Multi-microphone Source Separation in Reverberant Environments

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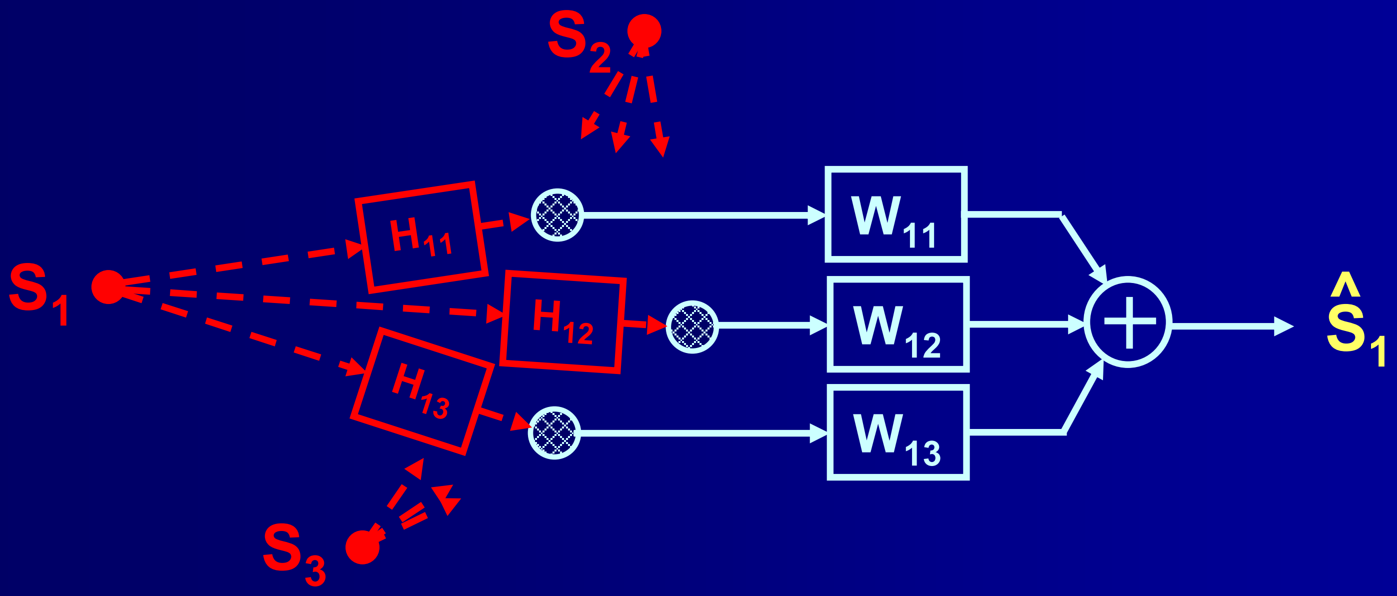
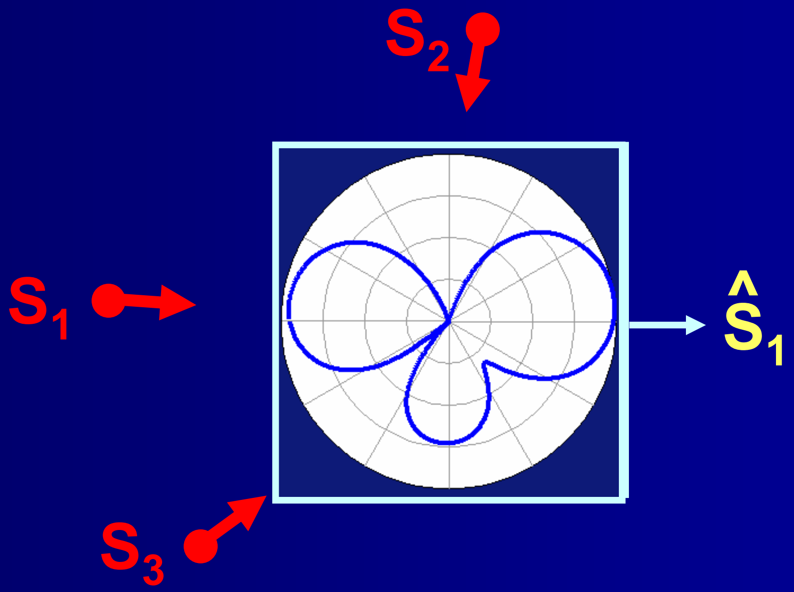
Problem Recap:



- Multiple sources propagating to multiple sensors.
- Filter-and-Sum to estimate each source.
- Filters chosen by:
  - Fixed Beamforming (FBF)
  - Adaptive Beamforming (ABF)
  - Indep. Component Analysis (ICA)

Reverberation Issues



- Location estimates become unreliable (FBF, ABF).
- Target reverberation introduces problems (FBF, ABF)
- SNR improvement becomes difficult (ABF, ICA).

Target Reverberation - ABF

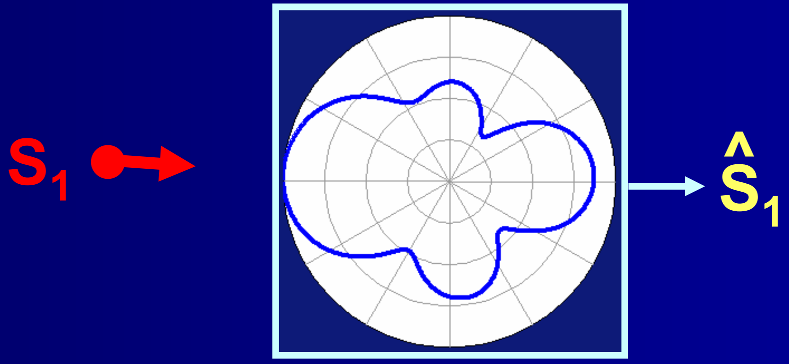
- Direct-path target preservation constraint is no longer adequate.
- Target echoes leak into the optimization.
- When target is strong, system uses target echoes to cancel the direct-path target!
- A great deal of research has addressed this issue: Greenberg and Zurek, 1992; Hoffman et al. 1992; Desloge, 1998; Doclo 2003.

Target Reverberation - FBF

<u>Fixed Beamforming</u> filters maximize DI while preserving direct-path target.

$$\text{Directivity Index (DI)} = \frac{\text{direct path target power}}{\text{avg. output power}}.$$

DI (e.g., 8-10 dB) can be interpreted as SNR improvement for **average** jammer location.



Target Reverberation - FBF

BUT… target has reverberant component:

$$P_{\mathrm{T}} = P_{\mathrm{T,direct}} + P_{\mathrm{T,reverb}}.$$

Simplifying (a lot!):

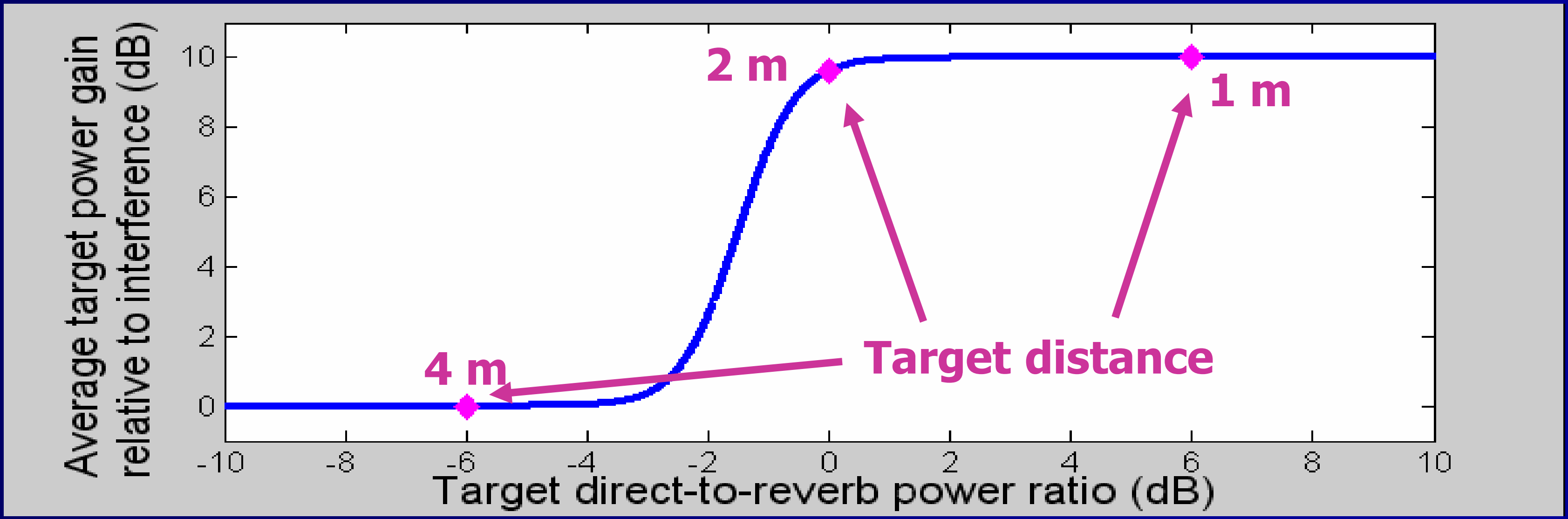
- $P_{\mathrm{T,direct}}$ preserved with unit gain.
- $P_{\mathrm{T,reverb}}$ attenuated by DI.

FBF benefit disappears for reverberant target.
Both target and interference are reduced by DI.

Target Reverberation - FBF

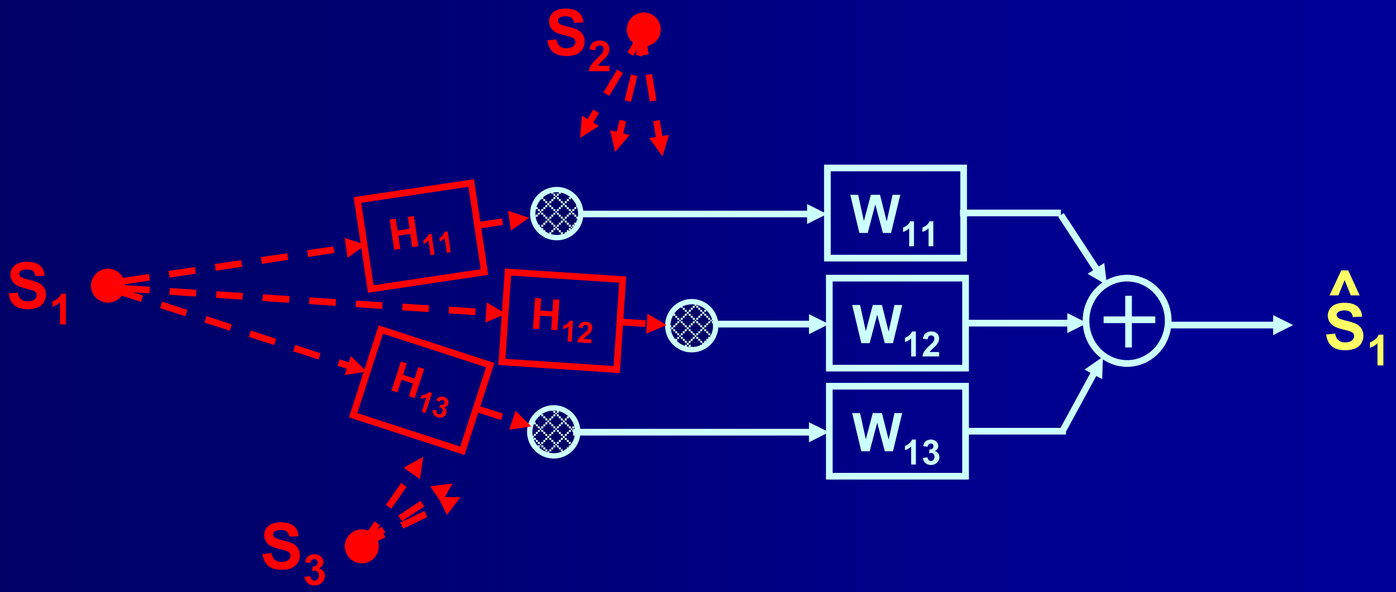
Consider :

- $P_{T,reverb}$ attenuated by DI = 10 dB.
- Interference attenuated by DI = 10 dB.
- Critical distance of room = 2 m.



Good performance if target within critical distance.

SNR Improvement – ABF, ICA

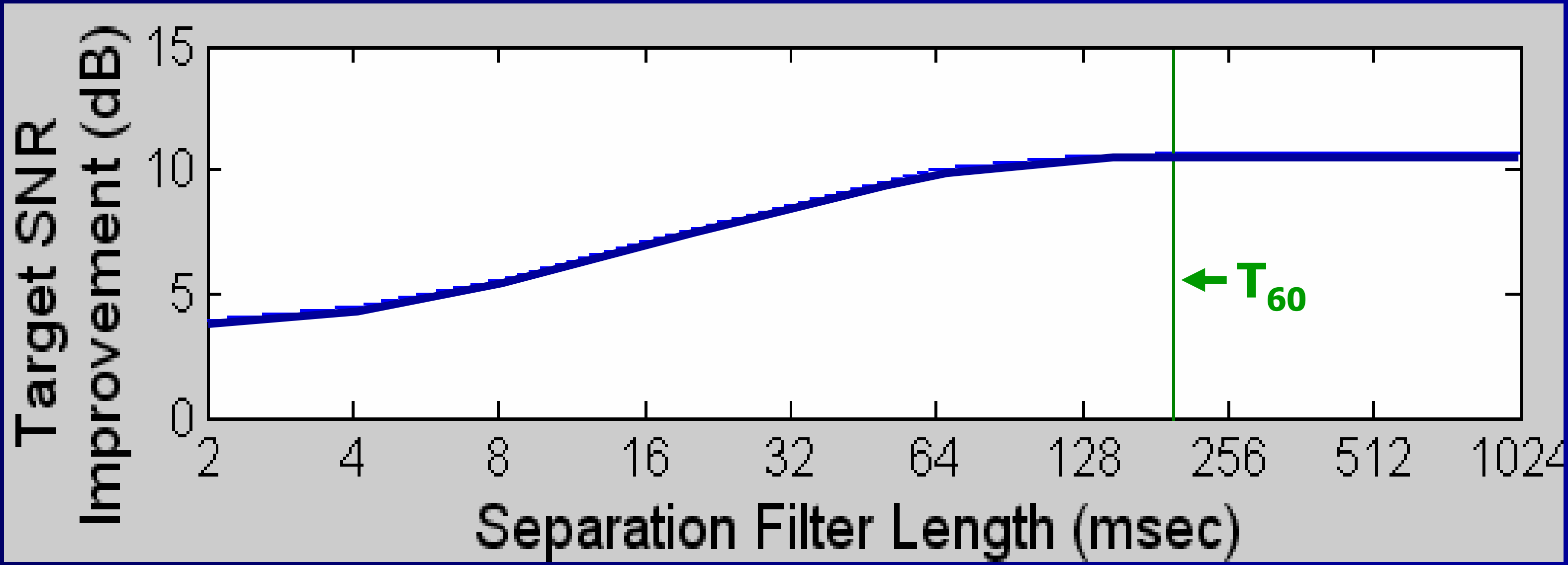


- W_{11}, W_{12}, and W_{13} preserve transformed target, $G(S_1)$, while attenuating S_2 and S_3.
- Transformation $G(S_1)$ influences resulting target output SNR and target distortion.

SNR Improvement – ABF, ICA

Consider:

- Two mic simulation (0.1 m apart, T_{60}=197 msec).
- Two sources, H_{11}, H_{12}, H_{21}, and H_{22} *known*.
- $G(S_1) = H_{11}S_1$= Source 1 at mic 1.



SNR Improvement – ABF, ICA

Why isn't SNR improvement bigger?

In this case, 'optimal' filters are

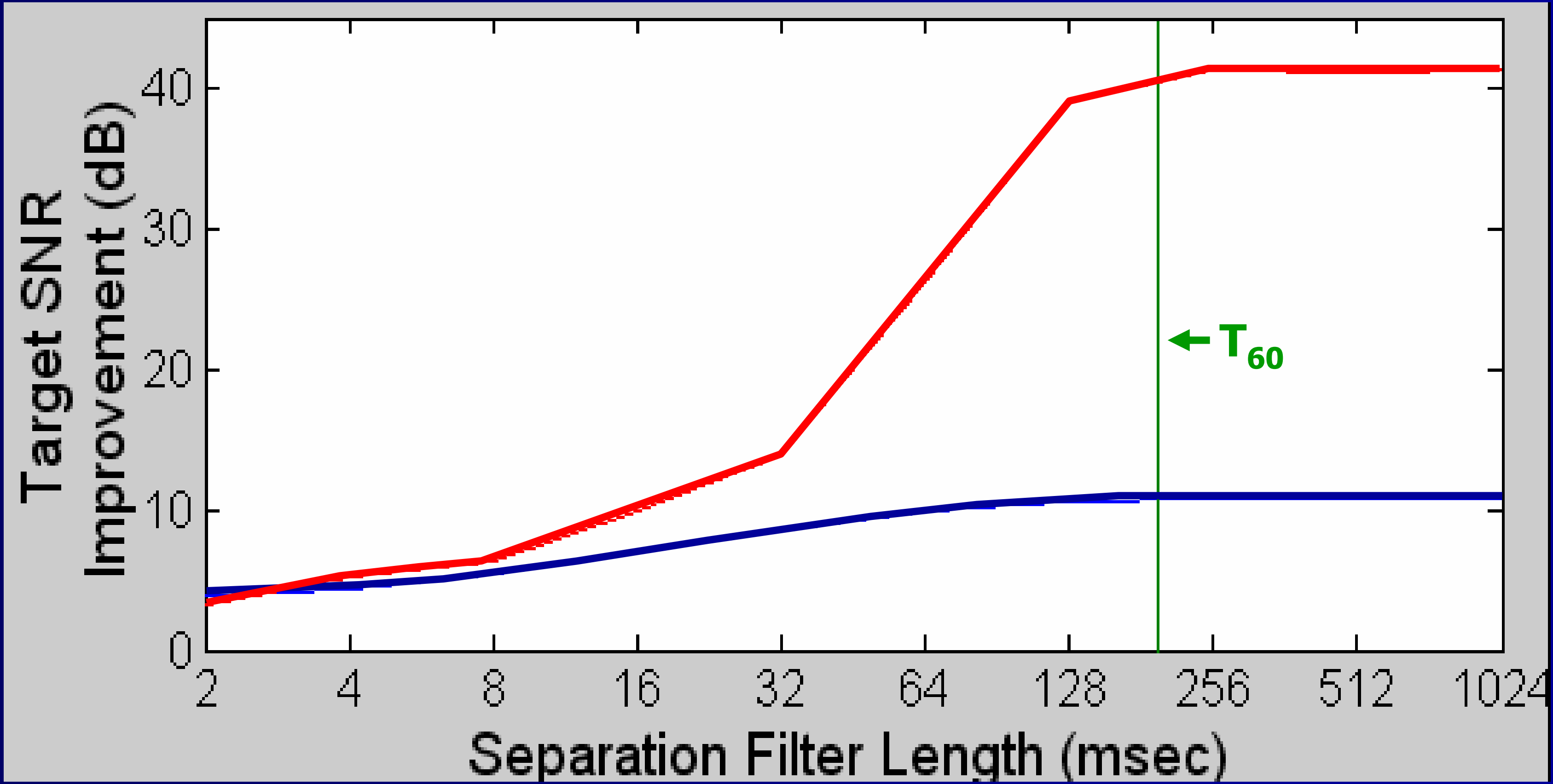
$$W_1 = \frac{-H_{22}}{H_{12}H_{21} - H_{11}H_{22}}, \quad W_2 = \frac{H_{21}}{H_{12}H_{21} - H_{11}H_{22}}.$$

'Undoing' reverb component (denominator) is both anti-causal and very long.

Not easy.

SNR Improvement – ABF, ICA

What if: $W_1 = -H_{22}, \quad W_2 = H_{21}.$



SNR Improvement – ABF, ICA

SNR improvement much (>30 dB) bigger.

Improvement comes as cost of more distorted target:

$$G(S_1) = S_1\,(H_{12}H_{21} - H_{11}H_{22}).$$

Double Reverb!

Multi-microphone Extensions (Time permitting…)

I believe that multiple microphone systems can reduce reverberation present at system input:

- Miyoshi and Kaneda (1988)*: two-mics can remove reverb from one source given propagation information.
- My recent research has yielded a blind, input-driven approach that *appears* to reach this goal.
- Moreover, results suggest that M mics can ‘dereverberate’ M-1 sources.

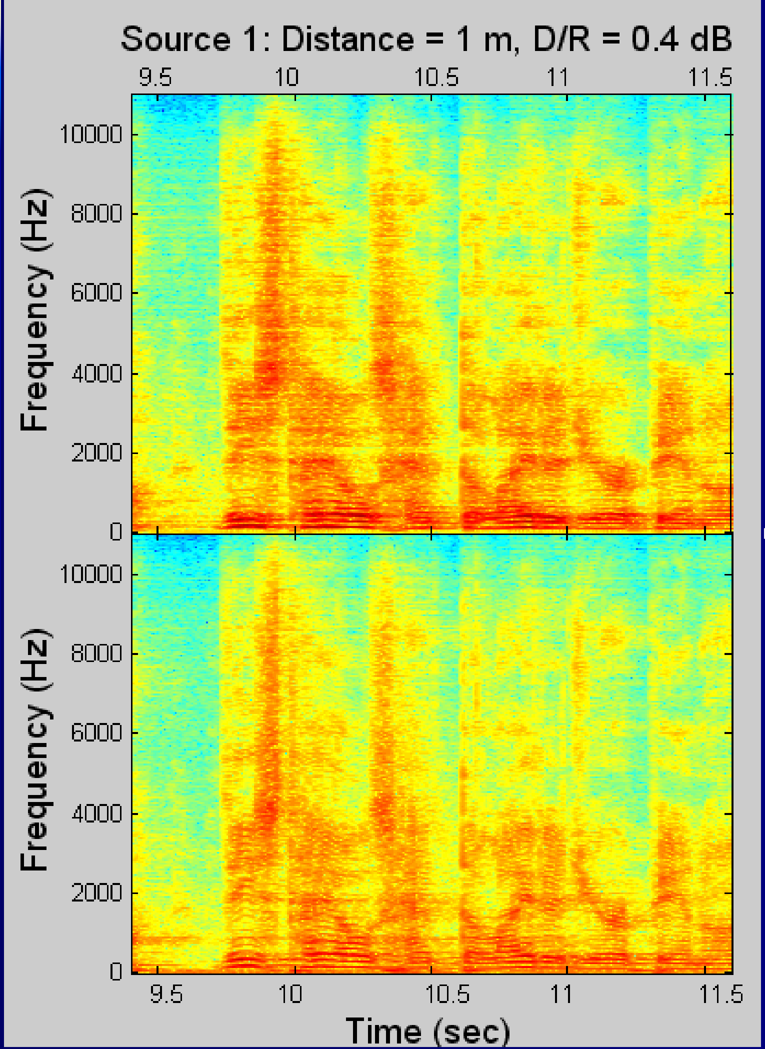
* “Inverse filtering of Room Acoustics,” *IEEE Trans. On ASSP*, 36(2), pp. 145-152, Feb. 1988.

Example: Two Source Simulation

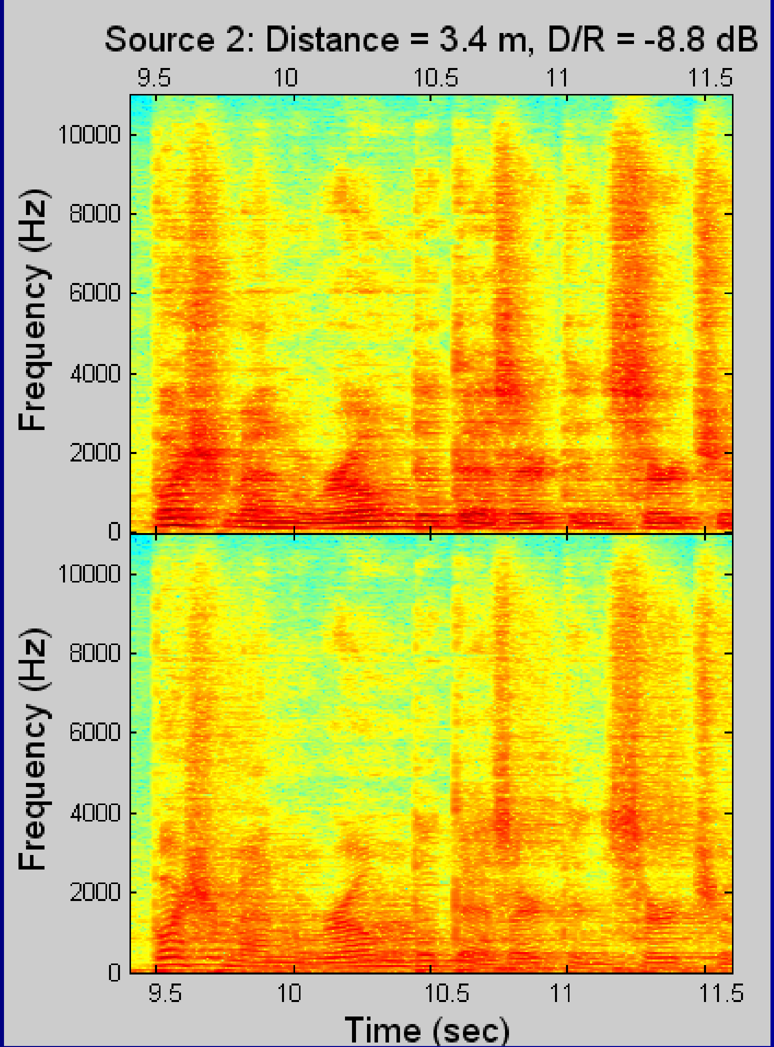
T_{60} = 250 msec, Filter Len = 136 msec

Original

Output

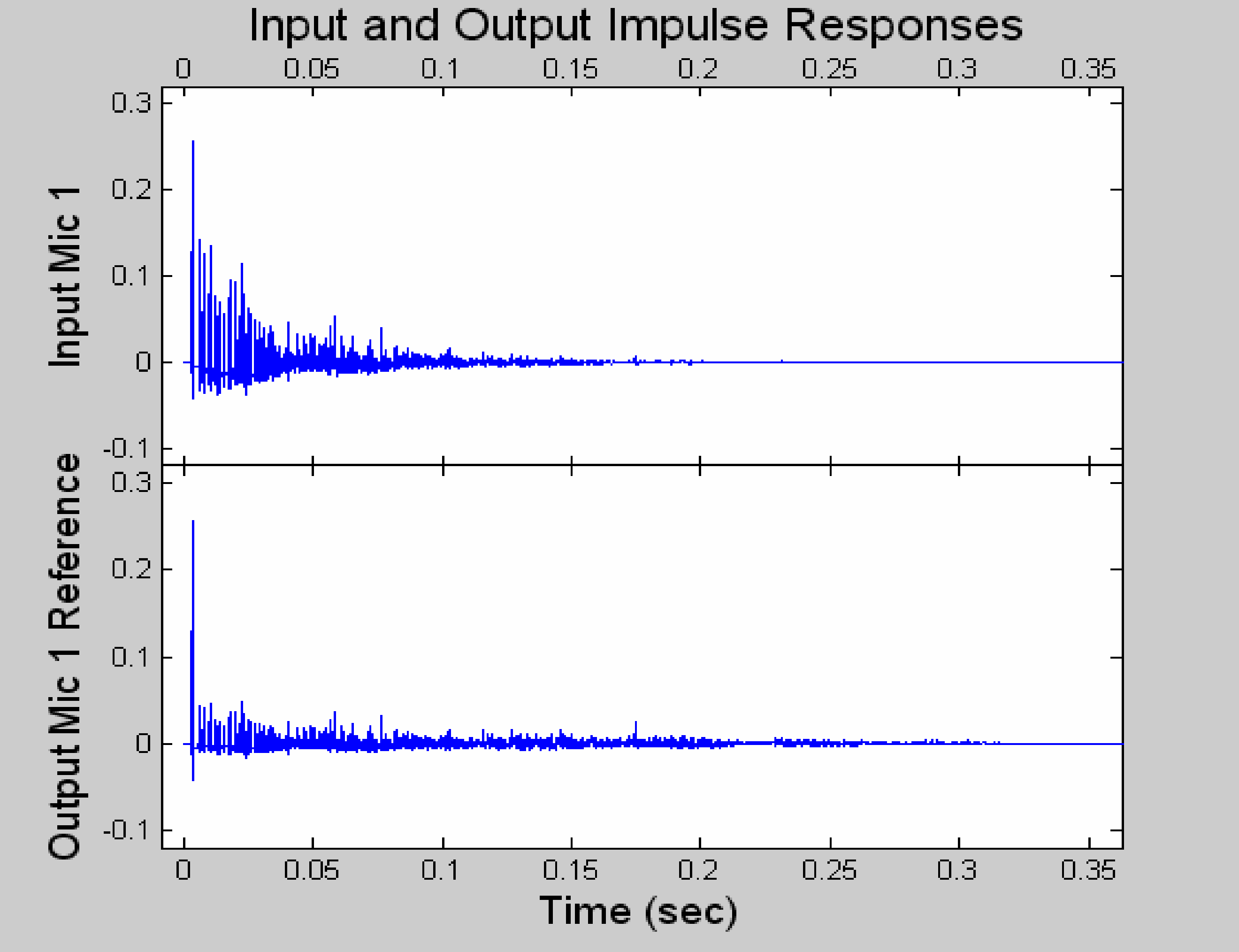


Source 1: Distance = 1 m, D/R = 0.4 dB



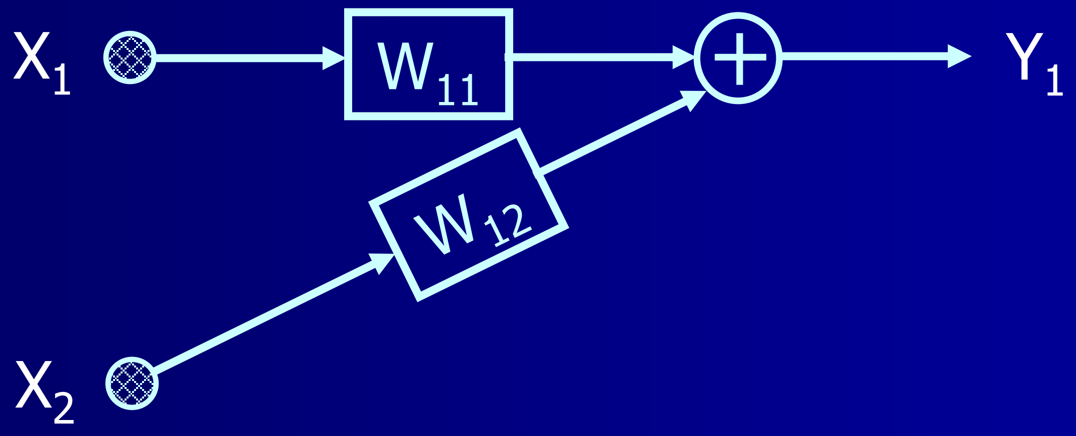
Source 2: Distance = 3.4 m, D/R = -8.8 dB

Example: Two Source Simulation What's happening?



Possible Uses

- Create single, reduced-reverberation channel for input to single-channel source-separation.



Possible Uses

- By using multiple references, create a virtual, reduced-reverb array for input to FBF, ABF, ICA.