Raking Echoes in the Time-Domain

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École Polytechnique Fédérale de Lausanne, Switzerland

Tmonday Afternoon Meeting
April 1, 2015

Echoes are good!

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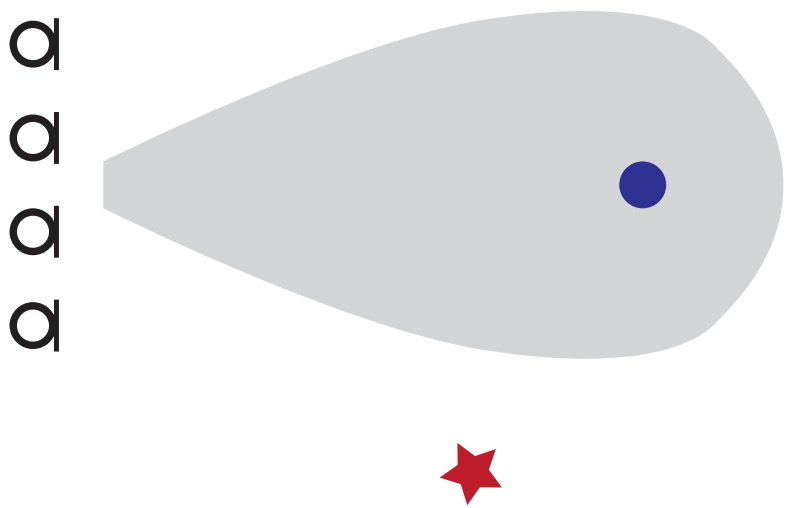

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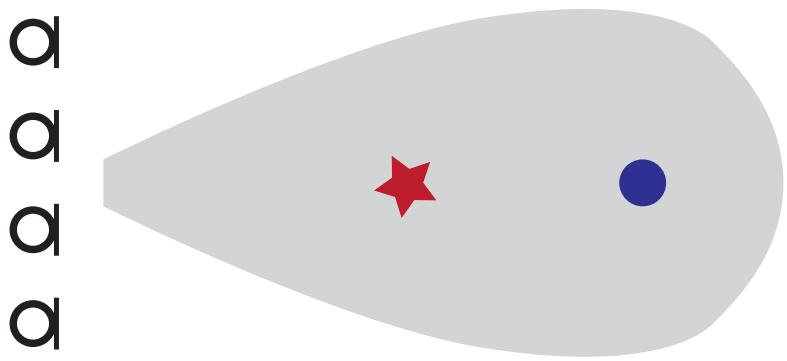

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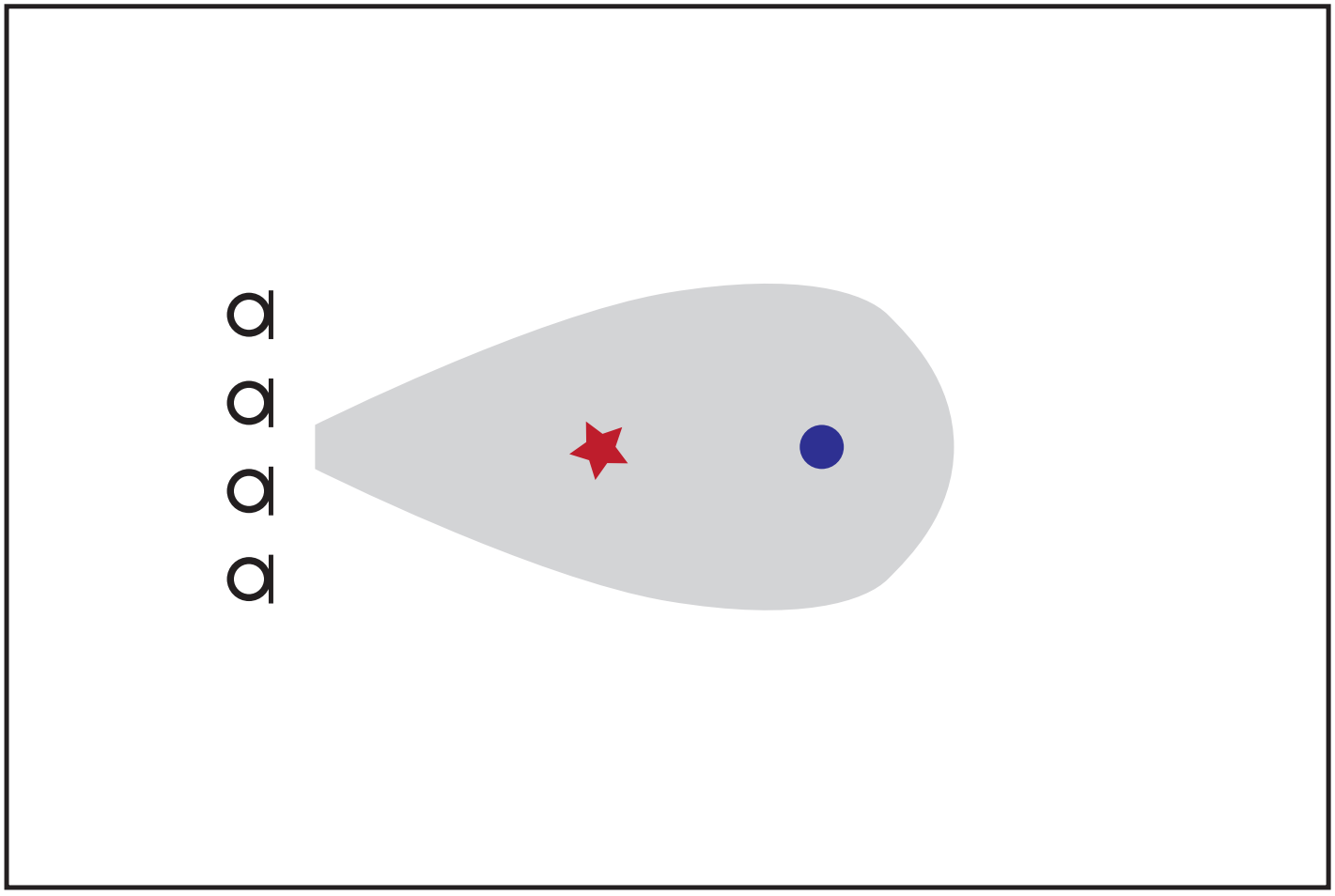

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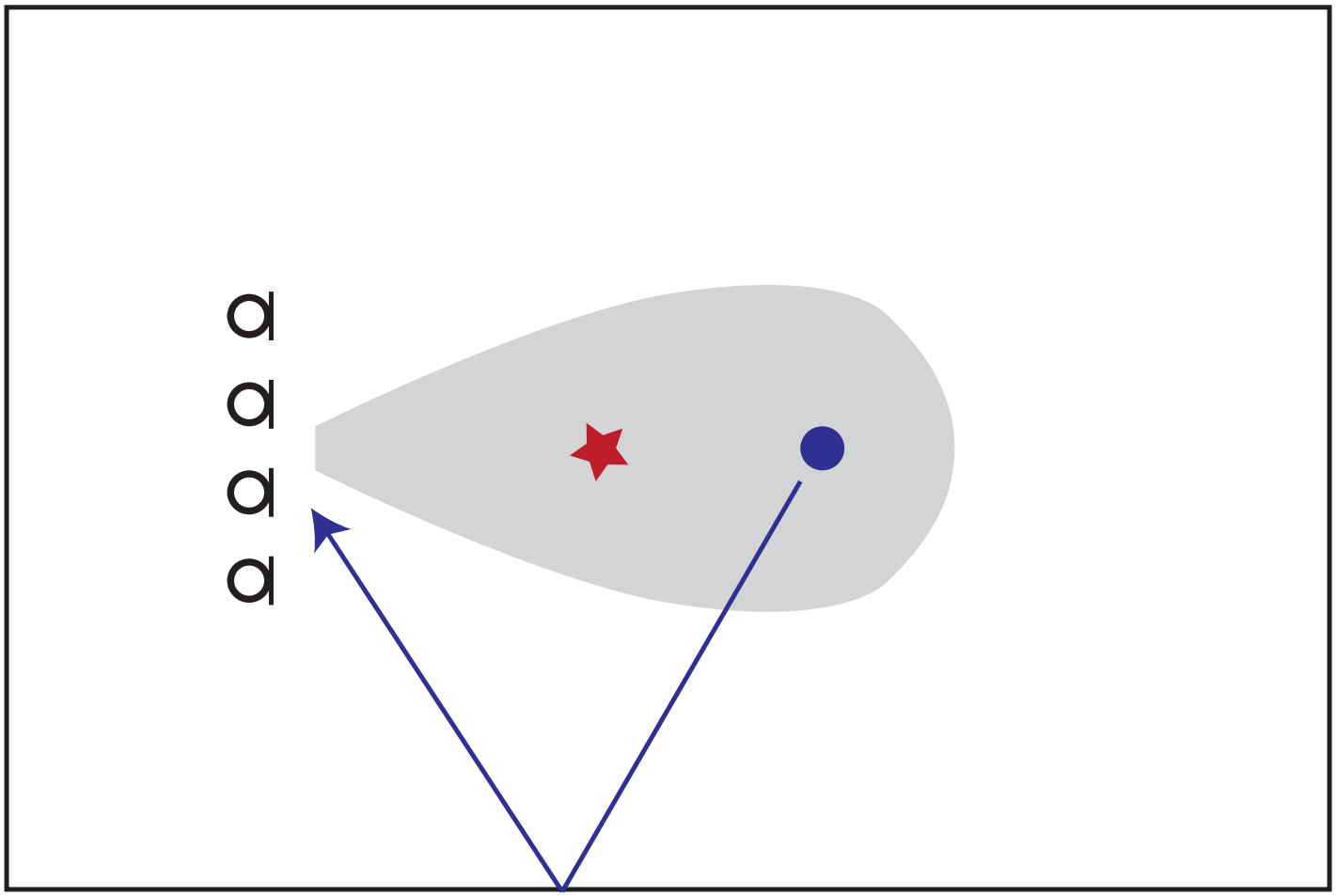

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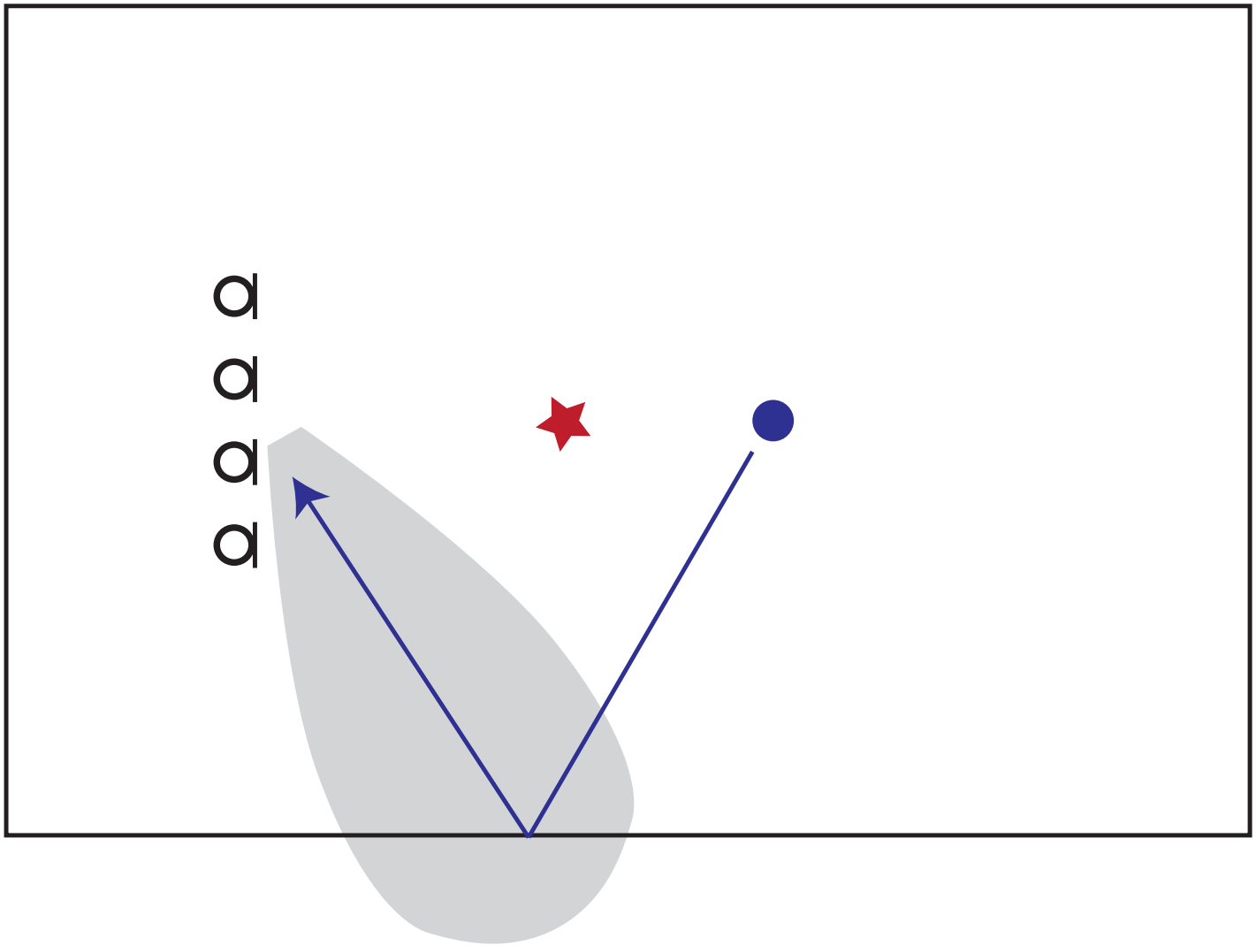

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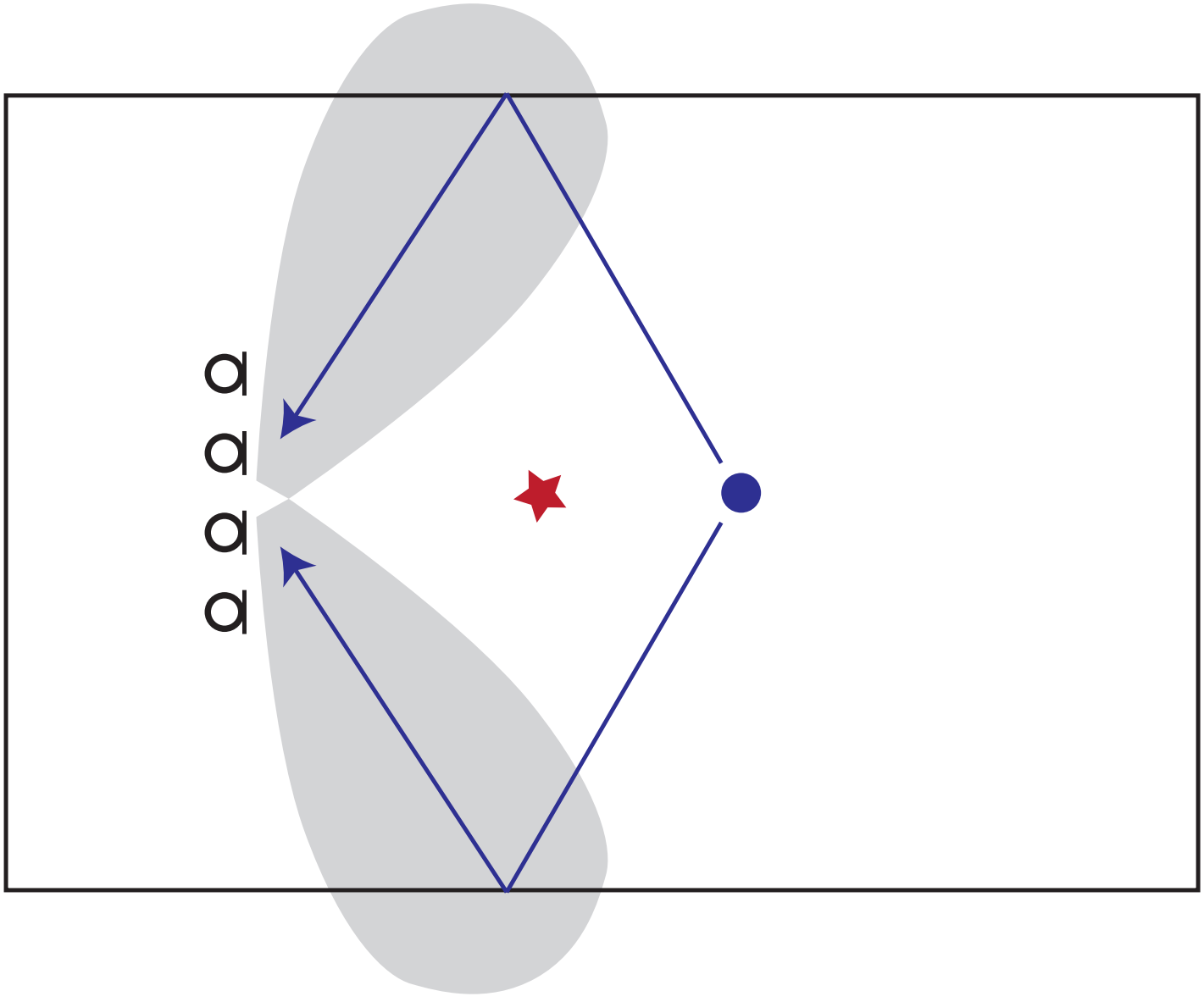
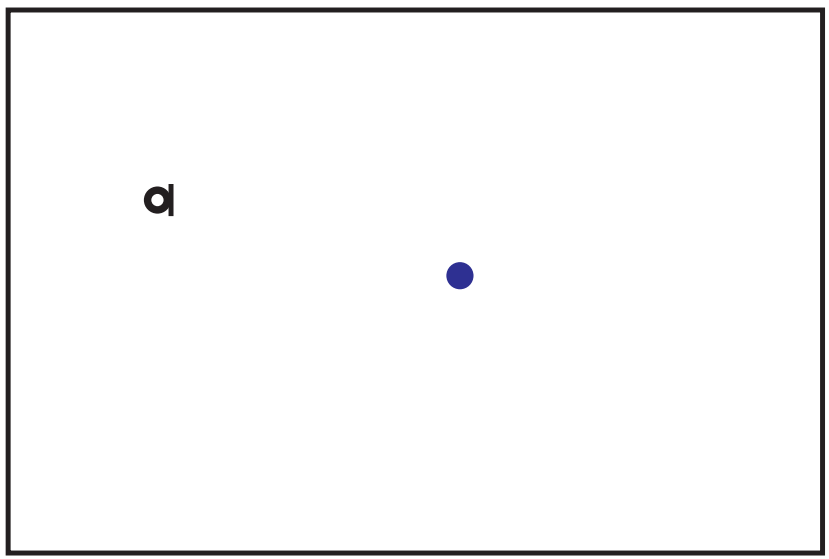


Outline

1. Model and notation
2. Raking beamformers
3. Results

Image source model



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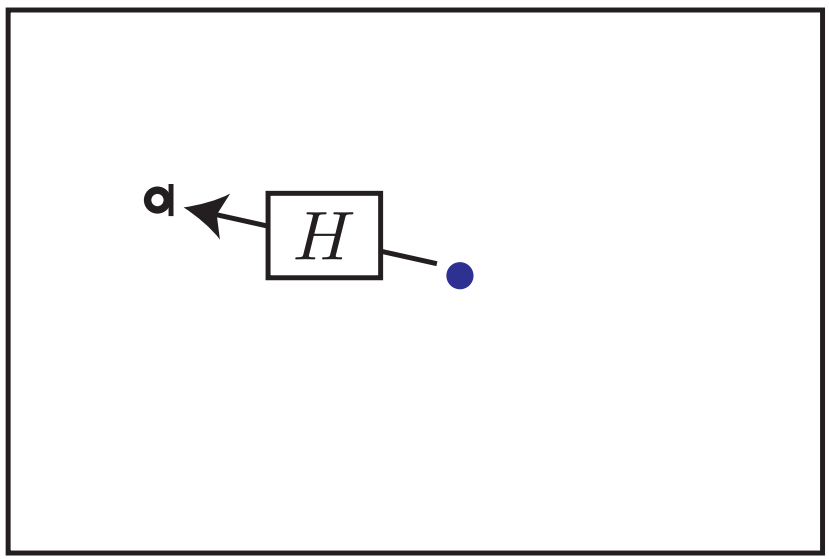

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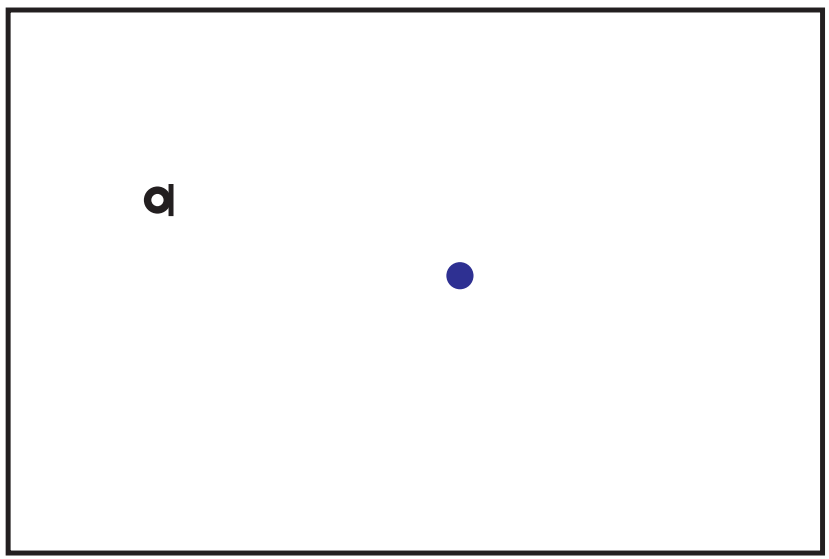

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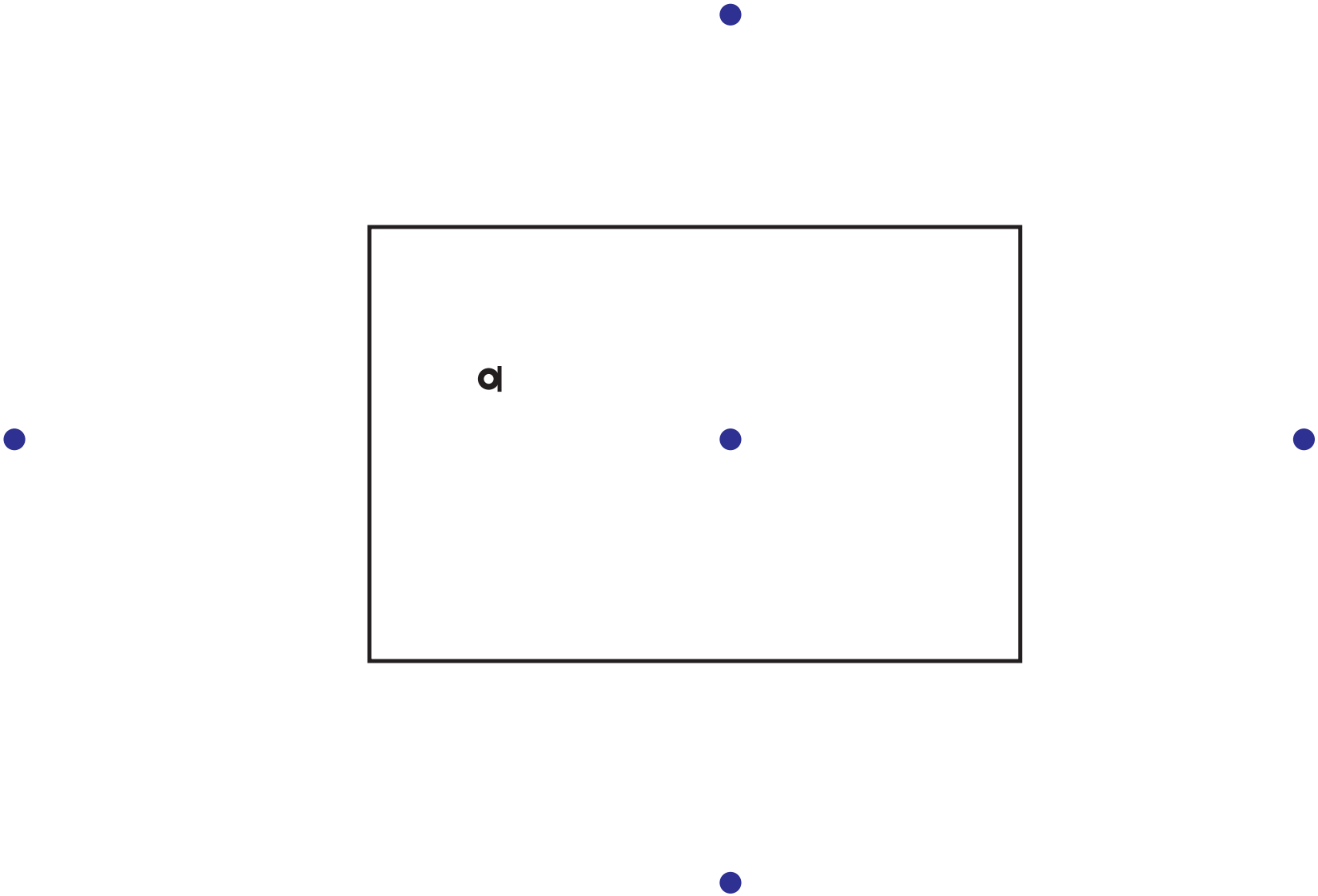

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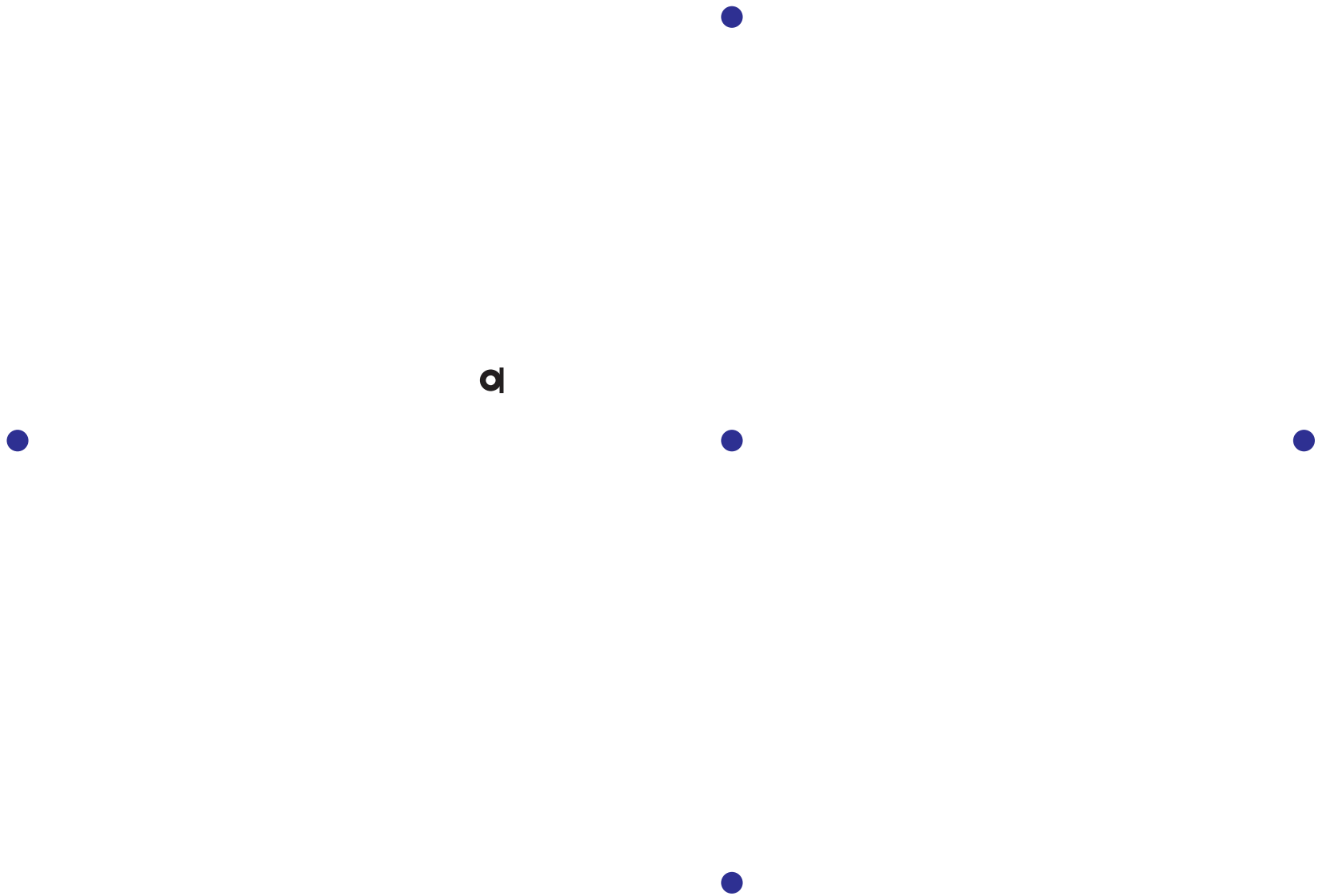

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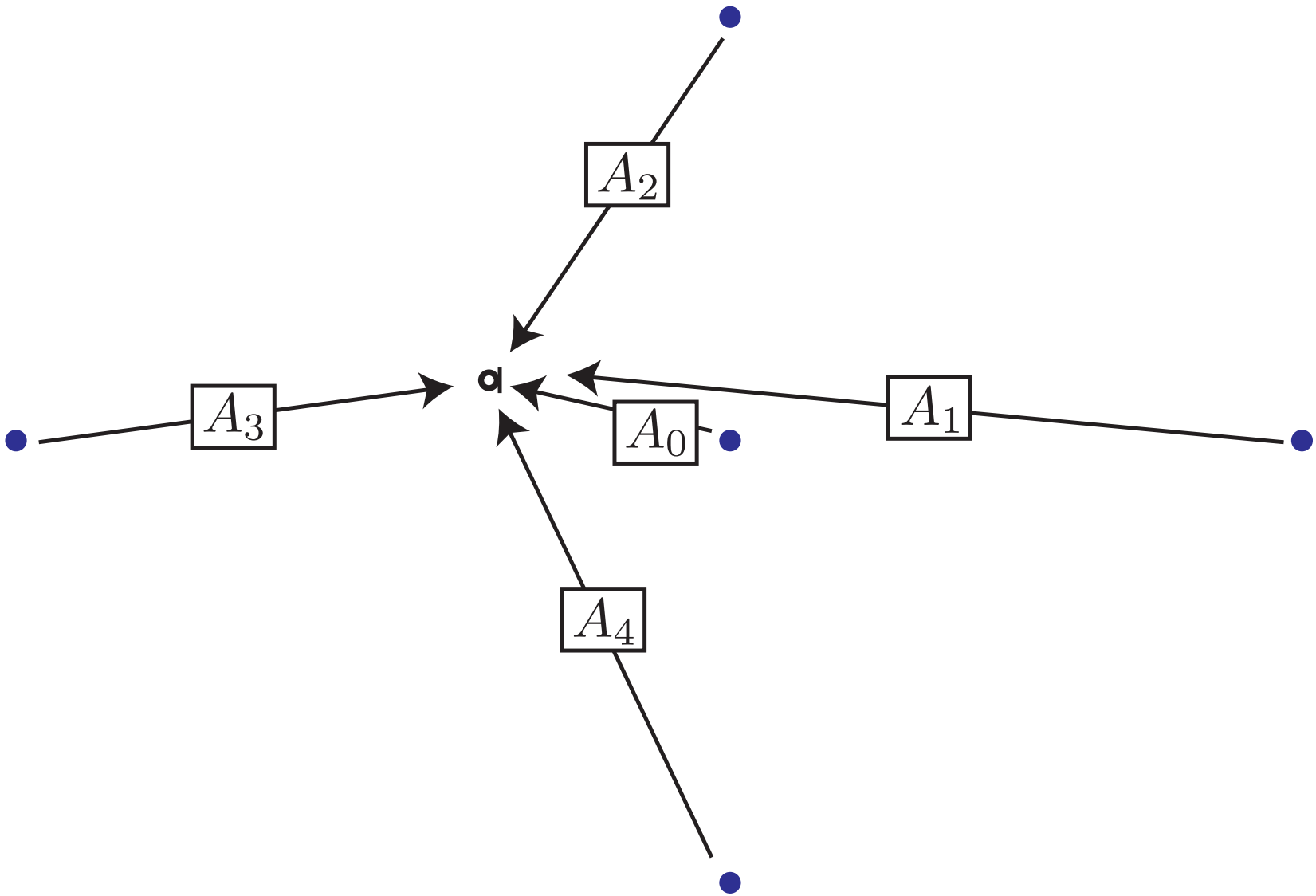
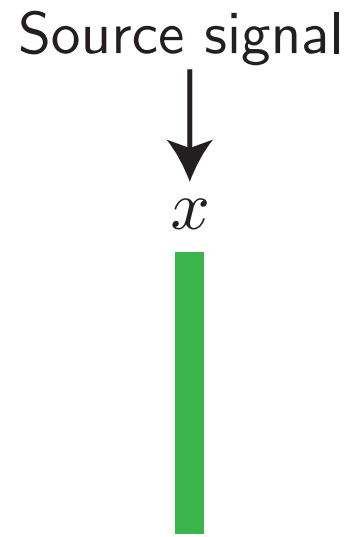


Compact notation



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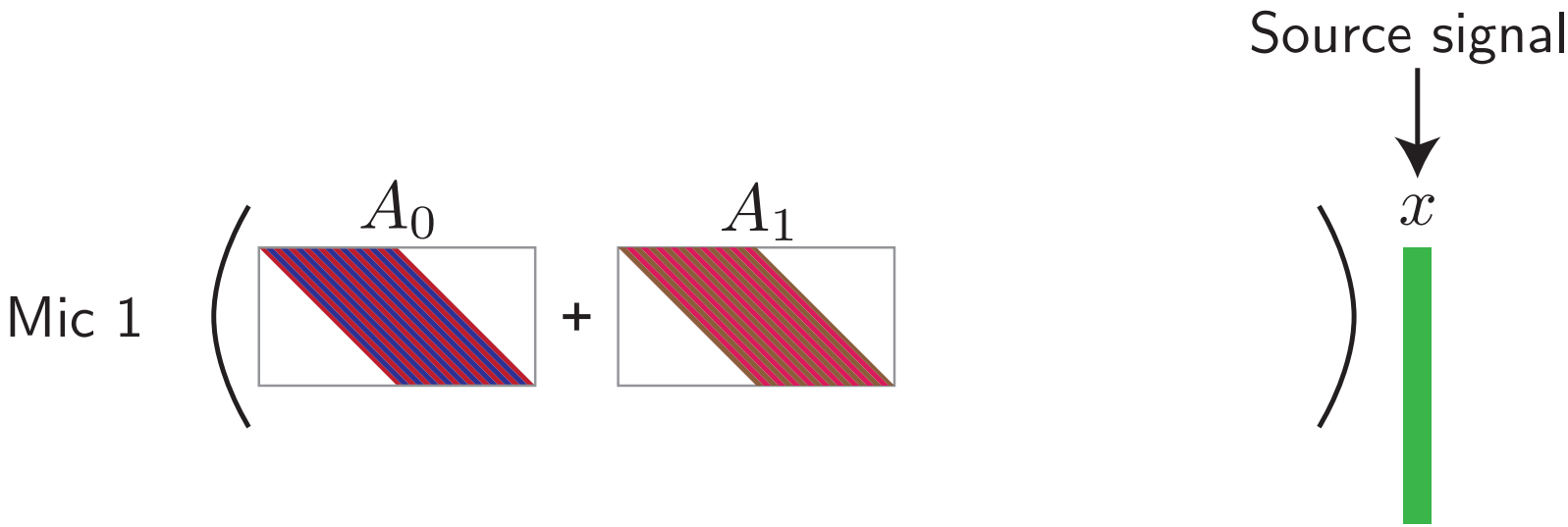

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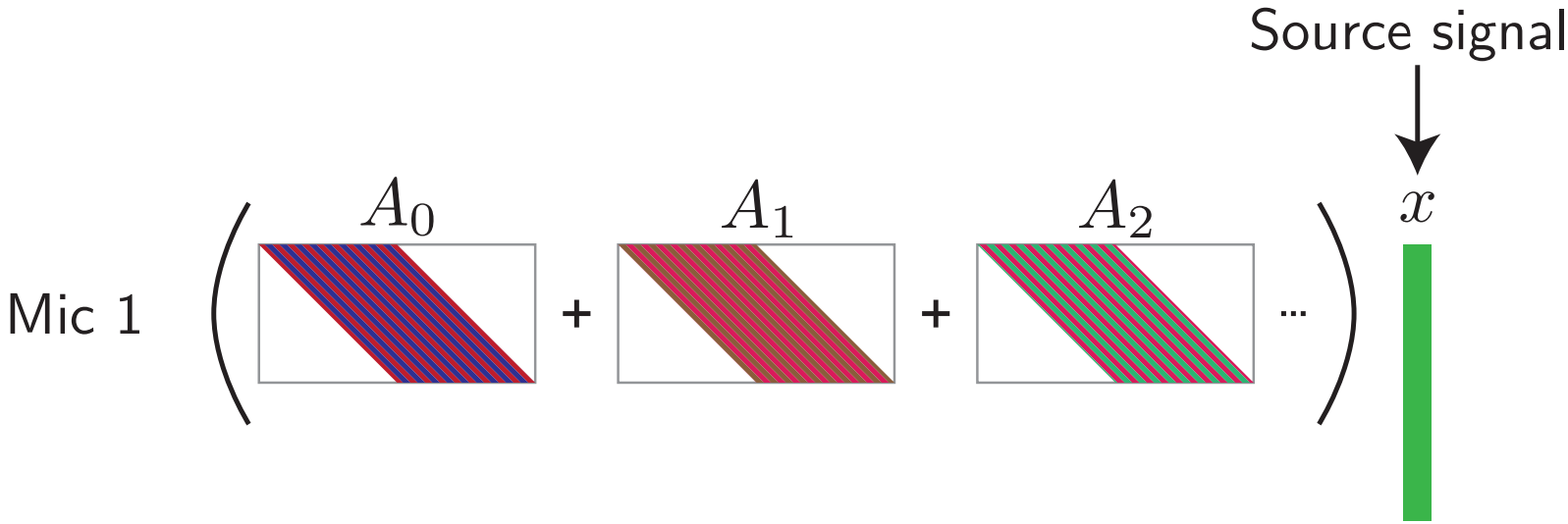

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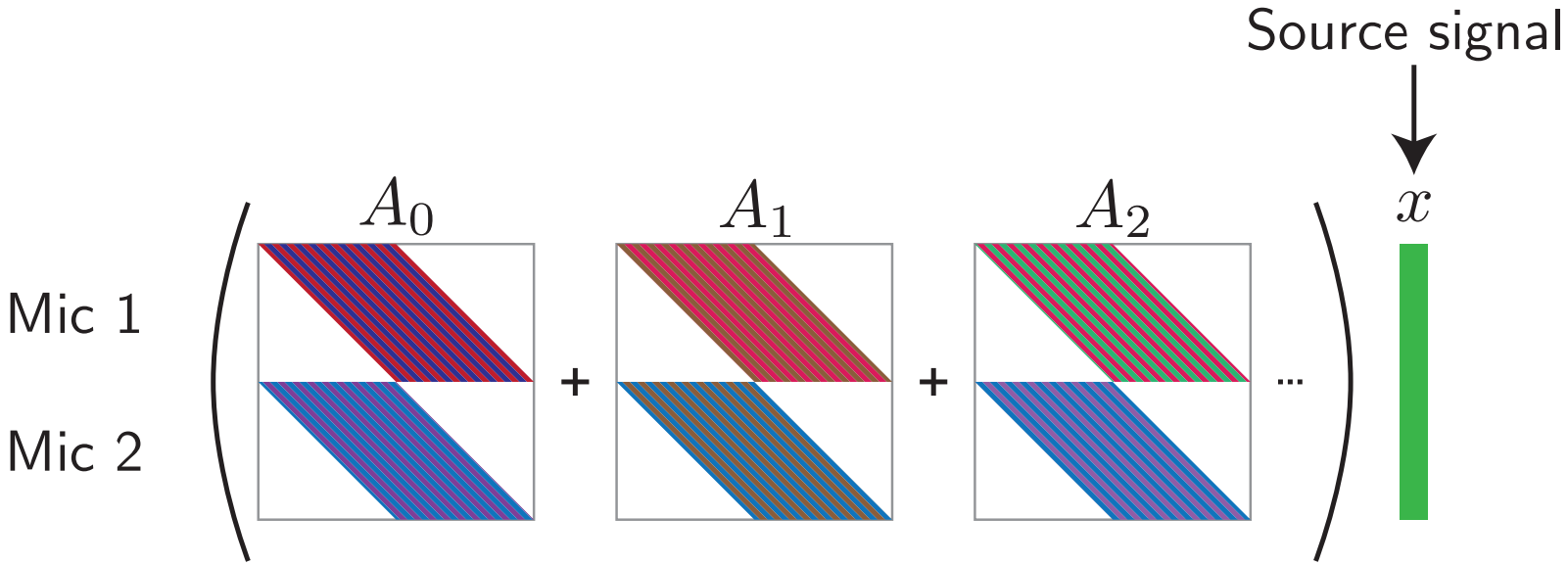

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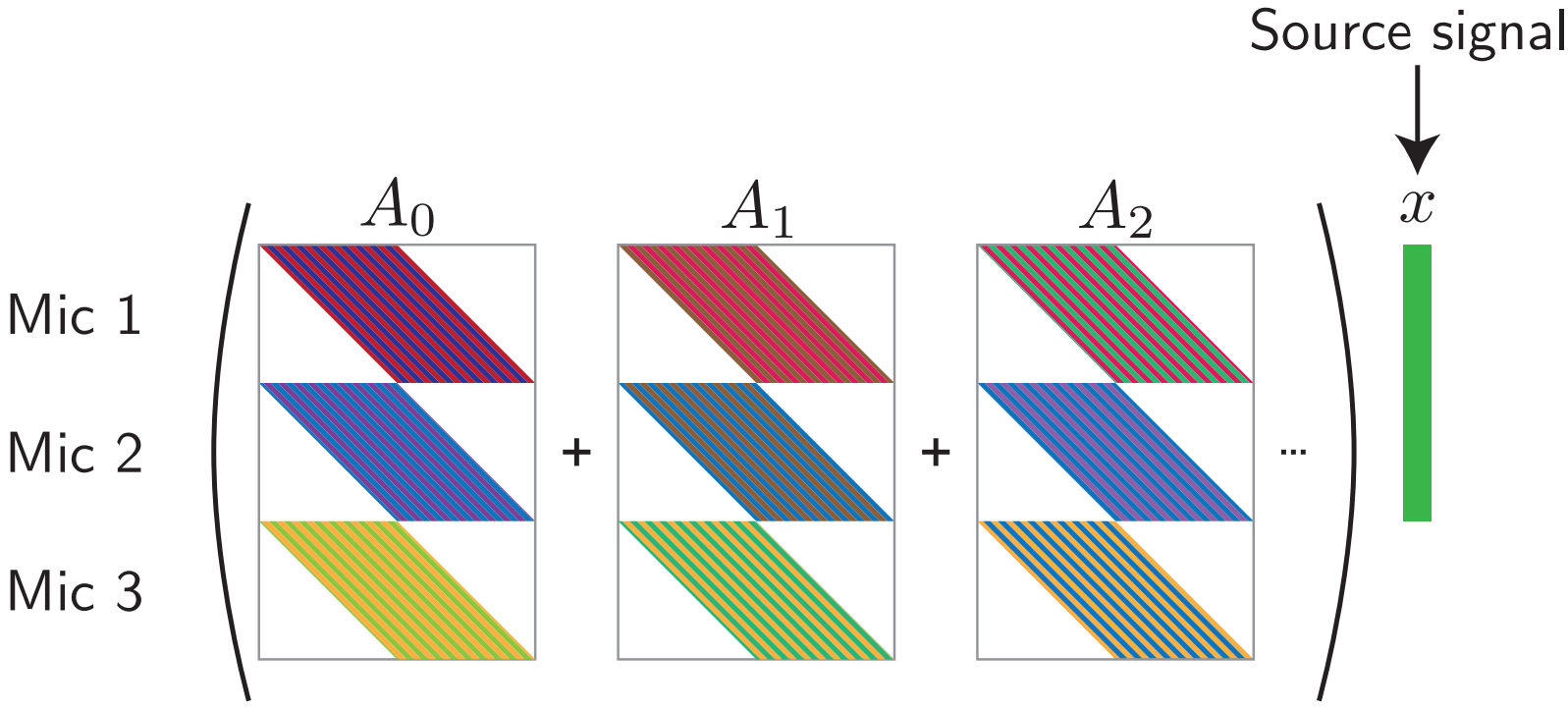

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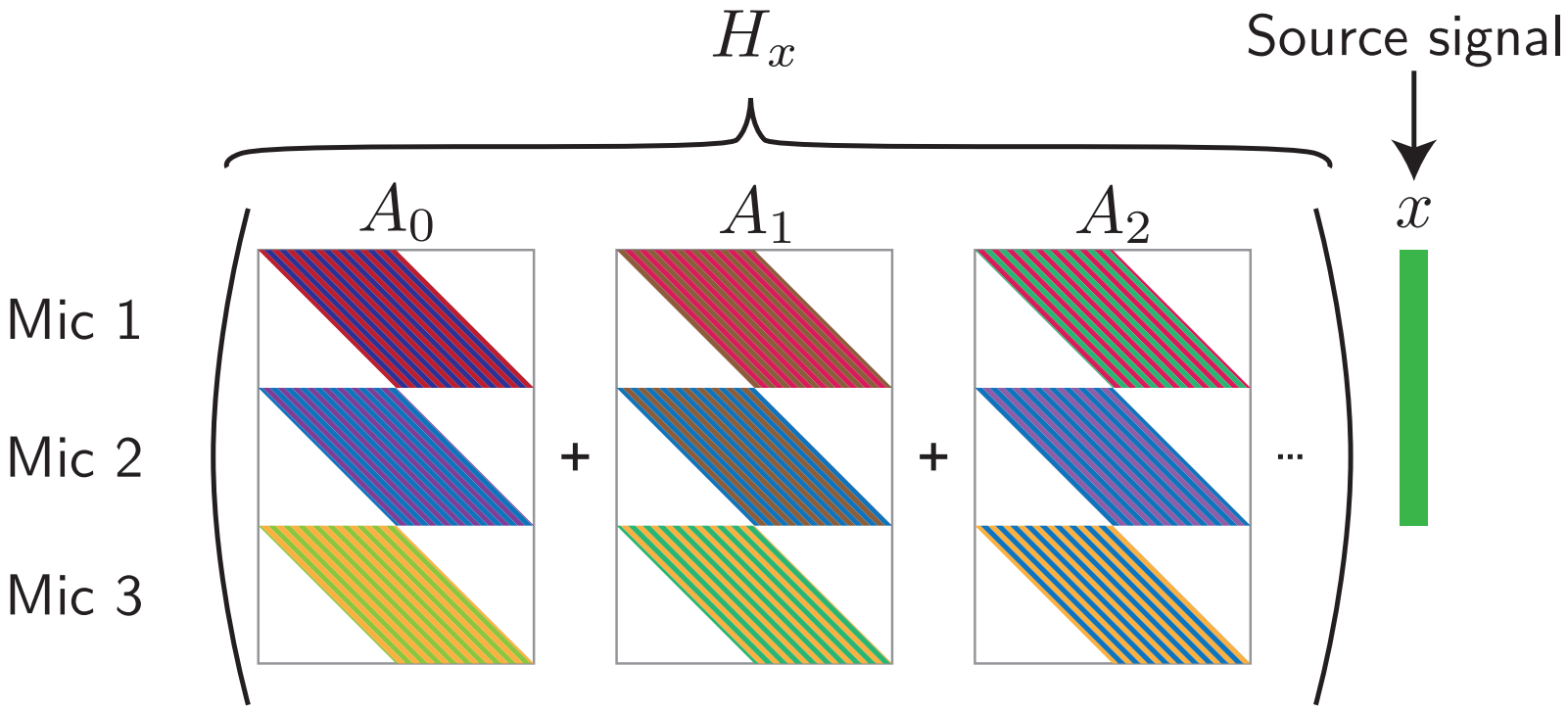

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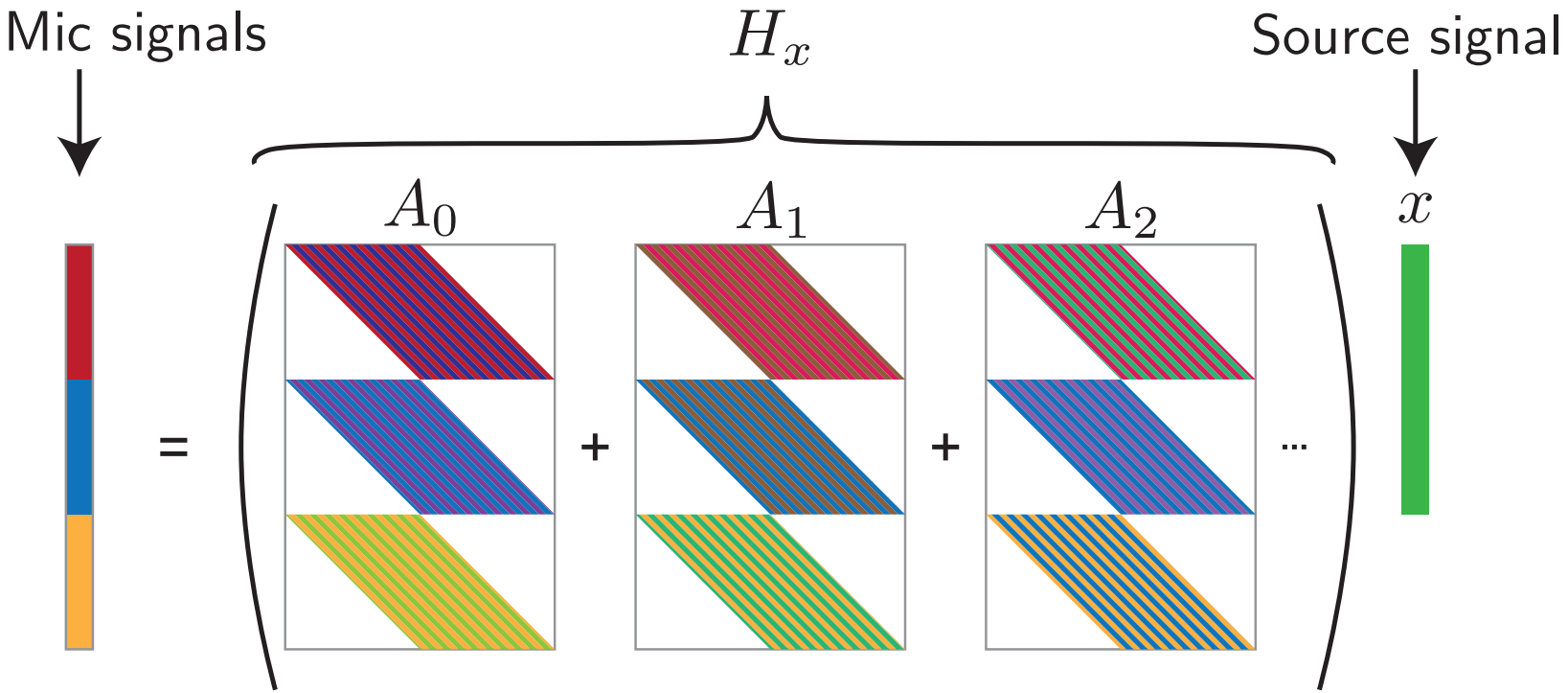

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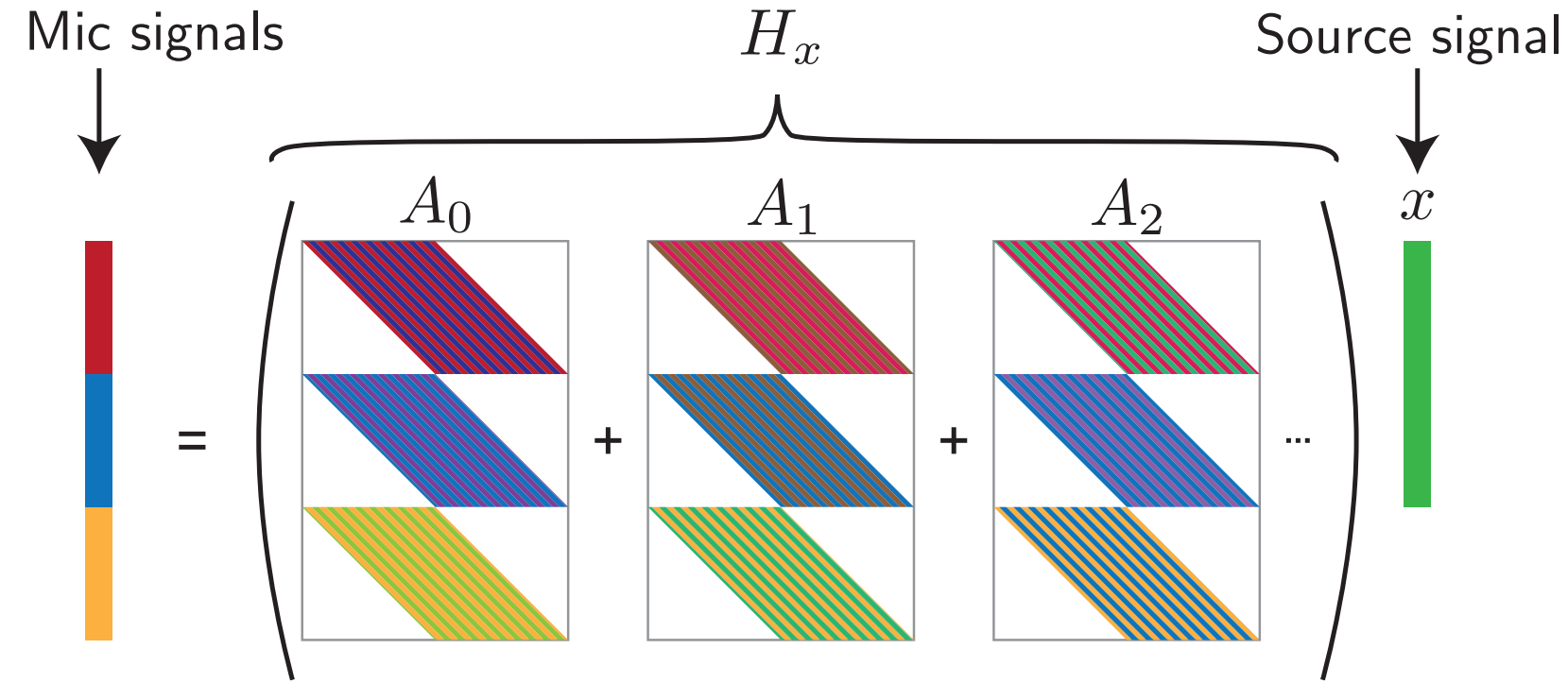
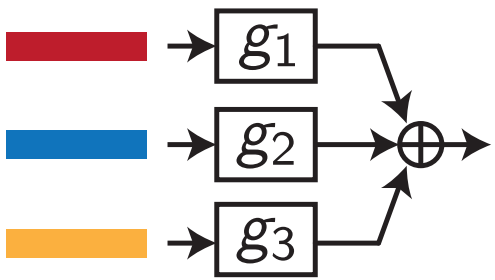


Beamformer



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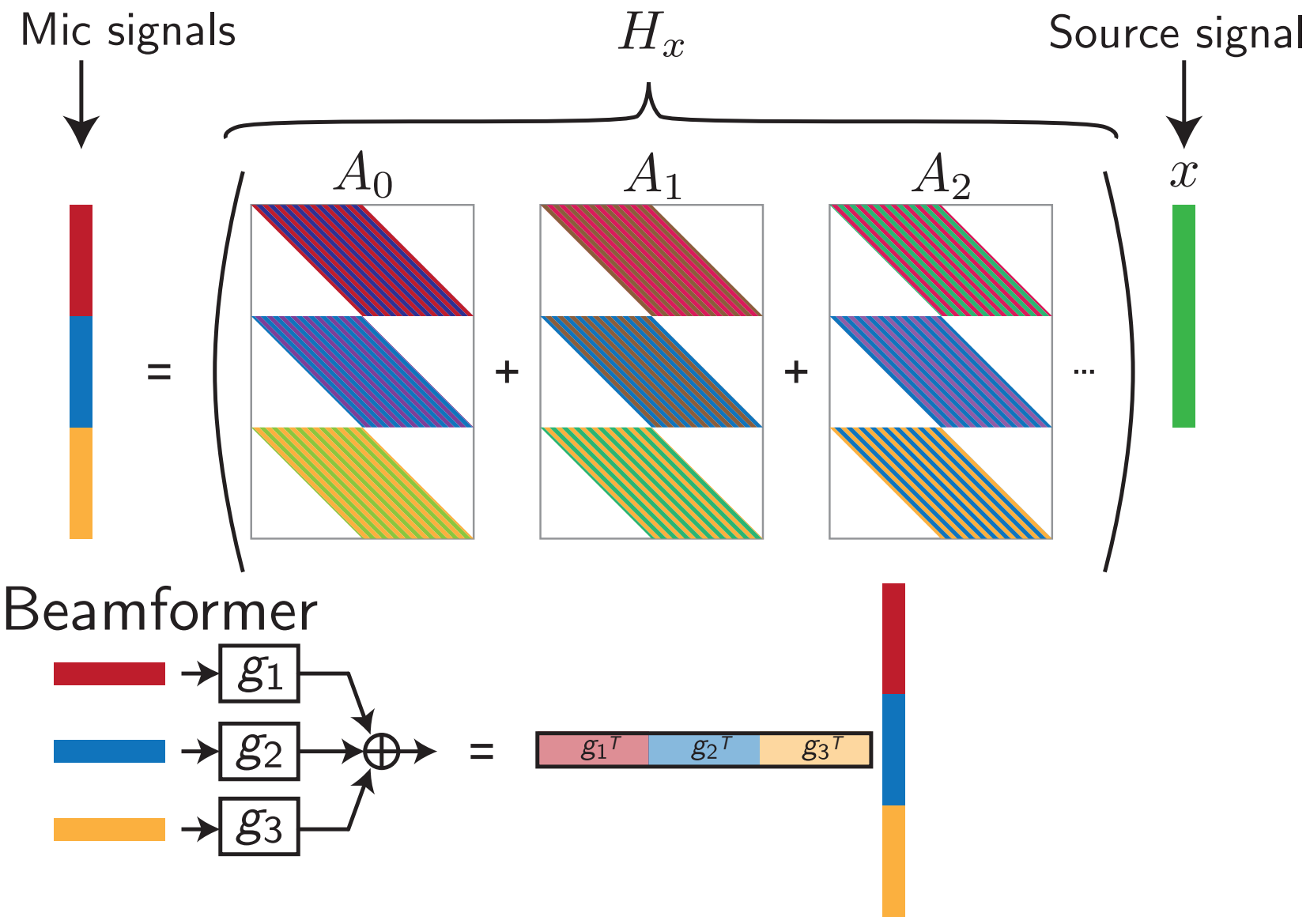

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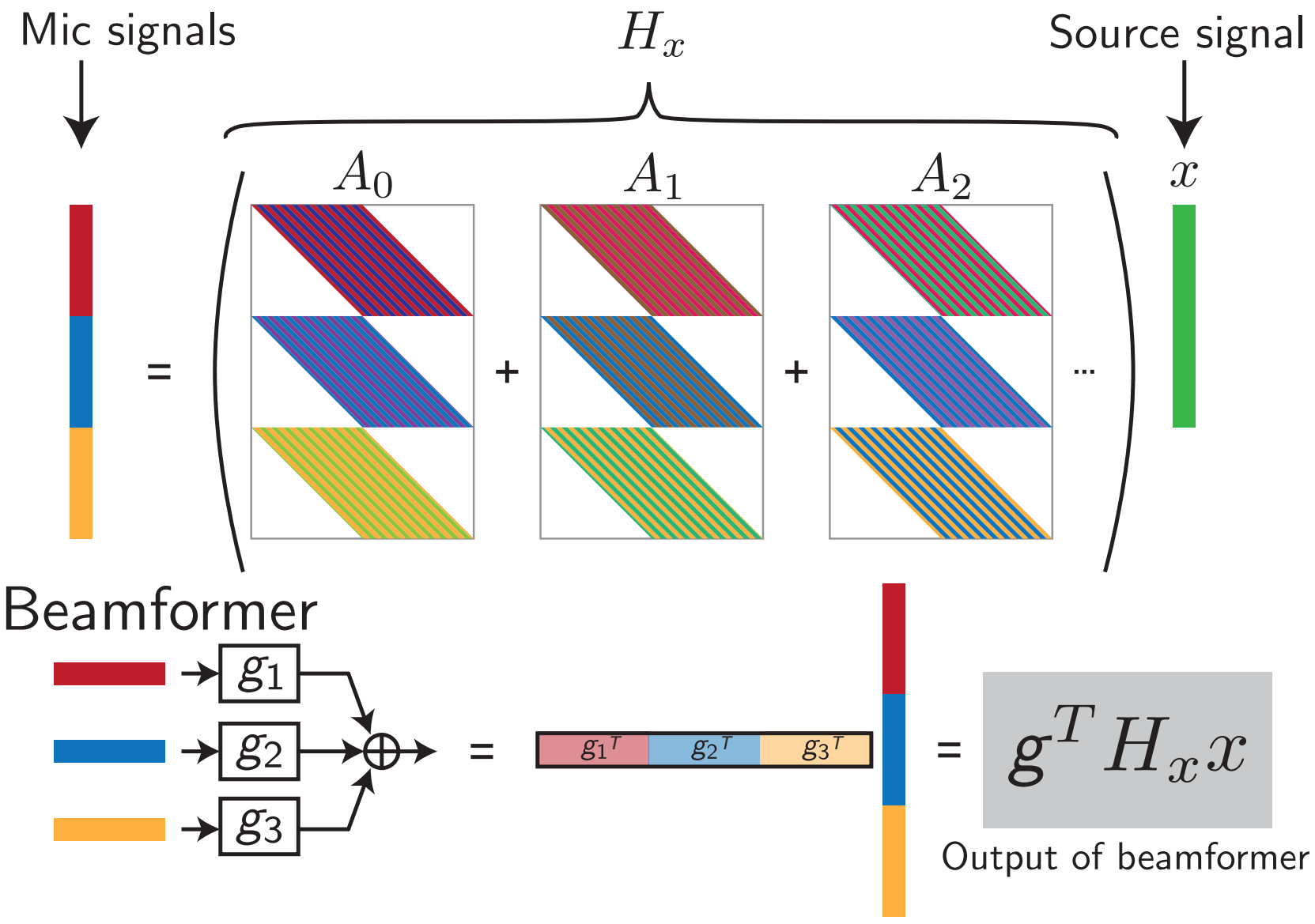
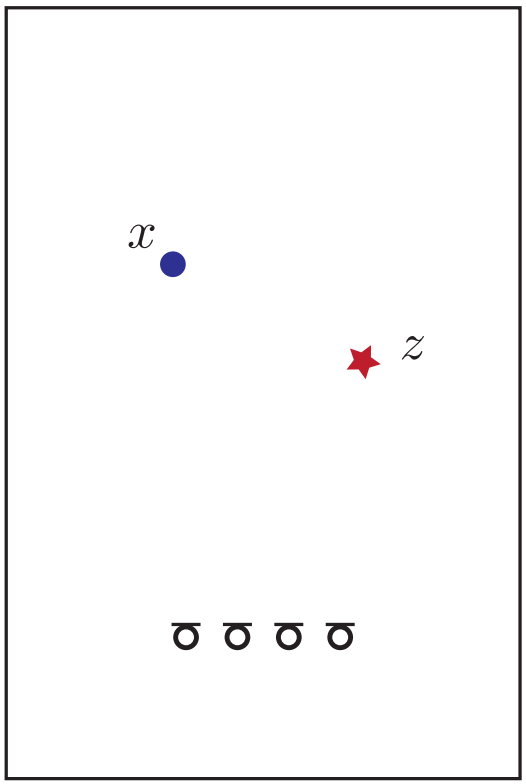


Scenario



- Signal model:

$$\boldsymbol{y} = \boldsymbol{H}_x \boldsymbol{x} + \boldsymbol{H}_z \boldsymbol{z} + \boldsymbol{n}$$

- $\boldsymbol{H}_x$ and $\boldsymbol{H}_z$ constructed from geometry
- Beamformer response

$$\boldsymbol{u}_x = \boldsymbol{H}_x^T \boldsymbol{g} \qquad \boldsymbol{u}_z = \boldsymbol{H}_z^T \boldsymbol{g}$$

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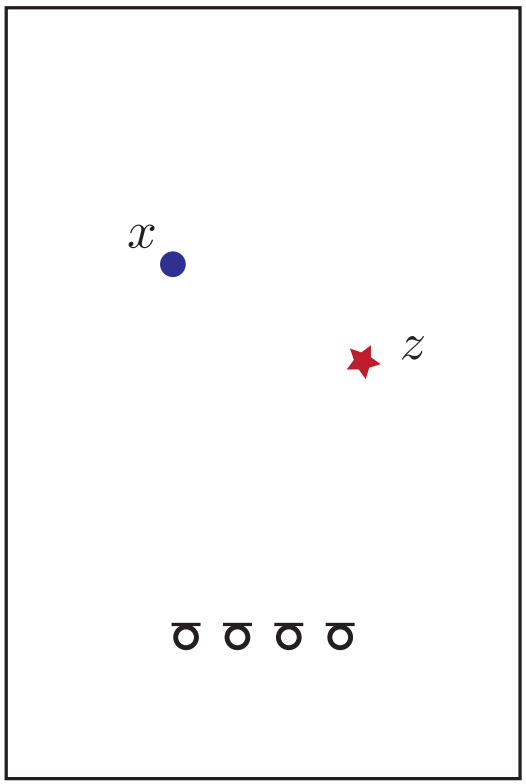

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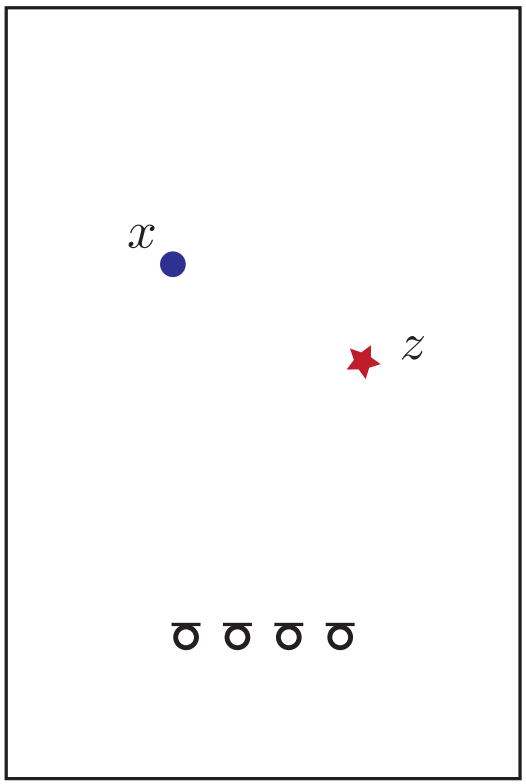

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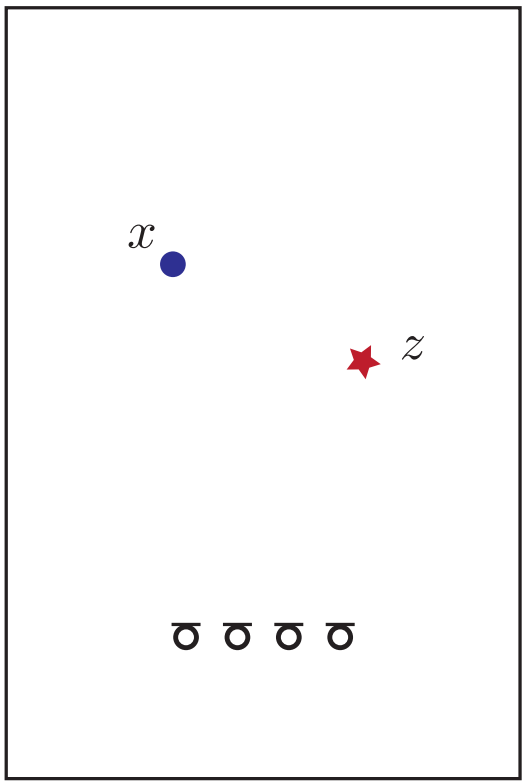

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Minimum variance distortionless response beamformer

$$\underset{\boldsymbol{g}}{\text{minimize}}\ \mathbb{E}\|\boldsymbol{g}^T\boldsymbol{y}\|^2 \quad \text{subject to } \boldsymbol{H}_x^T\boldsymbol{g} = \delta_\tau$$

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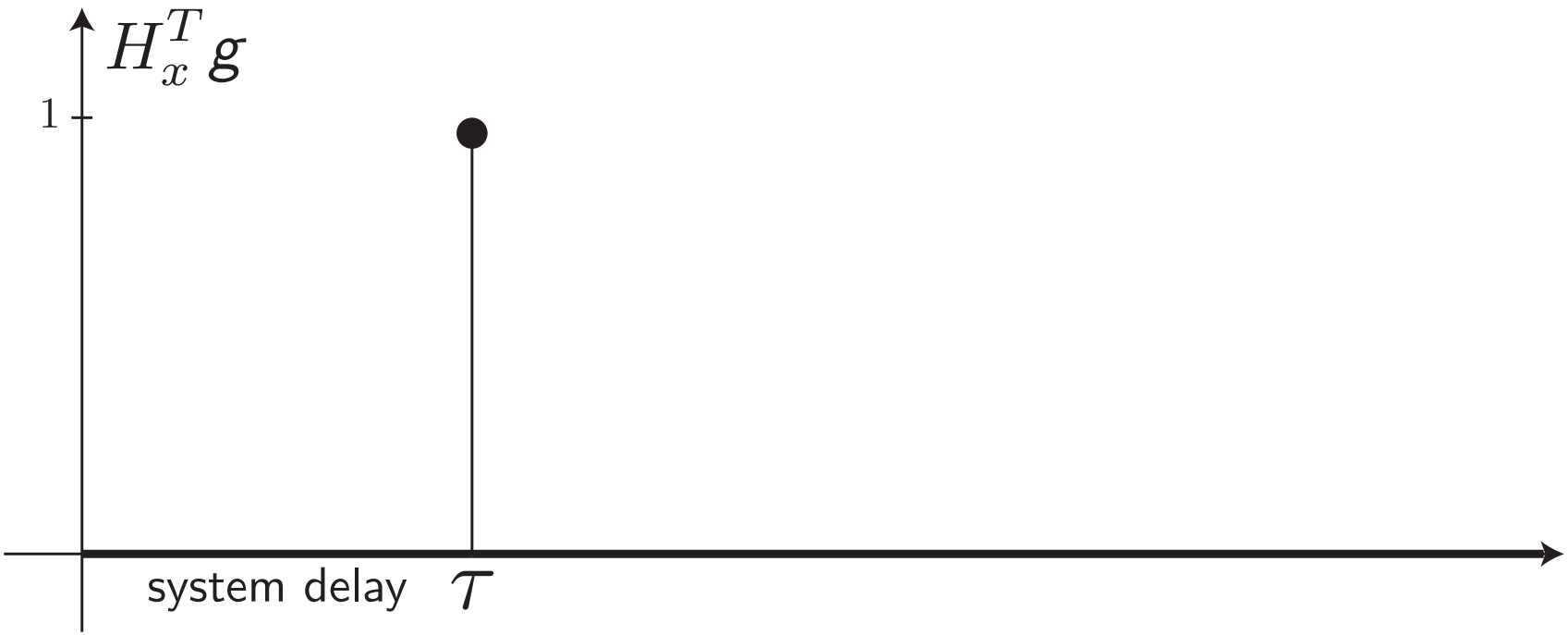
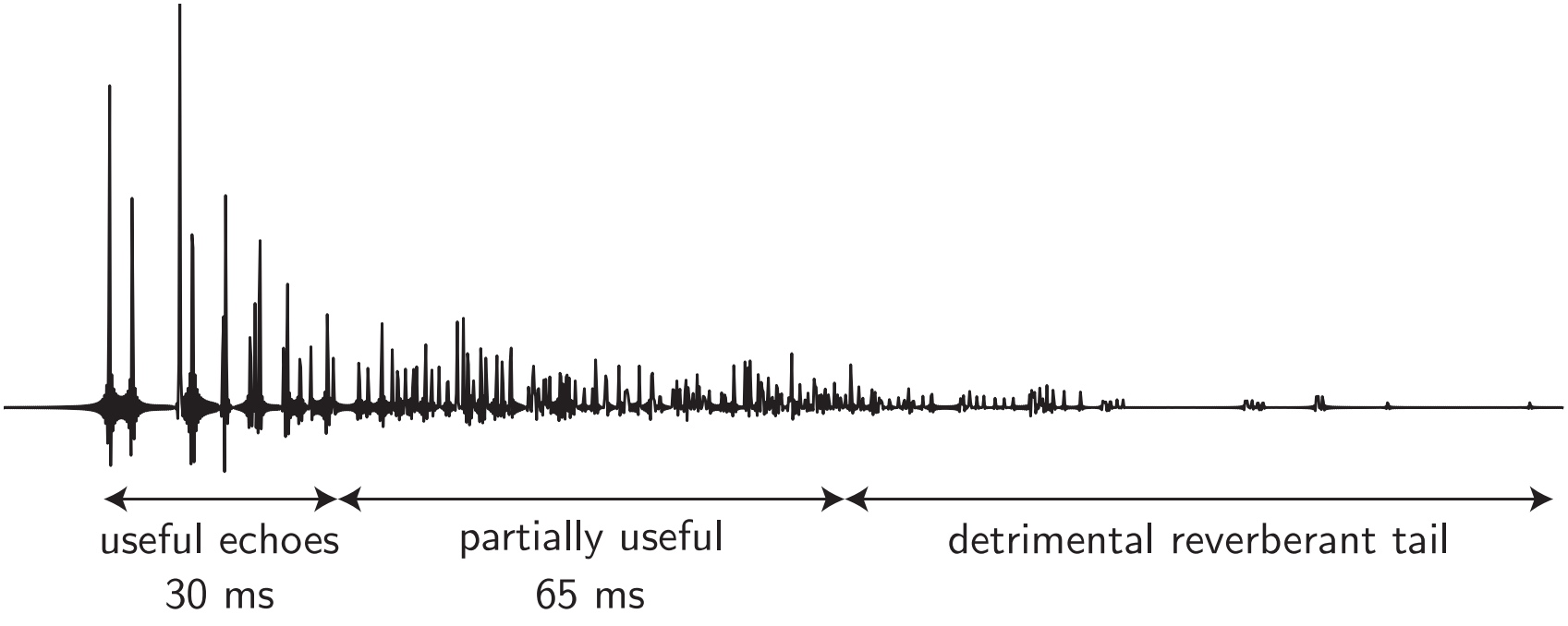


Clues from perceptual acoustics



J. Lochner, J.F. Burger, *The Influence of Reflections on Auditorium Acoustics*, 1964.

Relaxing the distortionless constraint

$$\underset{\boldsymbol{g}}{\text{minimize}}\ \mathbb{E}\|\boldsymbol{g}^T(\boldsymbol{H}_z\boldsymbol{z}+\boldsymbol{n})\|^2 \quad \text{subject to } \mathcal{M}\boldsymbol{H}_x^T\boldsymbol{g}=\delta_\tau$$

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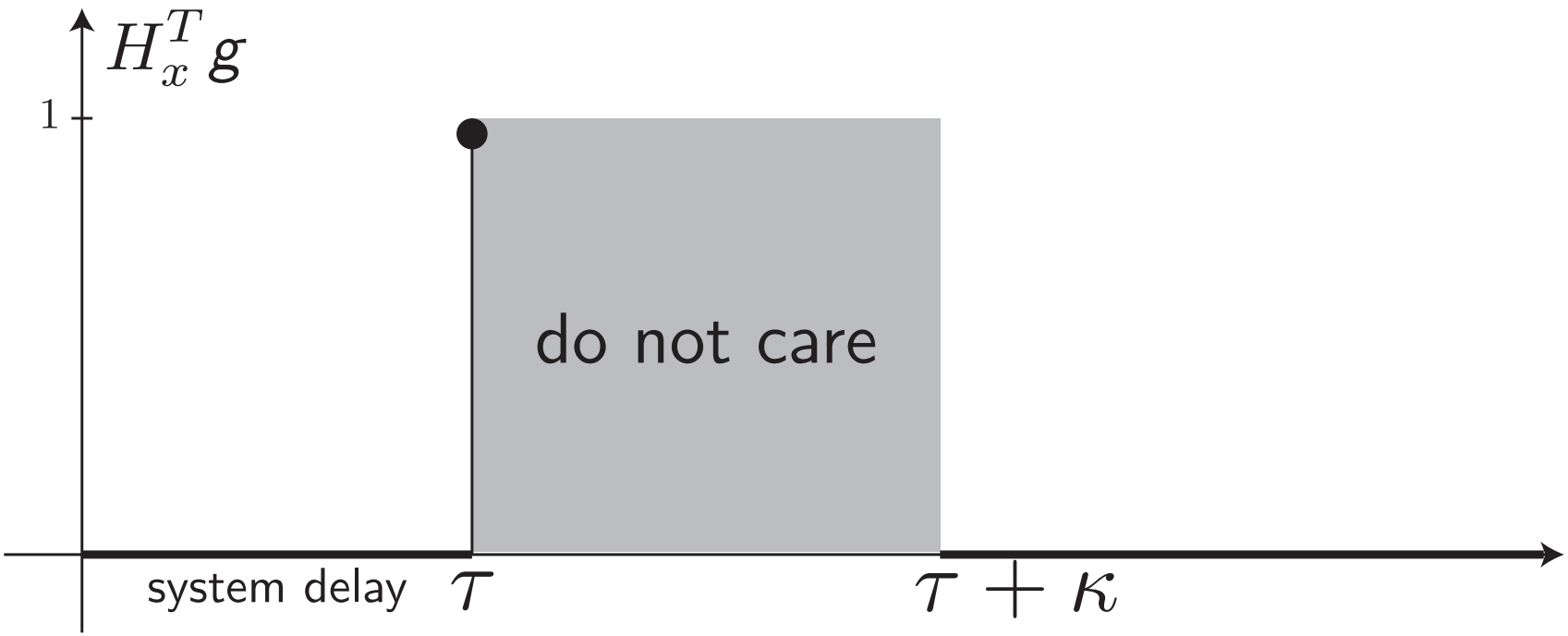
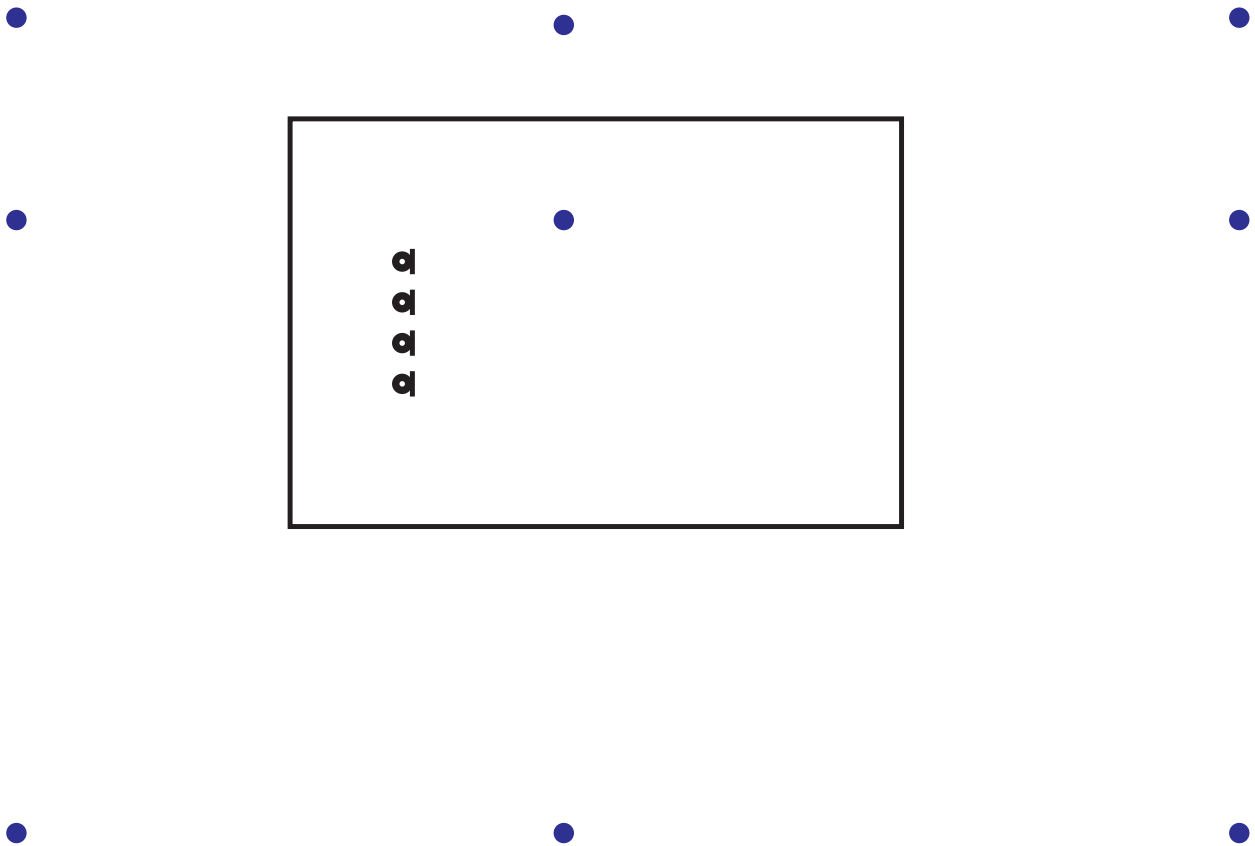


Image source picking

- MVDR: Sources within $c\tau$ contribute energy
- Perceptual: Sources within $c(\tau + \kappa)$ contribute energy



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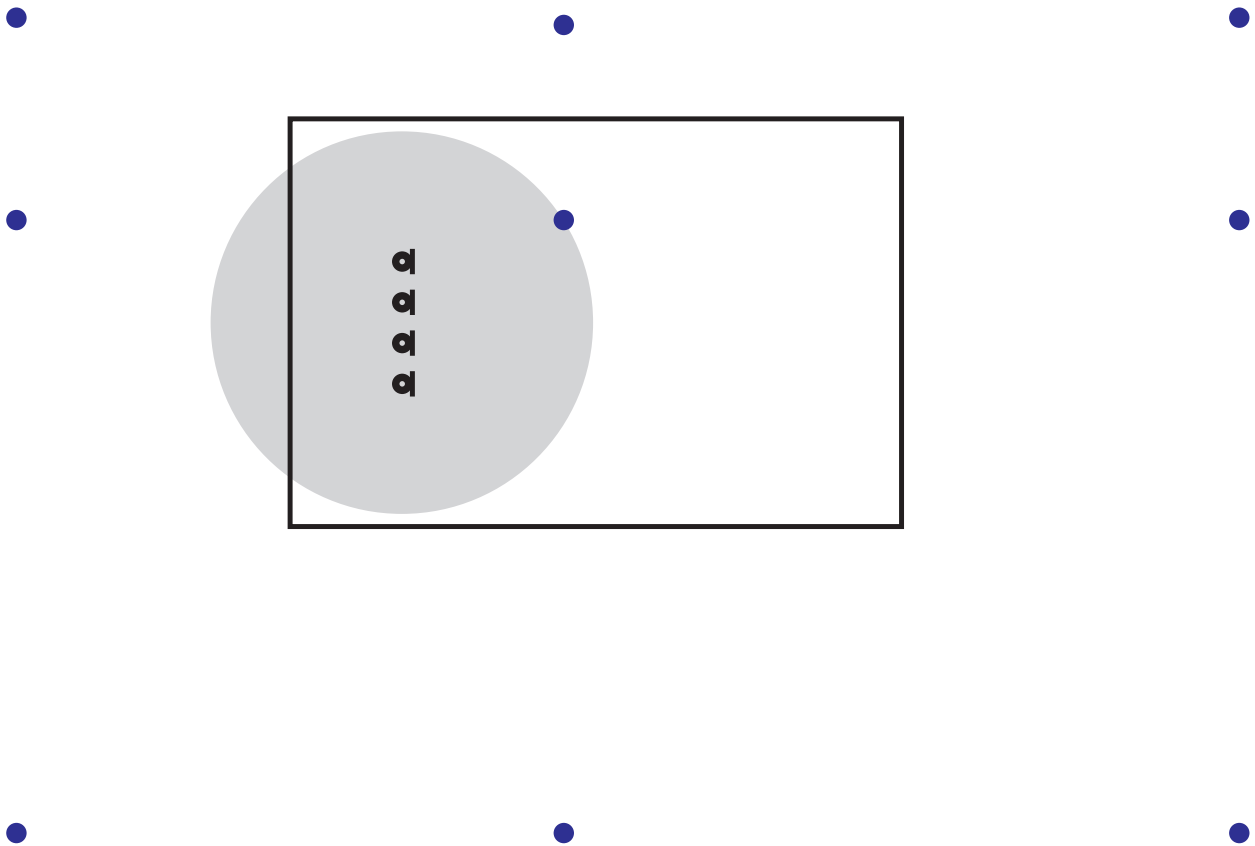

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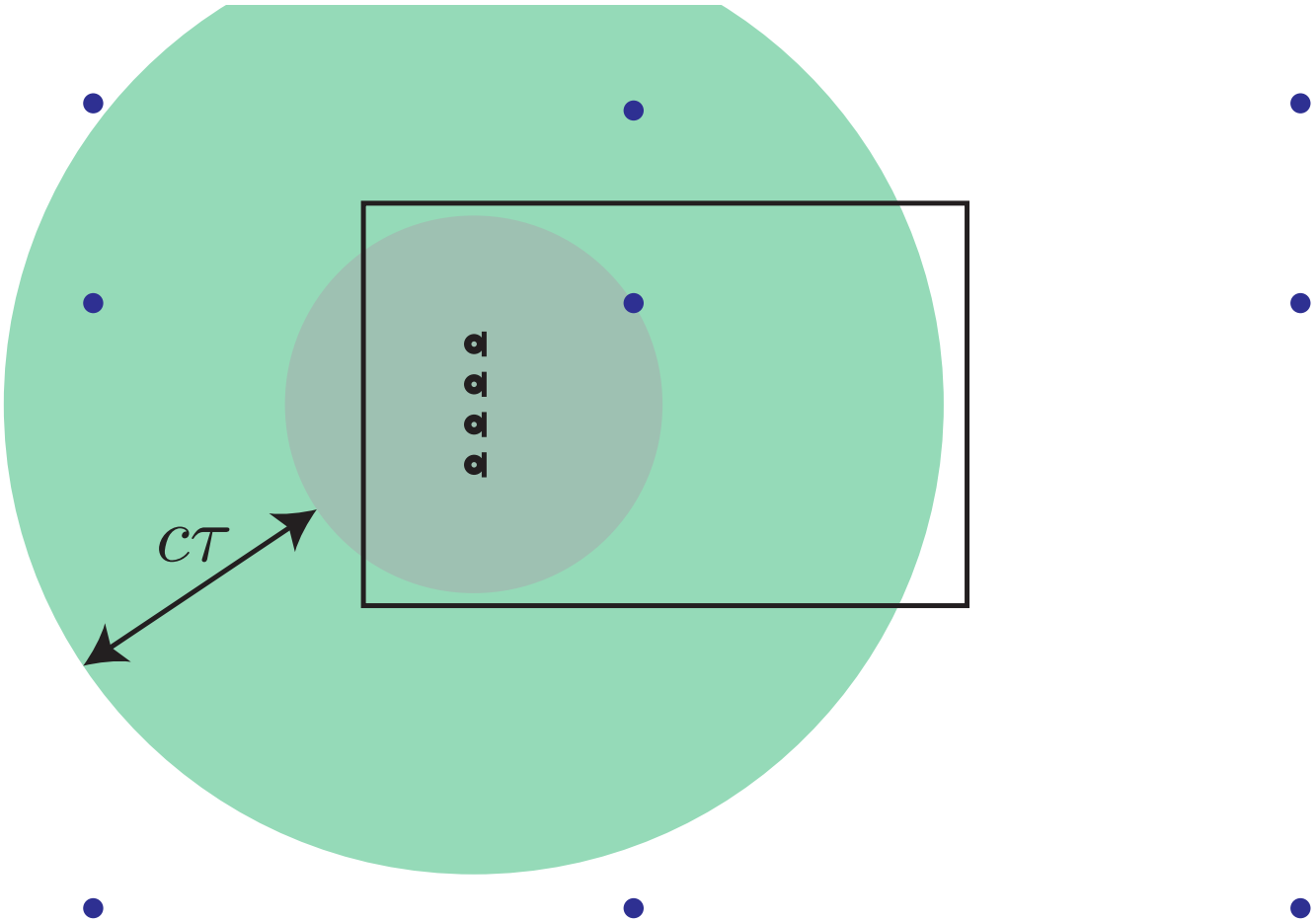

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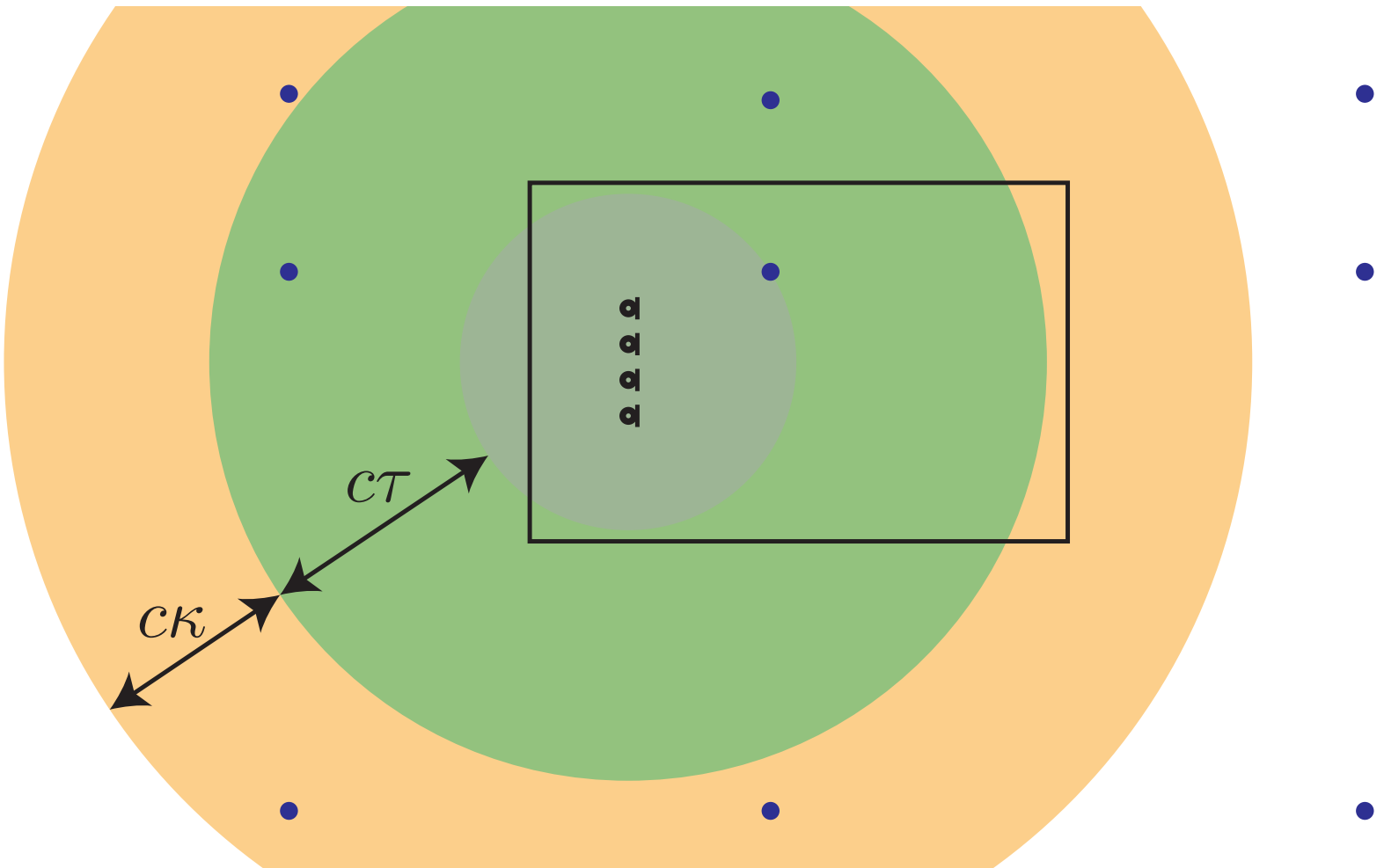

Signal-to-interference-and-noise metric

- Performance metric:

$$\text{SINR} = \mathbb{E}\left[\frac{\|\boldsymbol{g}^T \boldsymbol{H}_x \boldsymbol{x}\|^2}{\|\boldsymbol{g}^T(\boldsymbol{H}_z \boldsymbol{z} + \boldsymbol{n})\|^2}\right]$$

- Optimal beamformer:

$$\underset{\boldsymbol{g}}{\text{maximize}}\ \text{SINR}$$

– Response very distorted : not practical

\+ Upper bound

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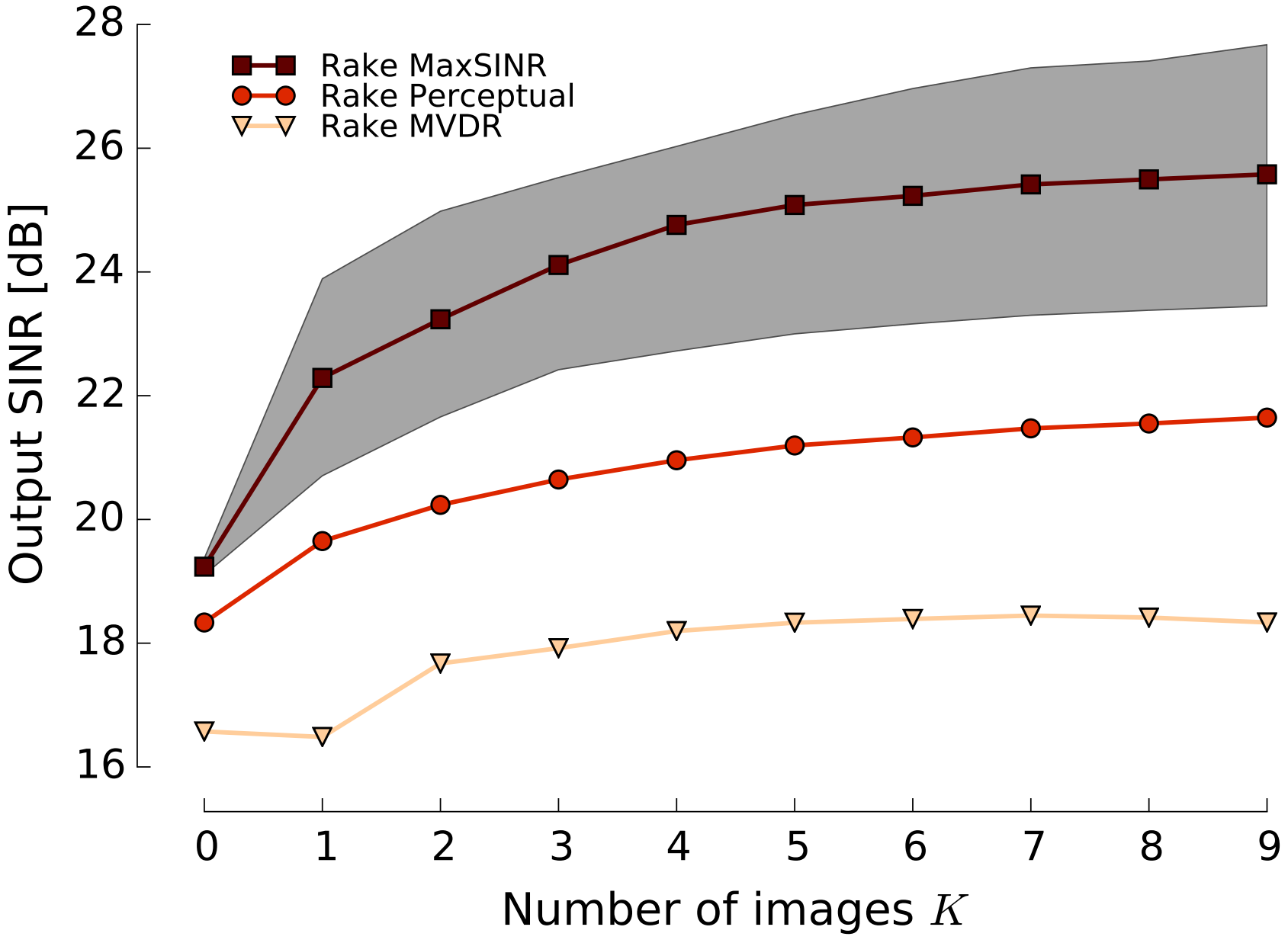
SINR improvements



Contribution

- A distortionless raking beamformer
- A perceptually motivated raking beamformer
- Time-domain designs allow control on:
  - Delay
  - Pre-echoes
- SINR increases with number of image sources
- Python framework

What's next ?

- Robust formulations
- Experiments

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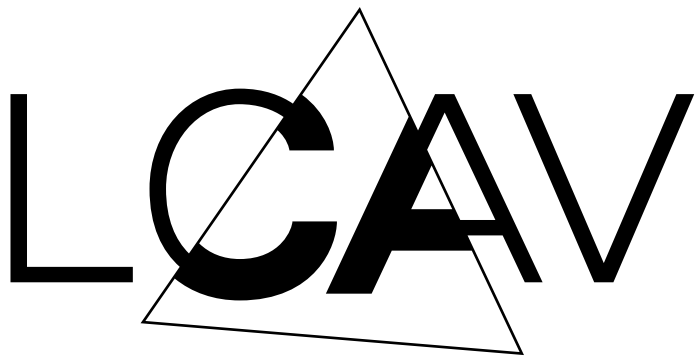

Code and figures available at

`http://lcav.github.io/TimeDomainAcousticRakeReceiver/`