The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION

BARCELONA

17th-20th November 2013

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Detection and localization of electric arcs in large batteries

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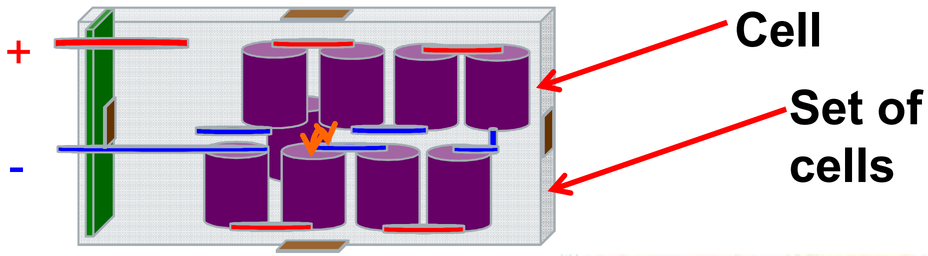
OUTLINE

1. Context of the study
2. Study of electric arcs
3. Acoustic study of vehicle noises
4. Acoustic propagation in the battery environment
5. Detection methods
6. Localization
7. Demonstrator
8. Conclusions and perspectives

1. Context of the study

- Battery = several cells arranged in series and parallel linked by connections (cables, bus bars, foils)



Fire in Prius Plugin
Origin : incorrect tightening of a nut on electrical connection

Damaged connections in a Prius Plugin

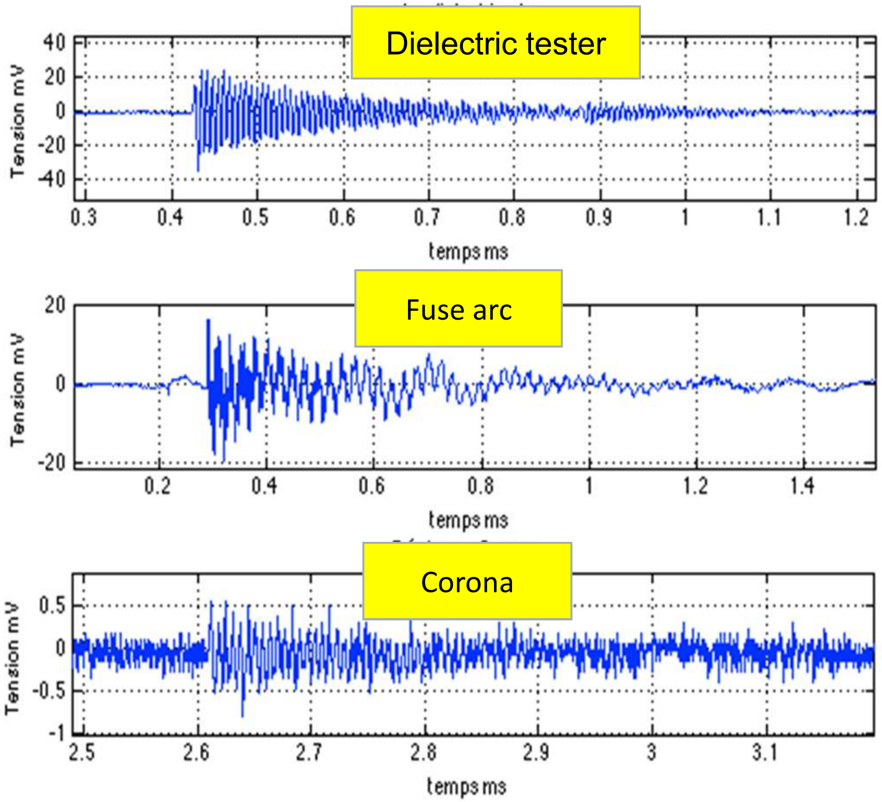
- Damaged connections → apparition of a maintained electric arc → thermal runaway in the battery → fire

→Need of a system to detect electric arcs precociously (robust to the vehicle environment)

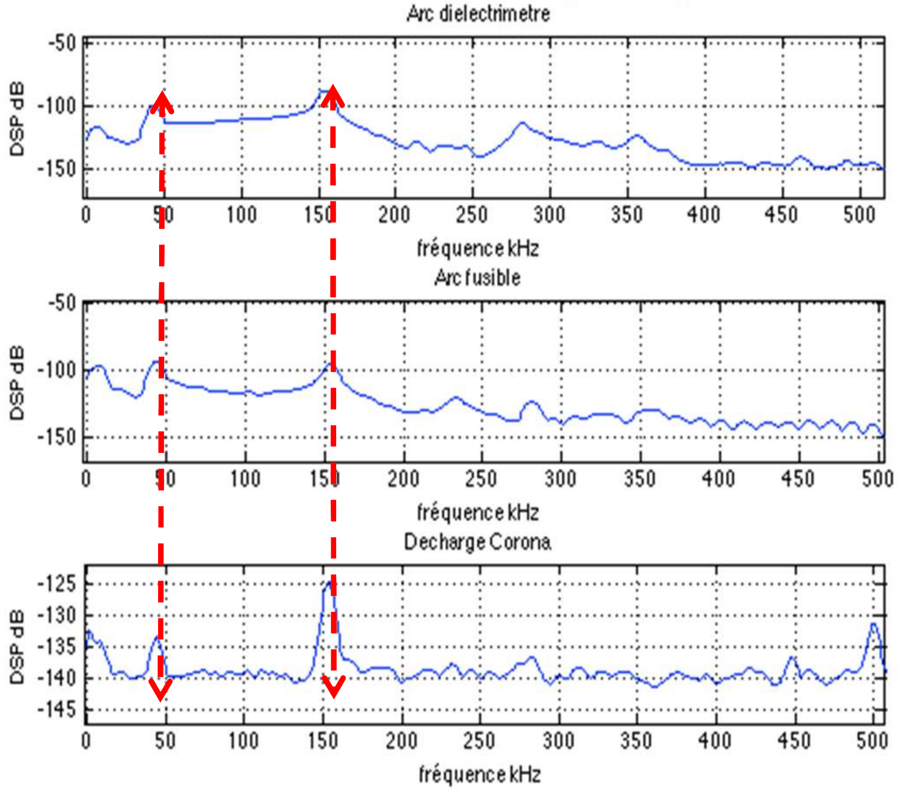
→We use an acoustic method: the most adapted to our detection problem

2. Study of electric arc: EPA sensor

Time area



Frequency area

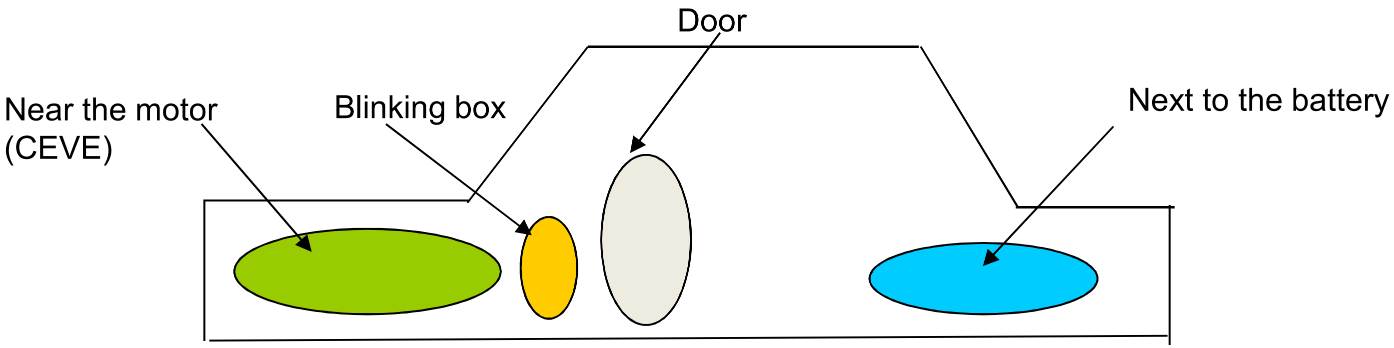


- Similar signature for the three kinds of arcs:
  - In the time area: oscillations with exponential attenuation
  - In the frequency area: white noise + sensor resonances

→ **Detection based on the temporal signature**

3. Acoustic study of vehicle noises

- Main acoustic sources measured in the vehicle



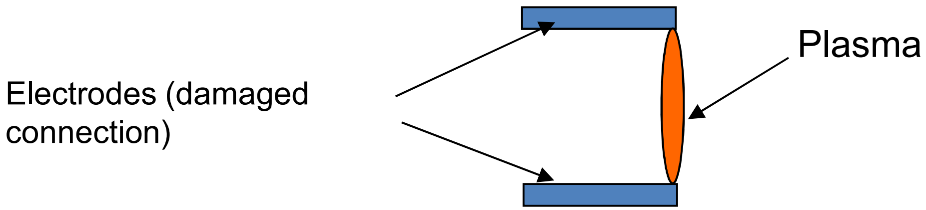
Position	Event	Frequency band of the signal
Blinking box	Blinker	10kHz→95kHz
Close to the handle	Car door slam	5kHz→75kHz
Next to battery	Normal driving	0→35kHz
	Acceleration	0→60kHz
	Brake	0→45kHz
Motor	Normal driving	0→85kHz
	Acceleration	0→40kHz
	Brake	0→250kHz

→ **Disturbances overlap with frequency band of the arc**

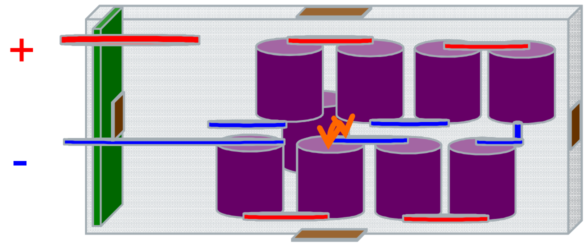
→ **Potential disturbances for the detector: can induce false alarm**

4. Acoustic propagation in the battery

- Location of apparition of the arcs : air → wave propagated mainly in the air



- Bad propagation of the wave through the cells :
  - Discontinuity of the battery structure
  - High acoustic impedance of the cells → attenuation of 99% for a wave coming from the air

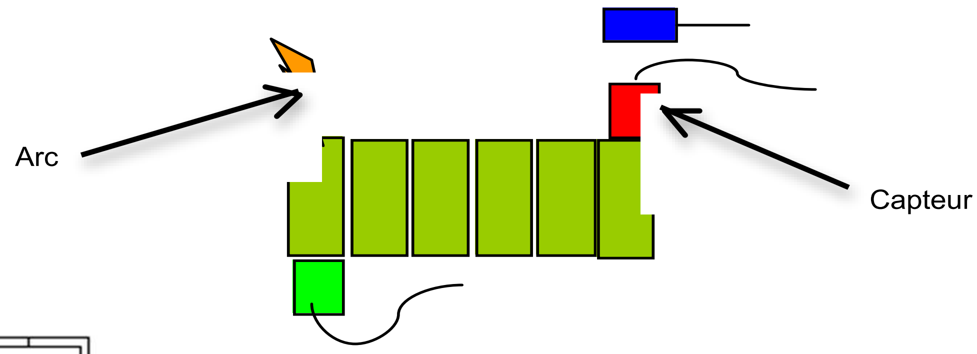


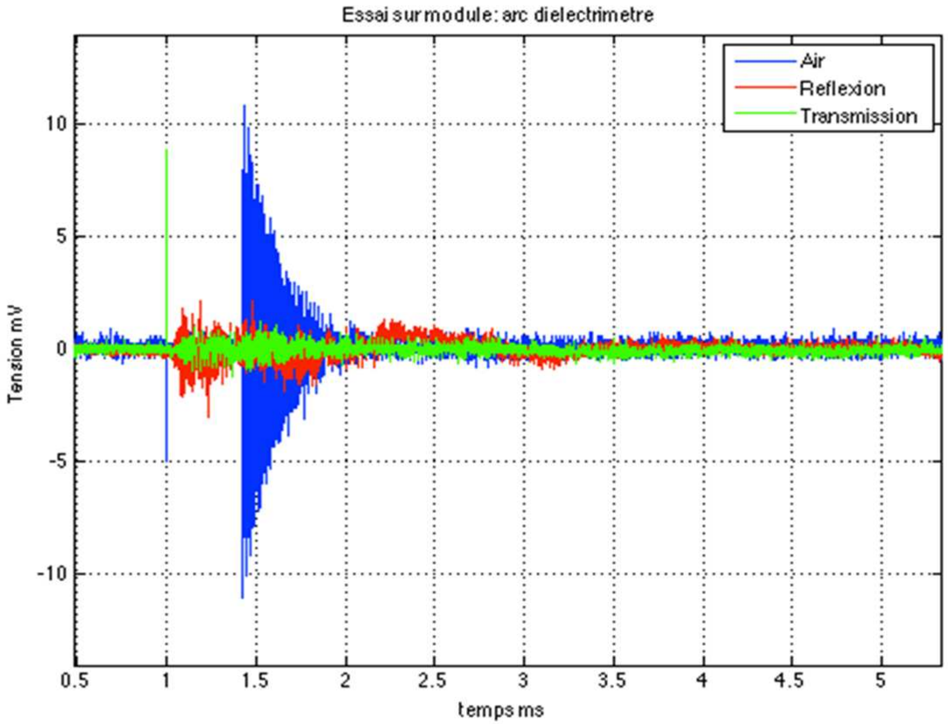
Battery structure

→Hypothesis: Propagation mainly in the air

4. Acoustic propagation in the battery

- Experiments realized on a set of A123 system cells
- Measures in three different locations :
  - Coupling with material (reflexion)
  - Coupling with material (transmission)
  - Measure in the air





- propagation in the air
- echoes on the walls and cells

→ **Utilisation of microphones is more suitable for our system**

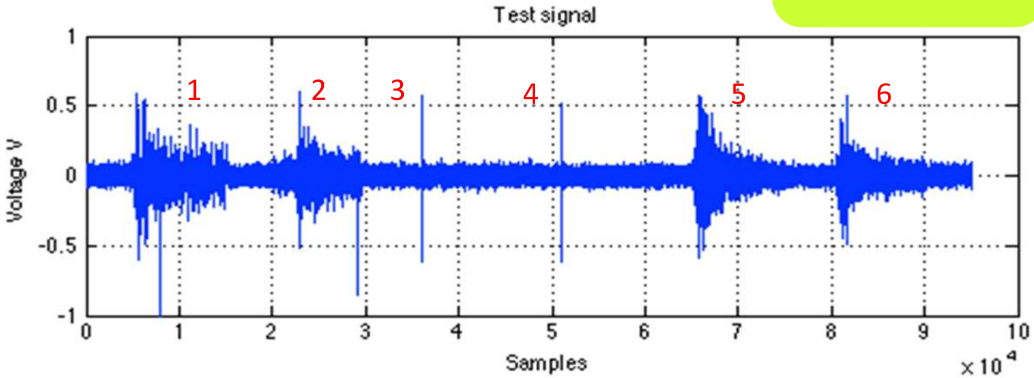
5. Detection methods: correlation

Principle

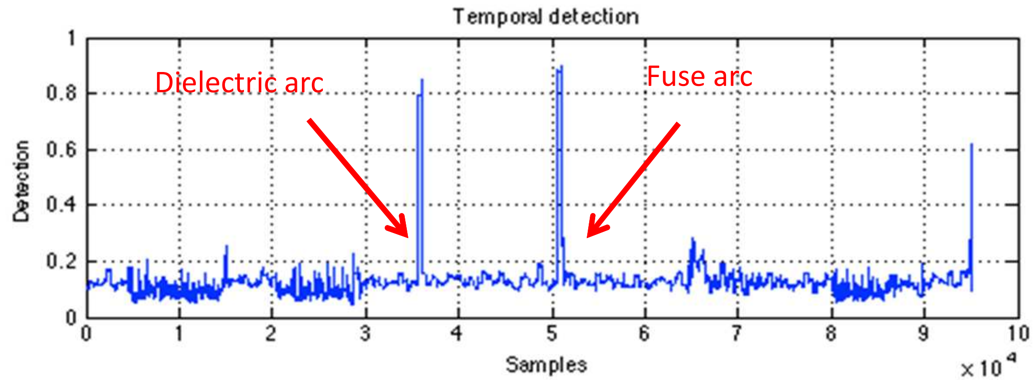
Learning base → **ARMA Model**

$$y_n = \sum_{r=0}^{M} b_r x_{n-r} - \sum_{k=1}^{N} a_k y_{n-k}$$

Recorded signal → **Window** → **Sliding correlation** → **Normalisation** → **Thresholding** → 0 / 1



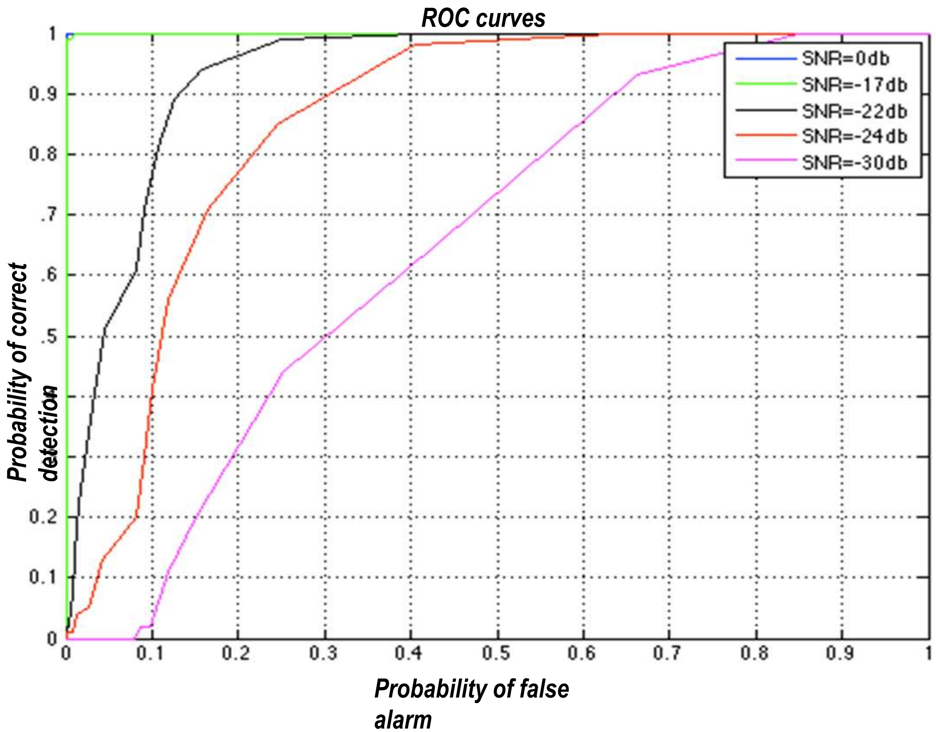
1: Brake
2: Acceleration
3: Dielectric arc
4: Fuse arc
5:Turn signal
6: Door



➔ **Good response of the detector to the arcs**

5. Detection methods: correlation

- **COR curves: a couple (Pd, Pfa) for each threshold (for a fixed SNR)**



- Advantage : functional detection :
  - Perfect up to -17 dB
  - robust to disturbances
- Drawback : ARMA model => specific to each sensor

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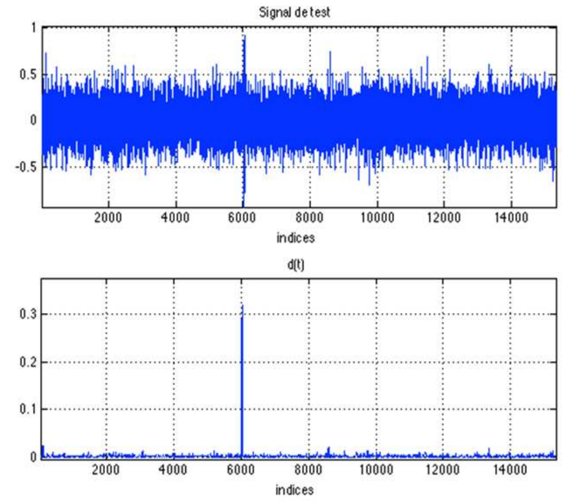
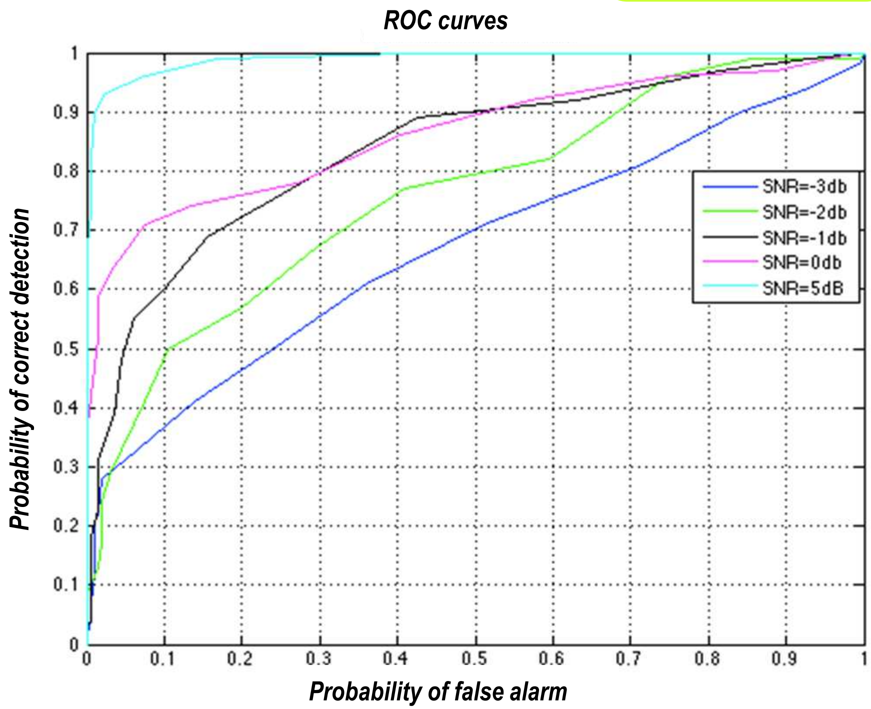
5. Detection methods: Higher Order Statistics

Sensor signal → Sliding window → Fourth order moment → Threshold → 0 / 1



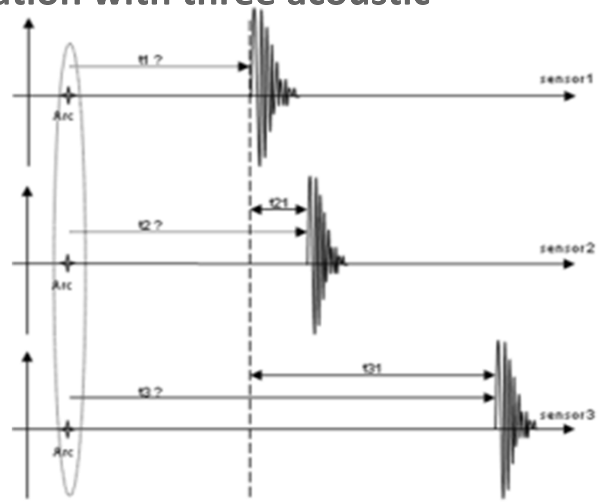


→Performances decreased in comparison with the 1st method
→However, perfect detection for SNR of 15dB

- Advantage :
  - No need of a time model
- Drawback :
  - Method more sensitive to noise and vehicle disturbances
  - Detection of all transient signal without distinguishing them

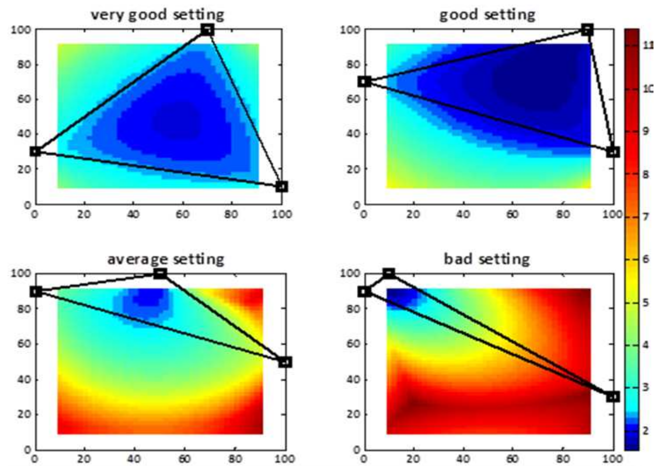
6. Localization of the arcs

- **Time Difference of Arrival localization based method : triangulation with three acoustic sensors**



→ **Synchronous system : one sensor is taken as the time reference**

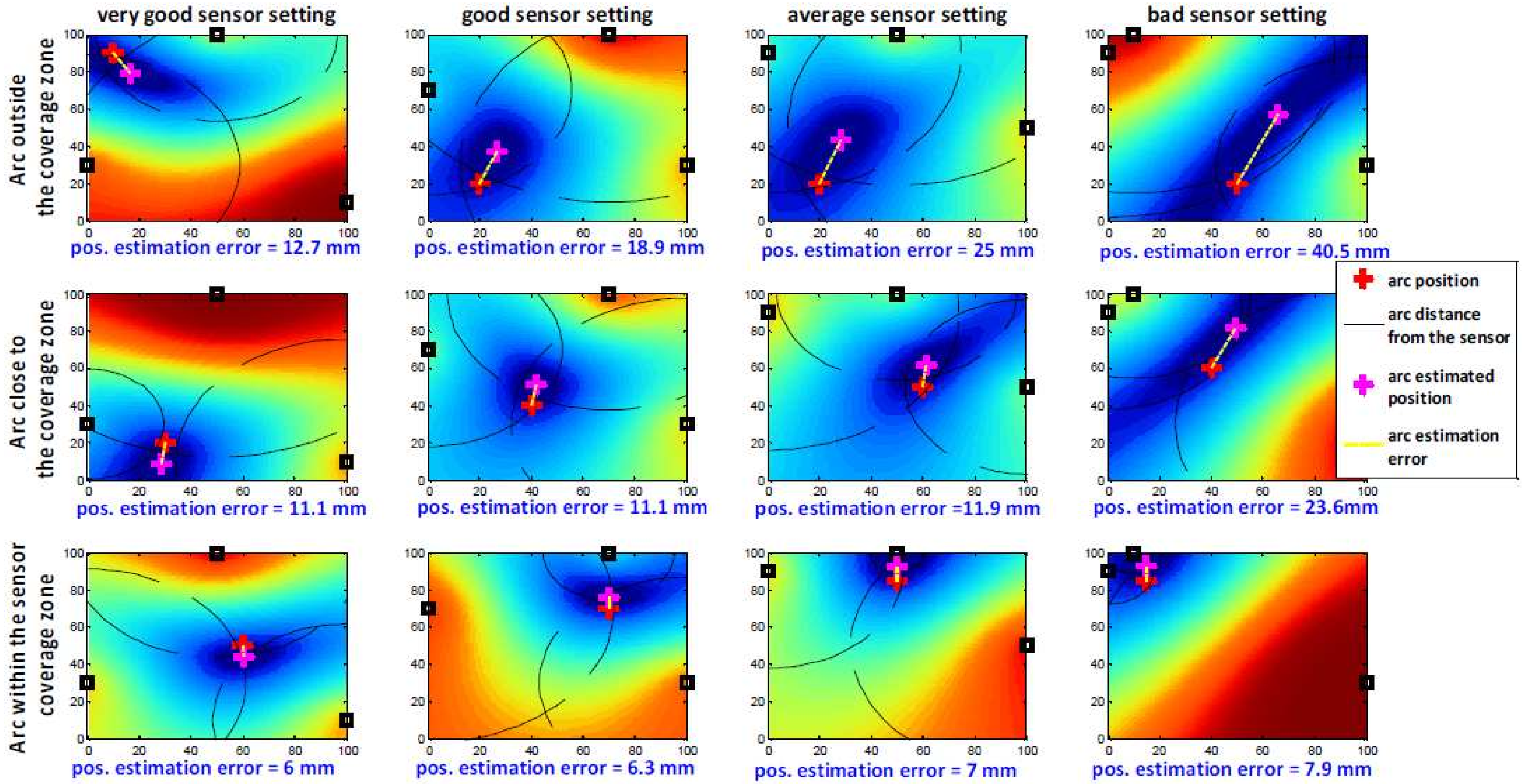
- **Importance of the localization of the sensors in the battery**



→ **The geometric dilution of precision require the area within the sensors to be the widest**

6. Localization of the arcs

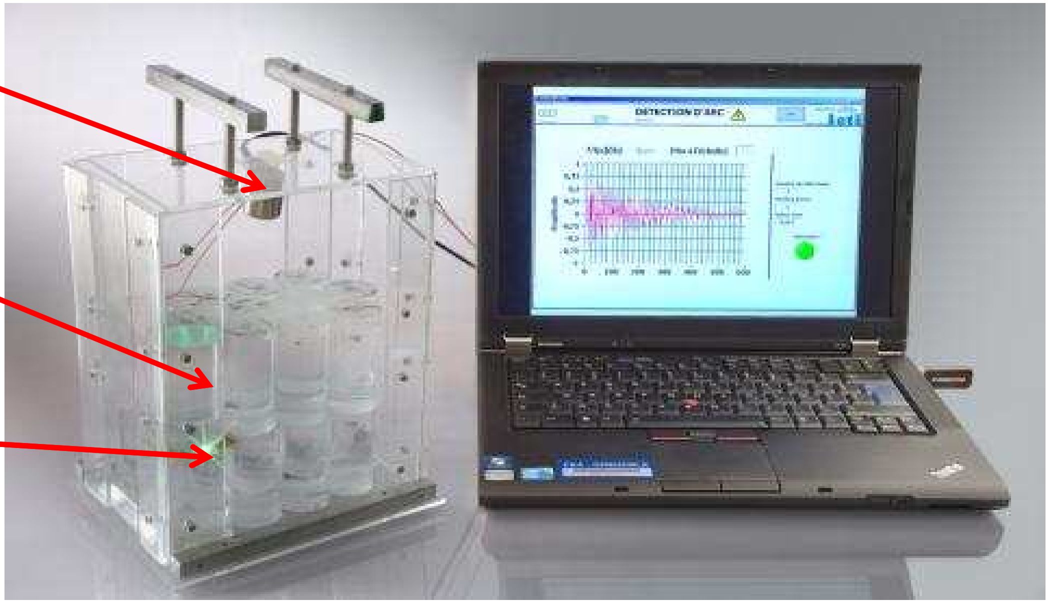
- Localization performance for different configurations



→ **The arc position estimation precision reach 6 mm**

7. Demonstrator

- A first operational demonstrator :
  - Cylindrical « Cells » in plexiglass
  - Acquisition with NI card (fs=1MHz)
  - Detection algorithm implemented in Labview
  - Ultrasound speaker plays acoustic disturbances
- Conditions close to reality



→ **Good detection with an appropriate choice of threshold**

8. Conclusions / perspectives

Conclusions

- Identification of the acoustic disturbances in a electric vehicle
- Study of the acoustic propagation in the battery environment
- Study of 2 detection methods : correlation and HOS
- Development of an operational demonstrator => good detection results
- Development of a localisation algorithm. Study of the sensors optimum deployment

Perspectives

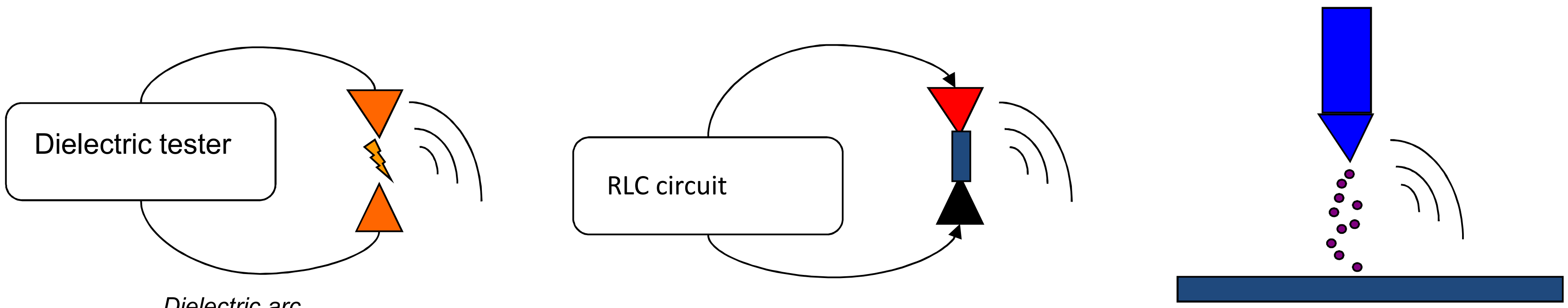
- Generic detection system adapted to any kind of battery
- Embedded system with a specific low cost sensor developed by CEA
- Miniaturization of the system and integration within the battery

THANKS !

ANY QUESTIONS ?

III Study of an electric arc : experimentation

- Goal: characterisation of the acoustic signature of the arcs → determination of the appropriate detection method
- Difficulty: realization of electric arcs created in real conditions (with connection defaults on battery cells)
- three ways to generate arcs:



Dielectric arc *Fuse arc* *Corona discharge*

- Results : the acoustic signature is independent from arcs characteristics (distance between electrods, arc voltage)

→ **Detection is robust to the conditions of the apparition of the arcs**

I Context of the study-problematics

- How to detect an arc → prevent thermal runaway in the battery
- What is the acoustic signature of the arcs ?
- How the acoustic waves emitted by the arc are propagated in the environment of the battery ?
- What kind of sensors should be used ?
- Will the Acoustic disturbances emitted by the electric arc interfere with the acoustic arc signal ?

→ **Distinguish acoustic arcs signal from the vehicle disturbances**

→ **Reach good detection performances**

III Study of electric arc : theory

– Acoustic signature of electric arc

- Transfer of energy by the charged particles to the neutral particles

– Amplitude of the acoustic wave generated by the arc :

$$A = \alpha \frac{\gamma - 1}{C^2} \frac{\partial W}{\partial t}$$

Variation of the power transferred to the arc

where:

- α coefficient inversely proportional to the temperature of the arc
- γ coefficient of adiabatic compression,
- C speed of sound,
- W electric power transferred to the arc.

- Connection default → big variation of the power transferred to the arc → important acoustic signature

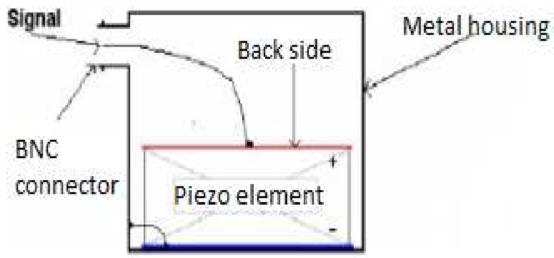
→ **Possibility of detection of the arc precociously**

III Study of electric arcs: acoustic sensors

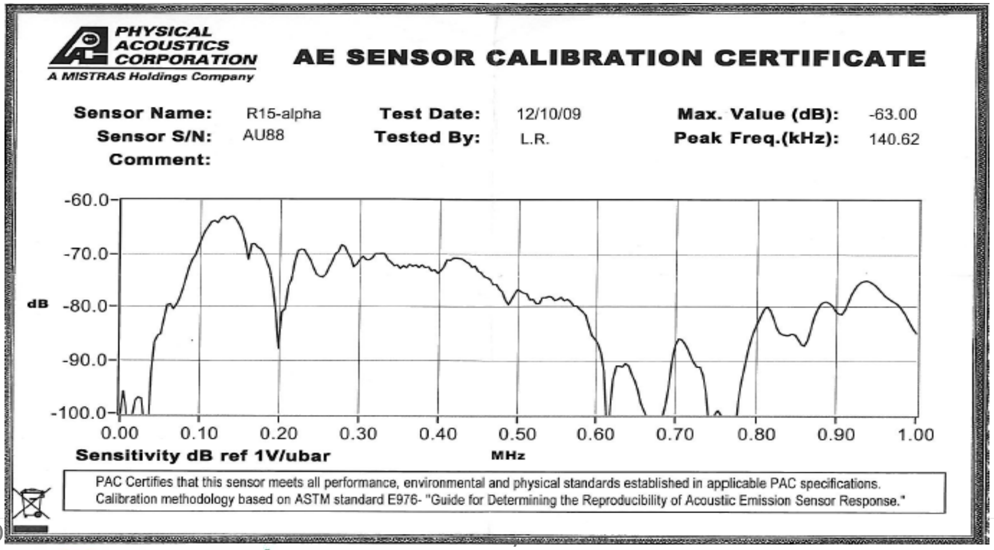
sors used:

Piezoelectric sensor: R15-a of EPA :

ceramic flange for coupling to a material



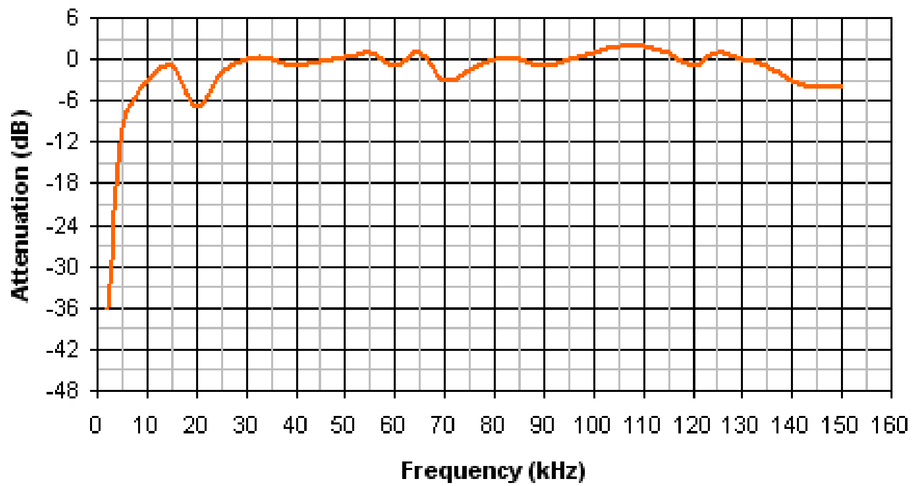
EPA sensor



Frequency respons of the sensor EPA

Condenser microphone: CM16 of Avisoft : *polarisation extern polarization → more dedicated to our problem of detection*

Avisoft sensor



Frequency response of the sensor Avisoft

V Experiments on vehicle : Goal and protocol

- Goal : identify the disturbances → avoid false alarms
- Step : Measure of acoustic signal emitted by electric vehicle (Renault Kangoo)
- Acquisition for different:
  - Locations : next to the motor, next to the battery, …
  - Events : brake, acceleration, turn signal …
- Utilisation : panoply of signals to evaluate the detector performances (simulation)
- Remarks:
  - The acquisition is not realized inside the pack
  - The Acquisition present big amplitudes (« worst case »)

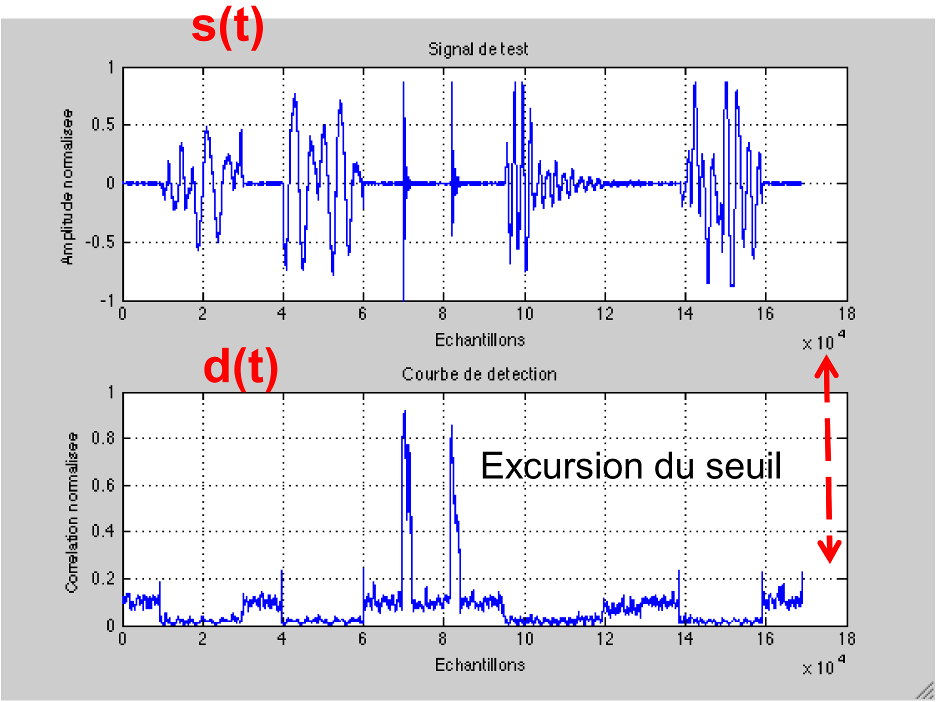
V Detection methods: theory

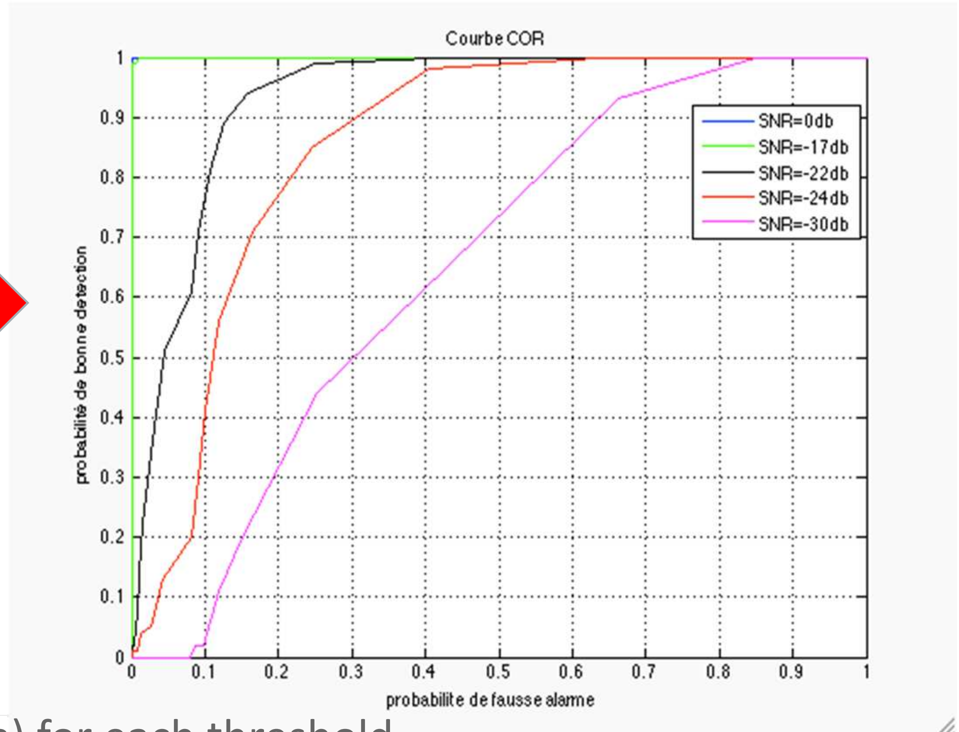
- Formulation of detection problem: *Testing the hypothesis H0 against H1: we have to decide which one is true ?*

$$\begin{cases} H_0 : x(t) = b(t) \\ H_1 : x(t) = s(t) + b(t) \end{cases}$$

- Pd=P(H1/H1)
- Pfa=P(H1/H0)

- Evaluation of the detection performances → ROC curves





- We have a couple (Pd, Pfa) for each threshold