Caracterization of noise sources on train using beamforming

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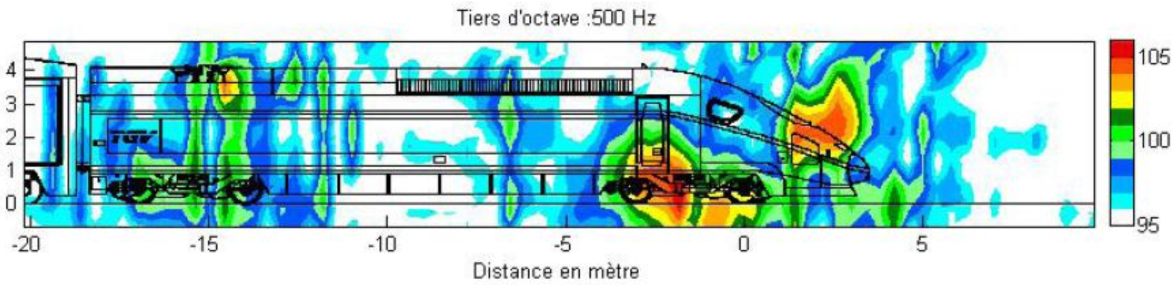
1.Context

Bypass measurements

Array processing



Yesterday [Poisson 95]

Noise map of the train

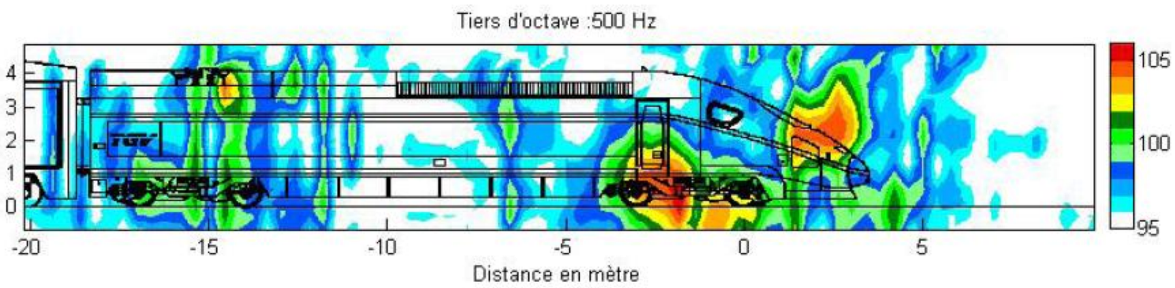
1.Context

Bypass measurements

↓

Array processing

↓



Yesterday

Noise map of the train

Today

Sources caracteristics

↓

Bypass sound prediction at different speeds, different configurations, etc.

[Bongini08]

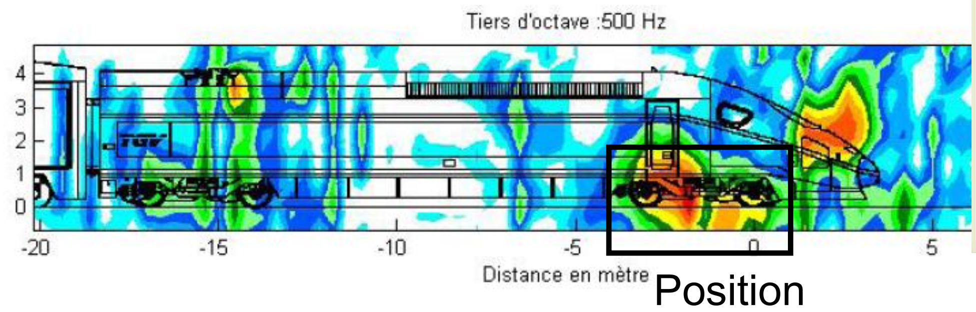
1.Context

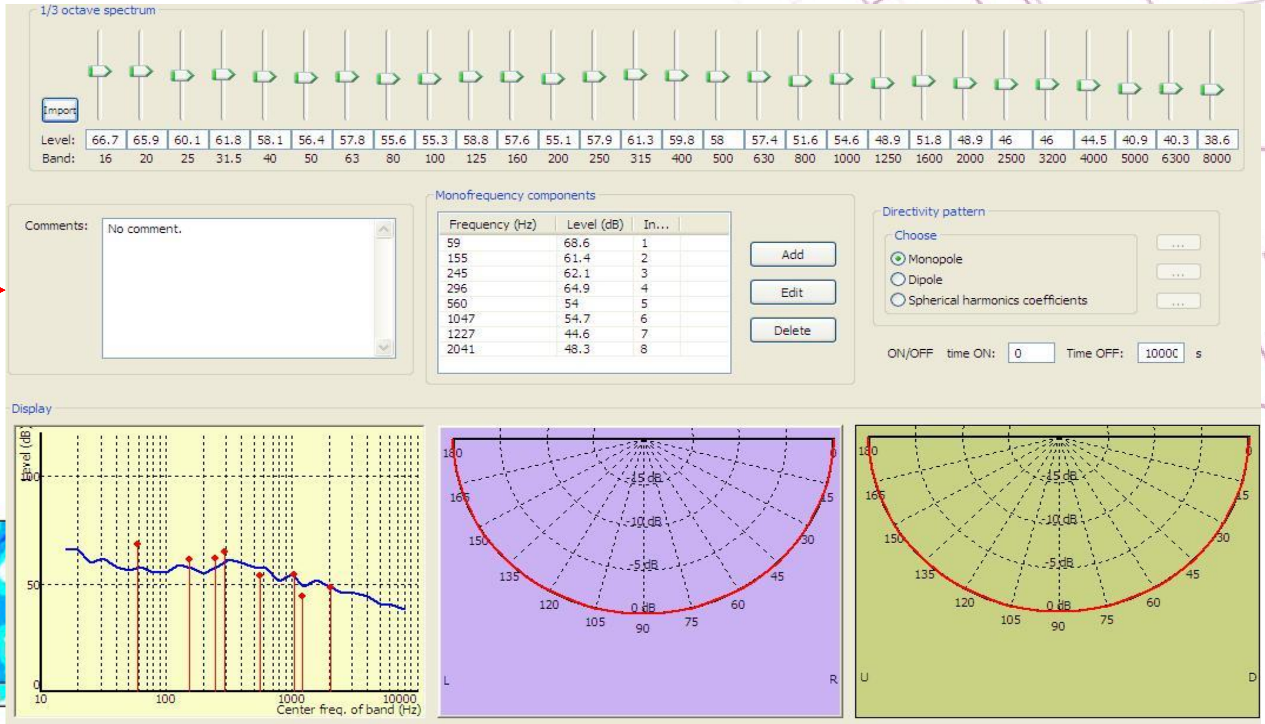
Bypass measurements

↓

Array processing

↓





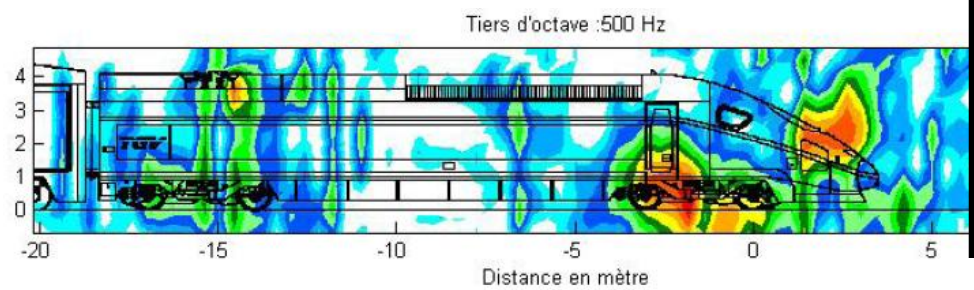
1.Context

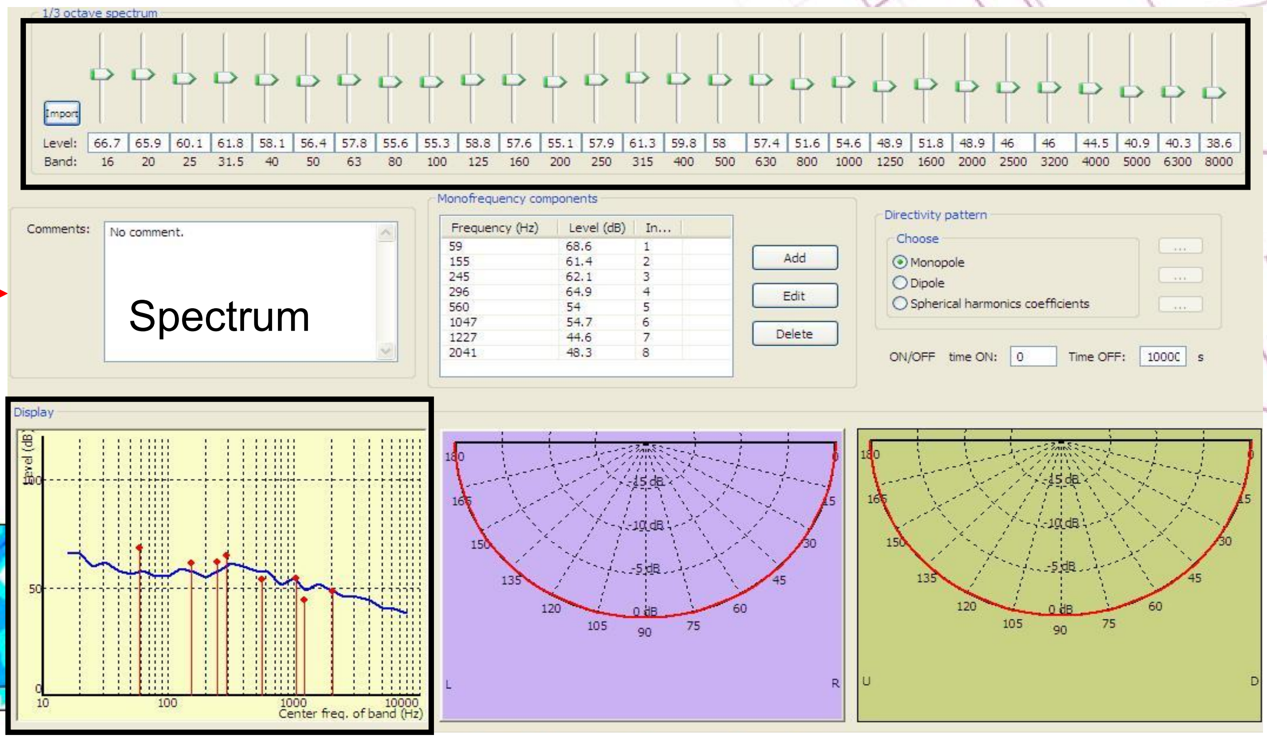
Bypass measurements

↓

Array processing →

↓





1.Context

Bypass measurements

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Array processing →

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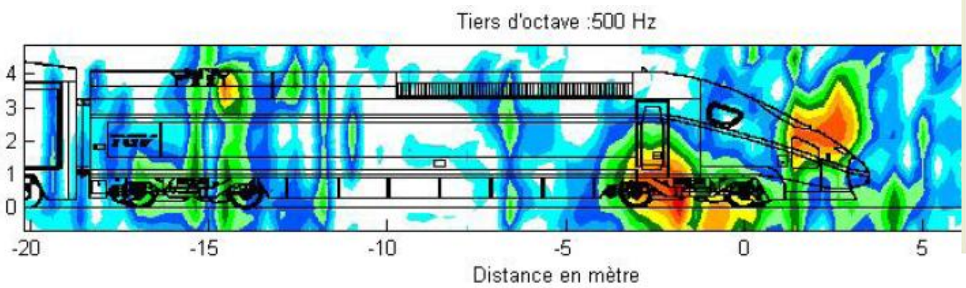

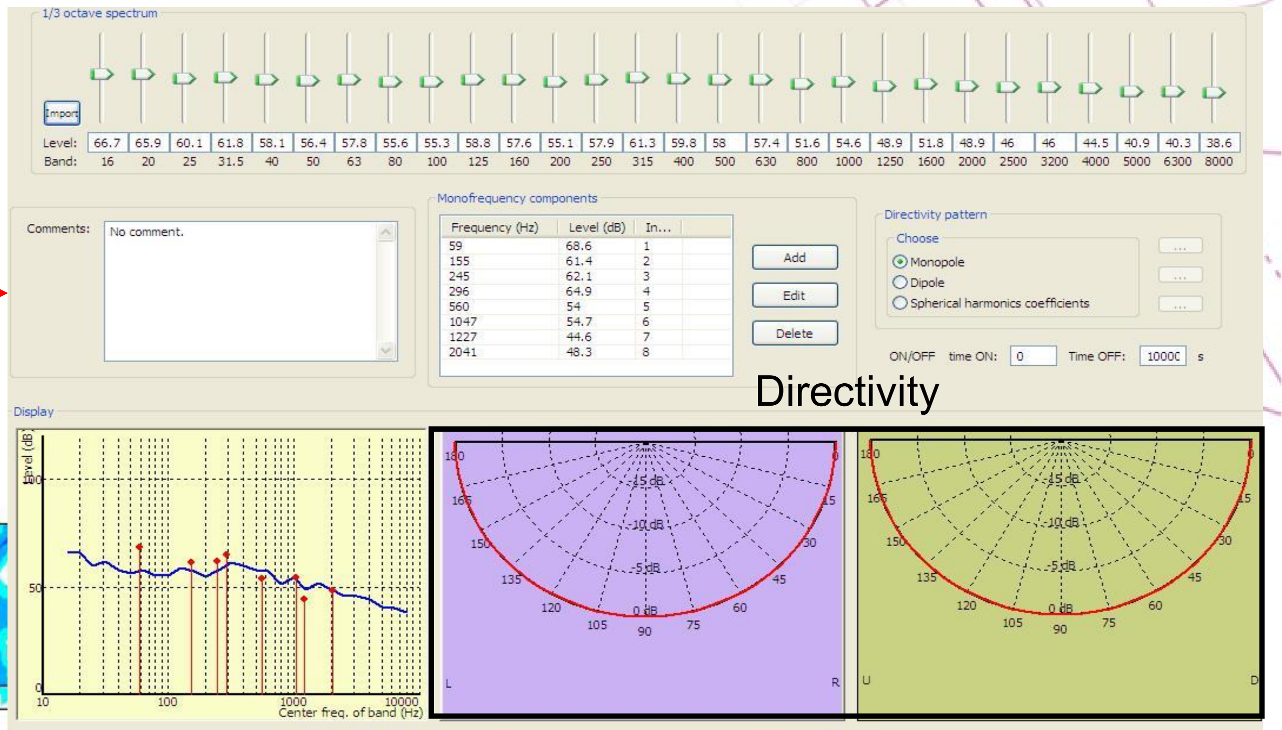

1.Context

Bypass measurements

↓

Array processing →

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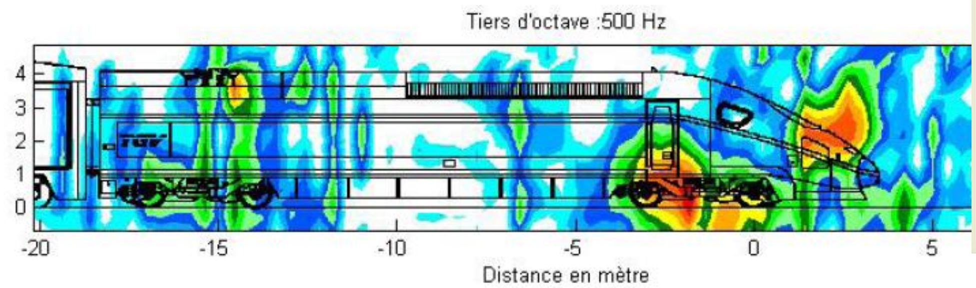

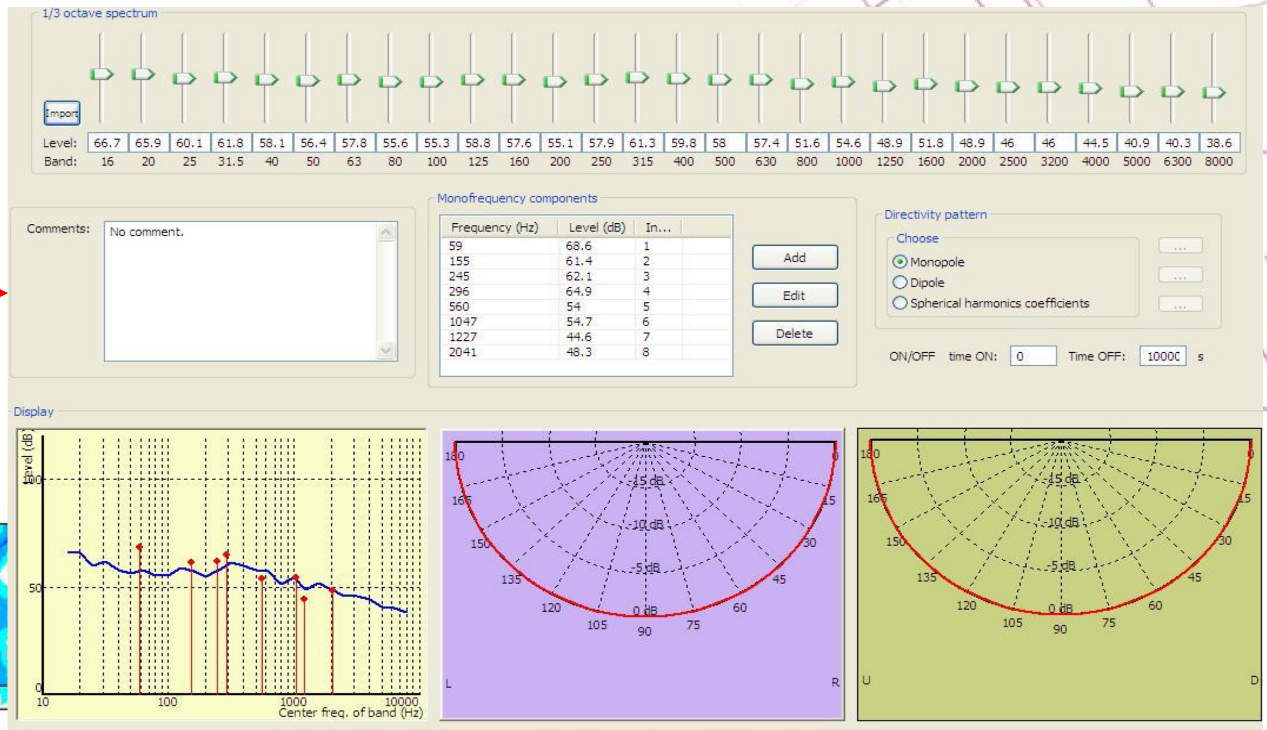

- Necessity of a better caracterization of the acoustical sources on the train
- Developpement of an adapted array processing to obtain those caracteristics

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1.Context

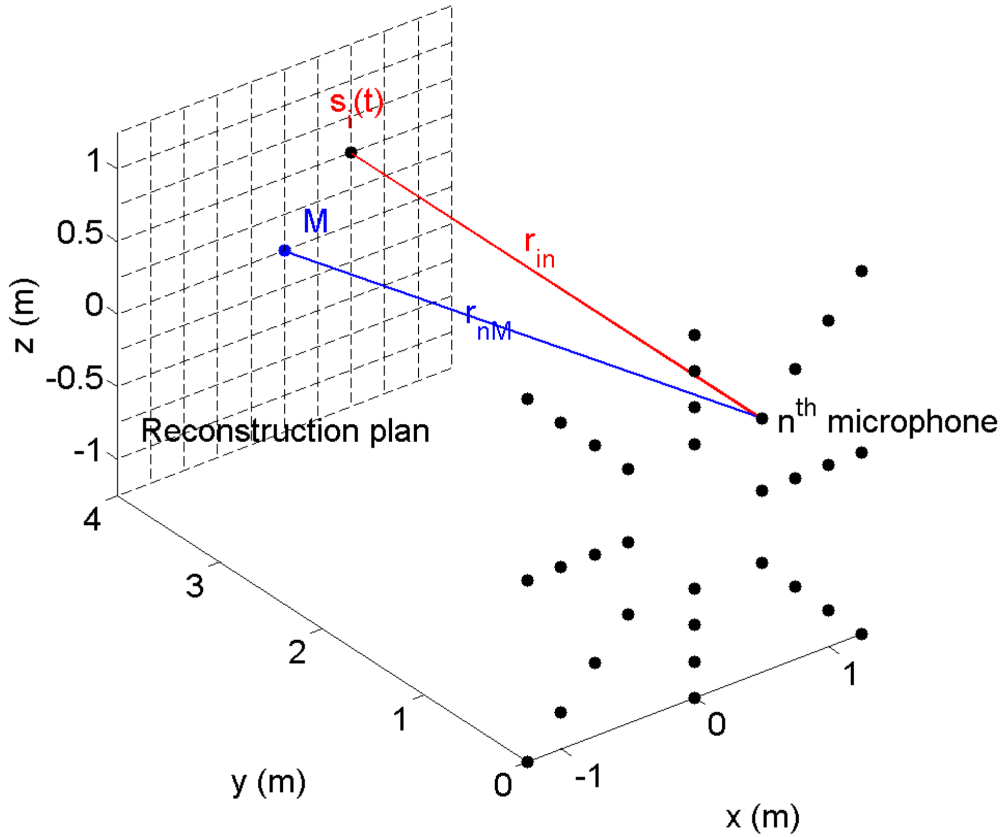
Objectives of the thesis:

- This method should be able to provide the sources characteristics:
  - Sources position ± 0.5 m
  - Sources spectrum ± 20 Hz
  - Sources radiation directivity
  - Sources power
- Computation time must be acceptable

- Use beamforming to estimate the rail and wheel contribution to rolling noise

2.Beamforming

1. Basics



Output of the arrays, p_n, are time advanced and summed to an arbitrary focus point M

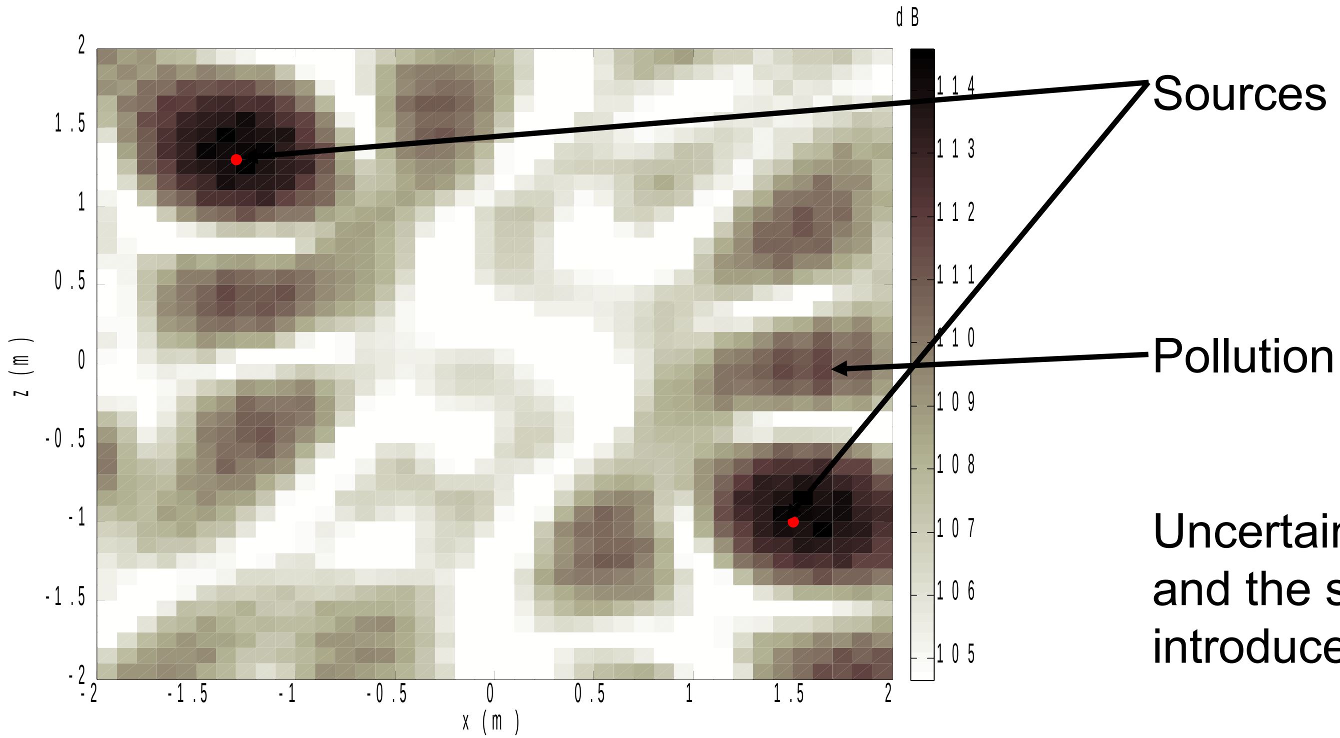
The geometric attenuation is also compensed

$$x_M(t) = \sum_{n=1}^{N} (4\pi r_{nM})\, p_n(t + r_{nM}/c)$$

x_M is the estimation of the acoustic radiation at M

2.Beamforming
1. Basics

By focusing in several M point, a reconstruction plan is created and the sources distribution is estimated



Uncertainty on the level estimation and the sources positions are introduced by the array response

Beamforming operates a filtering operation around the focusing point, the representation of the filter is the beampattern

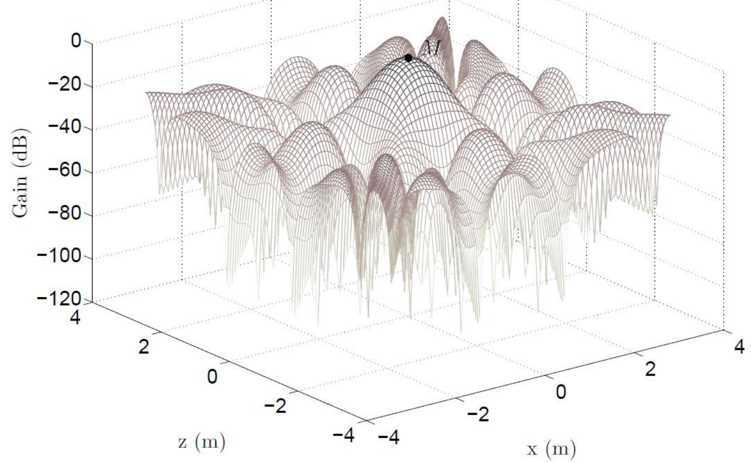
$$D_{M,f} = \left| \sum_{n=1}^{N} \frac{r_{nM}}{r_{in}} \exp\left(2i\pi f \frac{r_{nM} - r_{iM}}{c} \right) \right|^2$$

It represents the contribution of the i^{th} source in the estimation of the radiation in *M*

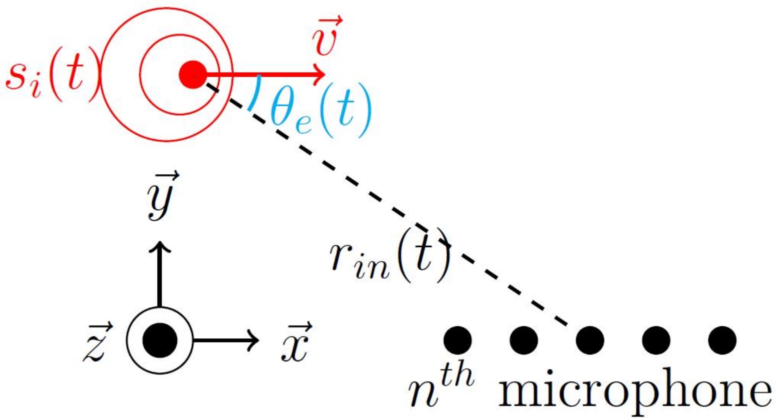
The beampattern depends mainly on the microphones placement toward the focus point and the frequency

The beampattern has the aspect of a cardinal sine, with a maximum in M and sidelobes which pollute the estimation

For the star shaped array at 800 Hz

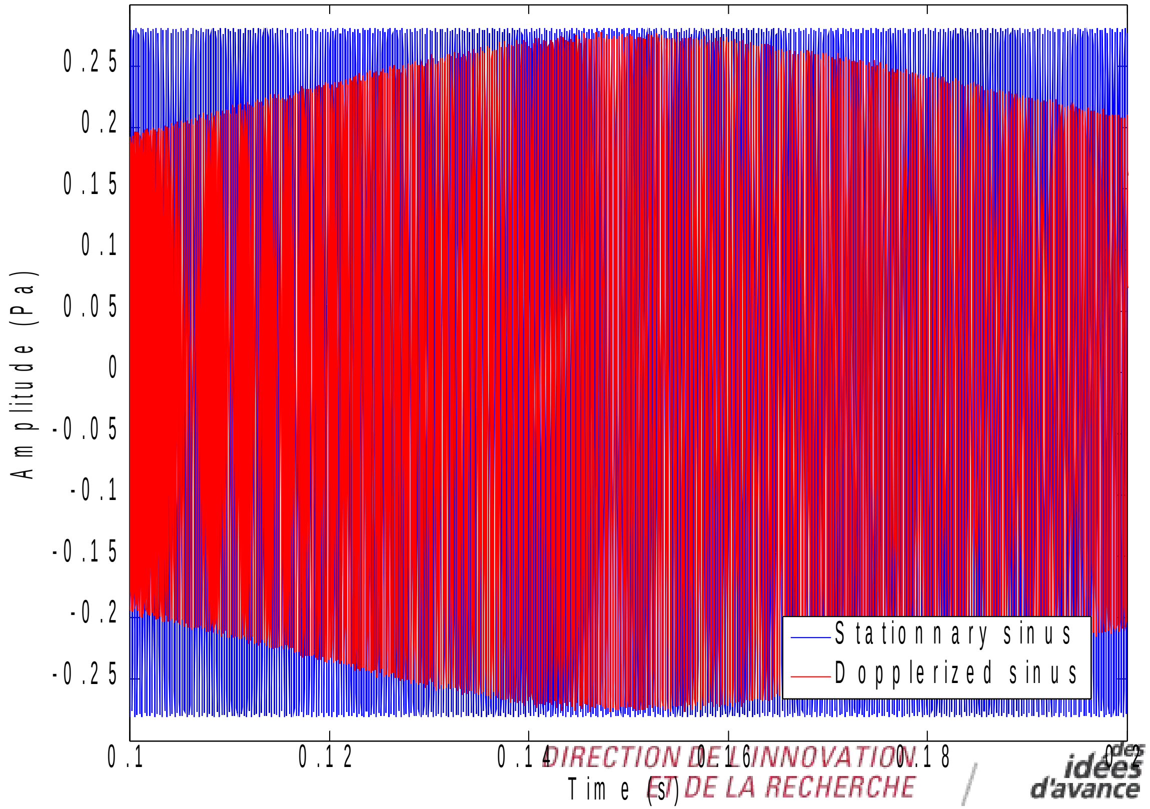


Sources in motion introduce a Doppler effect on the measurement; spectrum and amplitude are modulated with the distance beetween the source and the microphone (which depends on time)



Amplitude modulation

$$A_{in}(t) = 1/\left(r_{in}(t)\left(1 - Ma\cos\left(\vartheta_e(t)\right)\right)\right)$$



2.Beamforming

2. Taking the motion into account

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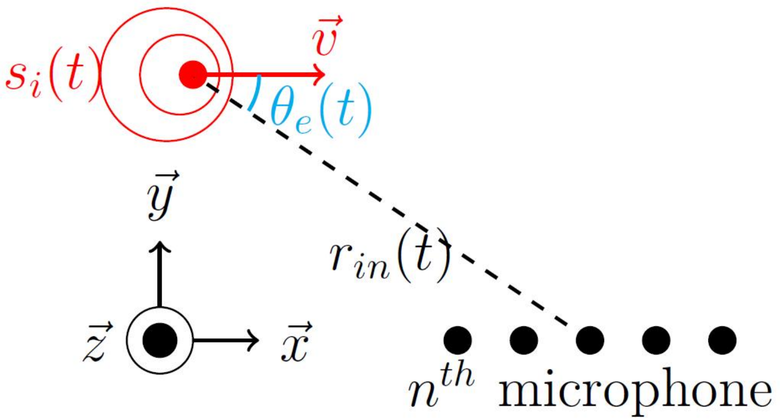
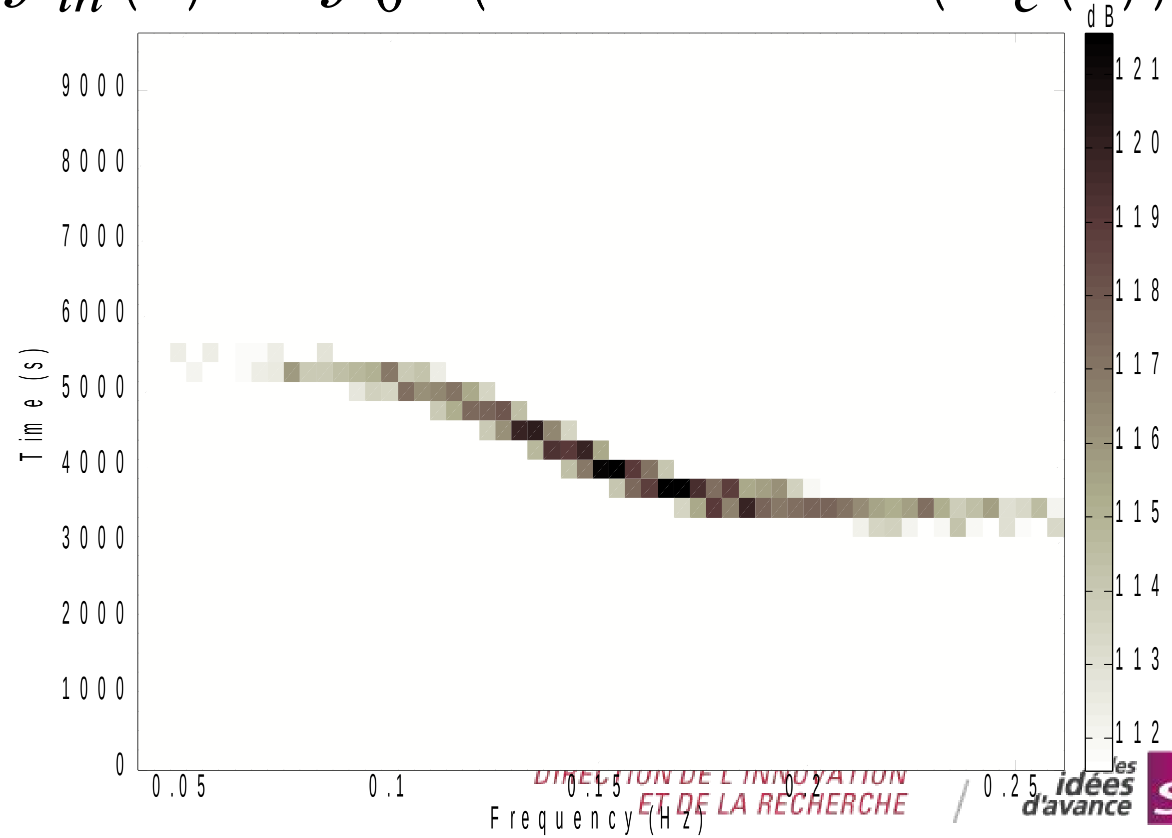


Frequency modulation

$$f_{in}(t) = f_0 / (1 - Ma\cos(\vartheta_e(t)))$$

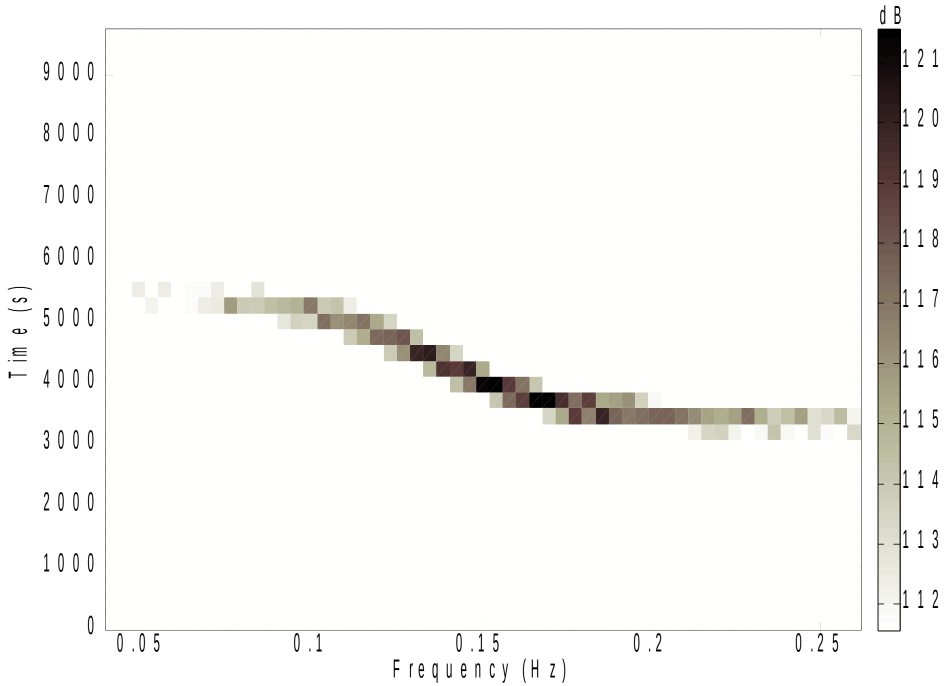


2.Beamforming

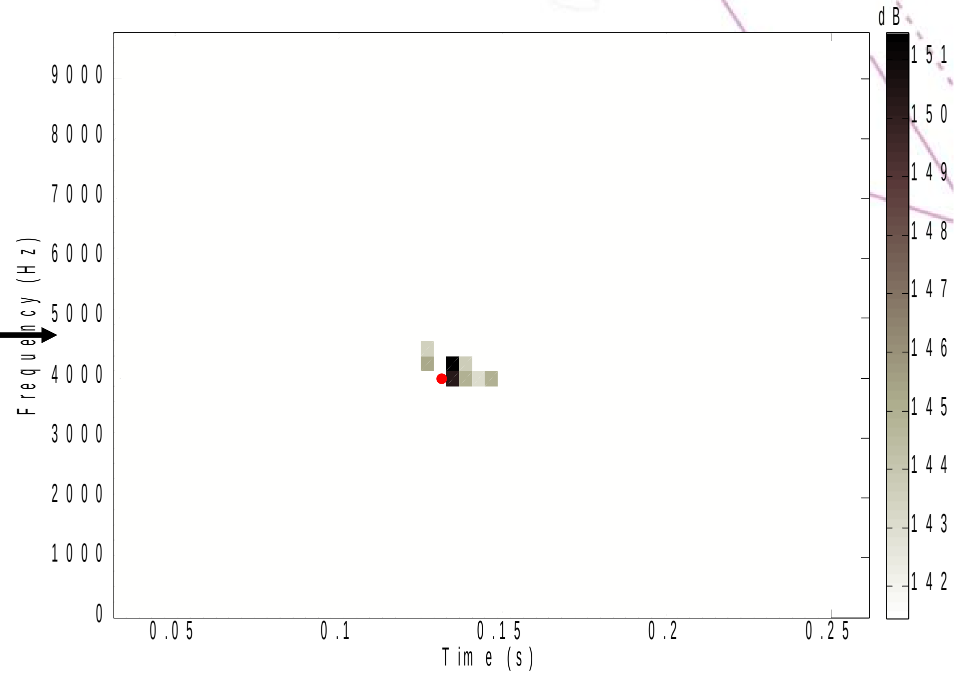
2. Taking the motion into account

To suppress the Doppler effect, beamforming could be adapted using two approaches

Focusing the array straight forward where the Dopplerized signal is equal to the source signal and performed a time-scale transform



Beamforming



+Short computation time

-Short time Fourier analysis resolution restriction

-Doppler effect is still present

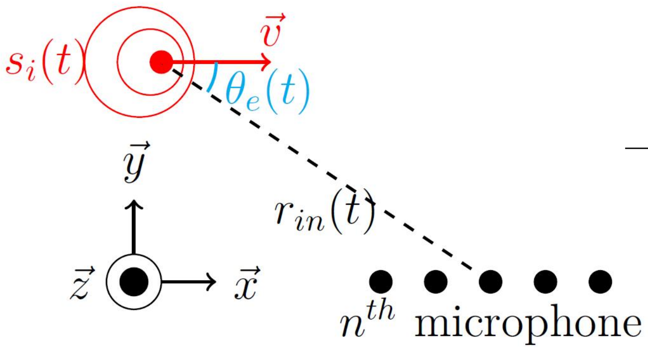
2.Beamforming

2. Taking the motion into account

To suppress the Doppler effect, beamforming could be adapted using two approaches

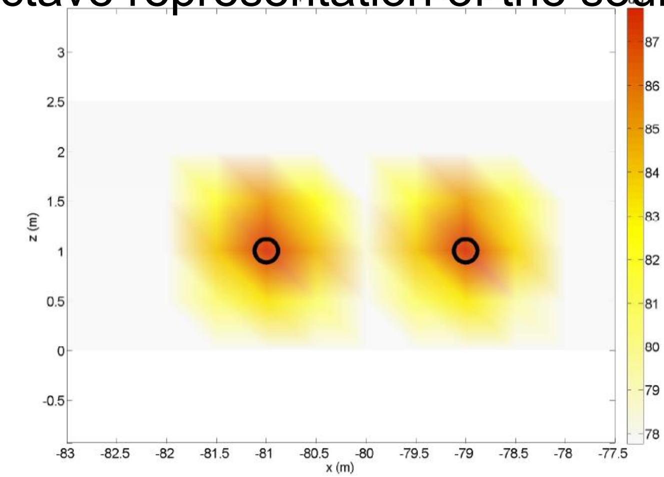
Dedopplerization method consists in adapting the time advance of beamforming, the Doppler effect is suppressed as the reconstruction plan moves with the sources at the same speed [Barsikow 88]

$$x_M(t) = \sum_{n=1}^{N} \left(4\pi r_{nM}(t)\right) p_n\left(t + r_{nM}(t)/c\right)$$



→ Short time signal of the source →

Third octave representation of the sources



+Suppression of the Doppler effect

-The properties of the array are evolving with the time (the beampattern evolves with the focus point)

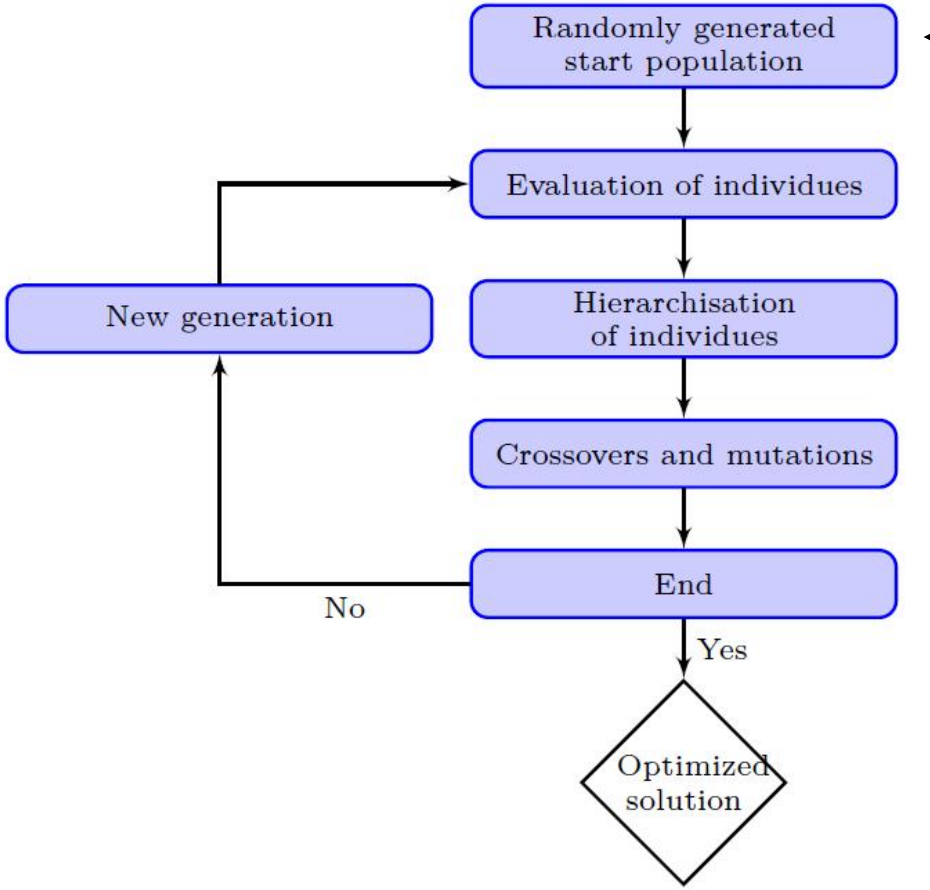
-Heavy computation time

3. Optimization of arrays geometry

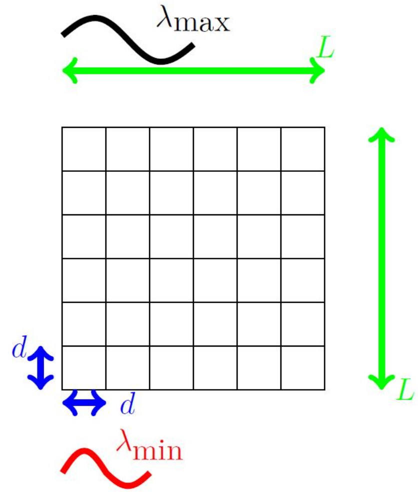
The use of those methods requires specific array properties

We decide to optimize the microphones placement to obtain the desired array performances

The optimization is performed using a genetic algorithm [Holland75]



Random placement of microphones on a mesh



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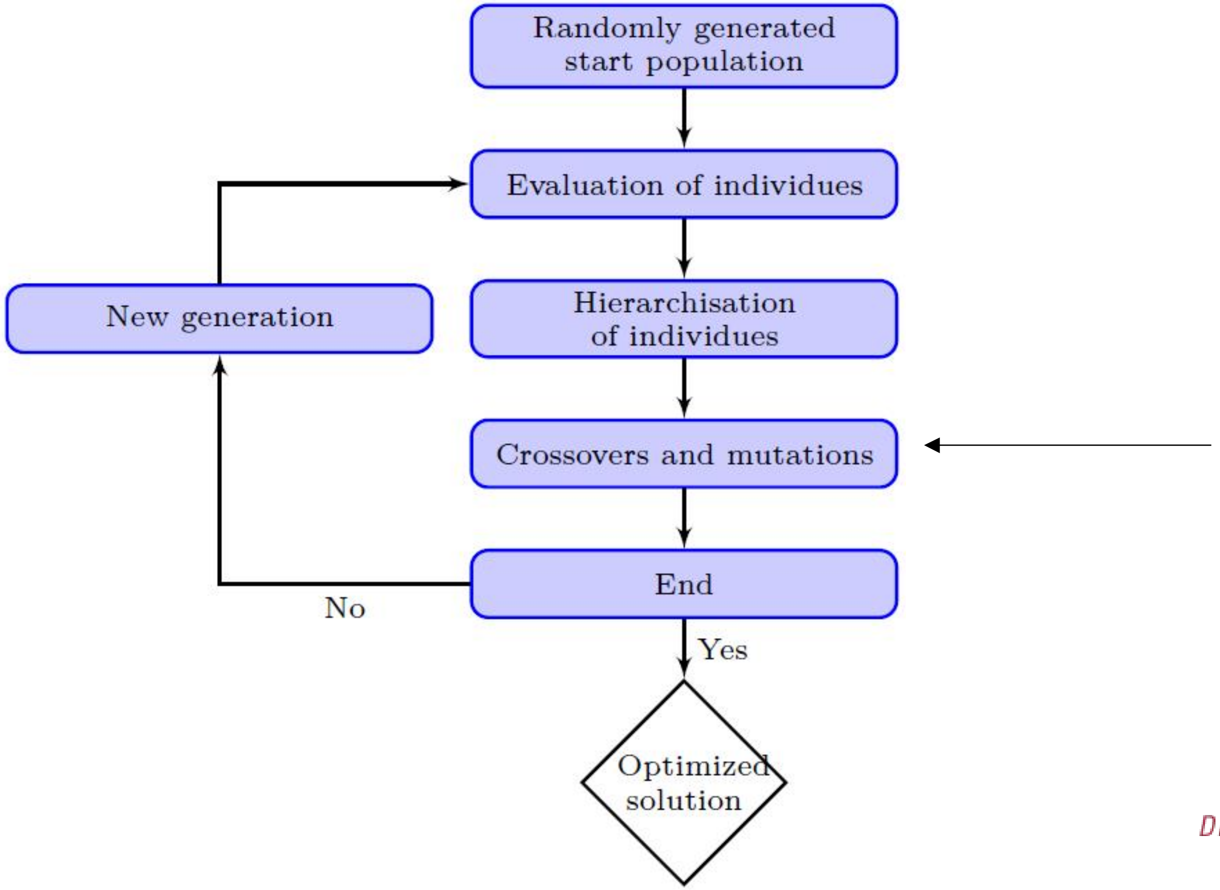
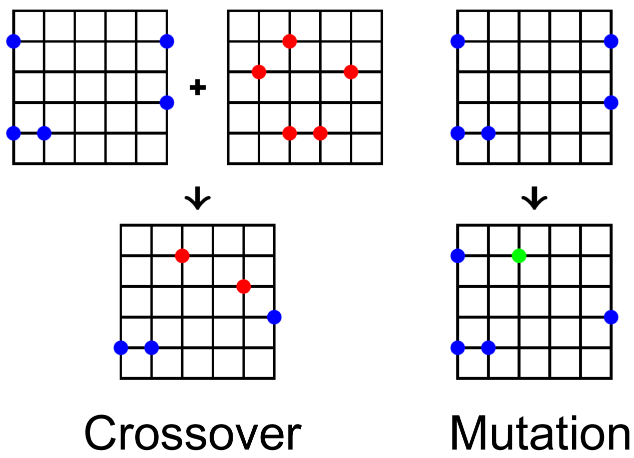


Renewing the population



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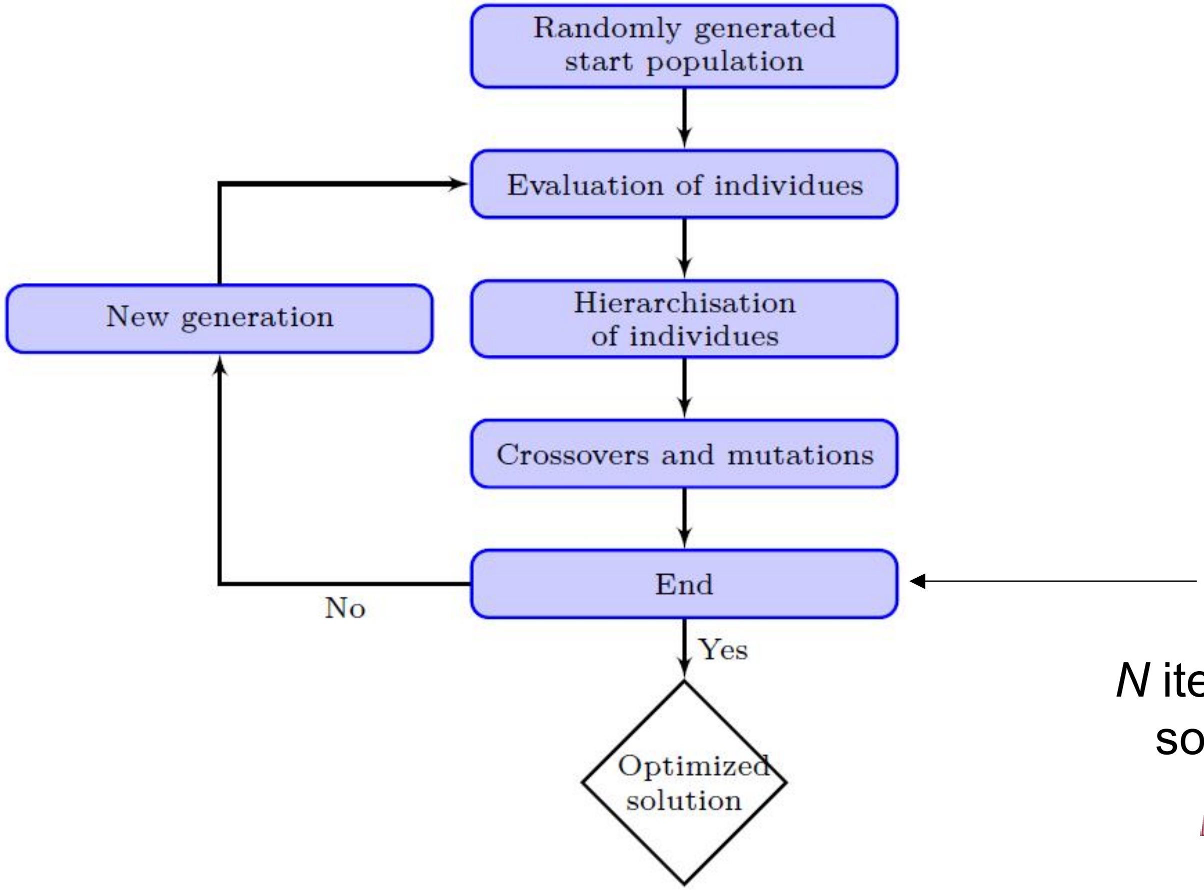


End criterion:

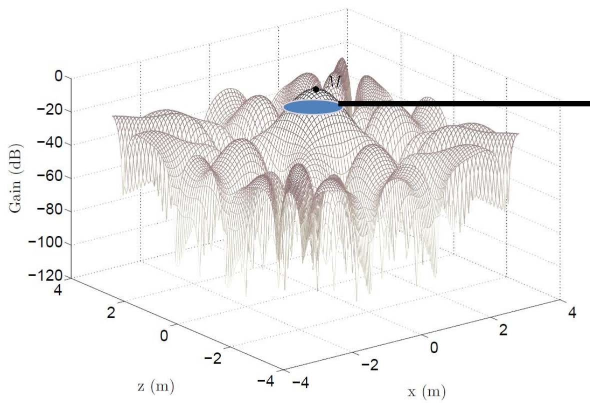
N iterarions processed, unmodified solution for the last iterations…

3. Optimization of arrays geometry

The evaluation is performed on quality criterion defined on the beampattern

We introduce two quality criterion related to beamforming processing for sources in motion

•Optimization of the resolution of the array to obtain the best accuracy on the sources location

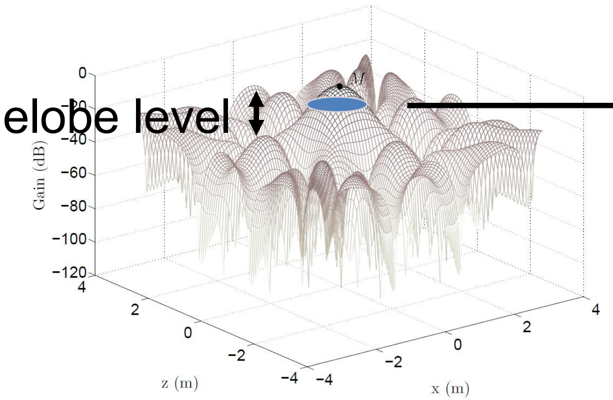


Minimize the apperture of the main lobe

Array adapted to the filtering method and the use of a deconvolution algorithm

[Brooks and Humphreys 2010]

•Obtain the array with the less variations on the beampattern during the dedopplerization



Minimize the standart deviation on the apperture and the sidelobes level for several focusing points

Array more polyvalent, adapted to dedopplerization method

3. Optimization of arrays geometry

Genetic algorithms, like many stochastic optimization methods, are not assured to converge to the global solution of the problem but they provide quickly enoughly optimized solution

Statistical tests are performed to ensure the reproductibility of the results

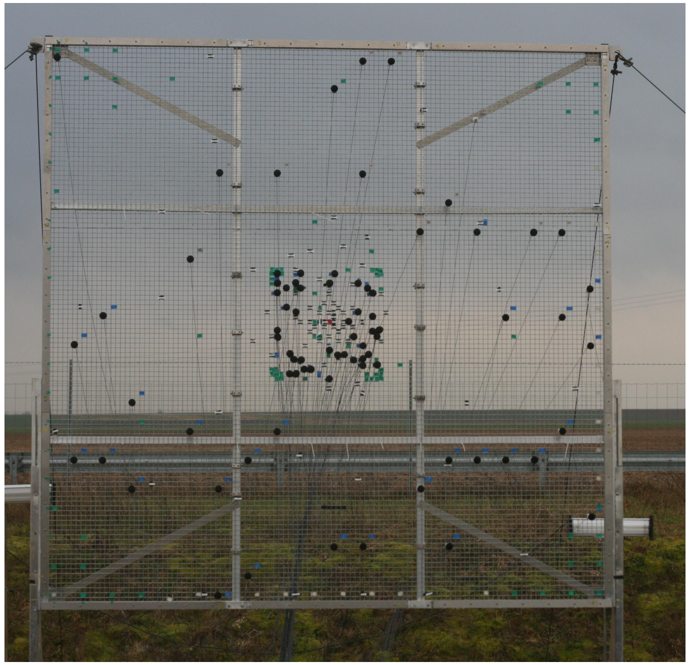
They offer a comprehension of the array design:

- A low sidelobe level and a small apperture are antagonistic optimization
- Large arrays provide small apperture
- Concentrate arrays provide low sidelobe level

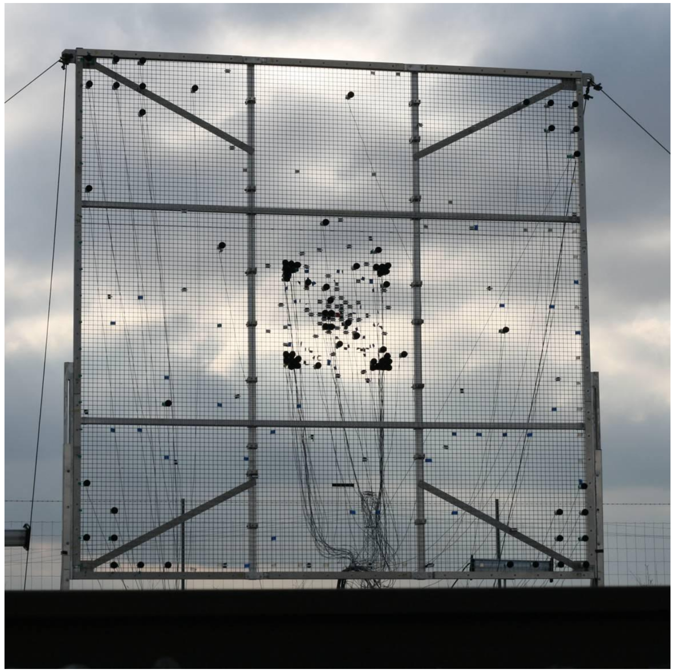
The tool, as it has been defined, is open to improvement (new criterion, new mesh forms, more microphones…)

2.Measurement campaign

Two geometries have been realized and tested



Low variation of the beampattern



High focusing power

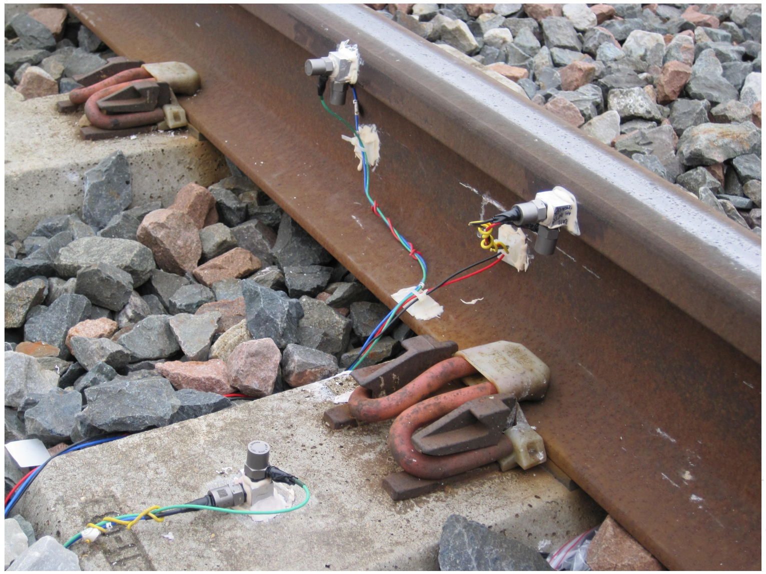
Small assembly time (1 h)

Light materials

2.Measurement campaign

- Caracterization of the rail radiation using beamforming
- Rail excitation using a shaker

- Accelerometers on the rail



Conclusion

- Charaterization of the noise sources on the train is a major issue for the future noise reduction solutions
- Beamforming offers an adapted solution to the railway noise context

- A geometry design tool has been developped and optimized arrays to the railway context have been found and realized
- A measurement campain has been managed:
  - Several trains have been measured with the two arrays data are in processing:
    - Improvement of the classical dedopplerization method thanks to an adapted array;
    - Developpement of a deconvolution dedopplerization method to estimate sources characteristics.
  - Rail radiation has been measured with the two arrays:
    - Comparisons with the rail radiation model [Kitagawa and Thompson 10]
    - Method for separation of the radiation of the wheel and the rail is tested.

- Proceedings : cfa 2008, internoise 2011
- Article jsv in redaction