



## **ULTRASONIC INTERROGATION FOR MONITORING AND MANAGEMENT OF AGM-VRLA BATTERIES**

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# CEA - LITEN ?

- CEA : French Alternative Energies and Atomic Energy Commission (since 1945)
- Liten : Research institute dedicated to the energy transition

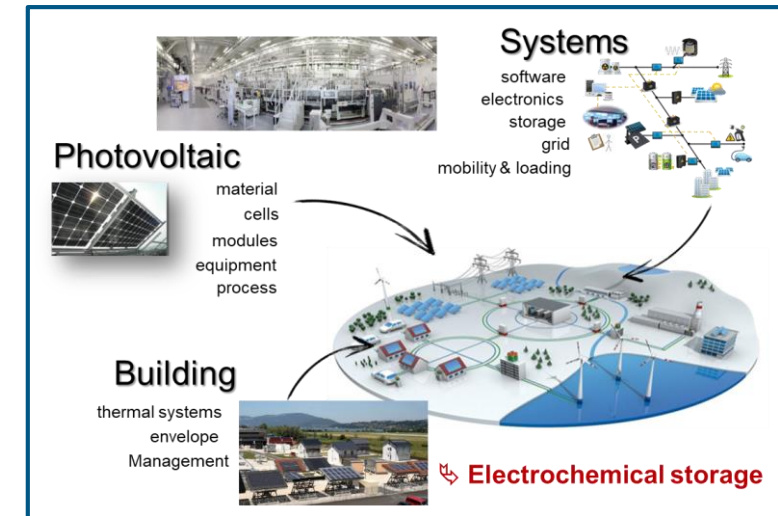


**LABAT'2021**  
LEAD-ACID BATTERIES CONFERENCE



Liten headquarters at **Grenoble** ~ 1100 researchers,

~400 at INES campus **Le Bourget-du-Lac**



### Stand-alone systems



### Grid-connected systems



### Integration in buildings



**Experts**  
Electrochemistry,  
Modelling, iElectrical  
engineering...

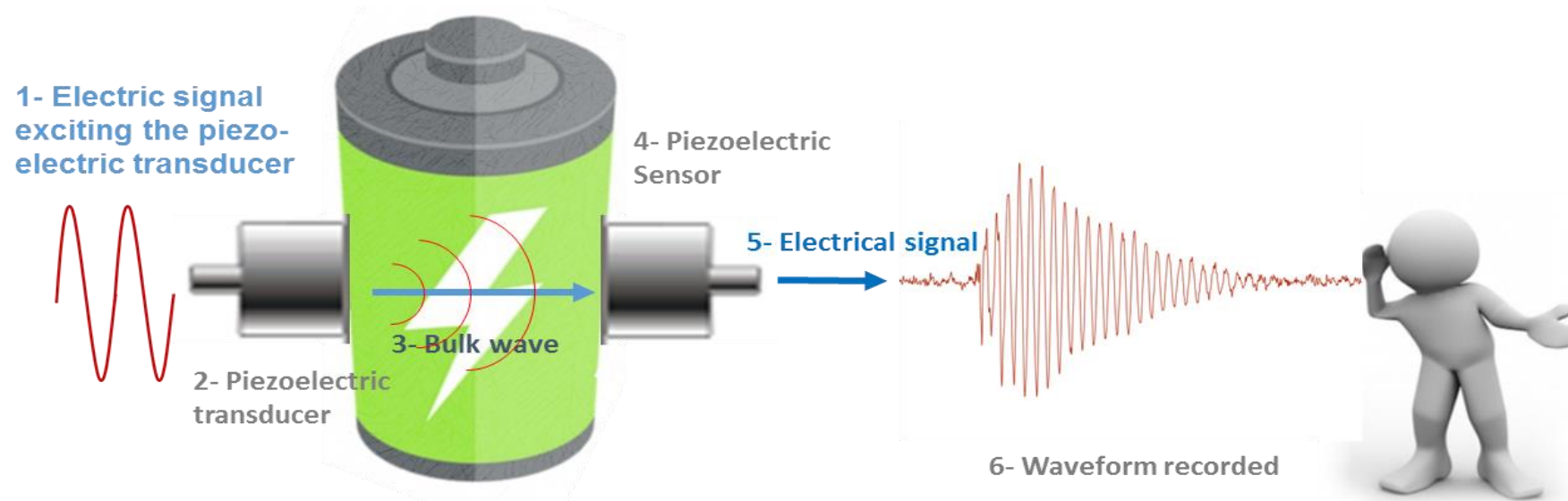


**Test facilities**  
350 battery testing  
channels, abusive  
conditions and safety  
tests, high voltage  
platform .....



- 1) Select the most appropriate storage systems for the intended application
- 2) Development of battery of advanced management strategies

# ULTRASOUND INTERROGATION FOR BATTERY MONITORING ?



- **Non-destructive test (NDT) method;**
  - Study the propagation of acoustic waves throughout the battery's materials;
  - Acoustic waves interact with materials and interfaces

↪ **Detect materials density variations, discontinuities, defects, bubbles generation...**

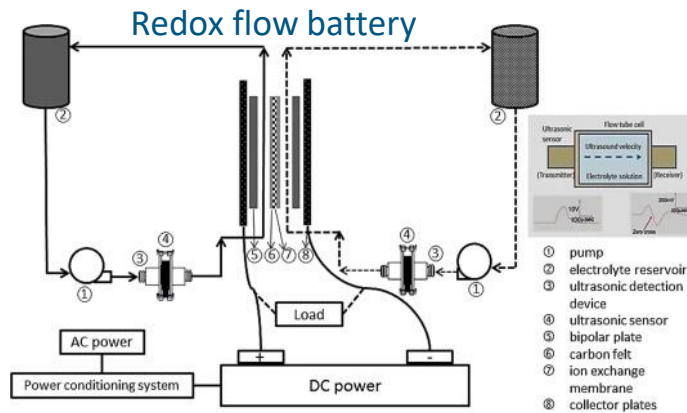


# ULTRASOUND INTERROGATION FOR BATTERY MONITORING ?



- Previous works

- Density of electrolyte measurement



Y.-S. Chou, N.-Y. Hsu, K.-T. Jeng, K.-H. Chen, and S.-C. Yen, "A novel ultrasonic velocity sensing approach to monitoring state of charge of vanadium redox flow battery," *Appl. Energy*, vol. 182, pp. 253–259, 2016.

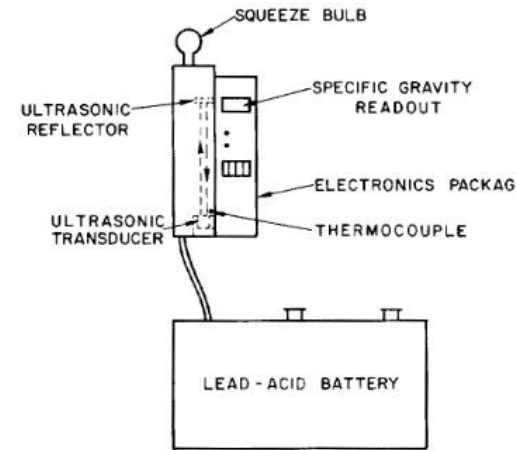


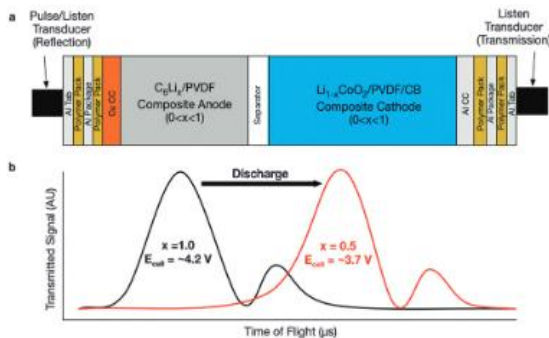
Fig. 10. Conceptual design of improved hydrometer.

## Lead – acid battery

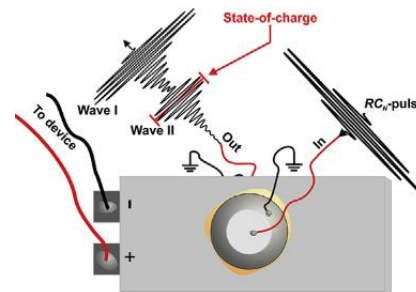
C. A. Swoboda et al., "Development of an Ultrasonic Technique to Measure Specific Gravity in Lead-Acid Battery Electrolyte," *IEEE Trans. Sonics Ultrason.*, vol. 30, no. 2, pp. 69–77, 1983

J. X. Liu, G. F. Li, W. Q. Xiong, H. J. Xiao, and L. Wang, "An ultrasonic approach to measure the density of battery electrolyte," *Proc. - Int. Conf. Electr. Control Eng. ICECE 2010*, no. 1, pp. 414–418, 2010.

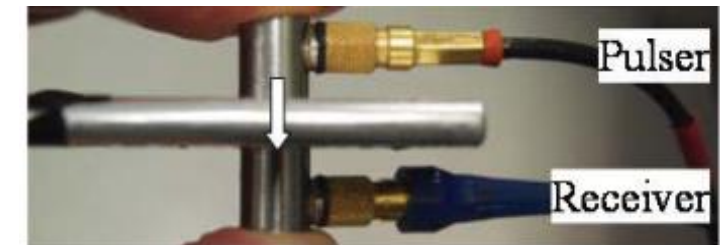
- Material change during cycling & ageing (Li-ion batteries)



A. G. Hsieh et al., "Electrochemical-Acoustic Time of Flight: In Operando Correlation of Physical Dynamics with Battery Charge and Health," *Energy Environ. Sci.*, vol. 8, no. 5, pp. 1569–1577, 2015



L. Gold et al., "Probing lithium-ion batteries' state-of-charge using ultrasonic transmission – Concept and laboratory testing," *J. Power Sources*, vol. 343, pp. 536–544, 2017.



B. Sood et al., "Health Monitoring of Lithium-ion Batteries," in *Proc. 2013 IEEE Symposium on Product Compliance Engineering (ISPCE)*, 2013, pp. 3–8.

# ACOUSTIC INTERROGATION

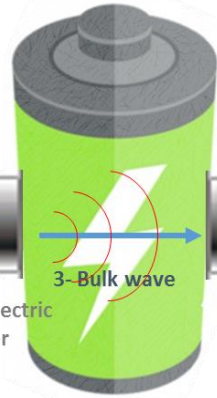


- Parameters of interest

1- Electric signal exciting the piezo-electric transducer

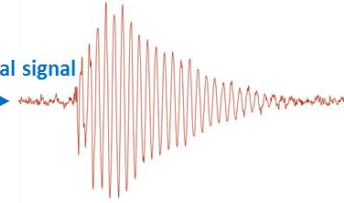


2- Piezoelectric transducer



4- Piezoelectric Sensor

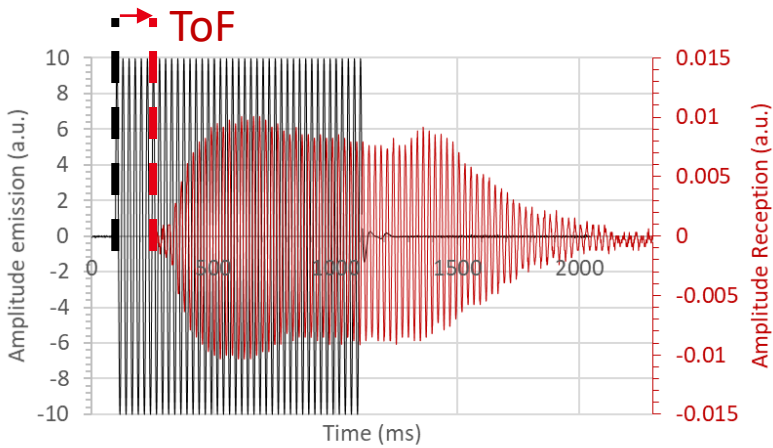
5- Electrical signal



6- Waveform recorded

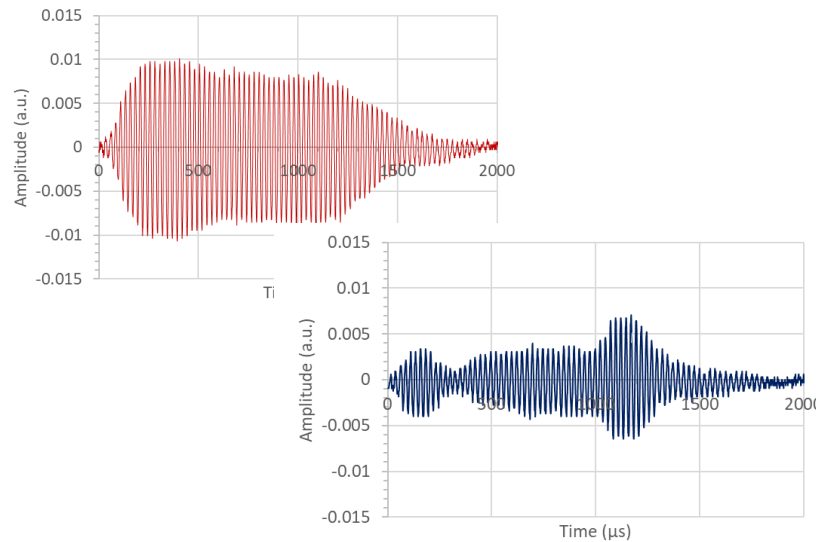


## Time of Flight (delay between emission and reception)



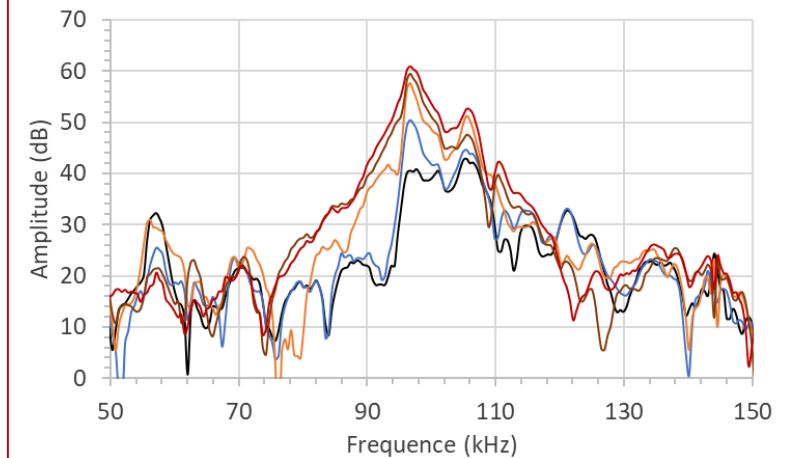
Depending on the distance between the transducers and the sound speed in the materials

## Shape of the waveform



Depending on the interactions of the acoustic wave with the materials / interfaces inside the battery

## Power spectrum density

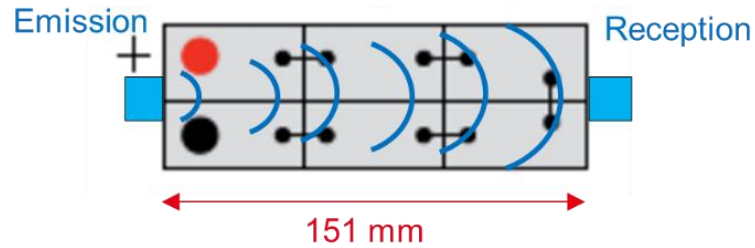
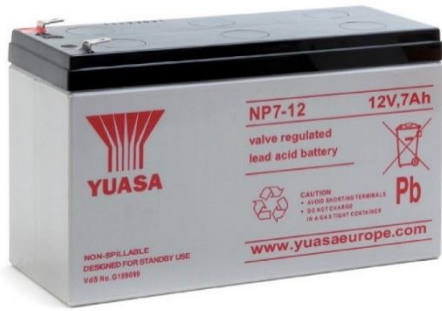


Energy and strength of the signal transmitted depending on the properties of the materials (density, Young modulus, porosity etc...)

## EXPERIMENTAL SETUP

- Example of AGM-type lead-acid batteries monitored

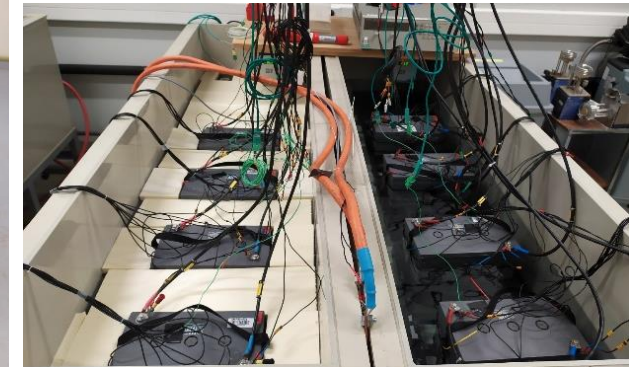
YUASA NP7-12 battery (12 V / 7 Ah)



GNB Sprinter XP6V2800 (6 V / 195 Ah)



$L = 295 \text{ mm}$   $l = 165 \text{ mm}$

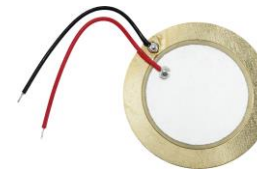


Accelerated ageing in water baths at 50 and 60 °C

- Piezo-electric transducers



PZT ceramic piezoelectric transducer (22.4 mm x  $\varnothing$ 19 mm)  
<https://www.physicalacoustics.com/by-product/sensors/F15a-100-450-kHz-High-Sensitivity-Flat-Frequency-Response-AE-Sensor>



Low-cost PZT piezoelectric transducer : EPZ-20MS64W (430  $\mu\text{m}$  x  $\varnothing$ 20 mm)



Coaxial wiring and BNC connections  
 Transducers imbedded in a 3D printed holder using epoxy resin for sealing and mechanical fixation

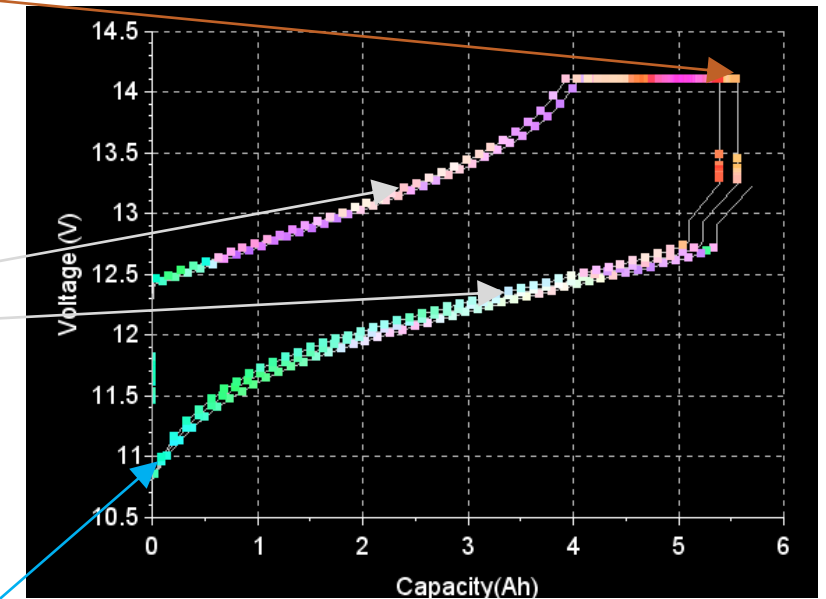
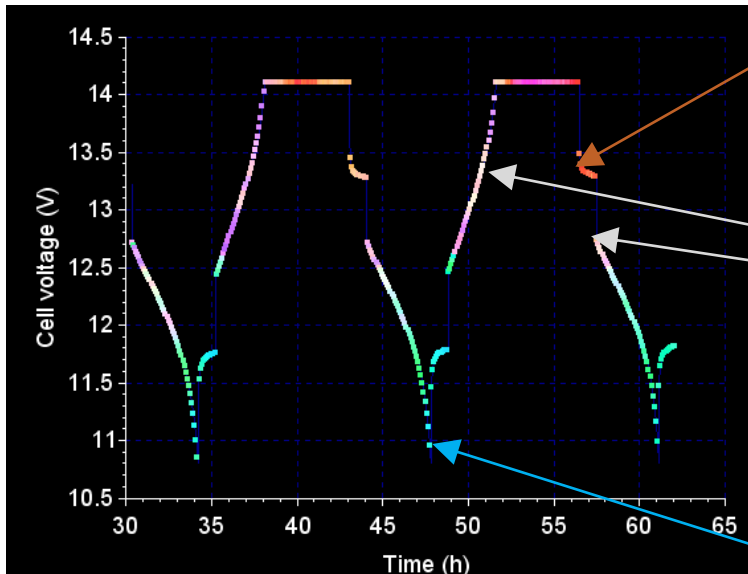
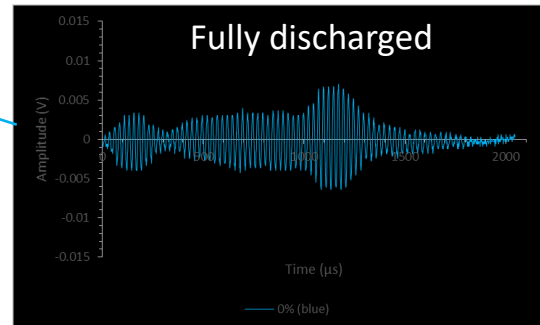
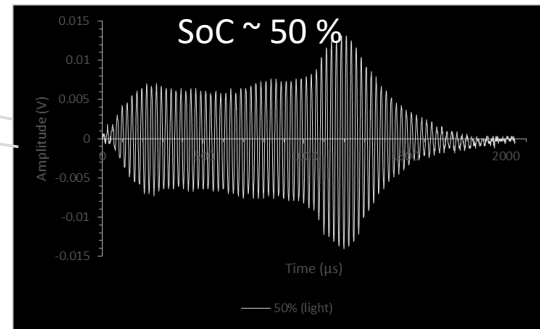
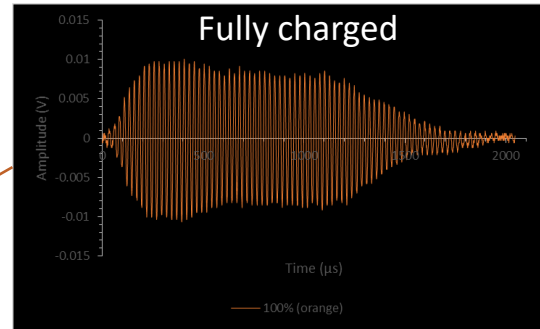
# ACOUSTIC INTERROGATION DURING CYCLING



- Example on Yuasa NP7-12 battery (12 V / 7 Ah)



## Shape of the waveform



Evolution of the cell voltage with time during cycling CC 2 A – CV  
14.0 V , 283 mA// CC 850 mA, 10.8 V

Each colored dot corresponds to an acoustic measurement

The color of the dots is attributed according to the different families of detected waveforms

Evolution of the cell voltage with capacity during cycles

The colored points correspond to the different families of detected waveforms



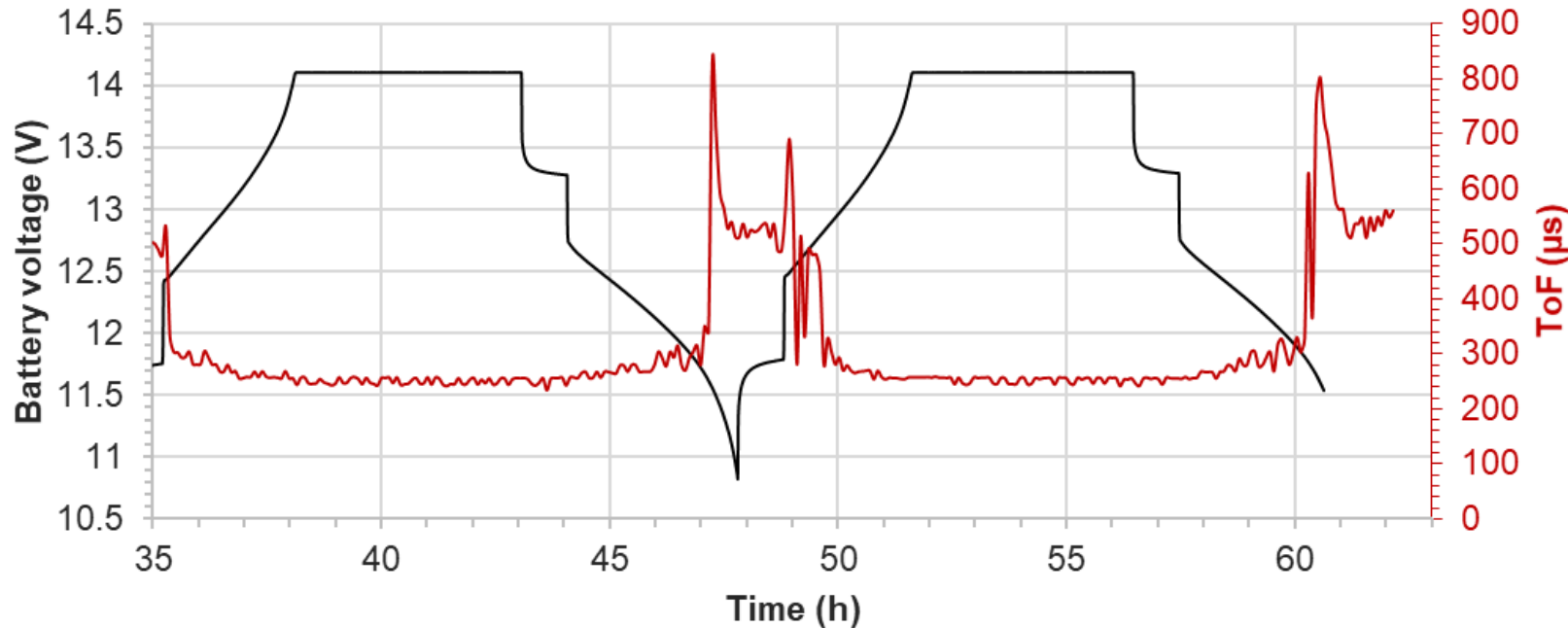
# ACOUSTIC INTERROGATION DURING CYCLING



- Example on Yuasa NP7-12 battery (12 V / 7 Ah)



**Time of Flight**  
(delay between emission and reception)



- ↪ **Weak evolution of the time of flight with the state of charge (decreases when the SoC increases)**
- ↪ **But strong increase at low state of charge**

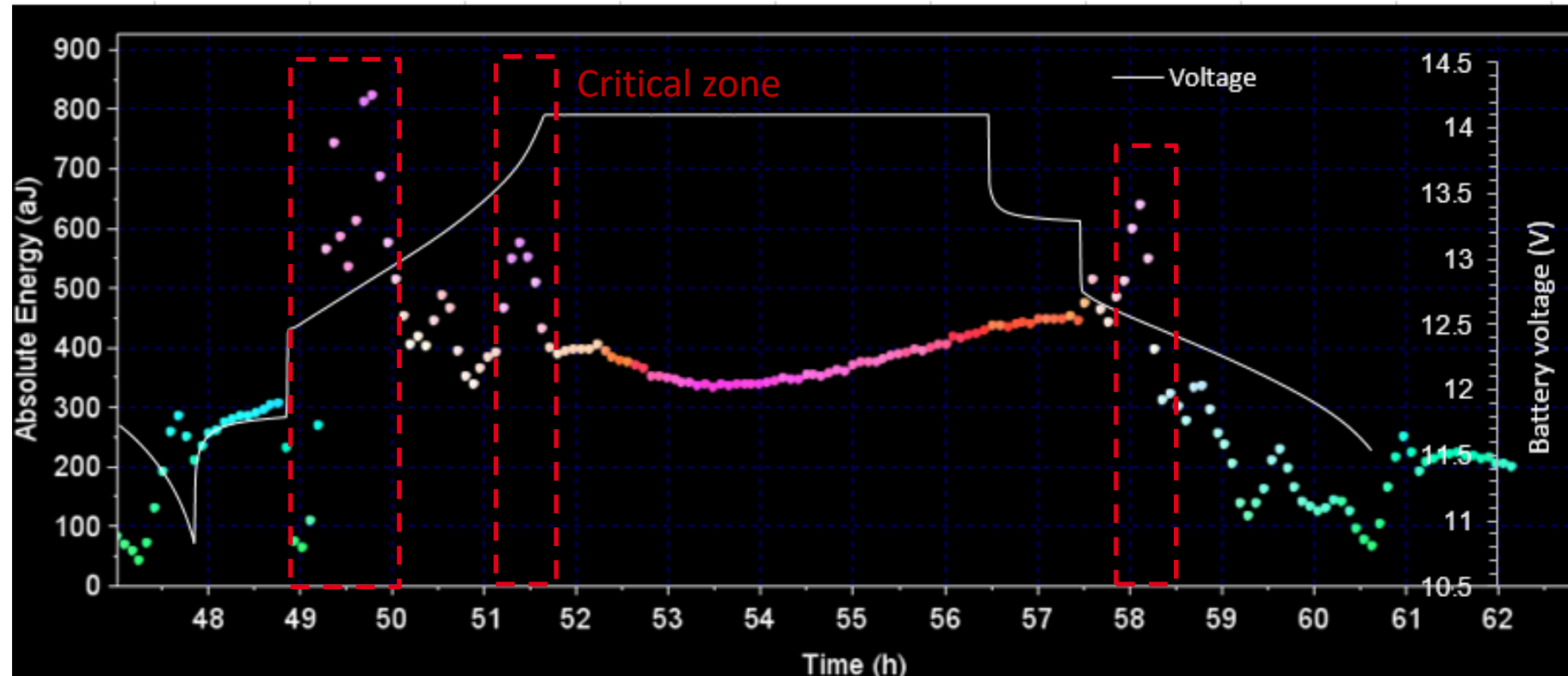
## ACOUSTIC INTERROGATION DURING CYCLING



- Example on Yuasa NP7-12 battery (12 V / 7 Ah)



Power spectrum density – Absolute energy of the transmitted signal

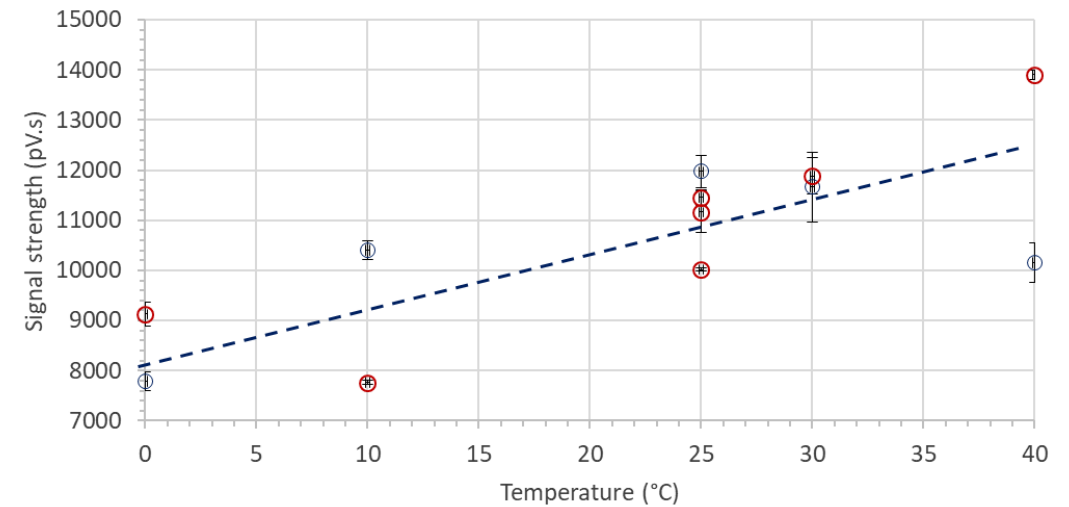
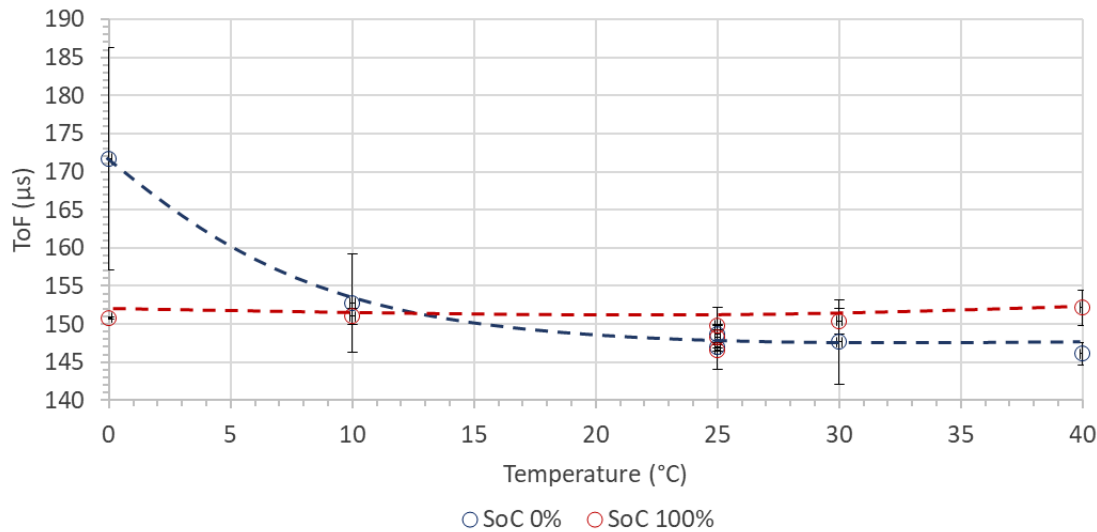


- ↪ Complex, significant and repeatable evolution of the energy of the signal transmitted during charging and discharging / Weak but significant evolution during CV and OCV periods
- ↪ A sign that the physical properties of the media crossed by the acoustic wave undergo notable, reversible and repeatable changes

# ACOUSTIC INTERROGATION DURING CYCLING



- Example on Yuasa NP7-12 battery (12 V / 7 Ah) : influence of temperature



- ↪ Only a slight influence of temperature on ToF (excepted at SoC 0% and 0°C – very weak signal, large error)
- ↪ Overall decrease of the transmitted signal strength when the temperature decreases whatever the SoC is



# ACOUSTIC INTERROGATION DURING CYCLING

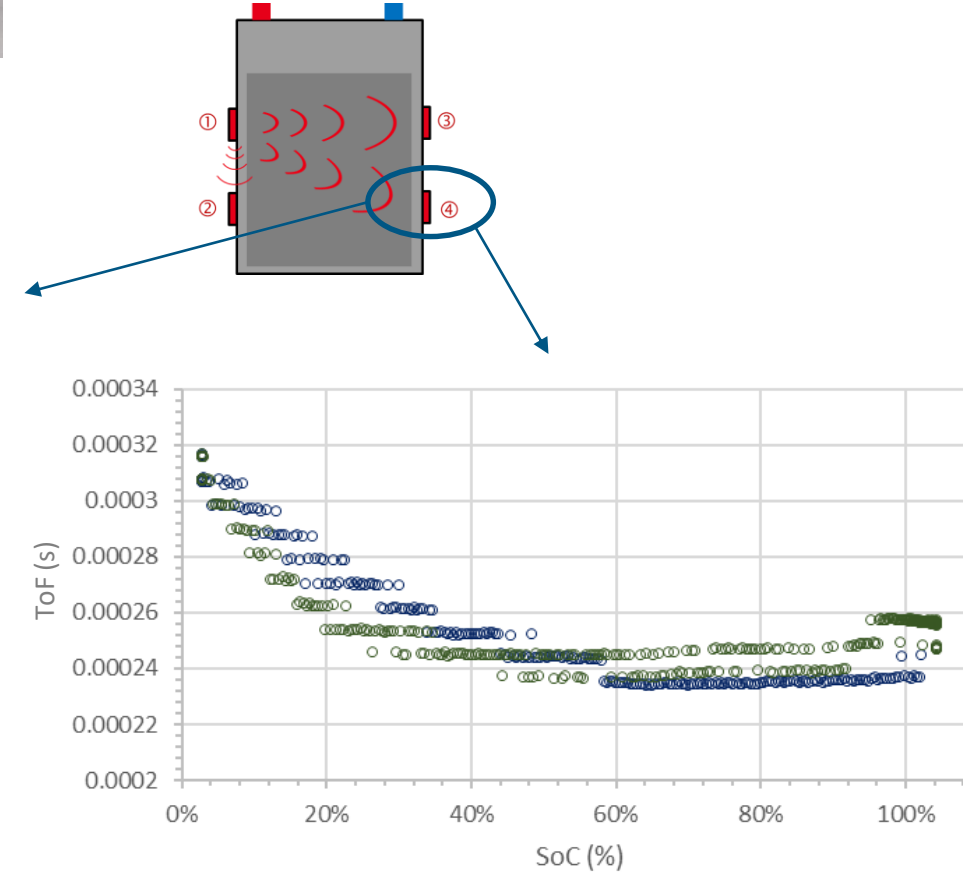
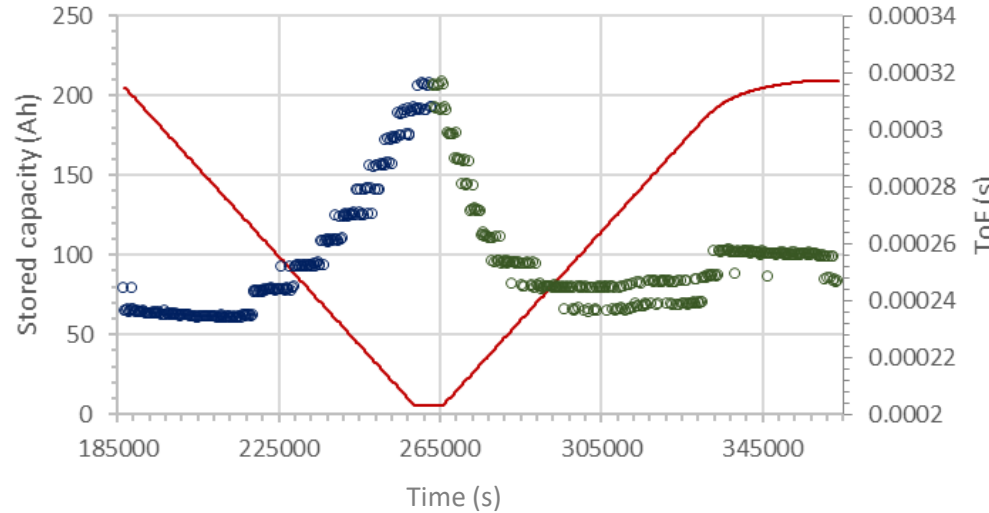
- GNB Sprinter XP6V2800 (6 V / 195 Ah)



10 A cycling (~C/20)



Measurements conducted on a cell of the battery (2 V / 195 Ah)



↳ ToF decreases when SoC increases (0.25 ms at SoC 100% → 0.3 ms at Soc 0%)

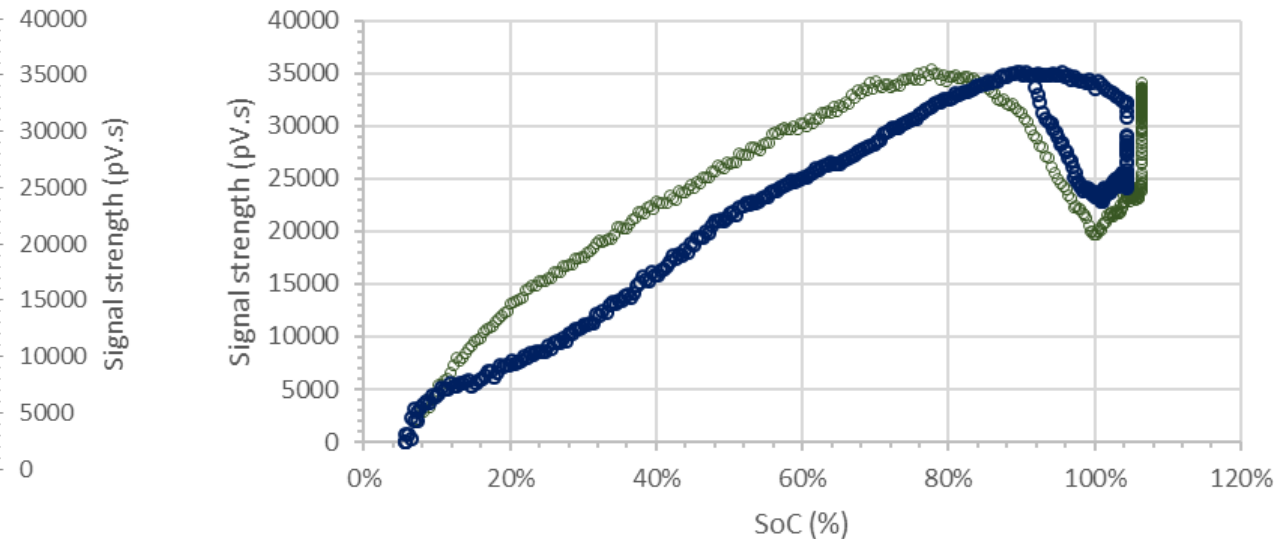
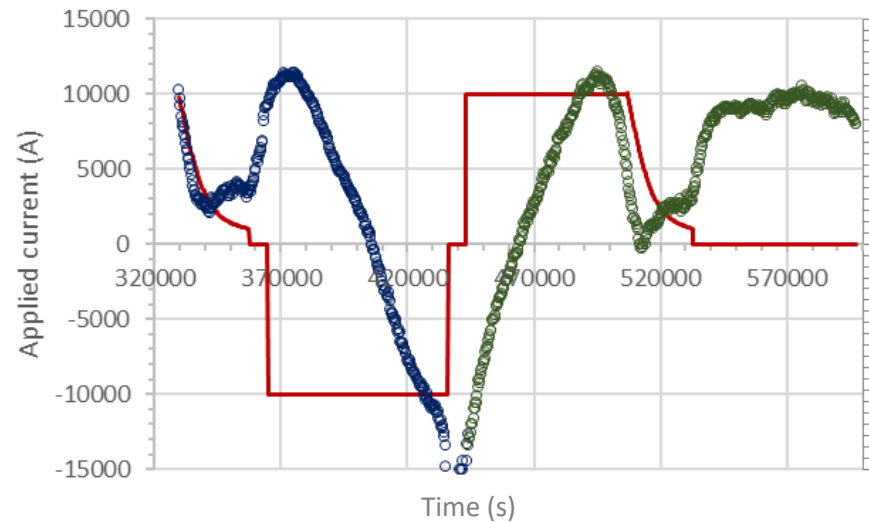
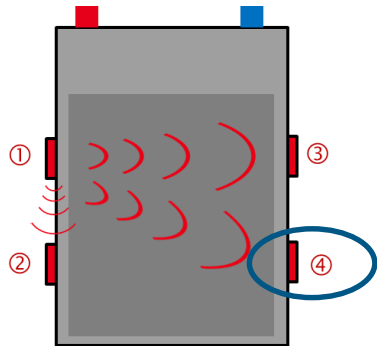
↳ Very high attenuation of the signal transmitted to ch #4 at low SoC (< threshold)

# ACOUSTIC INTERROGATION DURING CYCLING

- GNB Sprinter XP6V2800 (6 V / 195 Ah)



10 A cycling (~C/20)



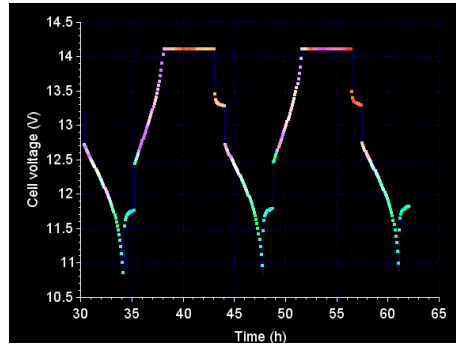
↪ Monotonic increase of the signal strength with SoC up to 80% SoC

↪ significant decrease of the signal strength during floating phase and overcharge (gas evolution ?)

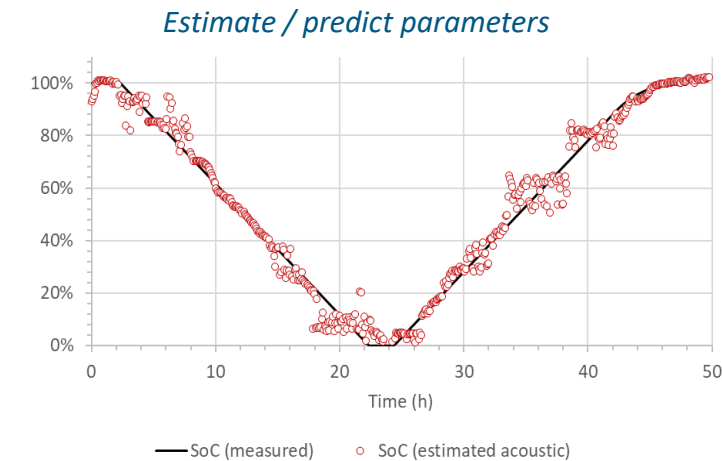
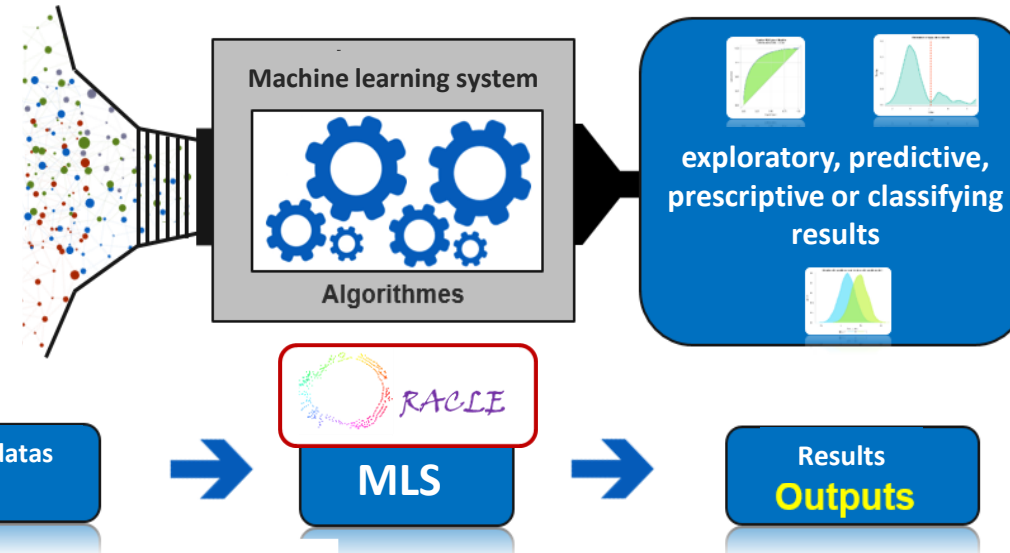
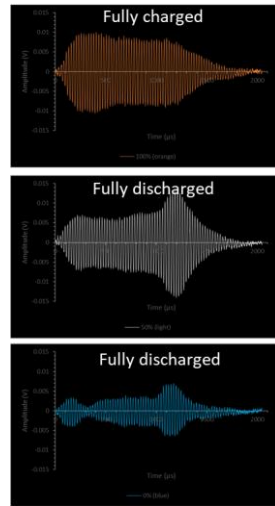
# SOC & STORED ENERGY ESTIMATION FROM ACOUSTIC DATA



- Data analysis using machine learning algorithms



Cell voltage, current, power, acoustic datas (ToF, DSP), temperature ...



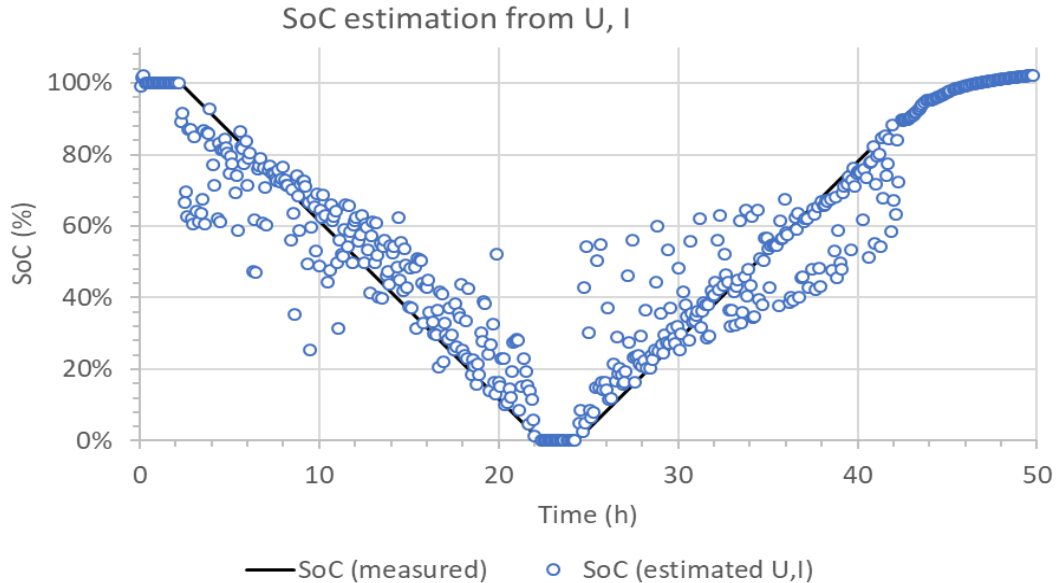
Machine learning system (Oracle tool, developed by CEA) → comparison of estimated value to measured value



# SOC & STORED ENERGY ESTIMATION FROM ACOUSTIC DATA

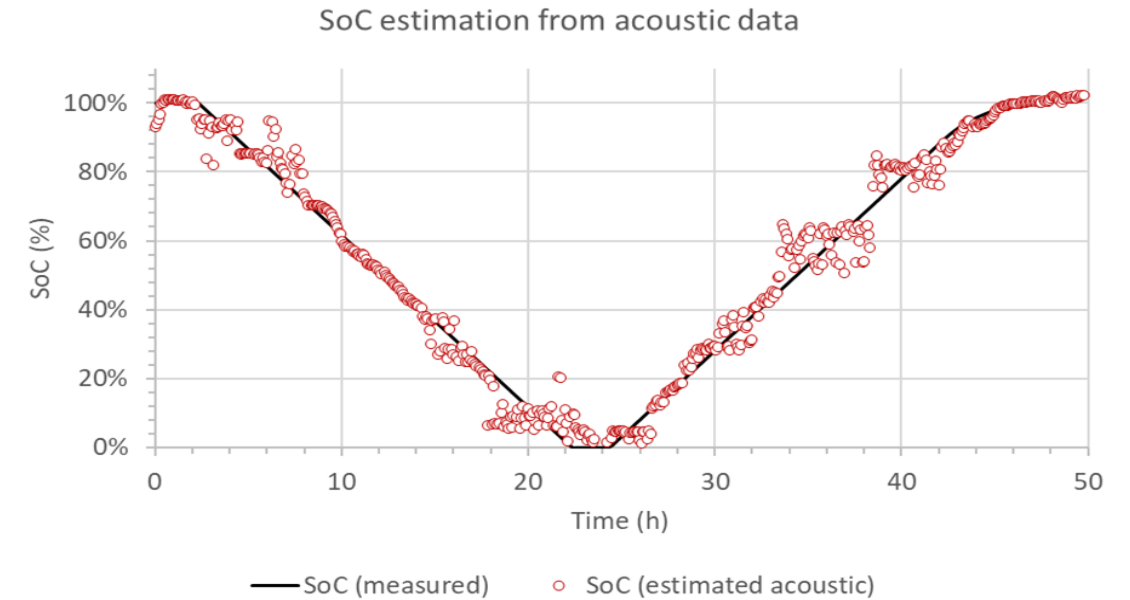


- Example on GNB Sprinter XP6V2800 (6 V / 195 Ah)  
→ « Oracle » algorithm (machine learning)



→ Mean error on full cycle = 7.3 %

→ Max error on full cycle = 51.4%



→ Mean error on full cycle = 3.2 %

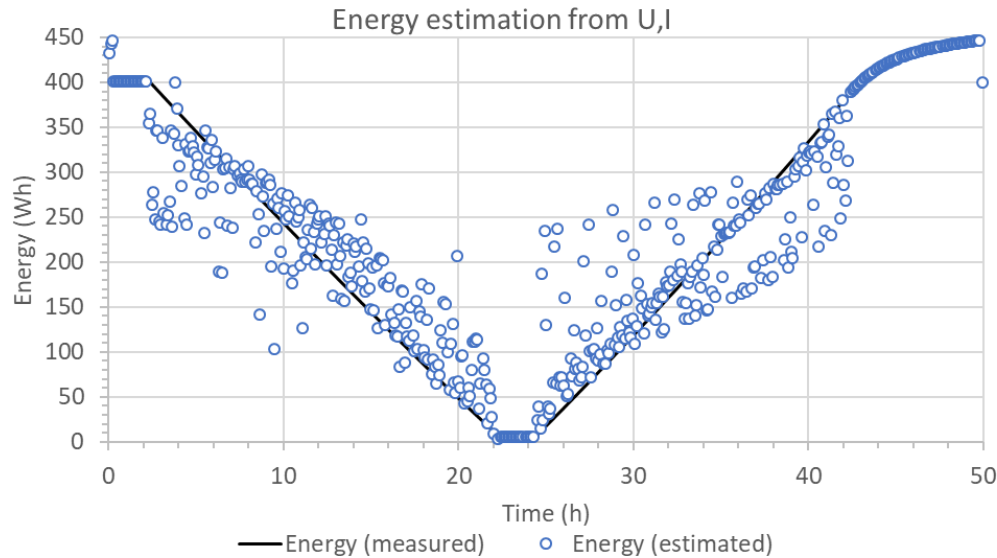
→ Max error on full cycle = 18.1 %

→ Possible to estimate accurately the state of charge of the battery independently of the electrochemical data

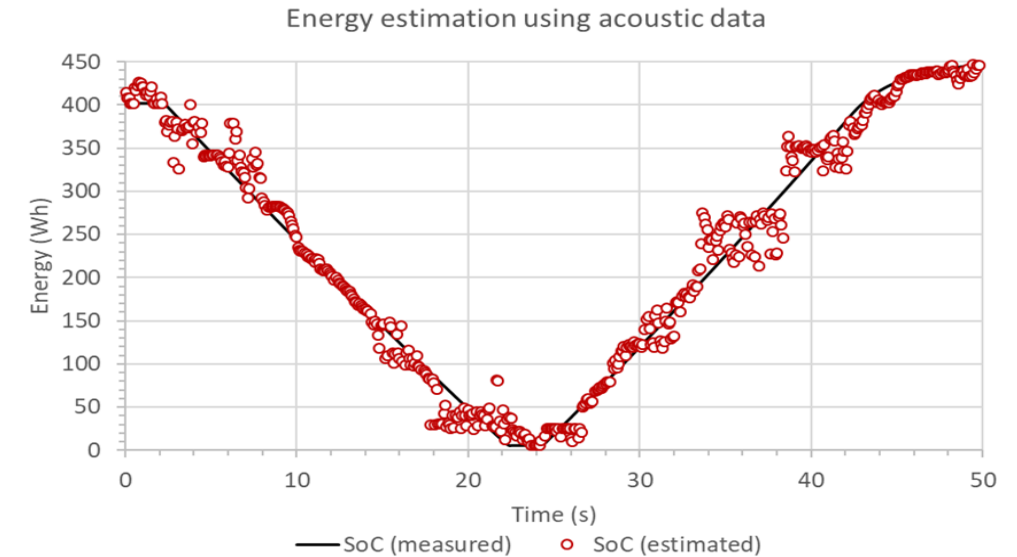
# SOC & STORED ENERGY ESTIMATION FROM ACOUSTIC DATA



- Example on GNB Sprinter XP6V2800 (6 V / 195 Ah)  
→ « Oracle » algorithme (machine learning)



- Mean error on full cycle = 6.8 %
- SoCMax error on full cycle = 48.7 %



- Mean error on full cycle = 3.1%
- Max error on full cycle = 17.6%

↳ Possible to estimate accurately the remaining energy available in the battery independently of the electrochemical data

## CONCLUSIONS & PERSPECTIVES



- **Ultrasonic interrogation technique:**
  - Non-destructing testing method - non intrusive,
  - Simple to put in place and non expensive
- **Can be useful for monitoring and management batteries**
  - Identification of the main changes in physical properties of the materials inside the battery during operation
  - Improve the estimation of SoC and SoE
  - Detect abnormal behavior and prevent safety issues
  - Quality check for manufacturers...
- **Next works !**
  - Improvement of the testing setup
  - Integration to the BMS for better performance and longer uselife of the batteries
  - Ageing test / SoH estimation (transducers + battery 😊)





Thank you for your attention

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Any questions?

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<http://liten.cea.fr/cea-tech/liten/en/>