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Characterisation of shutting noise of car doors using binaural sound and beamforming technique

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Context

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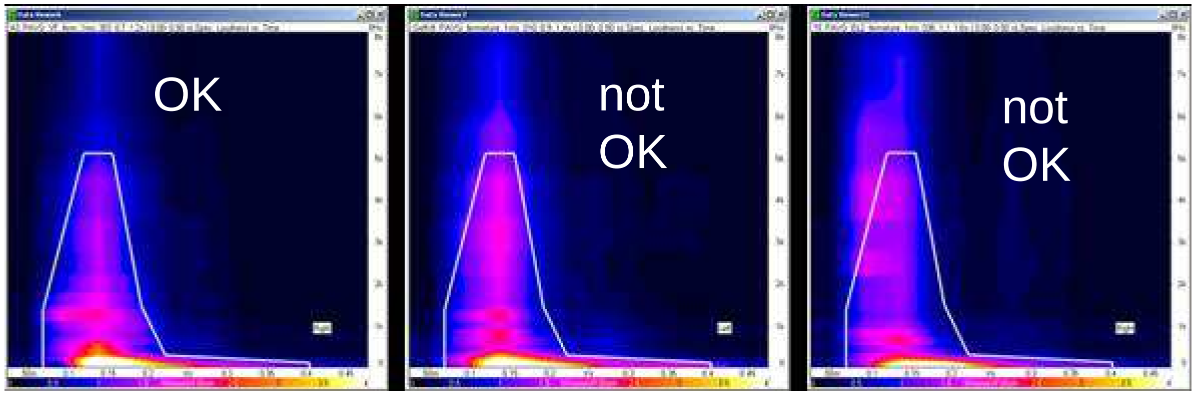
- **Preliminary studies**
  - Study of car door noise (door-shutting noise)
  - Measurement with an acoustic head outside the door
  - Definition of a master template for the optimal time-frequency diagram
    - a low frequency spectrum
    - a short sound
    - a small influence of the level



Objectives

- **Some door components influence the door-shutting sound**

→ **Tests with optimized lock**

→ **Identification of the door components which have the strongest influence**

→ **Study of simplified door design (cost reduction)**

Methodology

1. **Definition of the measurement process**

2. **Design of experiments**
   - **to correlate components and acoustic signature**
   - **to identify the door components with the strongest influence on the door-shutting sound**
   - **test of modification of several components (striker, lock, seals, IFF, …)**

Methodology

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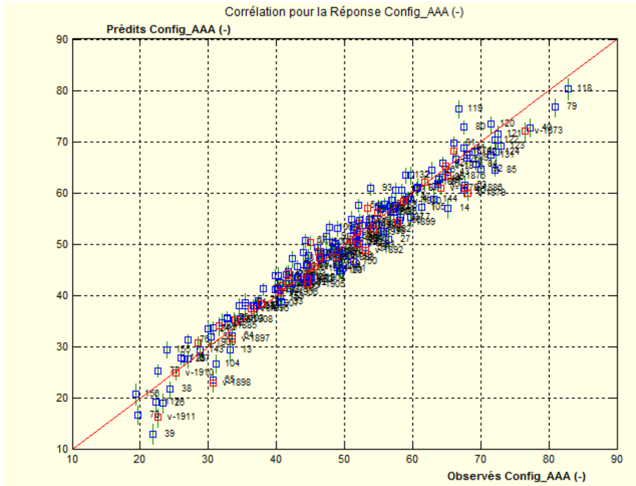
3. **Statistical approach (confidential)**
   - **Predictive model f**



Y = f(X)

acoustic performance (Y) — parameters influencing the performance (X)

4. **Advice for car designers**

⇨ **In this study, focus on measurement process and design of experiments**

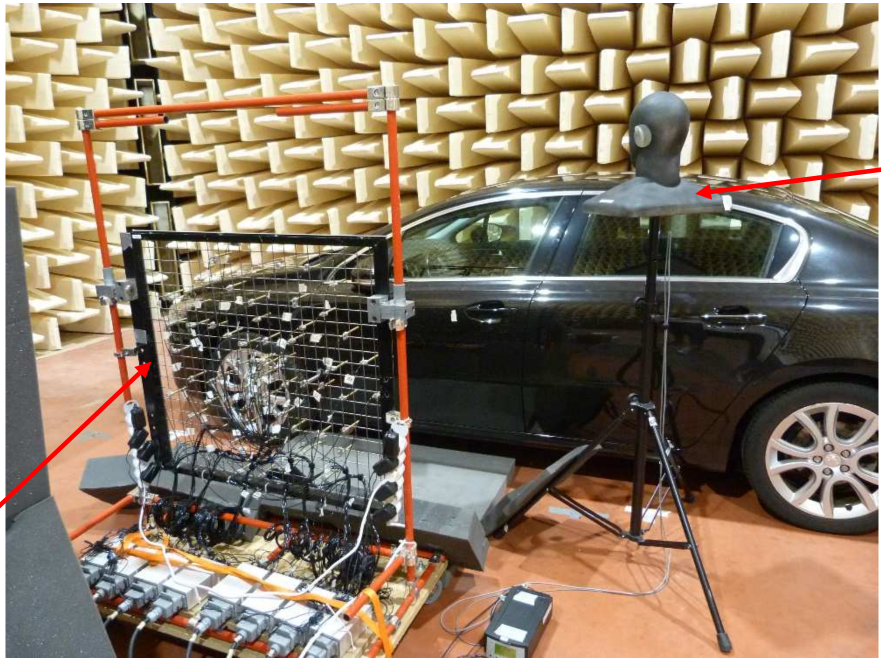
Measurement process

Measurement of the door-shutting sound for different configurations of the door using two techniques

Control of the door celerity using a gyroscope

2 - Recording of pressures on a microphone array

- Beamforming technique
- Source localisation



1 - Recording of a binaural sound using an artificial head

- Same procedure as in preliminary study (PSA)
- Sound analysis
- Listening of the different sounds

Simultaneous measurement

Measurement process

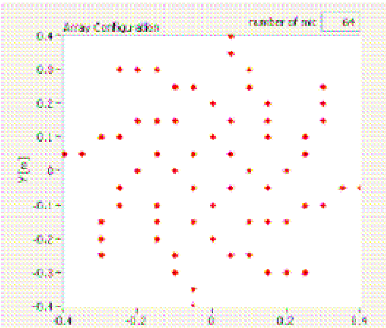
Measurement and analysis of binaural sounds

- **Acoustic head**
  - CTTM manufacturing including silicone moulds of real ears (use of 3D elastomer printer)
  - Some differences with the head used in the preliminary study
  - Correction (equalisation for listening)
- **Post processing**
  - Use of LEA (OPTIS) software
  - Time frequency representation
  - Loudness
- **Comparative study between the different configurations**

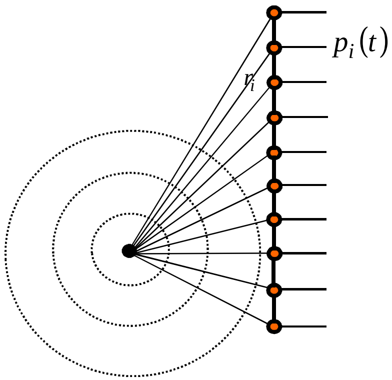
Measurement process

Beamforming technique using a microphone array

- **Microphone array set-up**
  - 64 CTTM microphones
  - Specific spiral design, 76.5cm x 76.5cm size
  - Frequency bandwidth : [800 – 8000 Hz]
  - Time signal recording using National Instrument Hardware and INTAC Software (CTTM product)

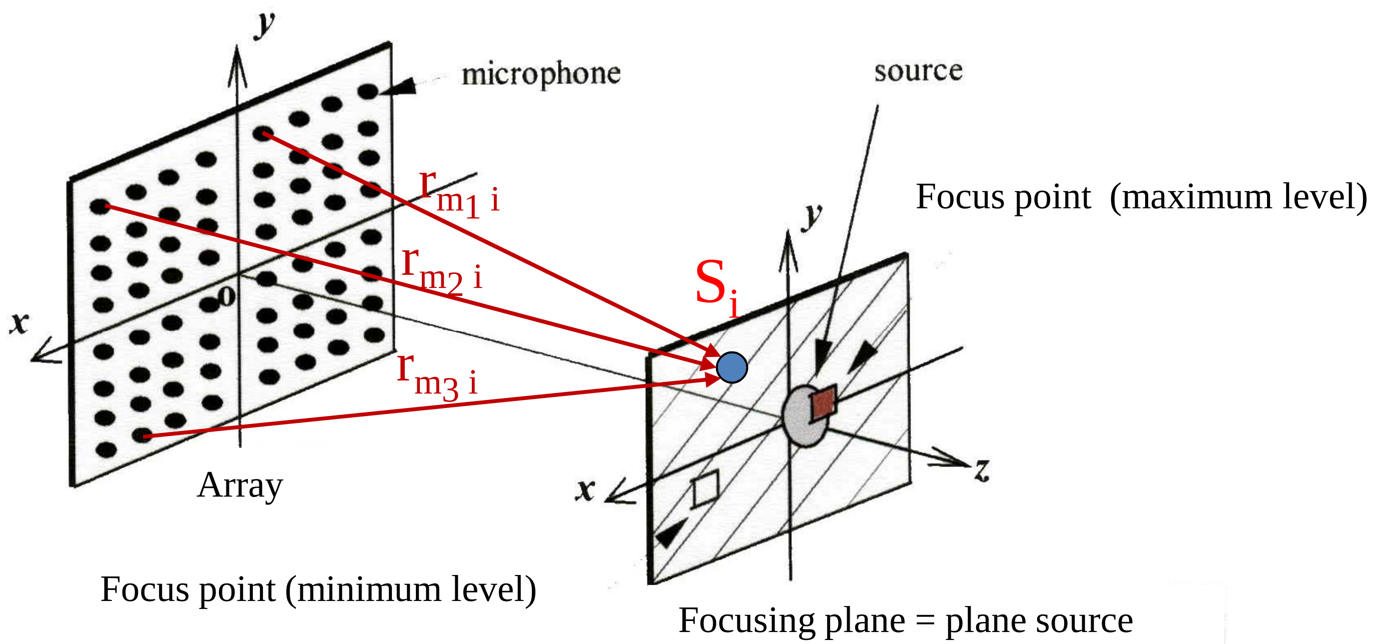


- **Post processing**
  - Use of time-beamforming algorithm developed by Jean-Hugh Thomas (LAUM)



Measurement process

- **Beamforming principle : delay and sum beamformer**



- Assumption: localization of the source on a point in the plane source, the focusing point.
- Compensation of the propagation delay for each signal of the array.

Measurement process

Beamforming principle : processing in the time-domain

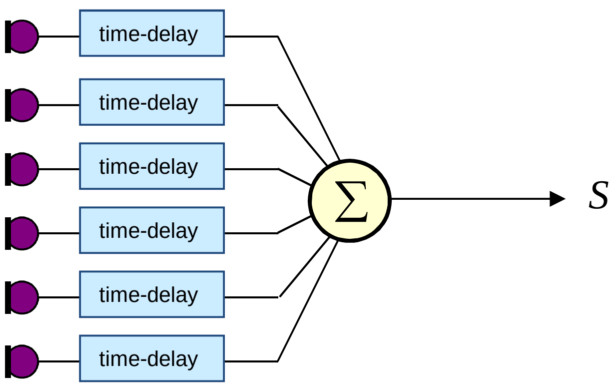
$$s_i(t) = \frac{1}{\Xi}\sum_{m=1}^{M} a_m\, p_m\left(t + \frac{r_{mi}}{c}\right)$$

$$s_i(t) = \sum_{m=1}^{M} a_m\, p_m(t) * w_{mi}(t)$$

with

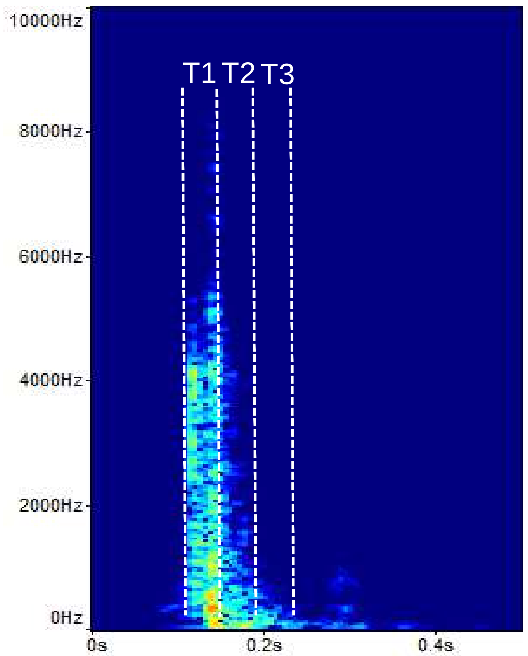
$$w_{mi}(t) = \frac{1}{\Xi}\delta\left(t + \frac{r_{mi}}{c}\right)$$

$$\Xi = \sum_{m=1}^{M} \frac{a_m}{4\pi\, r_{mi}}$$

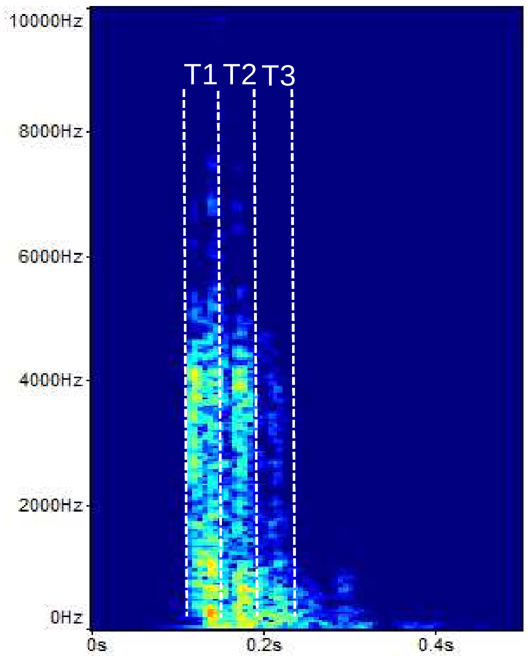


Analysis

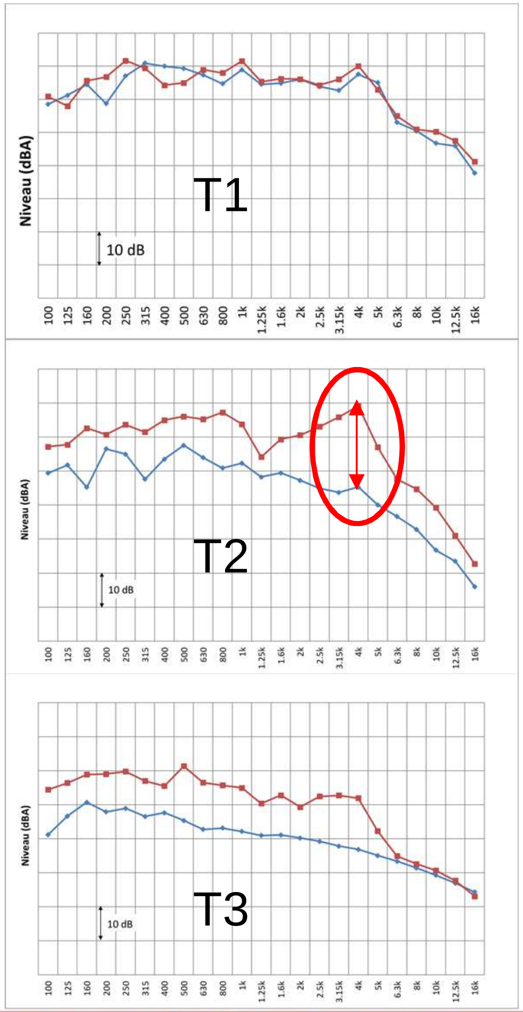
- **Analysis of binaural sounds**
  - **Time frequency representation**



Reference configuration



Modified configuration

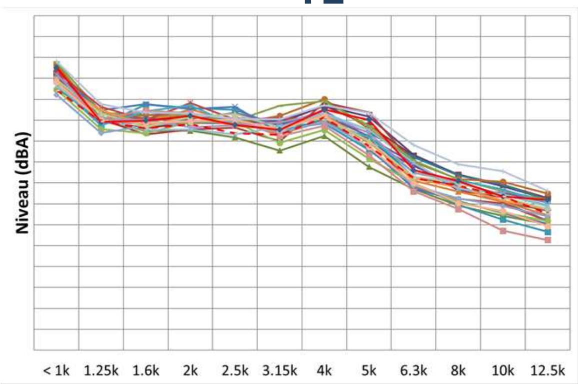


Analysis

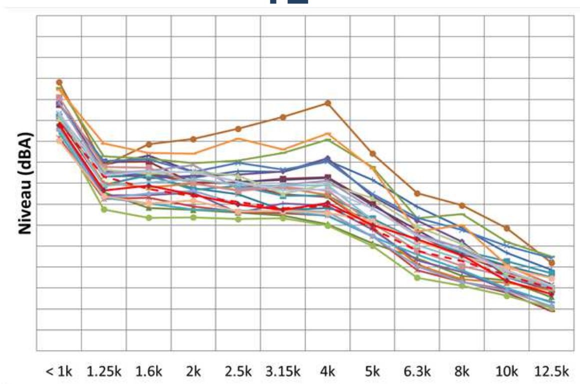
Analysis of binaural sounds

- **Spectra dispersion for T1 / T2 / T3 for the different configurations of the door**

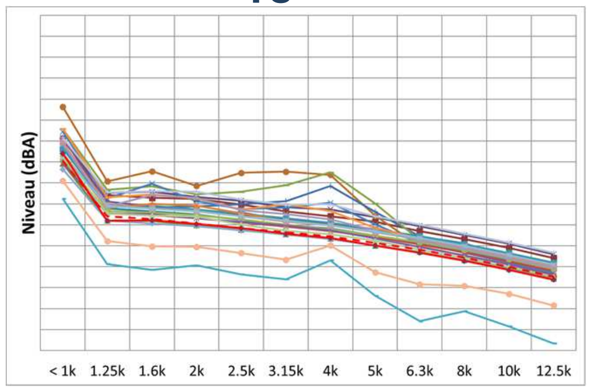
T1



T2



T3

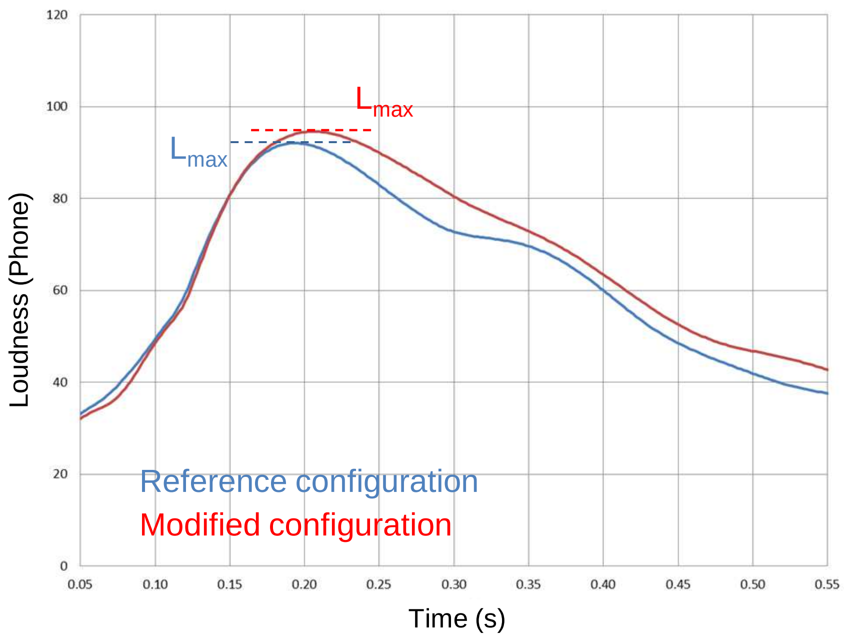


- **T1 : the highest levels but low dispersion**
- **T2 : high level and great dispersion**
- **T3 : low level and a general low dispersion**

Analysis

Analysis of binaural sounds

- **Loudness vs time**



- **Maximum of loudness L_{max}**

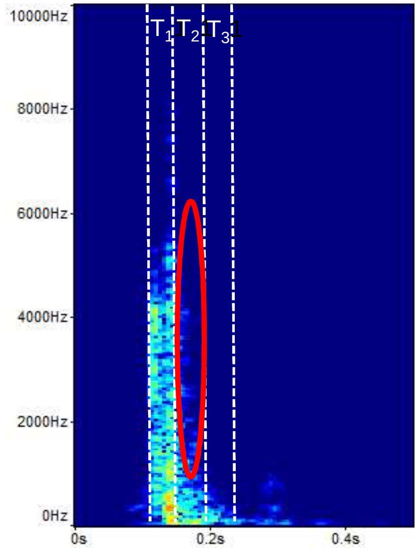
⇨ **Spectra and loudness used to define the statistical model**

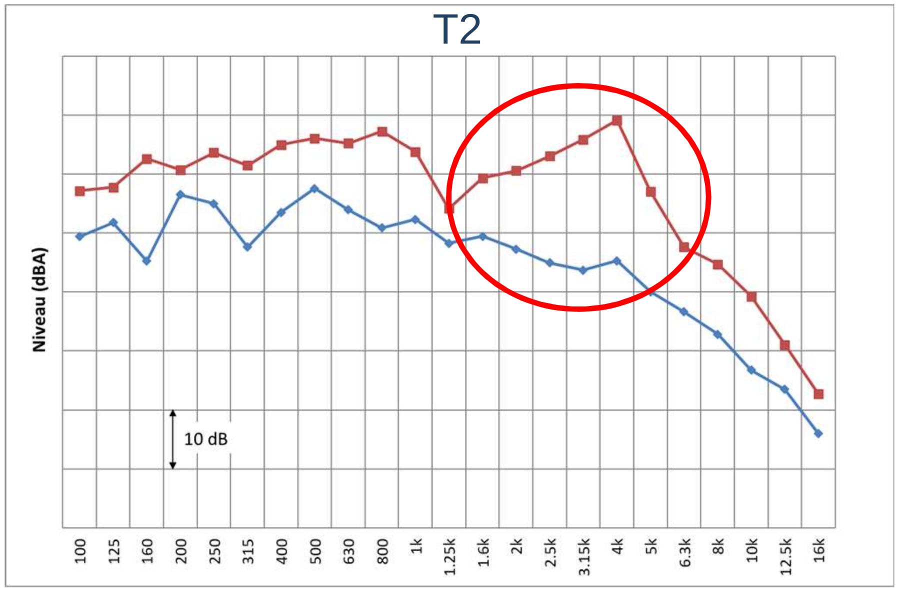
Analysis

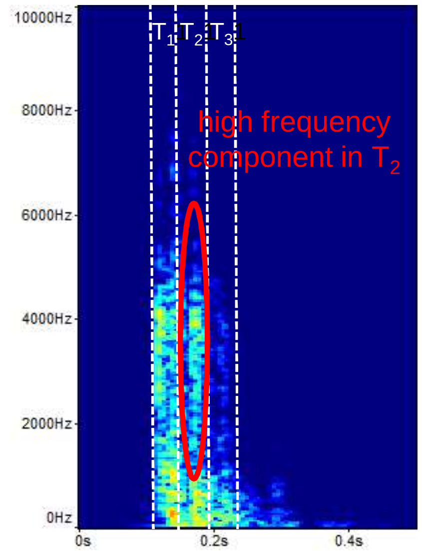
Example 1:

Reference configuration

Modified configuration 1
Striker, seals modified



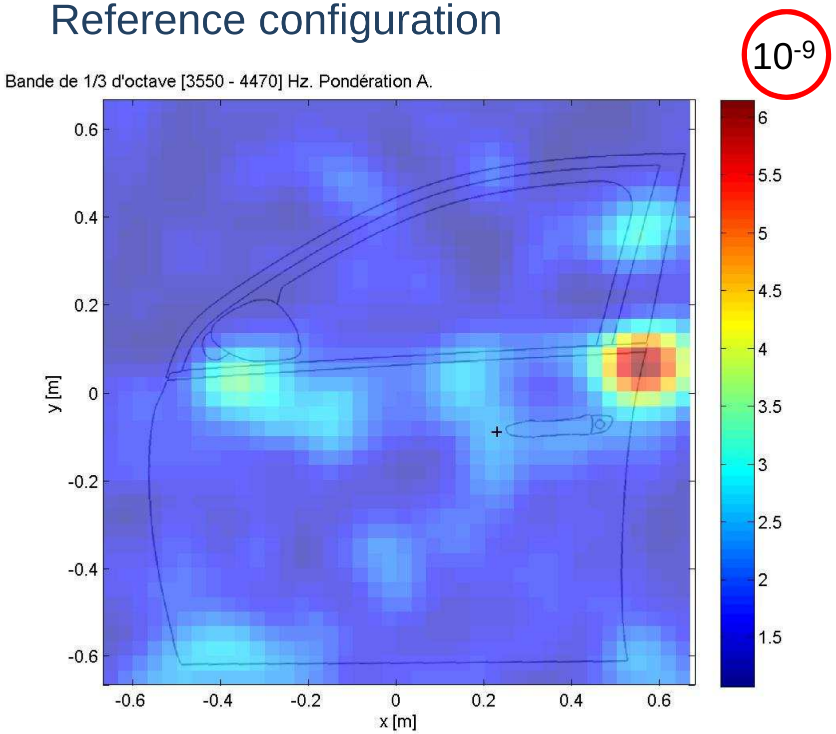




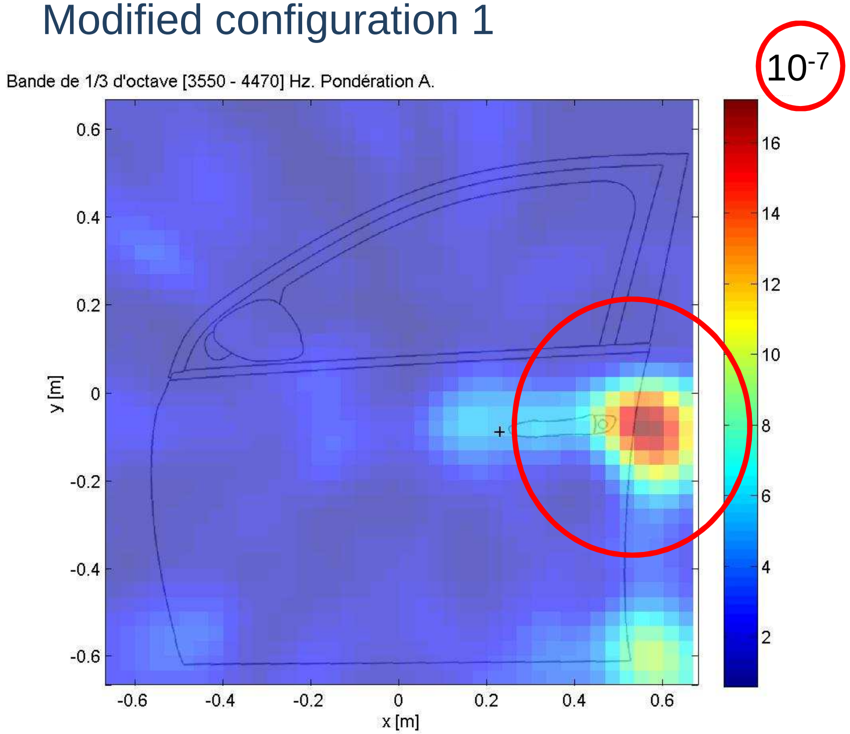
Analysis

Example 1:

Reference configuration



Modified configuration 1



⇨ **Help to understand modification of door behaviour -> link with the modified component**

Analysis

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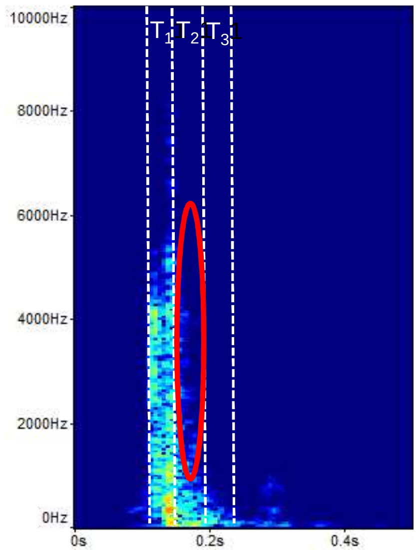
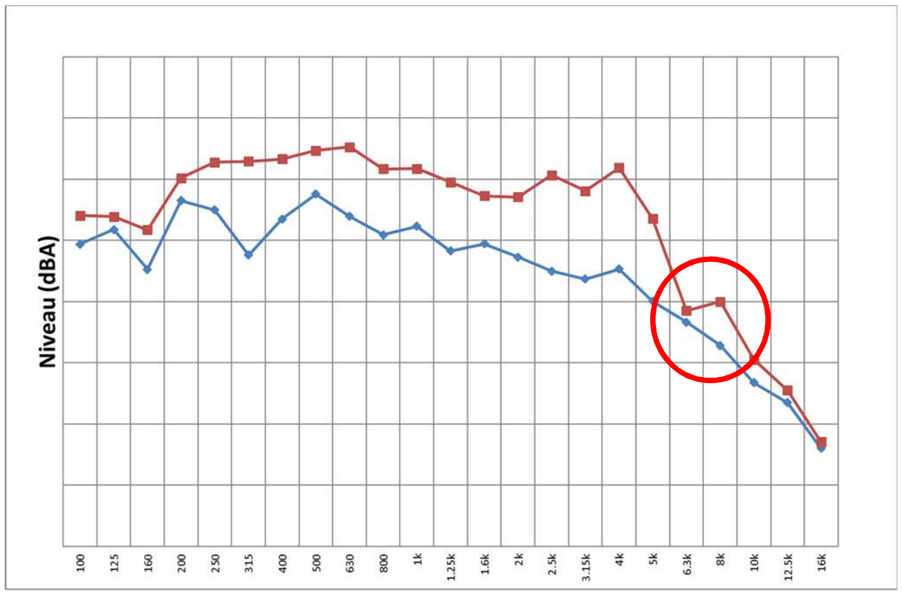
Example 2:

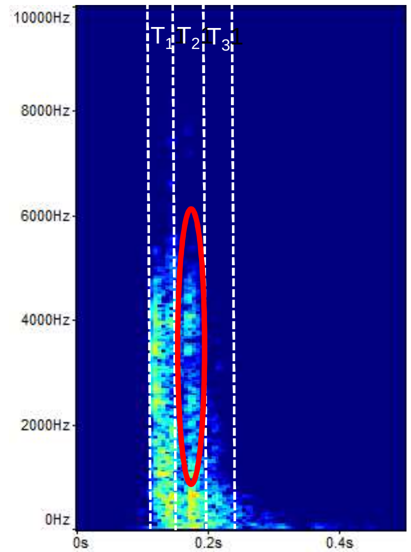
Reference configuration

Modified configuration 2
Lock, striker, seals, IFF modified



T2

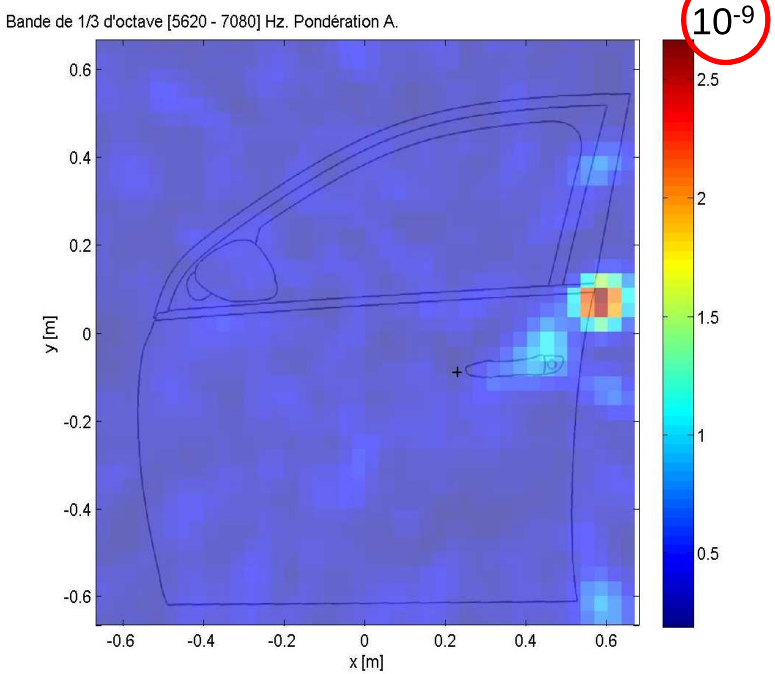




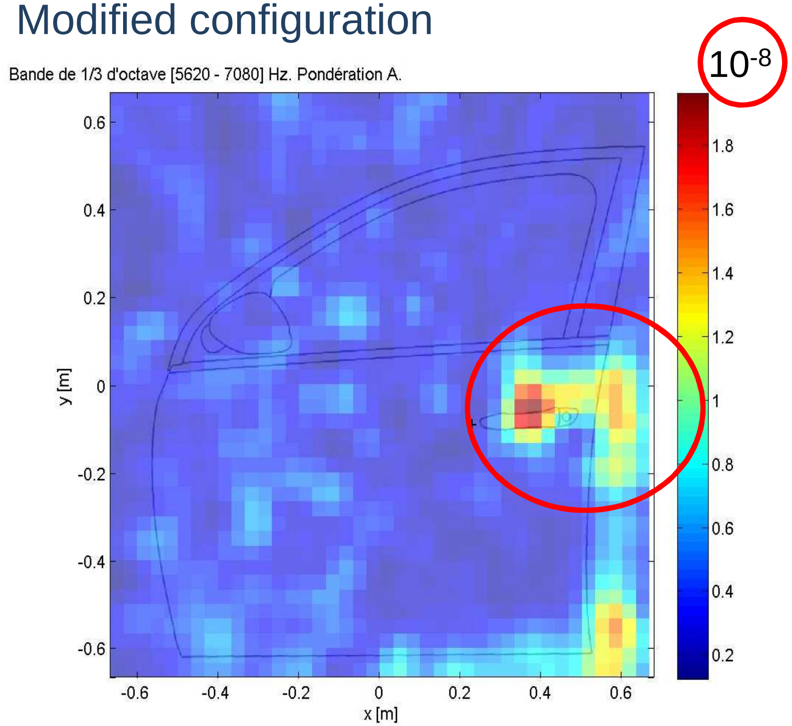
Analysis

Example 2:

Reference configuration



Modified configuration



⇨ **Help to understand modification of door behaviour -> link with the modified component**

Conclusions

- Definition of a measurement process to record door shutting noise
- Design of experiments to identify car door components with a great influence on the acoustic signature
- Modeling of the acoustic performance
- Possibility for car designers to anticipate technical choices having a strong impact on the door-shutting noise