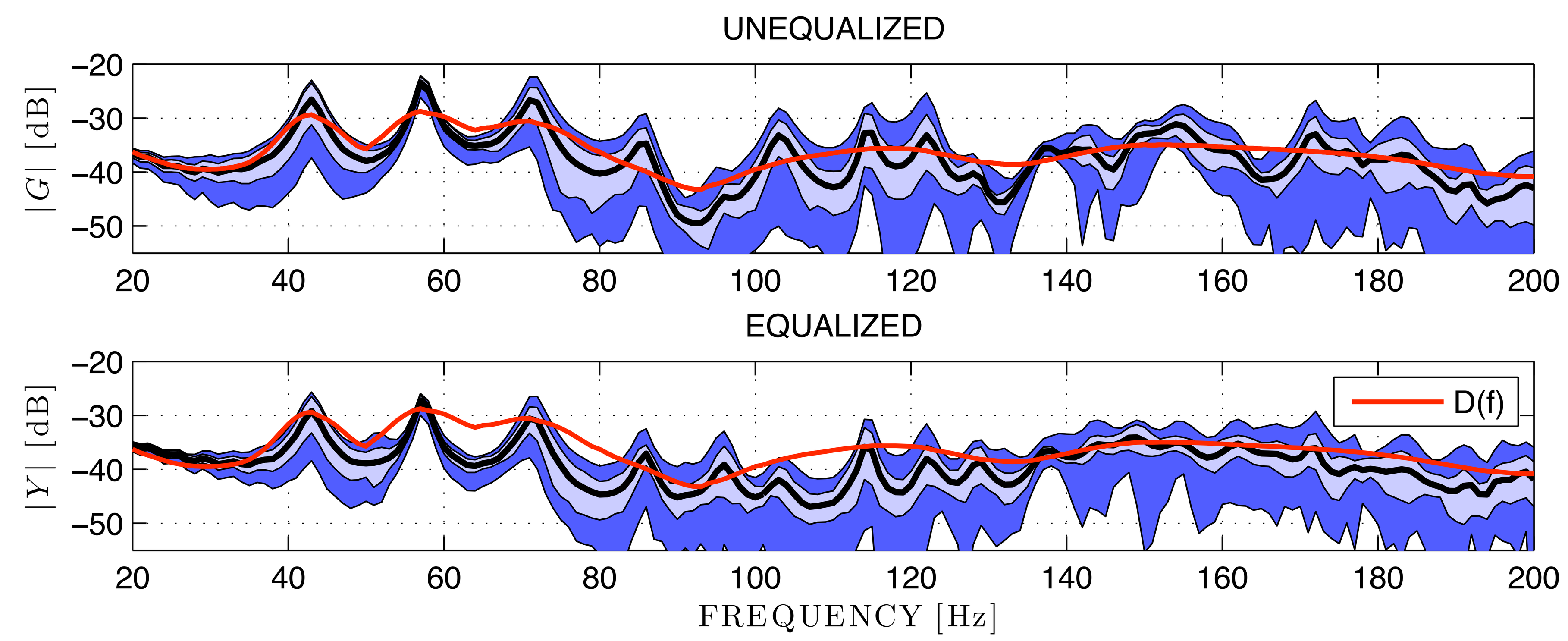
- Standard 5.1 setup
- Equalization up to 200 Hz $(f_S = 400 \text{ Hz})$
- Center loudspeaker equalized (main)
- Remaining loudspeakers auxiliary
- Equalization filters 16 samples long
- Listening area of 1.5 by 1.5 meters



Equalization filters



RIRs before and after equalization



Conclusion

- Systematic approach for optimized multichannel equalization
- Considers physical and psychoacoustical restrictions through convex constraints
- Extendible to high frequencies and single-loudspeaker equalization
- Amenable to efficient implementation in a downsampled domain

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