156th meeting of the Acoustical Society of America
Miami, Florida, November 13, 2008

Directional Sources and Beamforming

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Directional Sources and Beamforming

- Beamforming
- The directionality of some real world sources that deviate from an ideal point source
- Performance measures used to evaluate the properties of a beamformer
- Validity of assuming a point source
- Challenges for beamforming on non-point sources

Directional Sources and Beamforming

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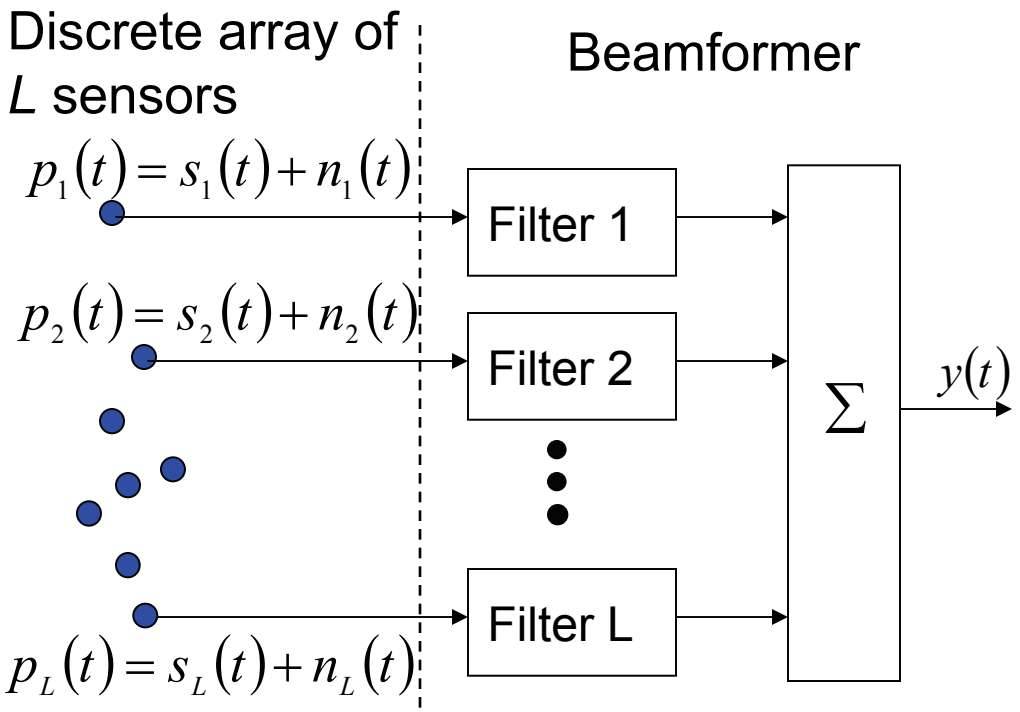
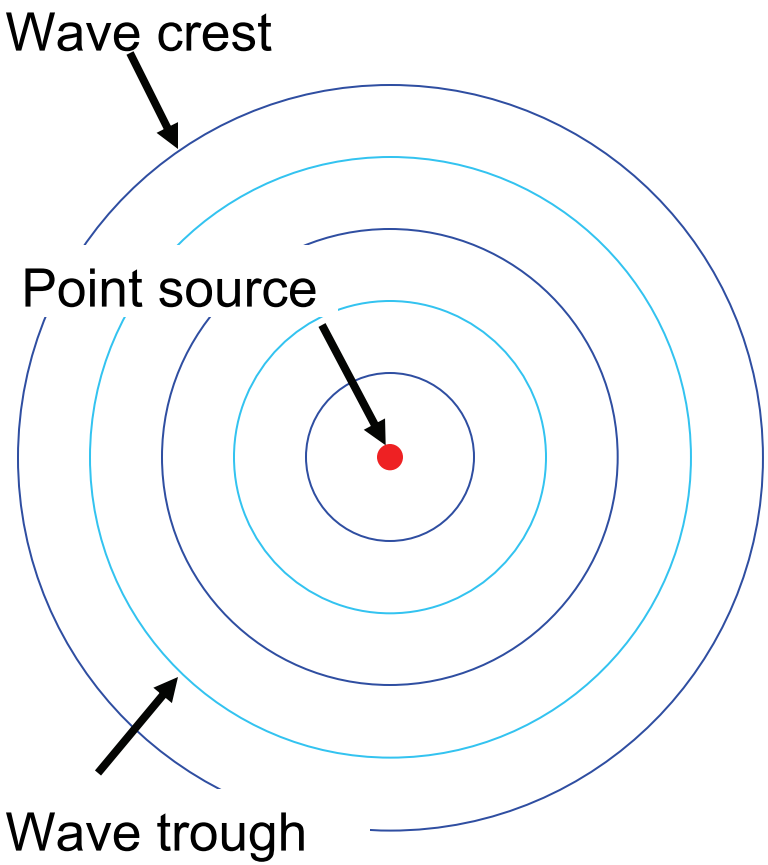
Beamforming

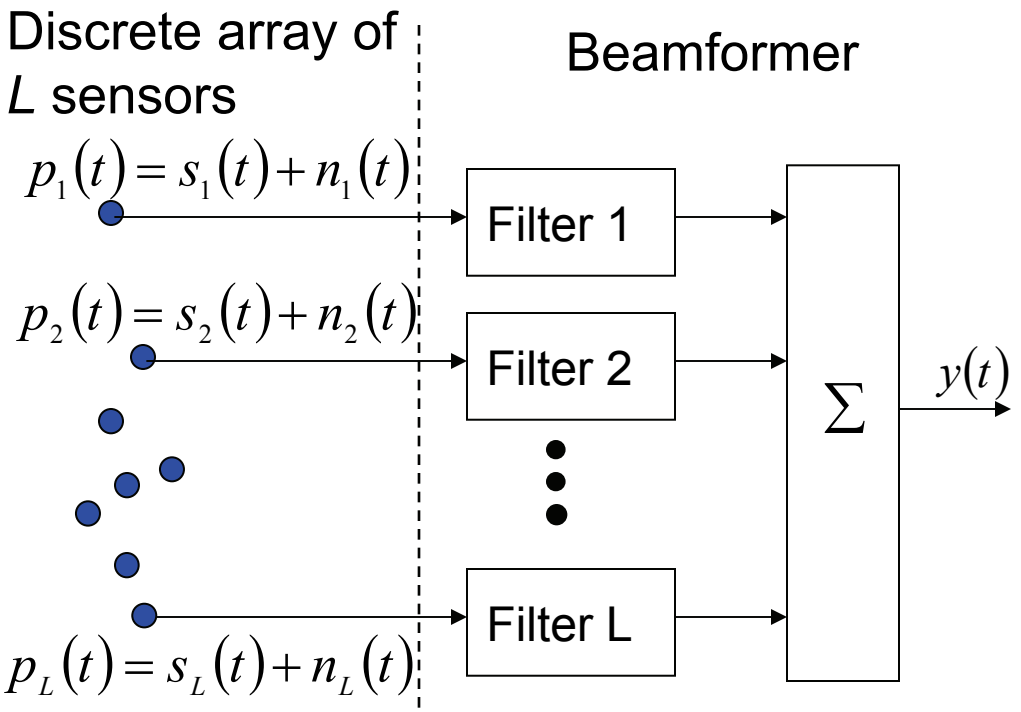


$$y(f) = \sum_l w_l^*(f) p_l(f)$$
$$= \mathbf{w}^H(f)\mathbf{p}(f)$$

Filter bank design will depend on array geometry, on source directivity, orientation, and position as well as array output optimization criterion

Beamforming on a Point Source





$$y(f) = \sum_l w_l^*(f) p_l(f)$$
$$= \mathbf{w}^H(f)\mathbf{p}(f)$$

Must know how the source radiates to coherently sum the received signals at the microphones: source model

Conventional beamforming: point source as source model

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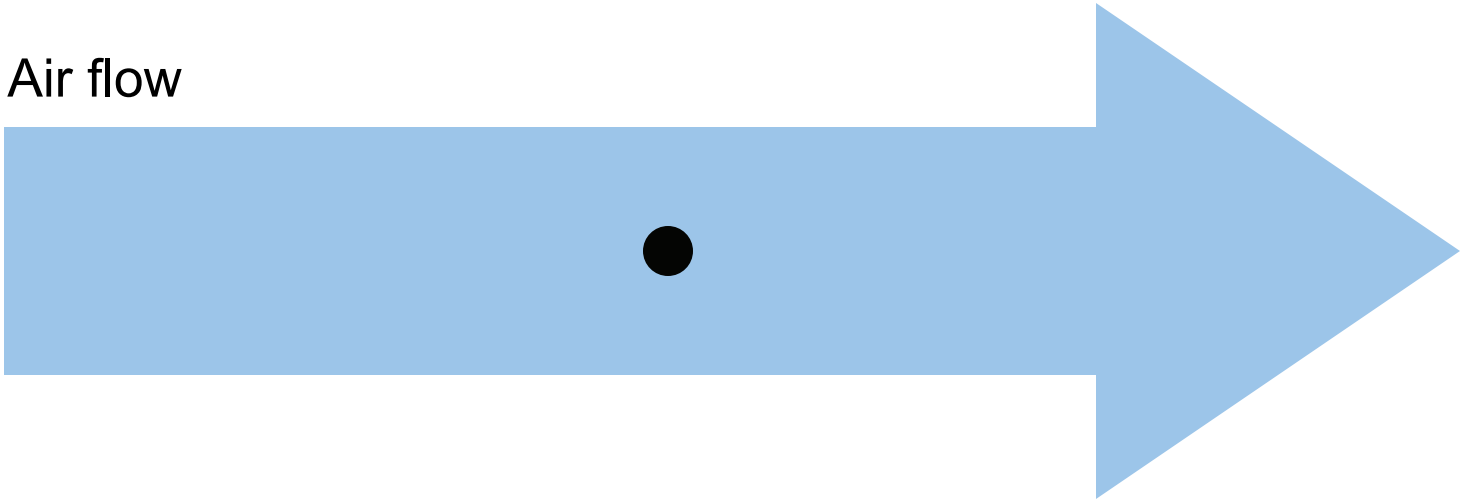
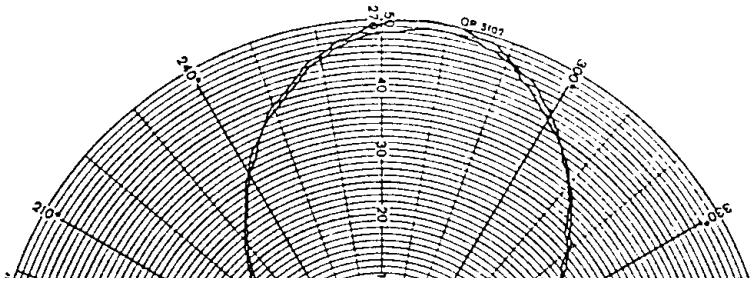
Aeroacoustics

Example: Solid object in an air flow

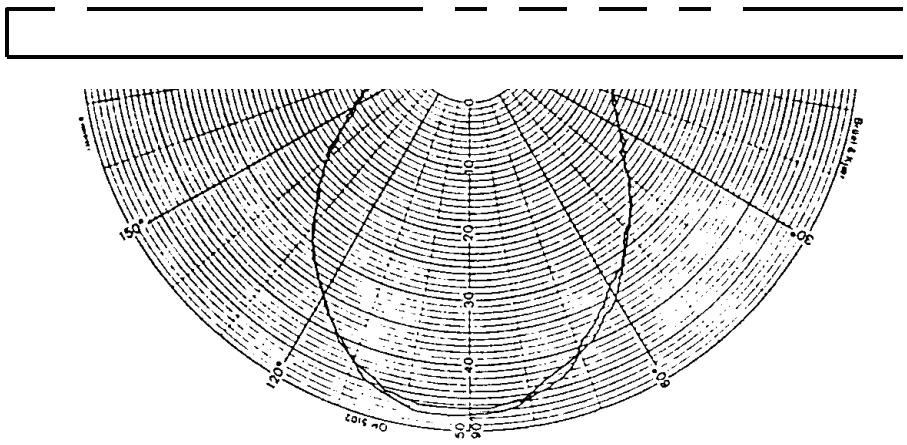


Measurements of Flute Directivity, With G Fingering (IRCAM)

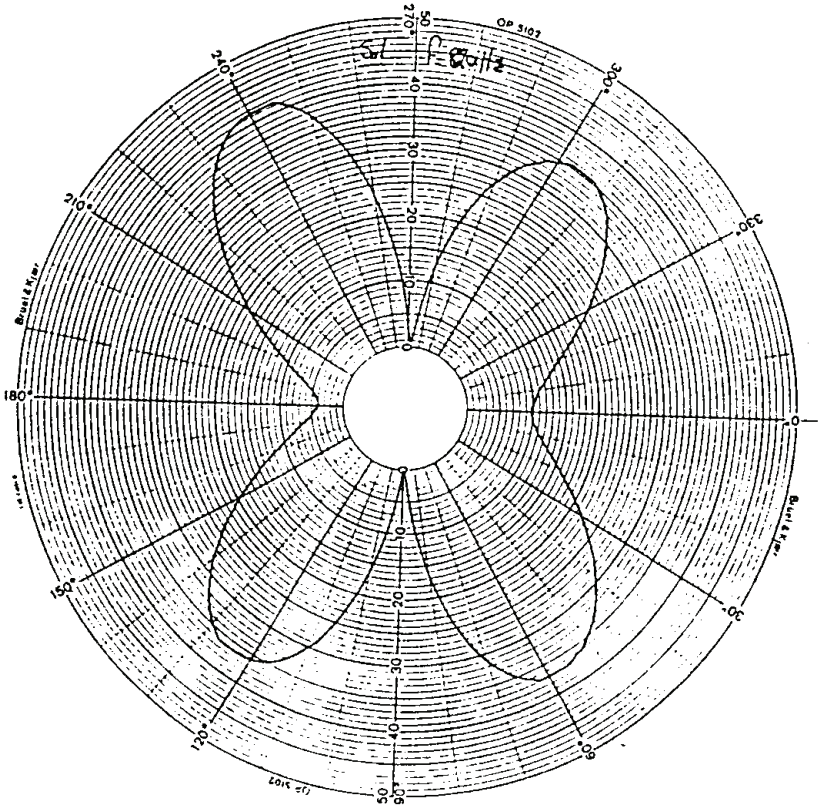
Fundamental 410 Hz



Mouth hole Tone holes



Overtone, 820 Hz



From: A. Rousseau, Institut de Recherche et Coordination Acoustique/Musique (IRCAM), Département d'acoustique instrumentale (IRCAM), Paris, May 1996.

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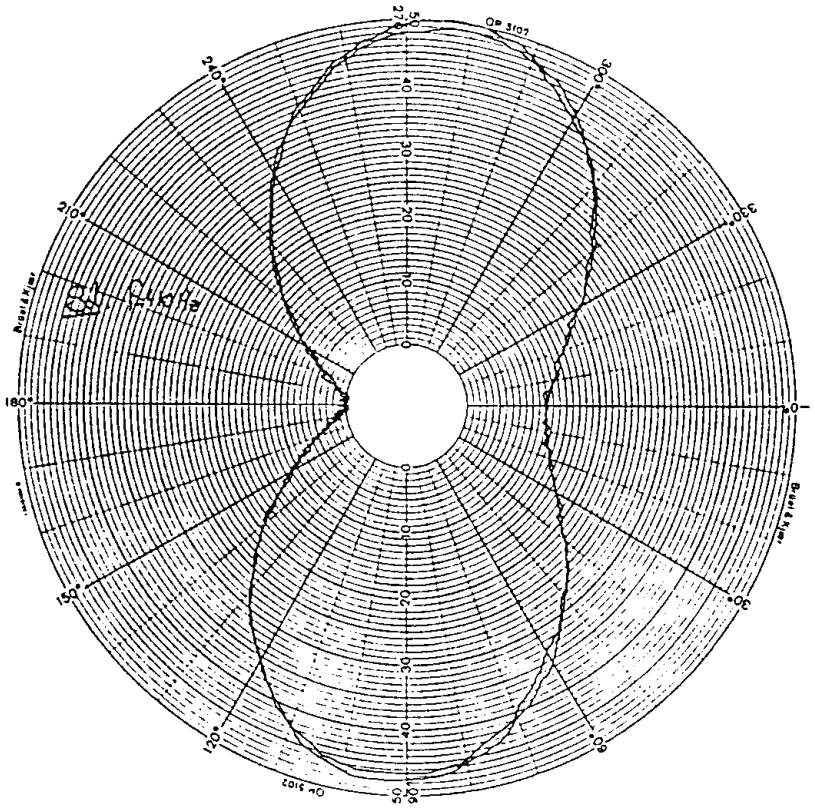

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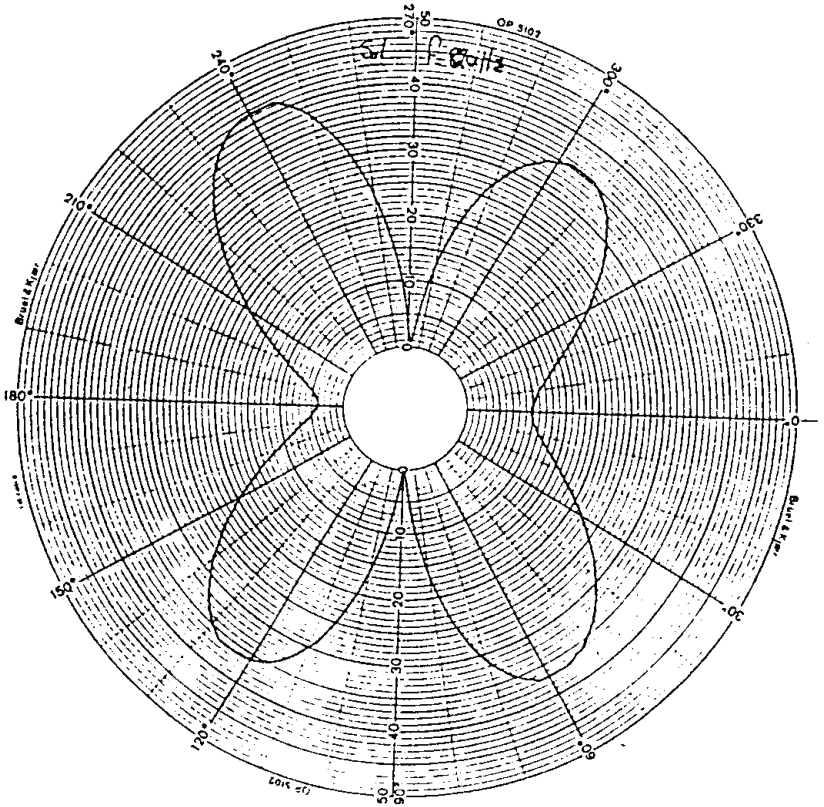

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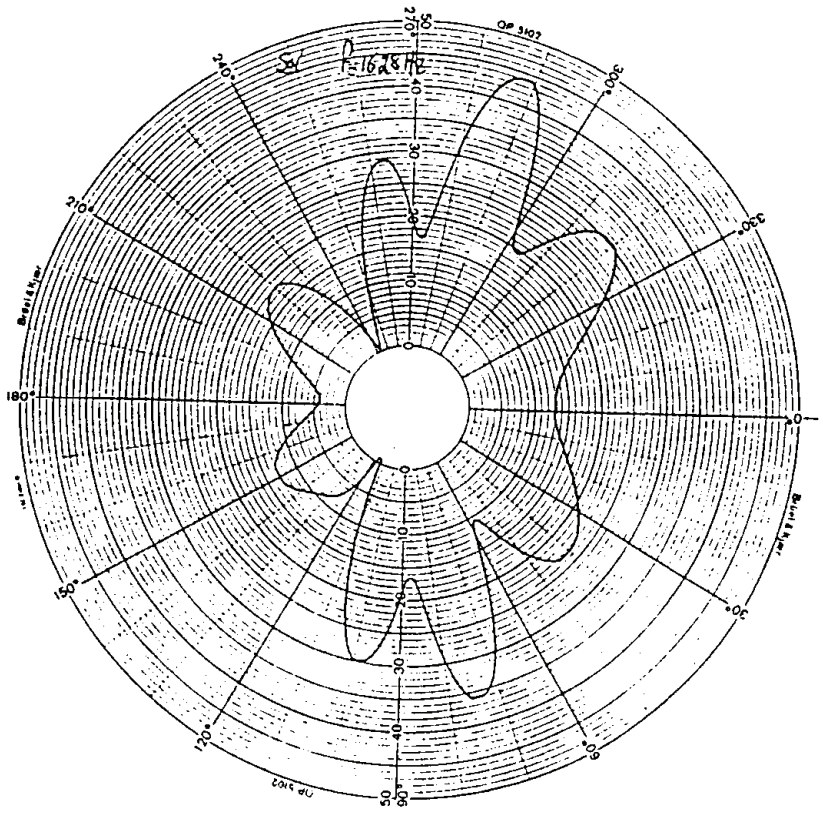
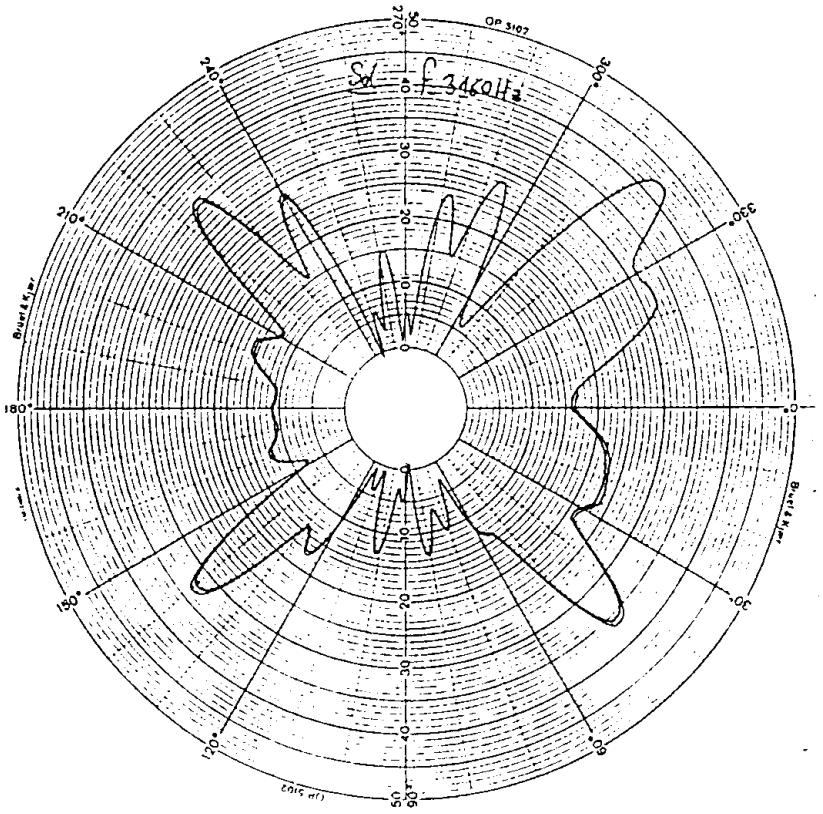
Overtone, 1628 Hz



Overtone, 3160 Hz



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Performance measures: Array Gain

Improvement in SNR

$$\text{Array gain} = \frac{\text{SNR at output of the array}}{\text{SNR at input of the array}}$$

$$\frac{\dfrac{\mathbf{w}^H(K)\mathbf{s}(K)\mathbf{s}^H(K)\mathbf{w}(K)}{\mathbf{w}^H(K)E\{\mathbf{n}(K)\mathbf{n}^H(K)\}\mathbf{w}(K)}}{\dfrac{\mathbf{s}^H(K)\mathbf{s}(K)_{/L}}{E\{\mathbf{n}^H(K)\mathbf{n}(K)\}_{/L}}}$$

White-noise gain is maximized when the source model and the source have the same

- directivity
- position
- orientation

Maximum white-noise gain equals the number of microphones

Performance measures: Directivity factor

Definition for a point source in the far-field of a receiving array:

$$\text{Directivity factor}\left(\theta_T, \phi_T\right) = \frac{\text{Array output power for direction of arrival}\left(\theta_T, \phi_T\right)}{\text{Array output power due to spherically isotropic noise}}$$

Possible definition for directional sources

$$\text{Directivity factor}\left(\text{Source directivity and orientation}, r_T, \theta_T, \phi_T\right) = \frac{\dfrac{\text{Array output power for a given source located at}\left(r_T, \theta_T, \phi_T\right)}{\text{Source Power at center of array}}}{\text{Array output power due to spherically isotropic noise}}$$

Directional Sources and Beamforming

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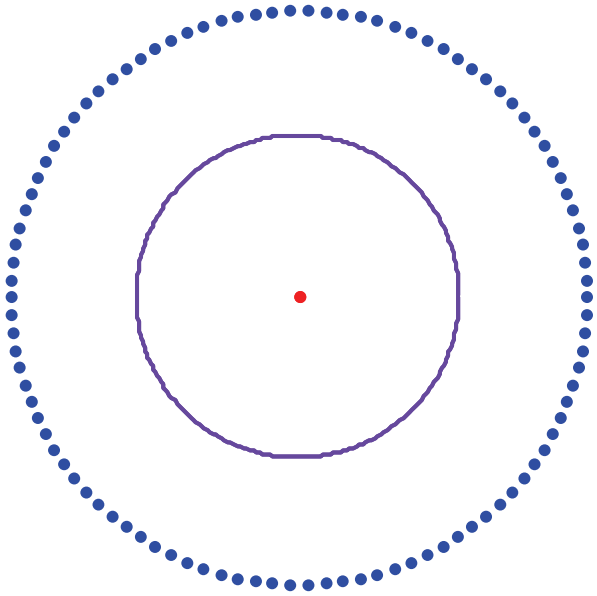
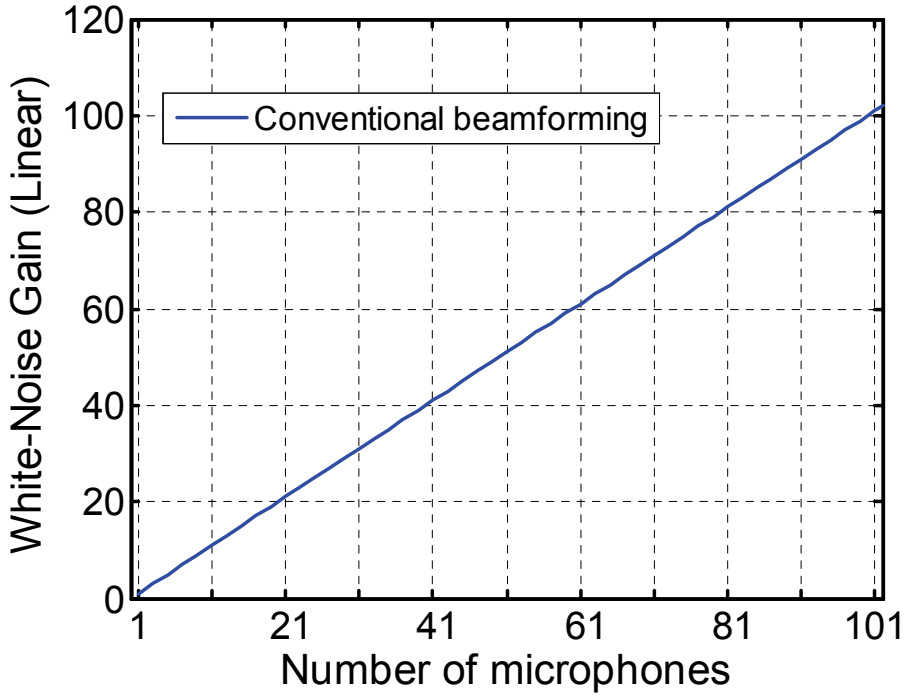
Beamforming on a Point Source

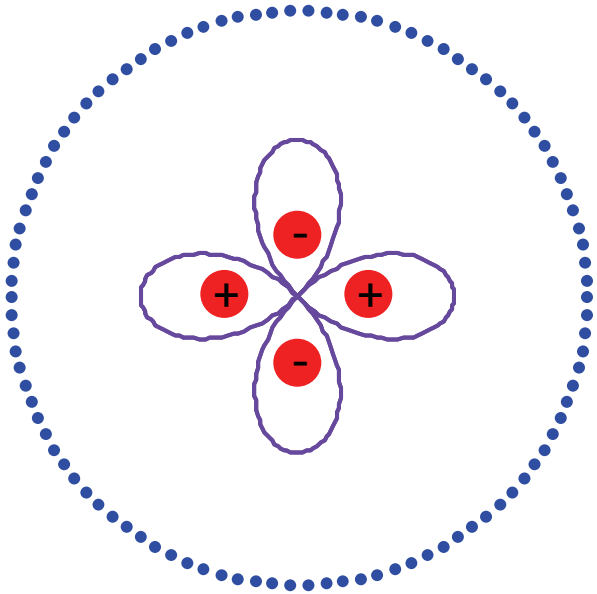
Array Geometry and Source

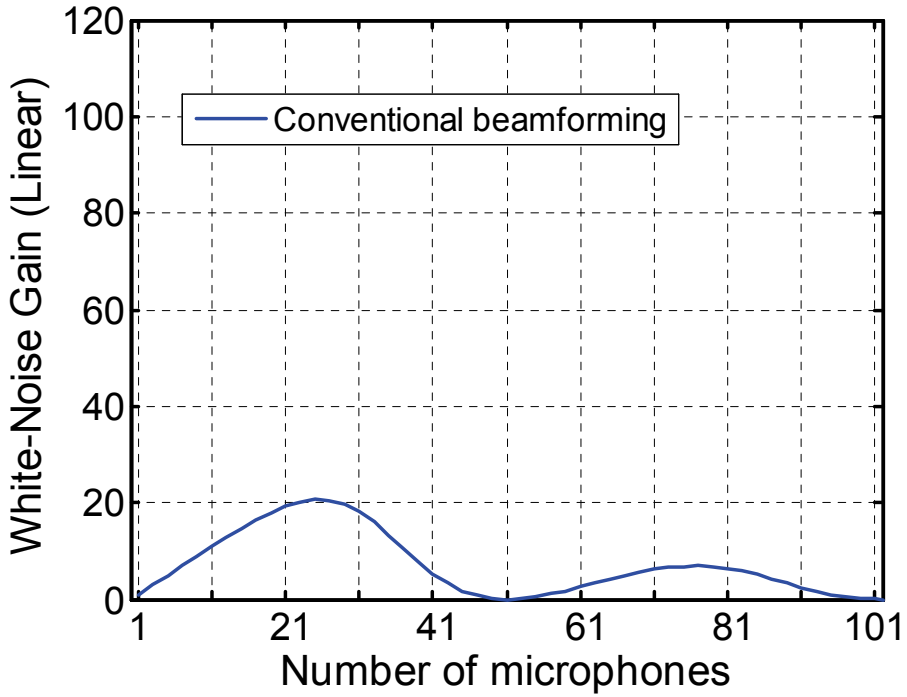




Beamforming on a Quadrupole

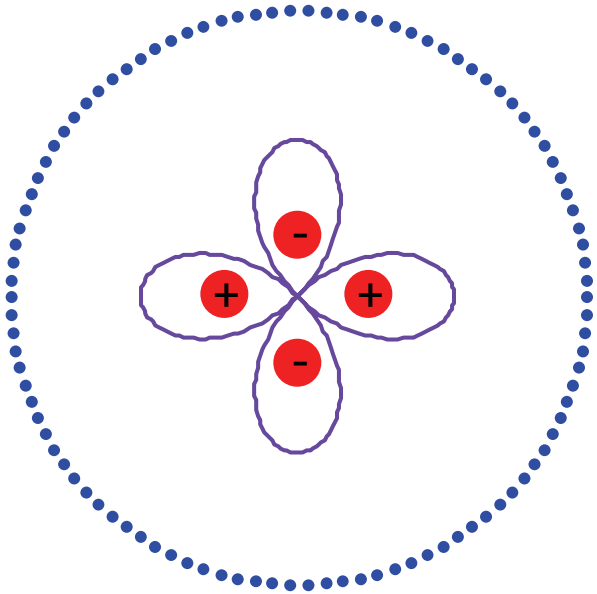
Array Geometry and Source

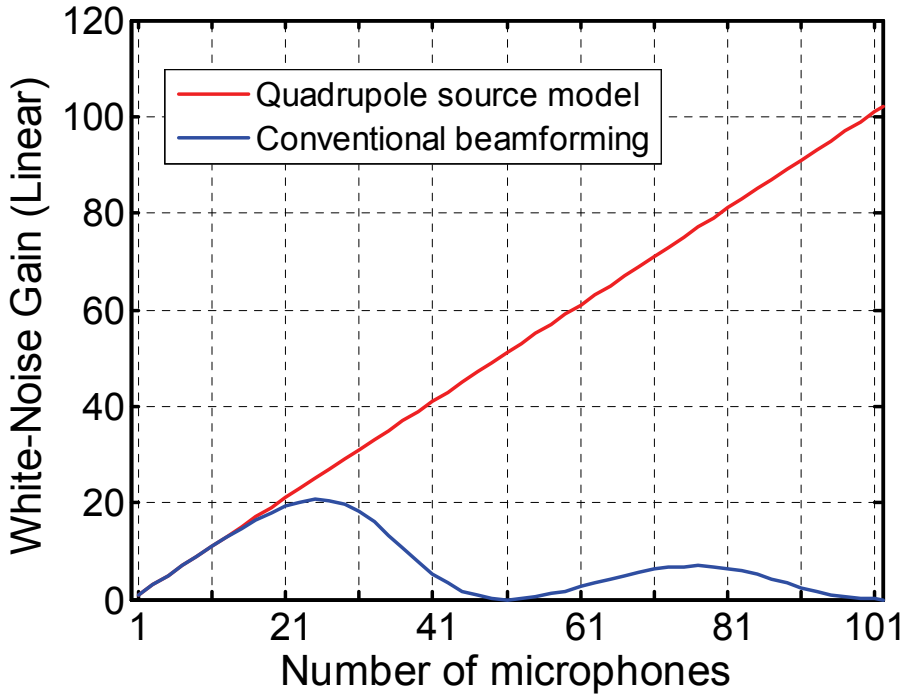




Beamforming on a Quadrupole

Array Geometry and Source





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Challenges for Beamforming on Non-Point Sources

- Often necessary to estimate the source directivity and orientation
- The source model needs to be computationally efficient (finite template sets?)
- Source directivity estimators may be affected by the presence of interferers
- Source directivity may change with frequency
- Array located in a directional null

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