Microphone arrays fundamentals

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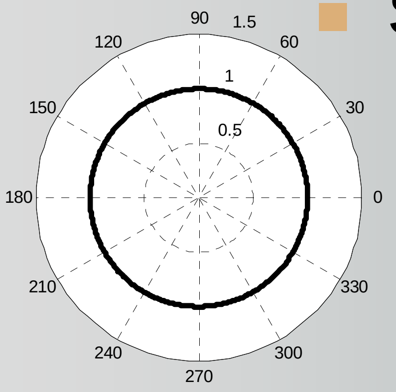
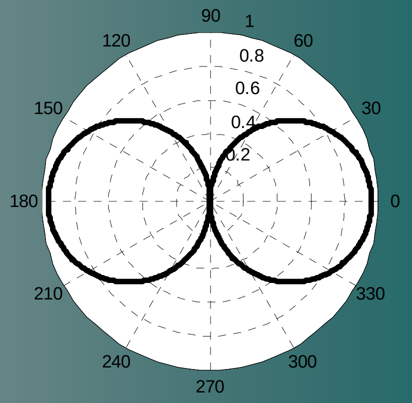
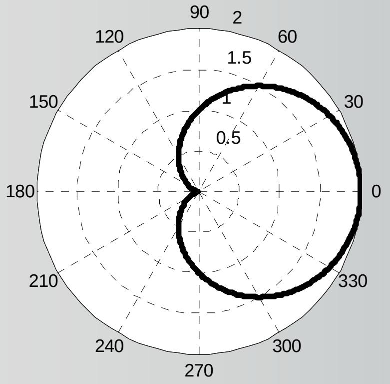
- Single microphones



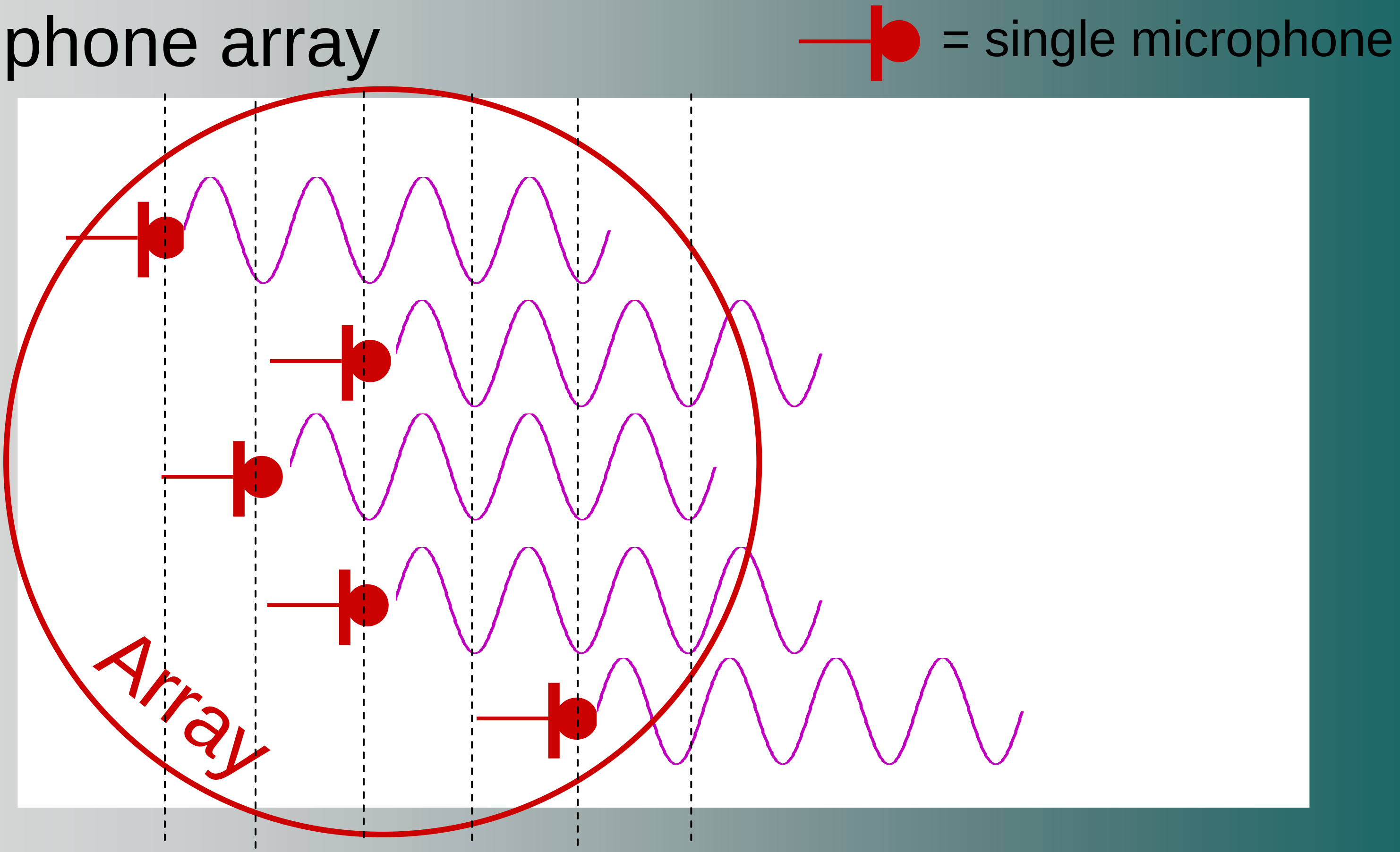
  - omnidirectional
  - bi-directional (figure-eight)



  - unidirectional (cardioïd)



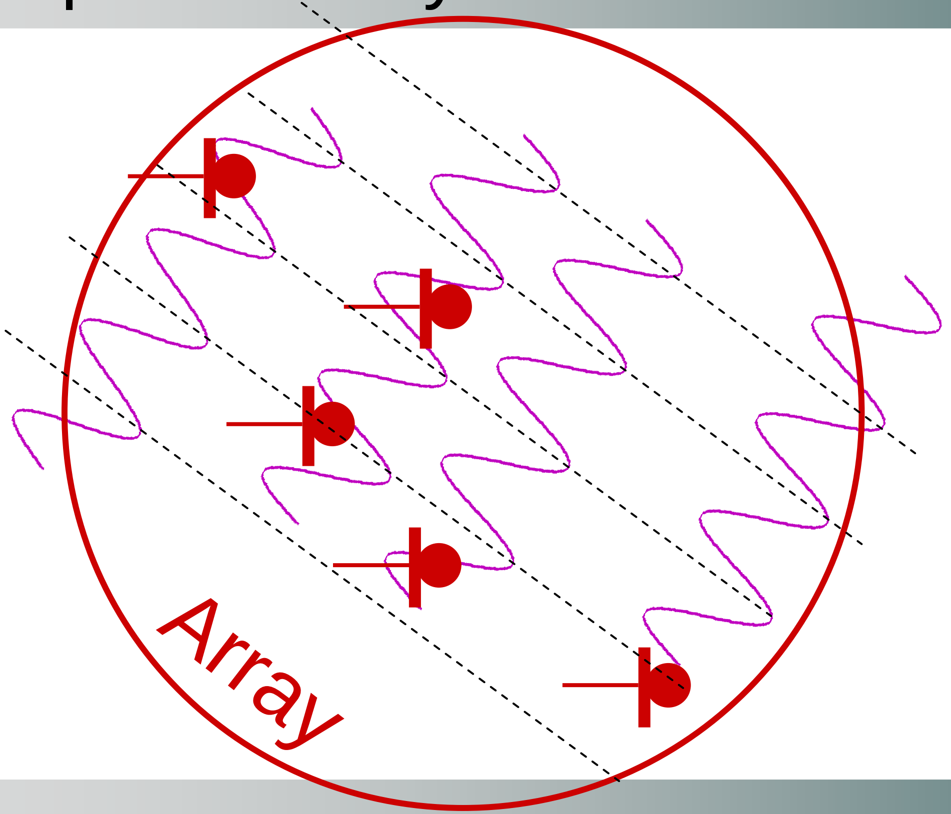
- Microphone array



In-phase: constructive interferences

- Microphone array

● = single microphone



Phases all different : destructive interferences

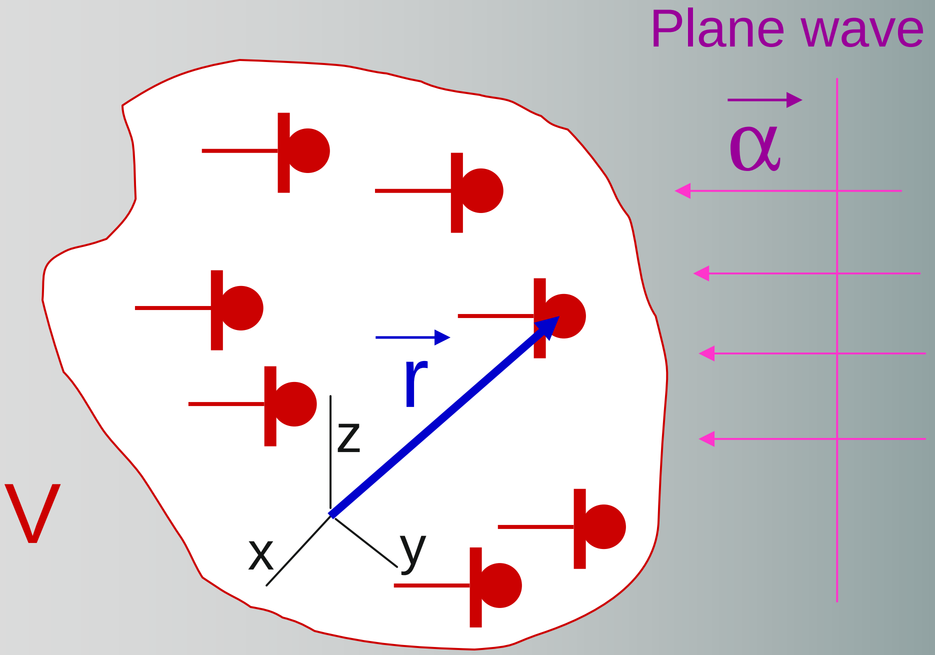
- Main references:

« Microphone arrays », Brandstein & Ward, Eds, Springer (2001)

« Microphone arrays: a tutorial », I. Mc Cowan, (2001)

http://www.idiap.ch/~mccowan/arrays/tutorial.pdf

- Theoretical expression of the directivity



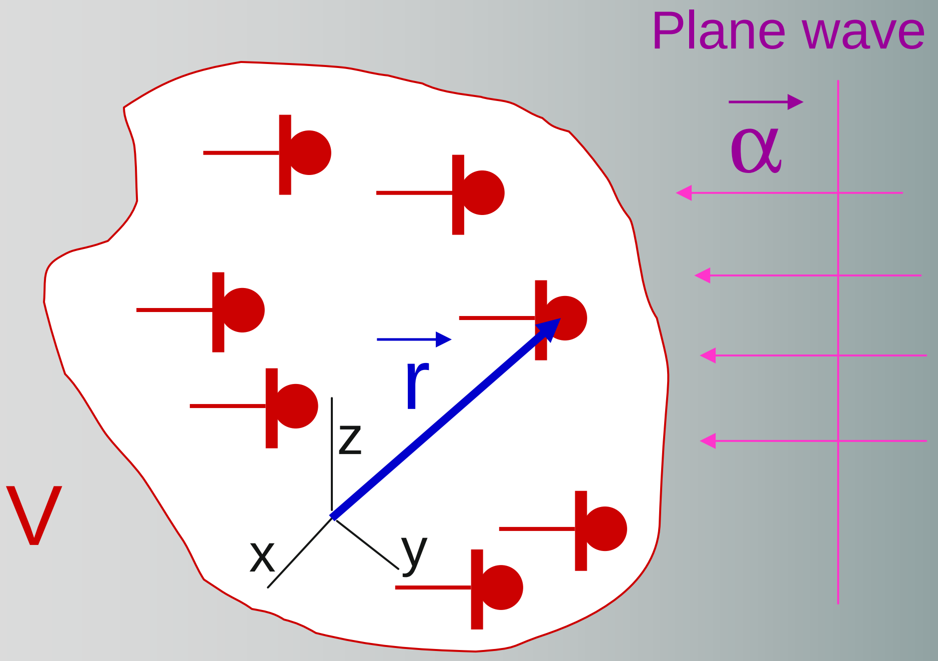
Response of 1 microphone:

$$X(f,\vec{r}) = P(f,\vec{r}).\,A(f,\vec{r})$$

Pressure

Aperture function

- Theoretical expression of the directivity



Directivity of the array:

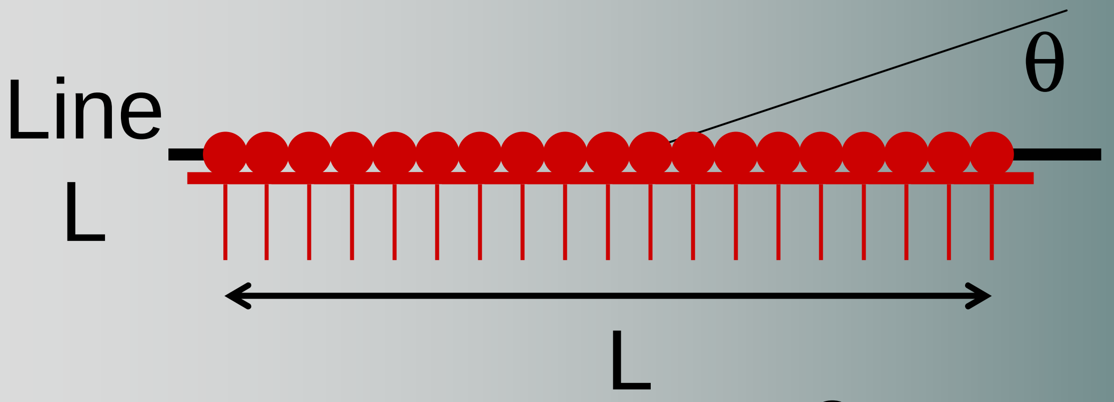
$$D(f,-\vec{\alpha}) = \int_V A(f,\vec{r}).\,e^{-jk\vec{\alpha}\bullet\vec{r}}\,dV$$

Pressure

Aperture function

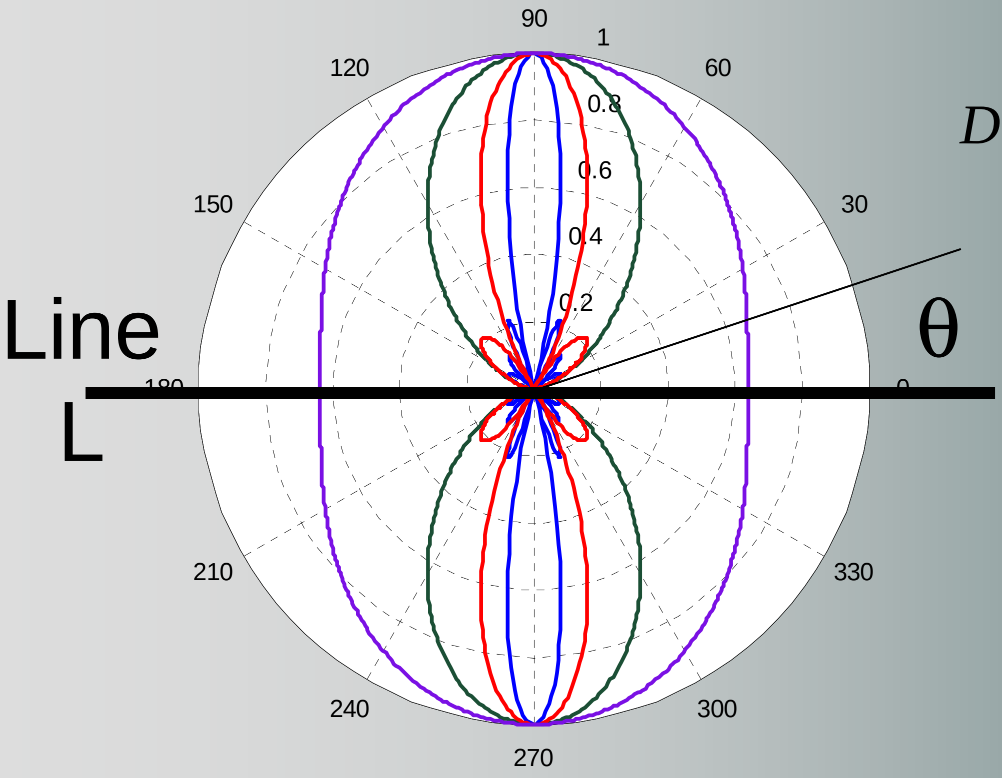
- Example: directivity of a continuous, linear array

$$D(f,\theta,\varphi) = A.L.Sinc\left(\frac{\pi.\cos\theta.L}{\lambda}\right)$$



Constant aperture : A(f,r) = A

- Example: directivity of a continuous, linear array



$$D(f,\theta,\varphi) = A.L.Sinc\left(\frac{\pi.\cos\theta.L}{\lambda}\right)$$

$L/\lambda = 0.5$

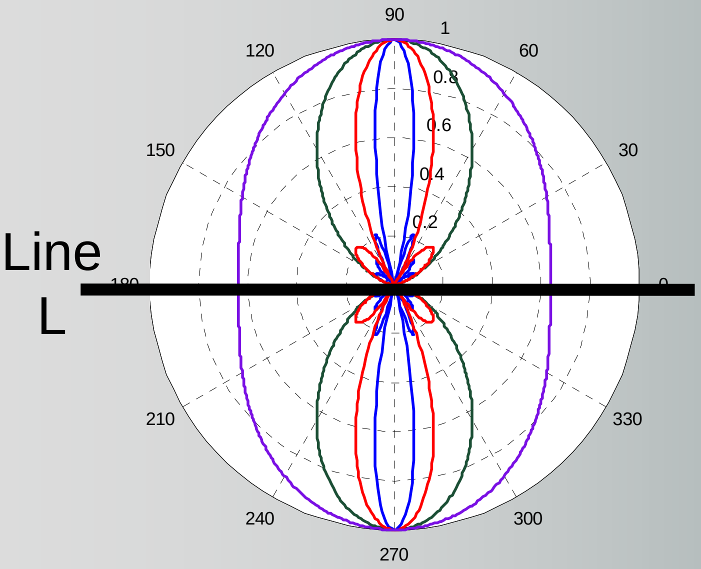
$L/\lambda = 1$

$L/\lambda = 2$

$L/\lambda = 4$

Main lobe:
Beam width ./. (1/fL)

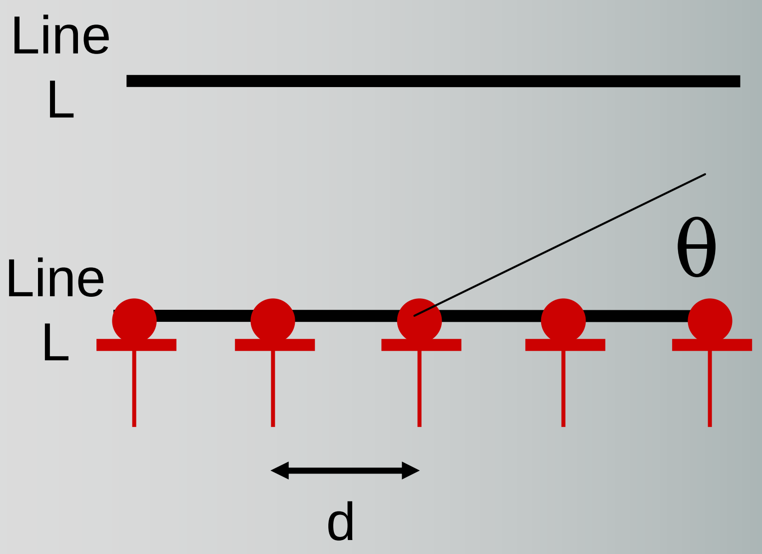
- Example: directivity of a <u>continuous</u>, <u>linear</u> array



For a given length L of the array, the directivity is essentially frequency dependent if the aperture function A is constant.

Discrete microphone arrays and aliasing

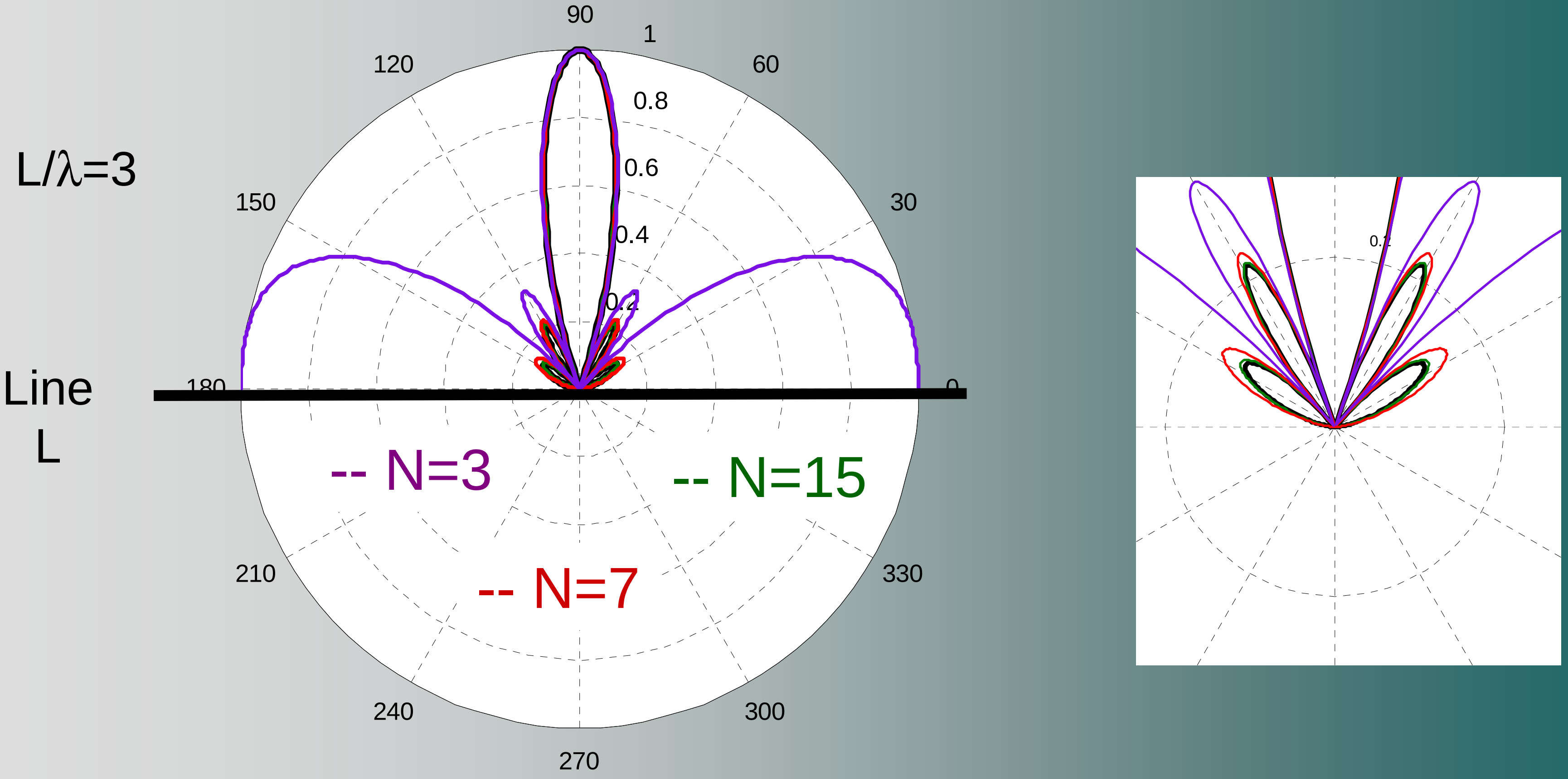
Discrete array = spatial sampling



$$D(f,\theta,\varphi) = A.L.Sinc\left(\frac{\pi.\cos\theta.L}{\lambda}\right)$$

$$D(f,\theta,\varphi) = \sum_{n=-(N-1)/2}^{(N-1)/2} A_n(f).e^{jknd\cos\theta}$$

- Discrete microphone arrays and aliasing

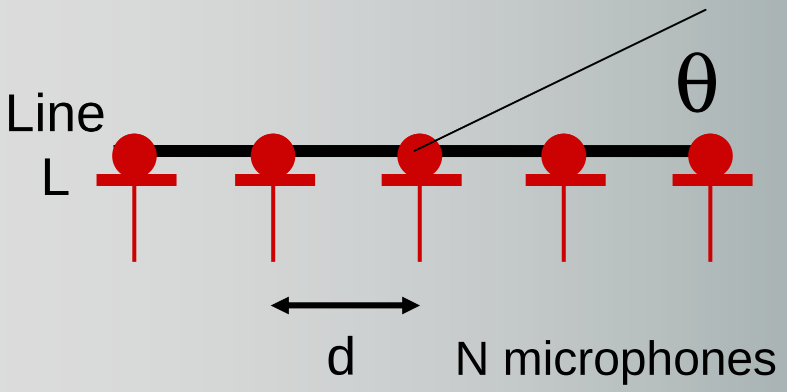


Beamforming

« Beamforming is a method to discriminate between signals, based on the physical locations of the sources»
Brandstein & Ward (2001)

Beamforming techniques include:
- beam shaping, and
- beam steering.

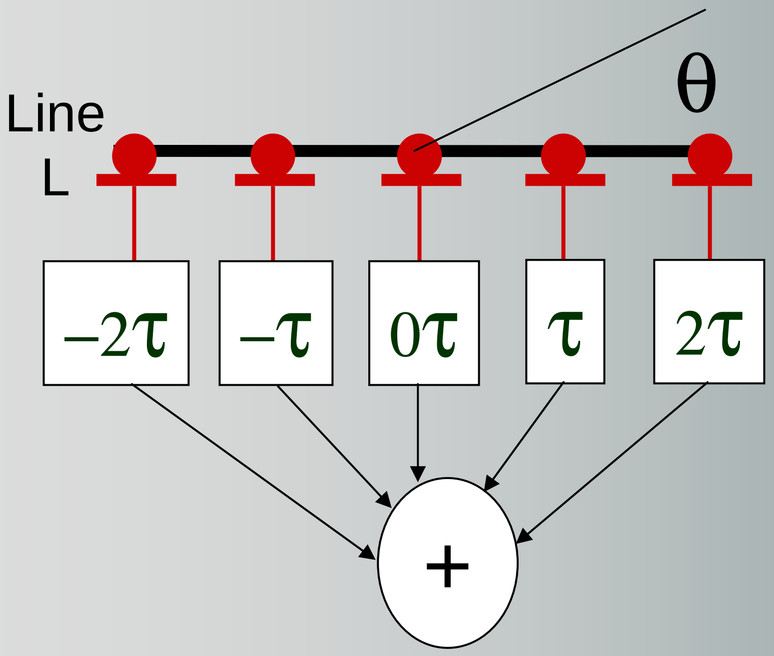
Beamforming: example of a discrete linear array



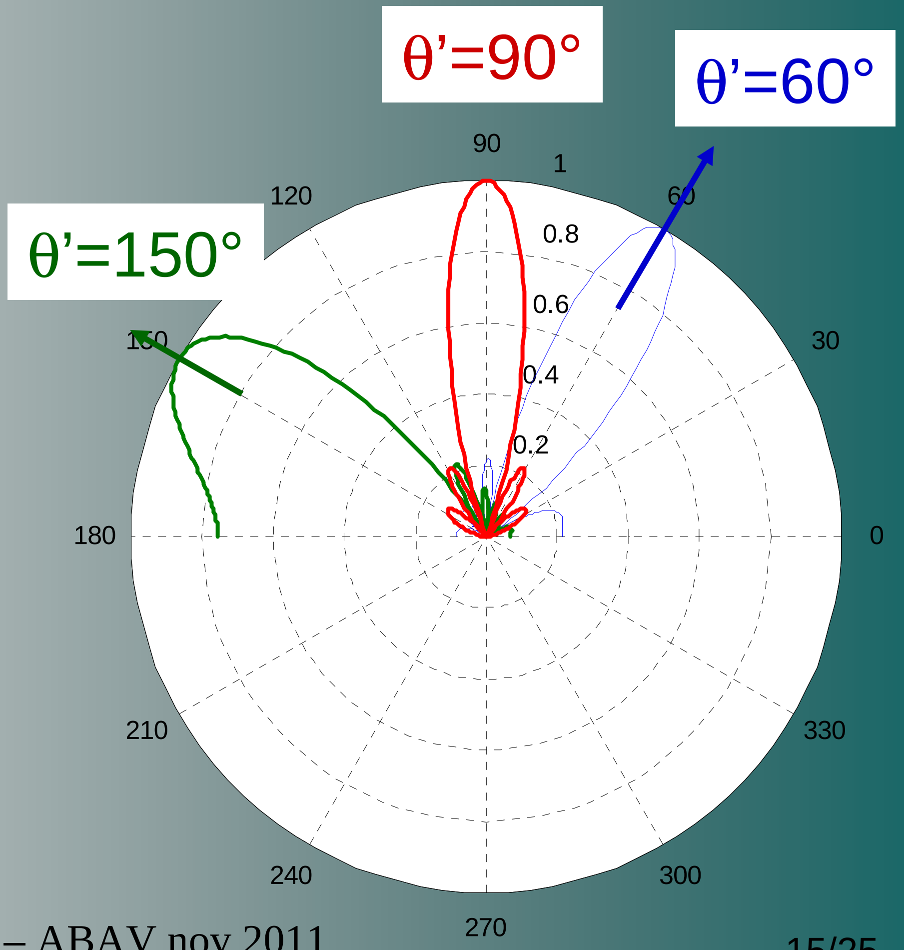
$$D(f,\theta,\varphi)=\sum_{n=-(N-1)/2}^{(N-1)/2} A_n(f).\,e^{jknd\cos\theta}$$

$$\underbrace{\left|A_n(f)\right|}_{\text{Beam shaping}}.\,\underbrace{e^{j\phi_n(f)}}_{\text{steering}}$$

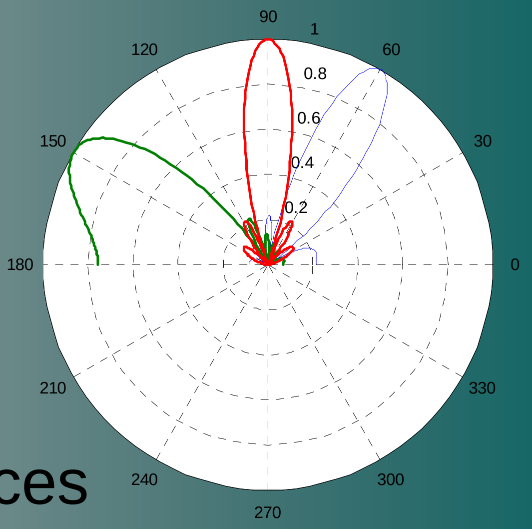
Beamforming: **delay-and-sum beamforming**



$$\tau = d.\cos\theta'/c$$



Source localization and steering

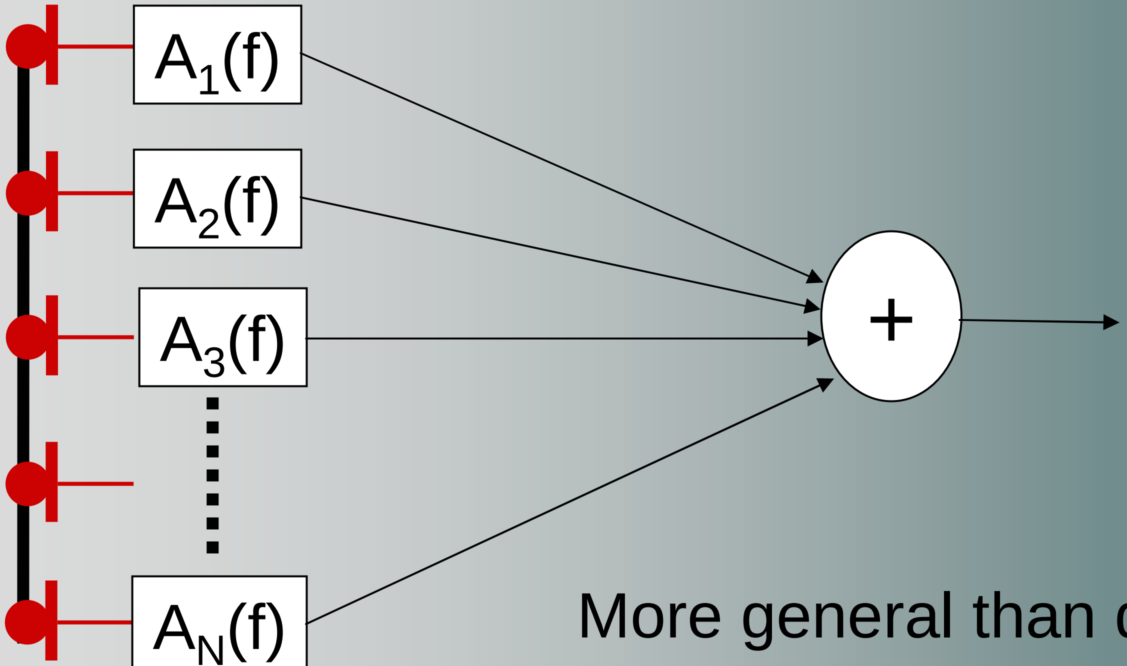


Automatic search of a source localization,

- by steering the array and searching for a maximum in output power,

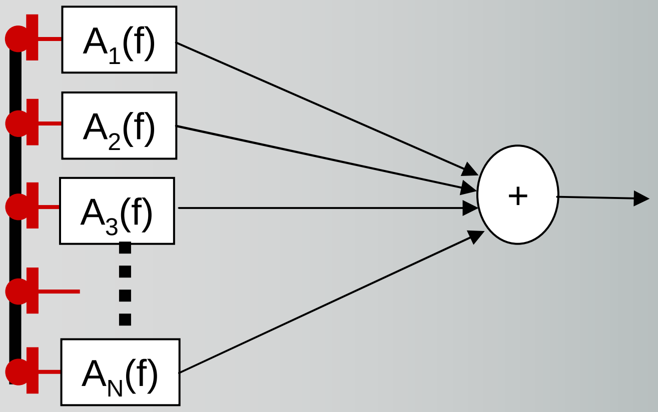
- or by estimating the delays (time differences of arrival) between each microphone and a reference microphone chosen in the array.

- Beamforming: **filter-and-sum beamforming**



More general than delay-and-sum:
the amplitude and phase of the aperture functions are different at each microphone.

Beamforming: **filter-and-sum beamforming**



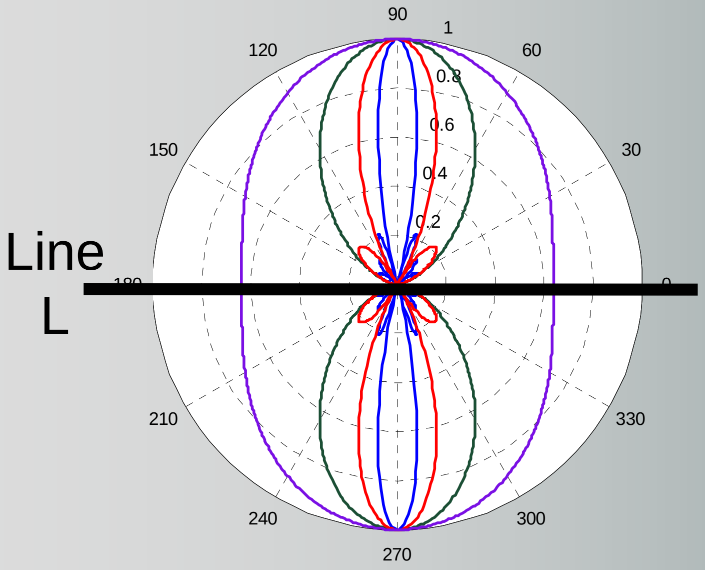
Some applications:

-To maximise the SNR in a particular direction (e.g. noise=diffuse field).

- Adaptive beamforming : $A_i(f)$ depend on the input signals.

- Constant directivity beamforming.

Constant directivity beamforming (CDB)

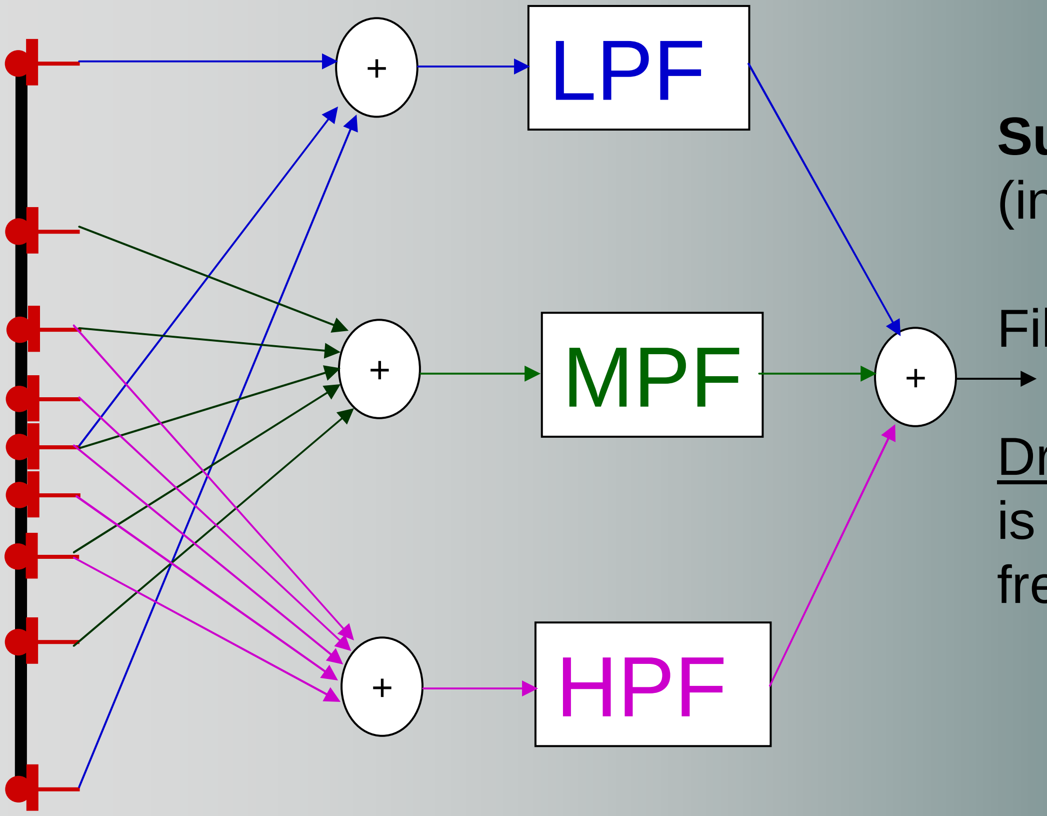


Without beamforming, the width of the main lobe depends on the product (f.L).

Objective of CDB: a constant directivity in a broad frequency interval.

Method: to work with longer arrays at low frequencies.

Constant directivity beamforming (CDB)



Sub-array structure
(inspired by McCowan, 2001).

Filter-and-sum structure.

Drawback: the total size is related to the lowest frequency of operation.

Conclusions

- Microphone arrays allow for sharp and controlled directivities.

- The main application is beamforming, including beam steering and shaping.

- Discrete arrays can create aliasing at high frequencies.

- Constant directivity can be obtained using appropriate signal processing.