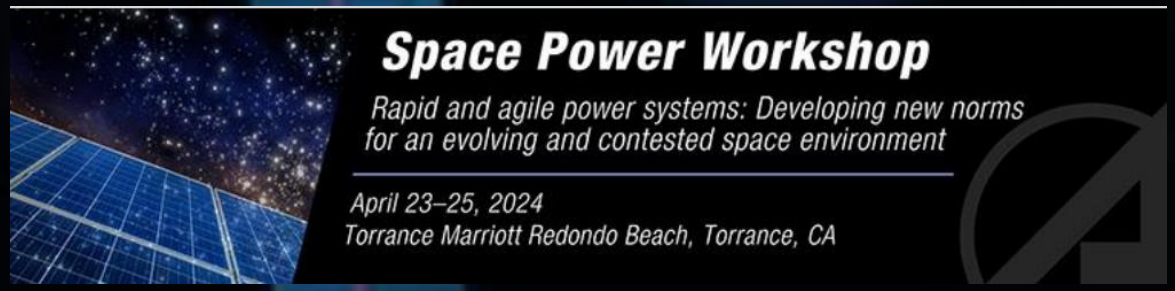
VL10ES Cell and Battery Qualification Update

Dr. Chengsong Ma, Dr. Yannick Borthomieu, Dr. Vanessa Armel



Summary

1. Products Roadmap
2. Cell development
3. Battery Performances
4. Conclusions

Saft Satellite Technology Road-Map

Corporate Cell Chemistry Roadmap
Advanced and Beyond Li-ion

Saft is adding a **new range of technologies** to its **portfolio**, reflecting the current market needs in **cylindrical, prismatic** or **pouch** format for both **power and energy applications**

➢Short and Medium Term

- **NMC/Gr+Si** for **high energy** applications : Specialty markets and high demanding applications
- **LMFP** for **safety** critical applications : Transport applications
- **LTO** for **high power cycling** applications with **very low Energy :** Transport and reduced recharge time applications

➢Long Term

- Saft is investing in key disruptive technologies : Solid State Batteries with **Li metal** based anode technologies
  - **Solid state batteries : >400 Wh/kg, 1100Wh/L** -> Energy density, safety, lower cost/Wh
  - **Advanced Li-S : >500 Wh/kg, 900 Wh/L** -> High Specific energy

Saft Li-ion in orbit heritage and reliability

383 satellites in-orbit with Li-ion (GEO, MEO & LEO) : 364 operational

More than 2,92 Billion of cell hours in orbit with **no failure or deviations**

Total over 4,1 MWh in-orbit with 680 batteries and more than 48 800 cells in orbit

- **211 GEO satellites** Launched + 1 Moon Mission :

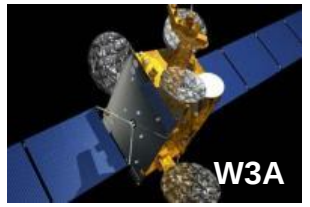
  2003 : Smart 1 has been able to reach Moon orbit thanks to ion thrusters' engines powered with Li-Ion battery

  1rst GEO Telecommunication satellite W3A launched 20 years ago (March 2004) with VES140 batteries

- **5 MEO satellite** flying with VES technology:

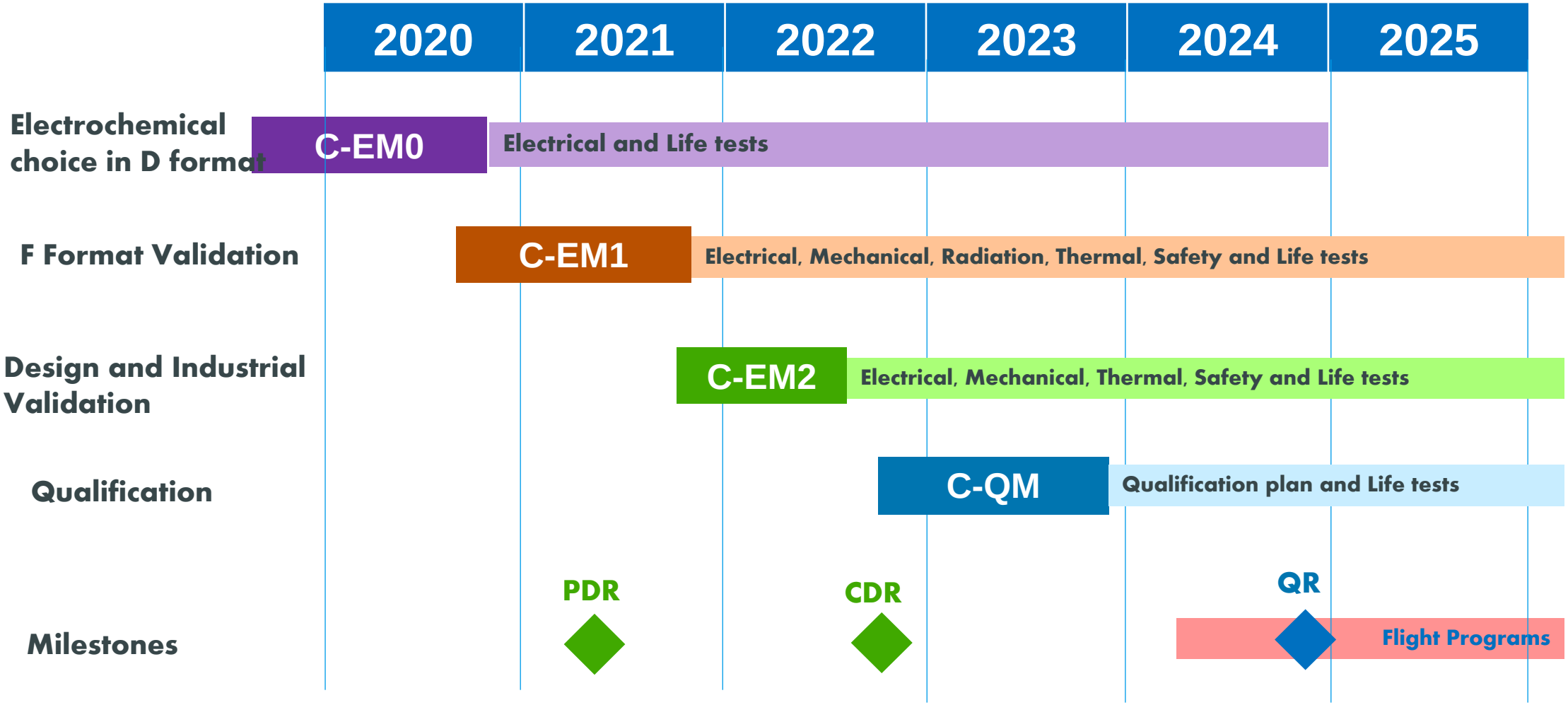
- **167 LEO satellites including** :

  80 first Iridium Next satellites with VES16 batteries



VL10ES Cell Development

VL10ES Cell Development Plan



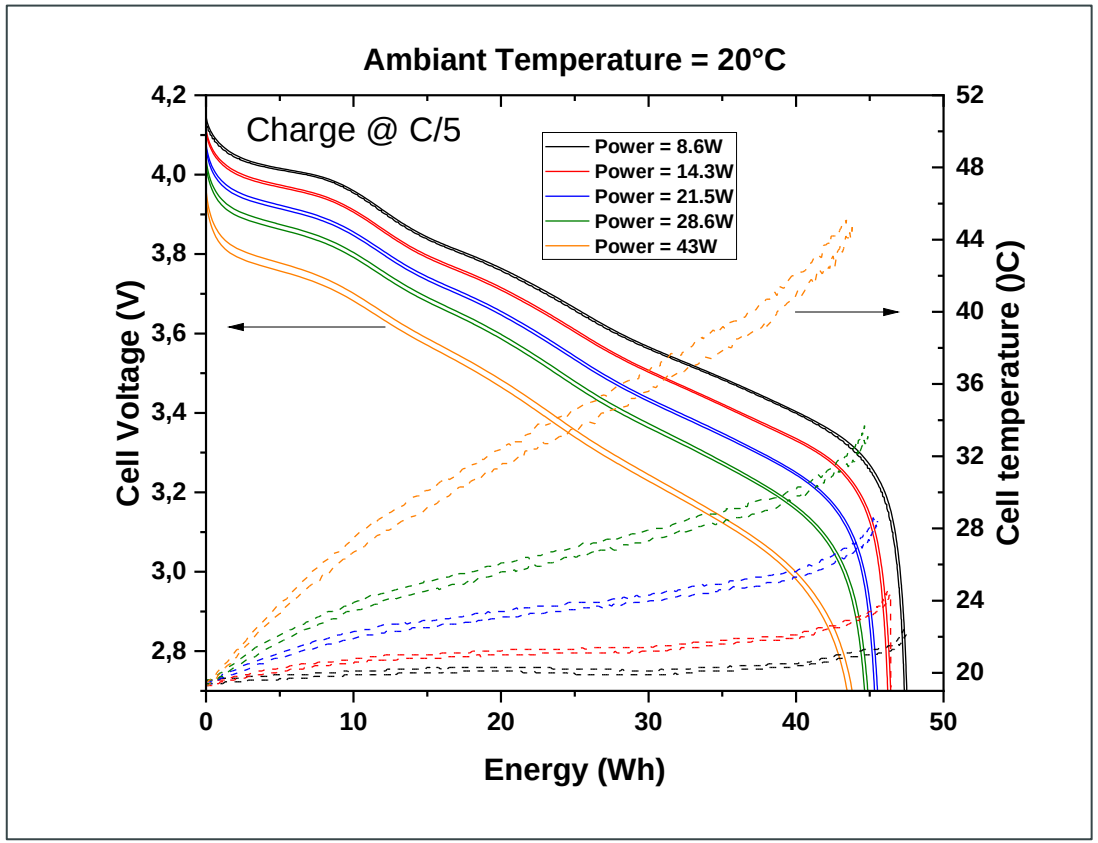
VL10ES Cell Qualification Matrix

VL10ES cell qualification Plan				
Electrical	**Mechanical**	**Thermal**	**Life Tests**	**Safety**
Dch vs T°	Vibration	T/V	LEO real time	Overcharge
Dch vs C rates	Shock	Dissipation	GEO semi-accelerated (EOR, PPS ,U cycles)	Over discharge / Reversal
Dch vs EOCV	T/V Cycling	Thermal Capacity	GEO accelerated	Ext. short
Dch vs Power rates	Leak Rate	Thermoneutral potential	Storage vs T° & SOC	Over temperature
Impedance, Ri	DPA		100% DoD	Nail / Pin Test
EMF vs SOC			Radiation Test	UN Transportation
			DPA	Exposure 60°C – 24 Hours

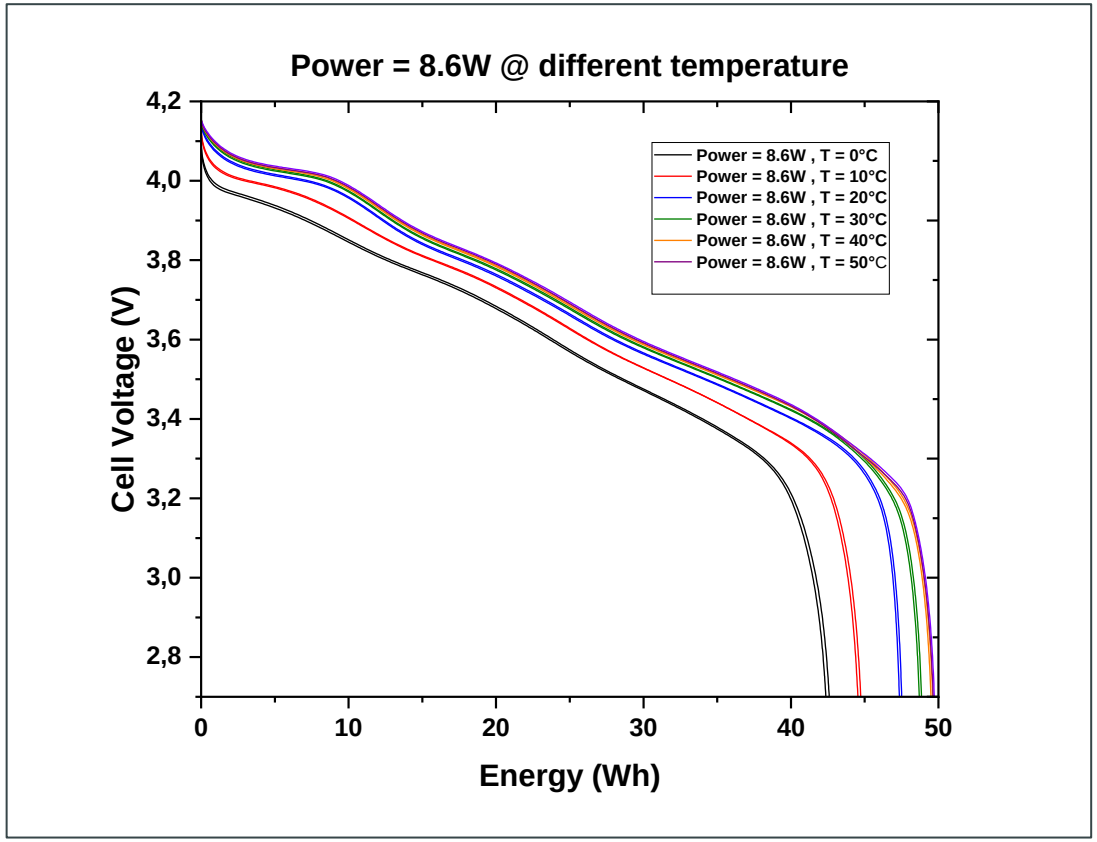
In orange color : Tests still running on QM cells

BOL Electrical Performances QM cells : Constant Power Discharge versus Temperature

Energy evolution vs Power at 20°C



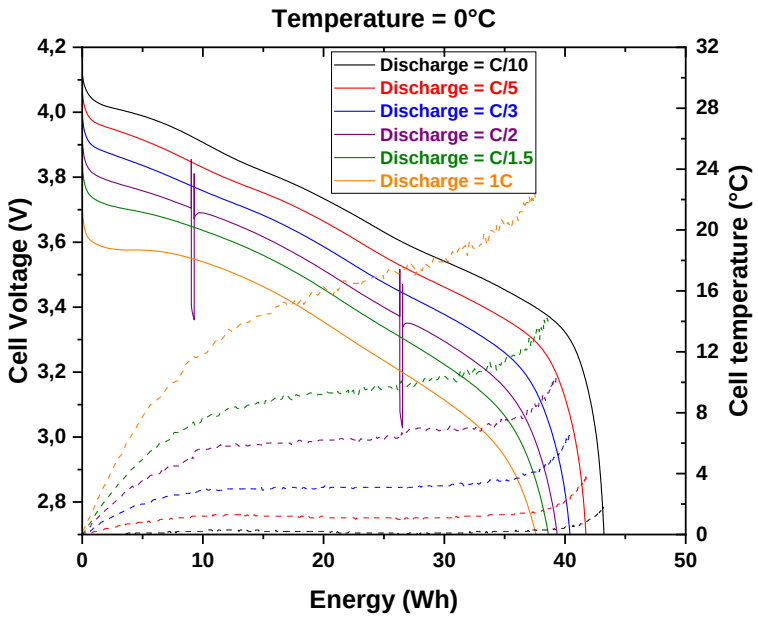
Energy evolution at constant Power vs Temperature



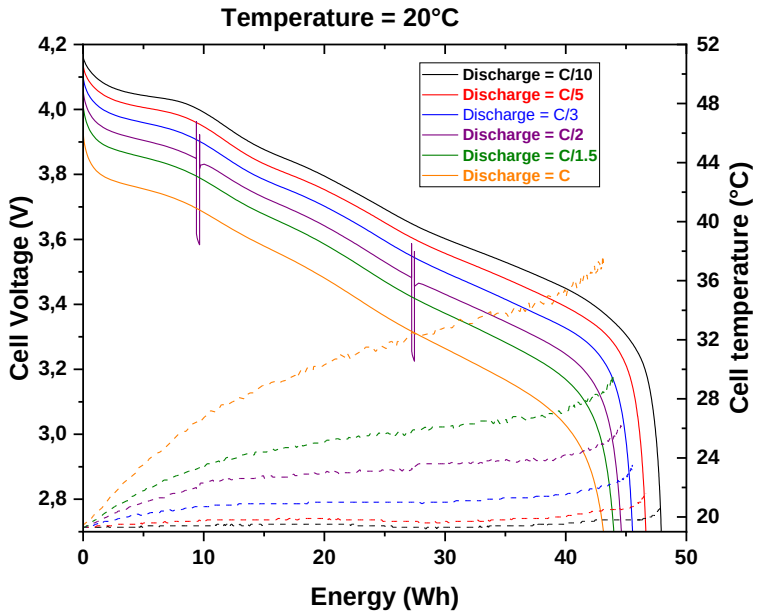
- Increasing discharge power leads to cell polarization together with a decrease in available energy and an increase in cell temperature.

BOL Electrical Performances QM Cells : Discharge Current versus Temperature

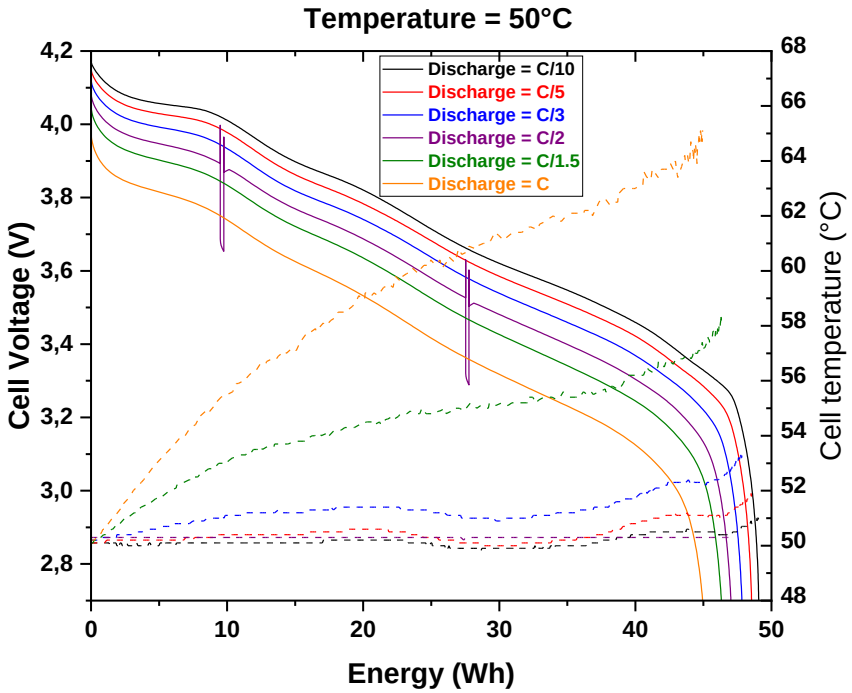
Energy evolution vs discharge rate at 0°C



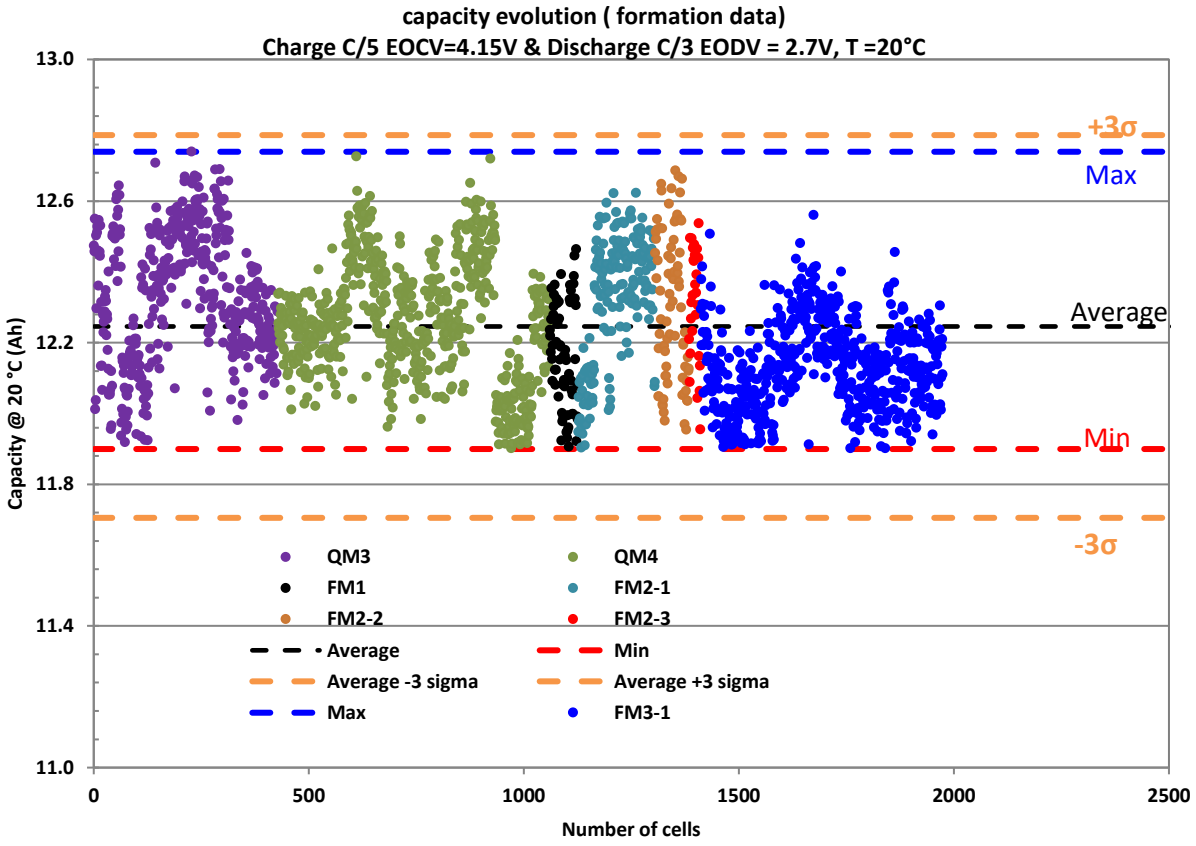
Energy evolution vs discharge rate at 20°C

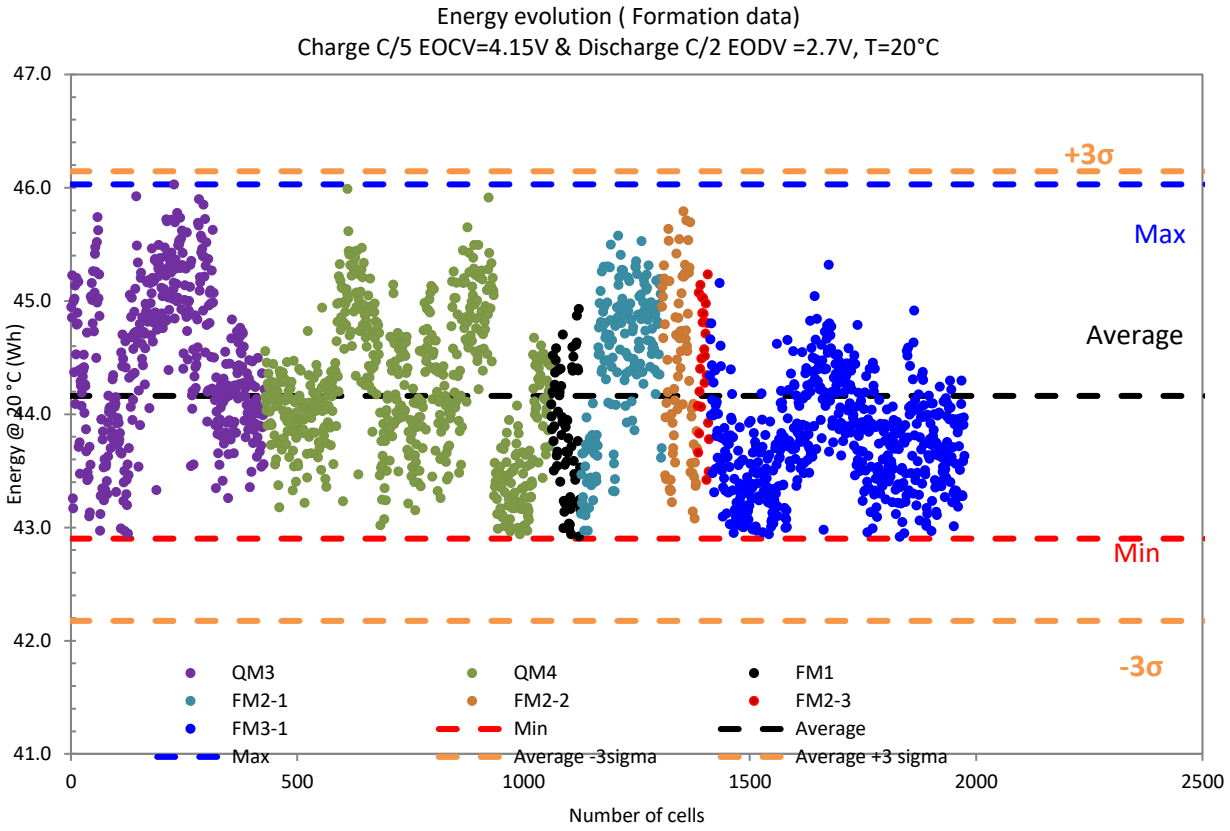


Energy evolution vs discharge rate at 50°C



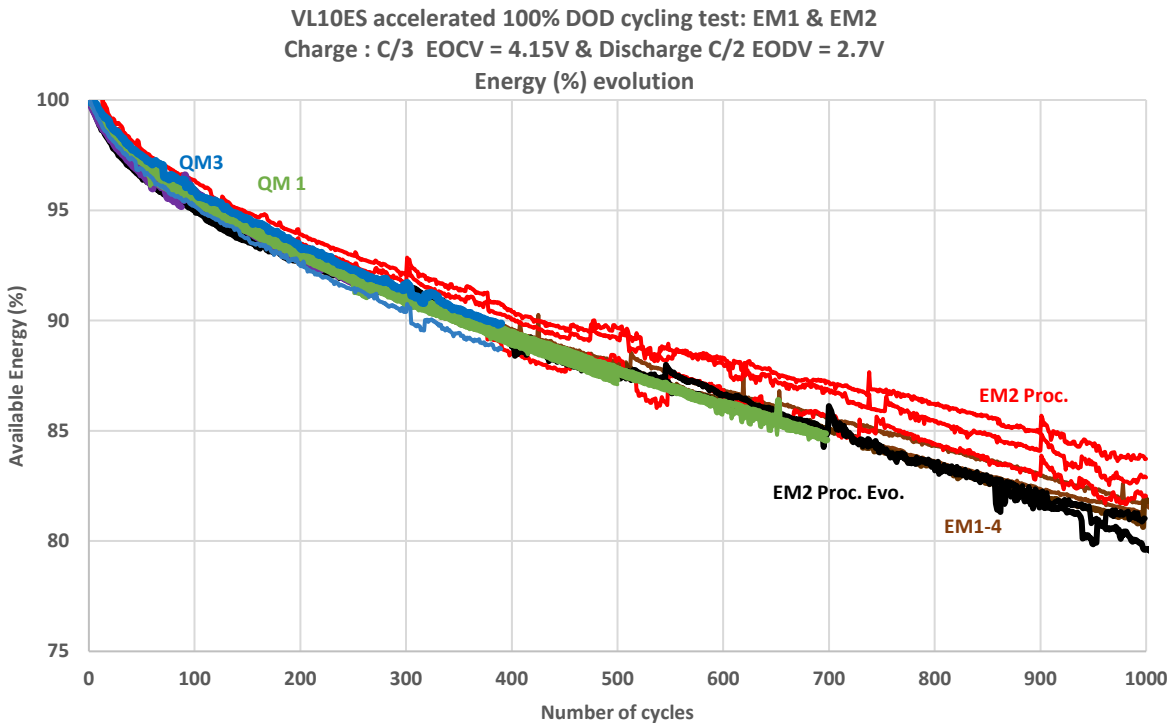
Electrical formation characteristics QM/FM batches

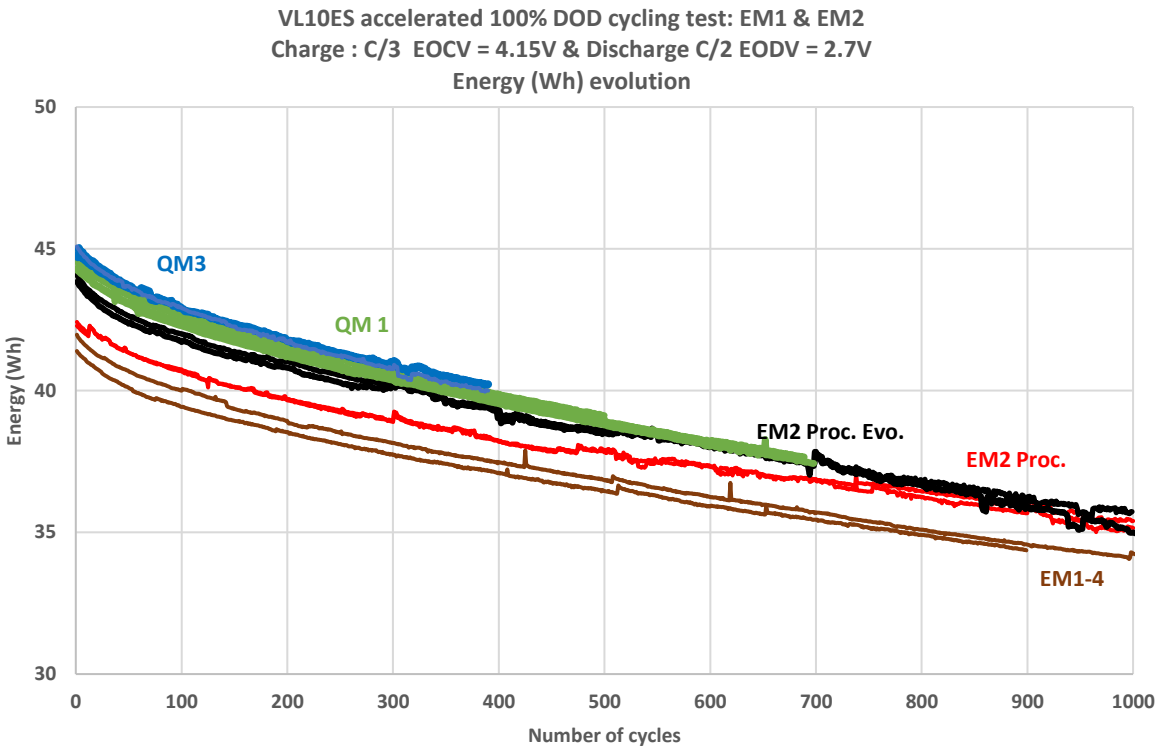




More than 2,000 cells built for QM and FM.

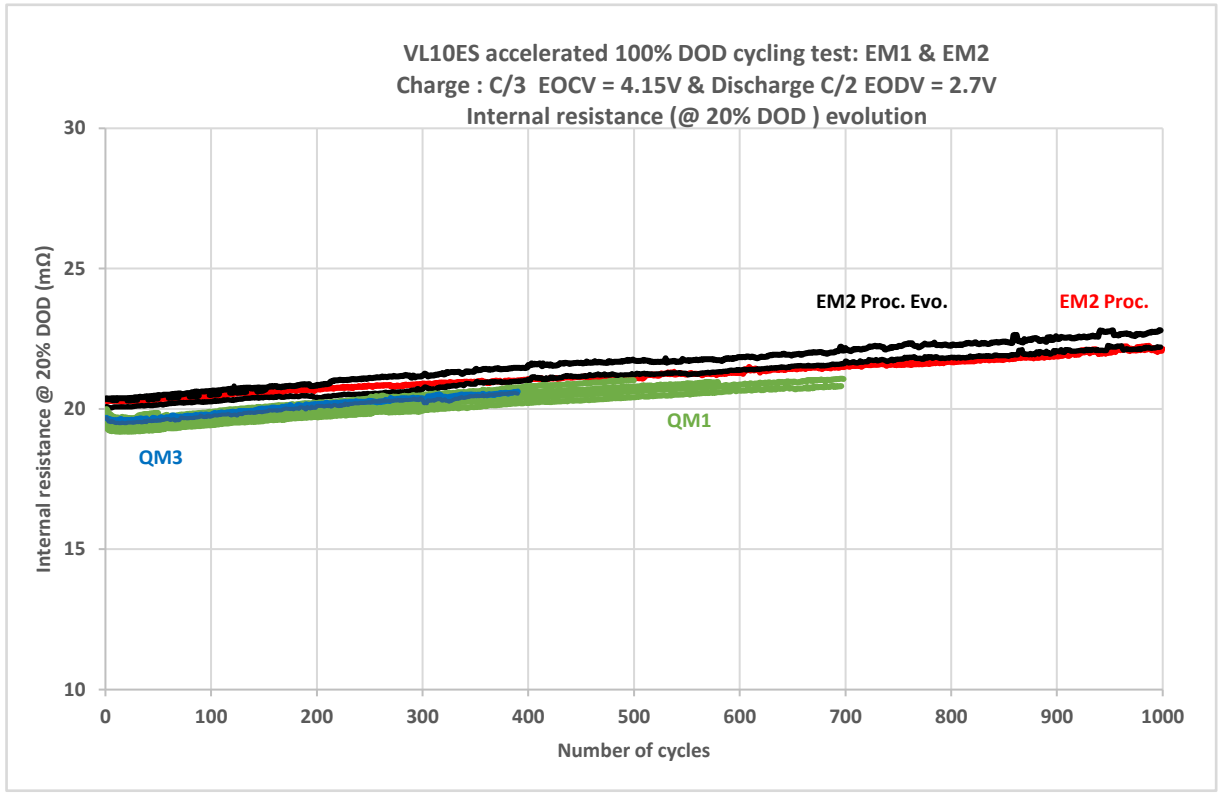
Accelerated 100% DOD Cycling: Energy Evolution

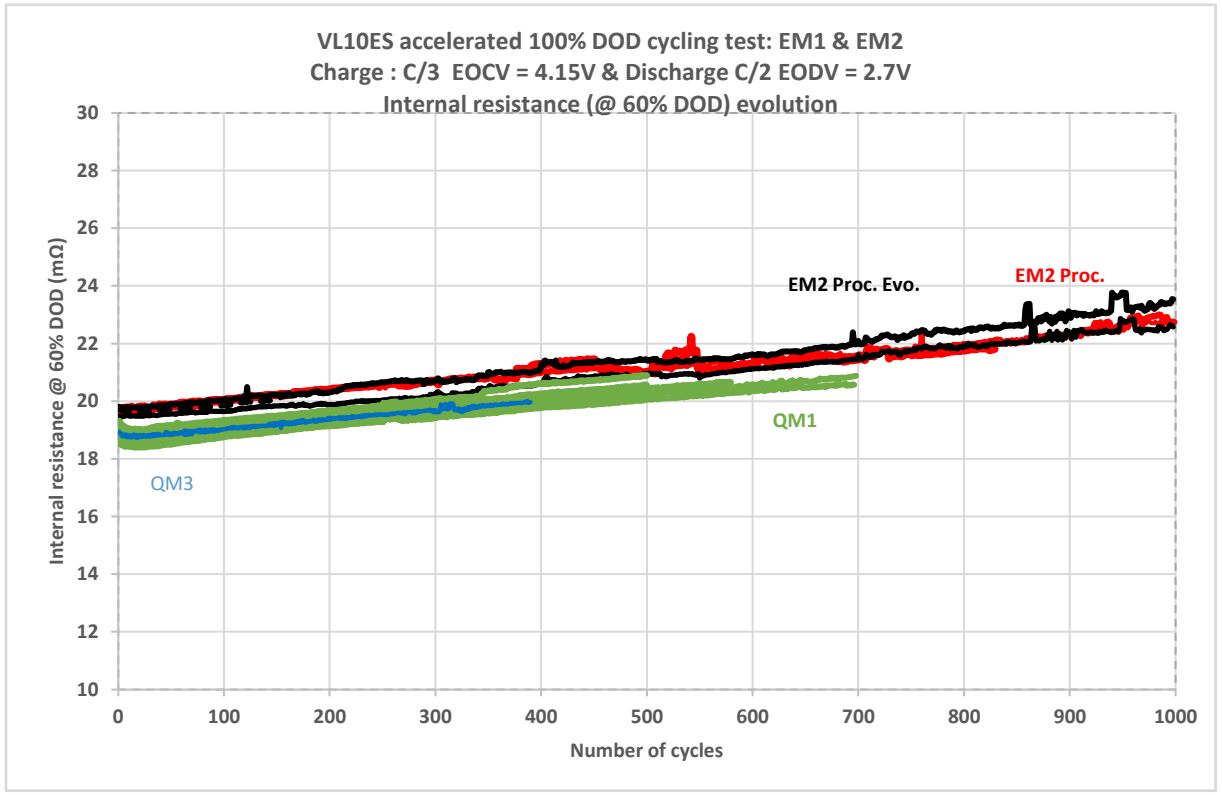




- All the batches (EM's, QM's and FM's) have been tested in Wear-out using 100 % DOD profile :
  - Similar EOL energy for all batches
  - Limited impact of BOL energy

Accelerated 100% DOD cycling : IR evolution

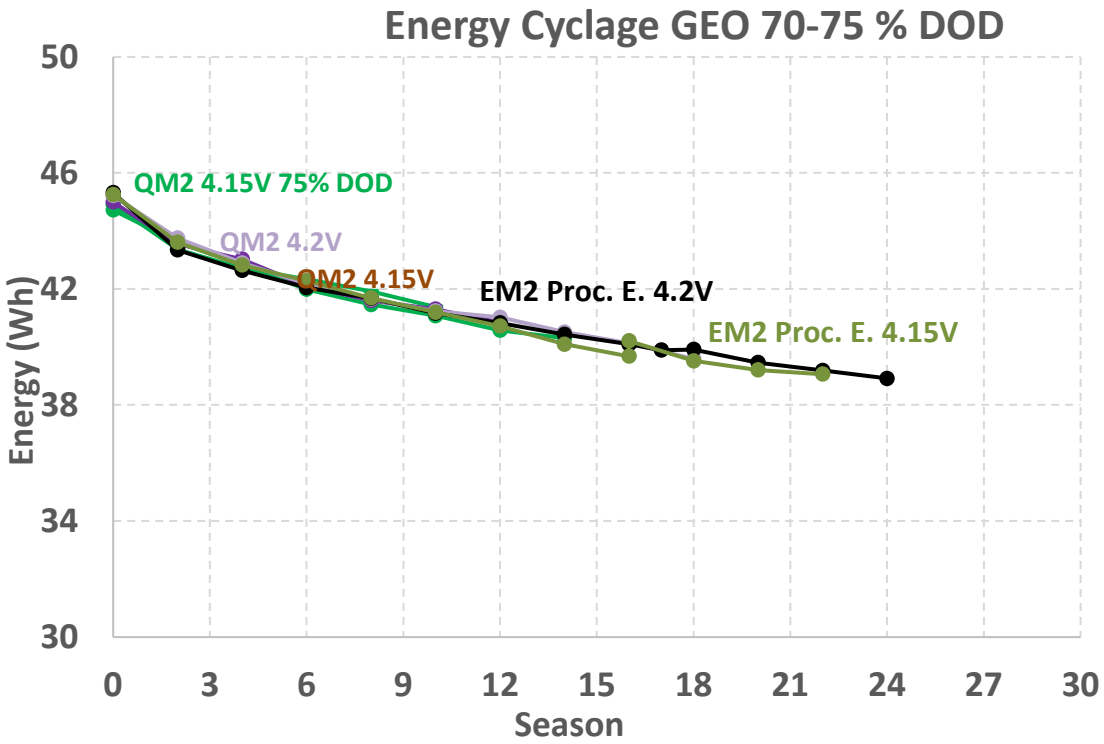


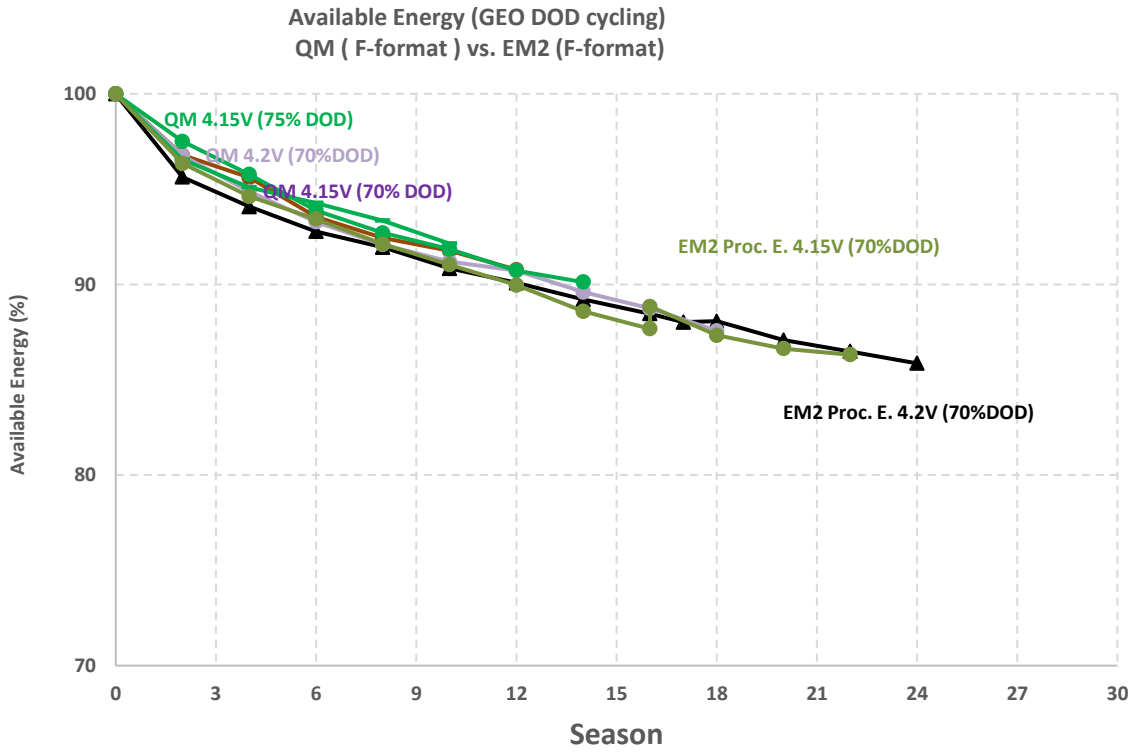


- VL10ES is showing a good stability of internal resistance during cycling.
- 20 % and 60 % DOD internal resistance evolution is linear with less than **10 % increasing** after 1000 cycles

Constant Internal Resistance (IR) Evolution with Cycling

QM GEO Life Tests (70 and 75 % DOD) : Energy Trend

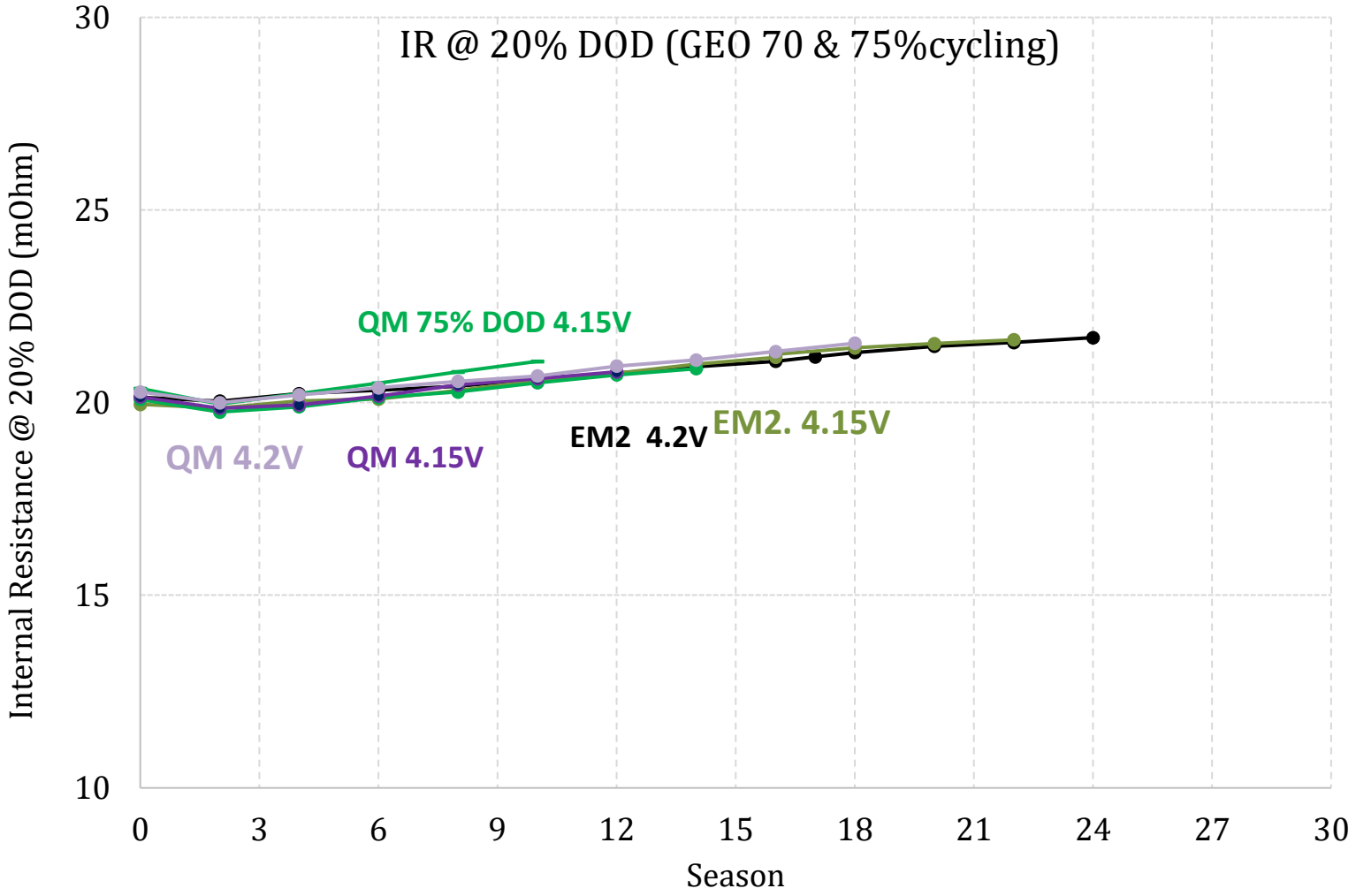




- Different GEO conditions tested :
  - EOR conditions : Electrical Orbit raising
  - 70% and 75 % DOD
  - EOCV from 4.15 and 4.2 V
  - With and without Electrical Propulsion system up to 2 cycles per day

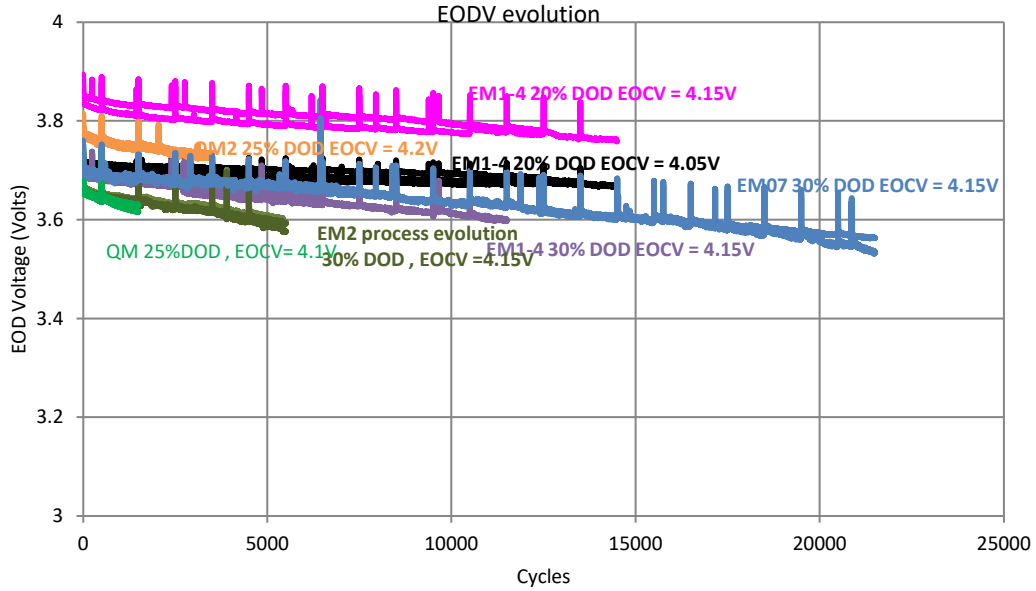
Similar GEO fading for all batches

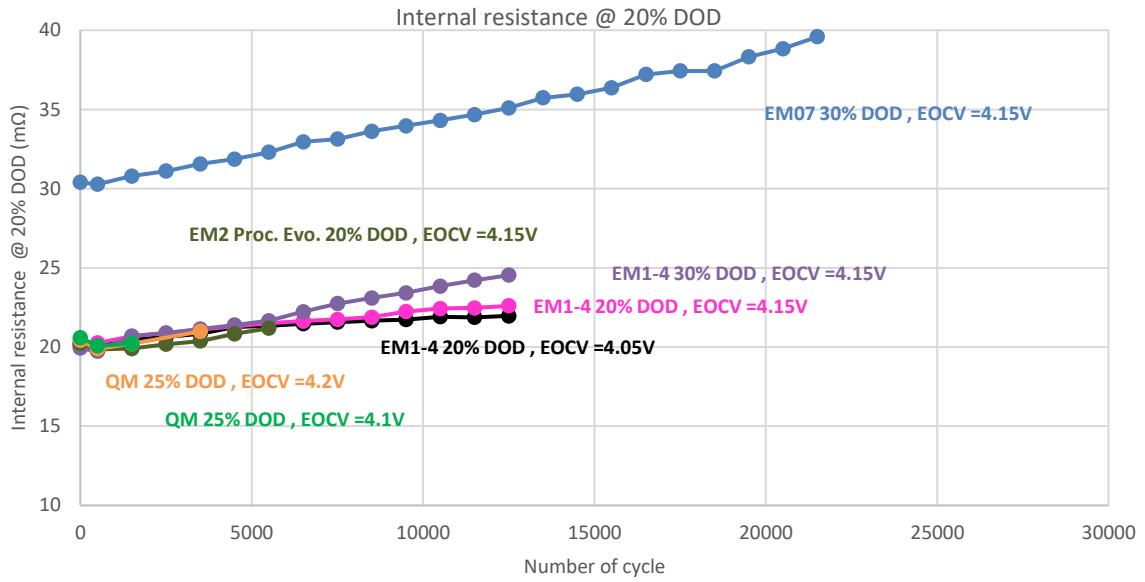
QM2 versus EM2 Process Evolution : Internal Resistance Trend

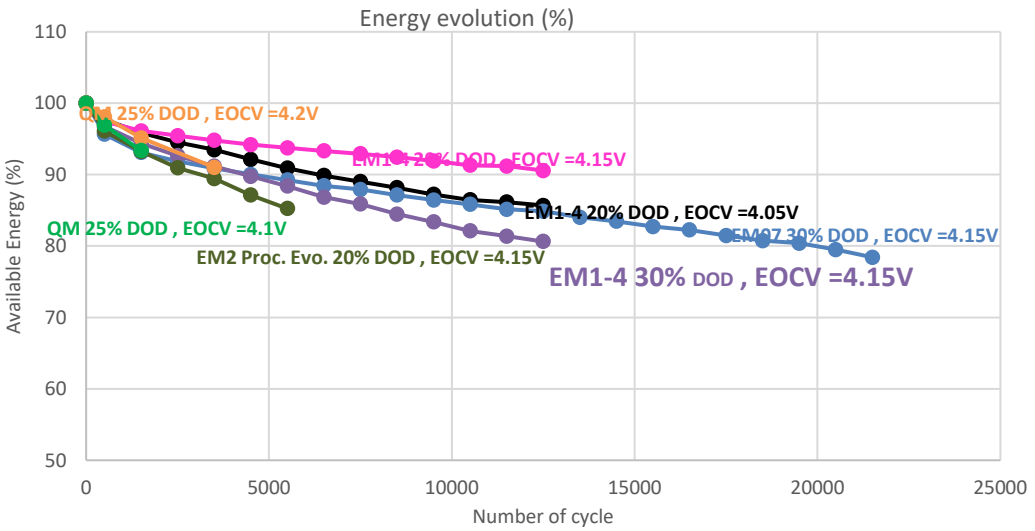


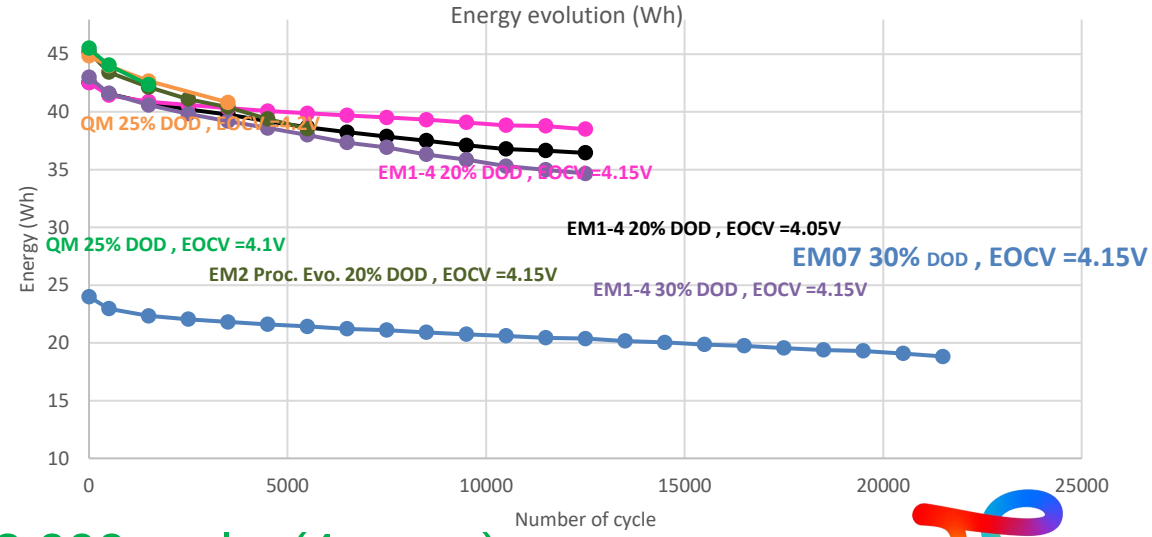
Stable internal resistance evolution on QM cells

Real Time LEO cycling : 20 to 30 % DOD @20°C









LEO cycling up to 22,000 cycles(4 years)

VL10ES Innovative Battery Concept

To answer to modularity (SP / PSP), to limits the no-recurring cost, a battery concept based on one main 4S pack

Independent block

With independent electrical, mechanical and thermal interface allowing easy replacement

Modularity

Blocks are mechanically linked to each other like the pieces of a puzzle in order to reach larger S-P configuration

4S1P Block with SBS

Autonomous electronics

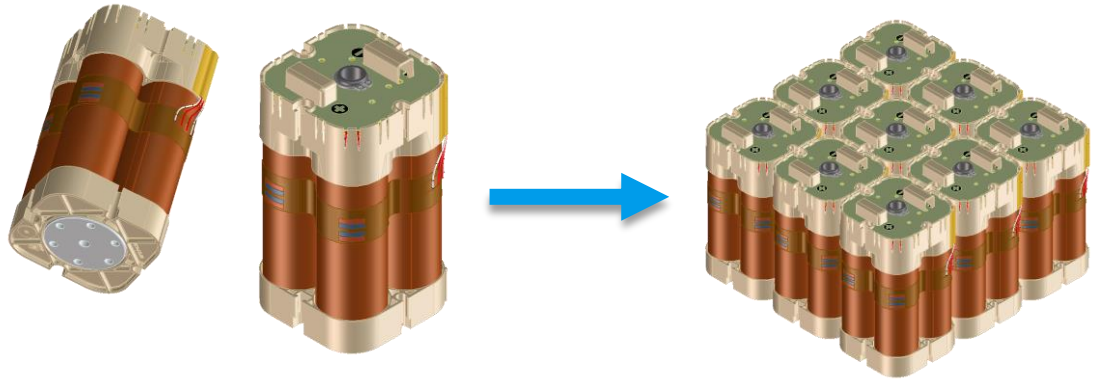
Each block is carrying its own autonomous electronics (4 Simplified Balancing System per block)

Assembly innovation

Each block is attached to the panel through a unique central screw.

4S1P block

12S3P Example



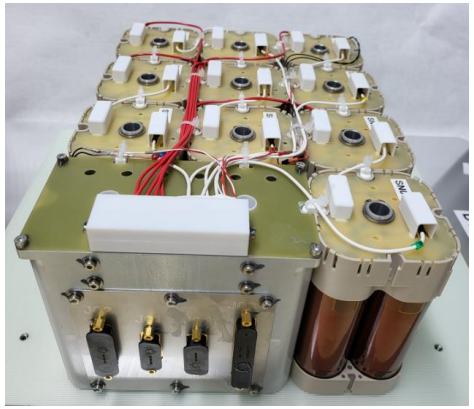
Individual Footprint
(mechanical / Thermal)

Battery Development plan

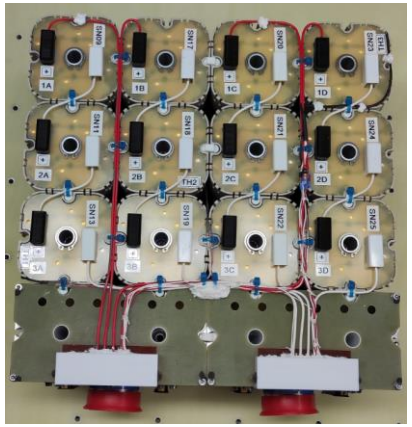
EM's Test Plan **Successful**
- Batt-EM1 **8S5P**
- Batt-EM2 **12S4P**
- Batt-EM3 **12S3P**

Electrical, Thermal, Mechanical (vibration, shocks), SBS tests

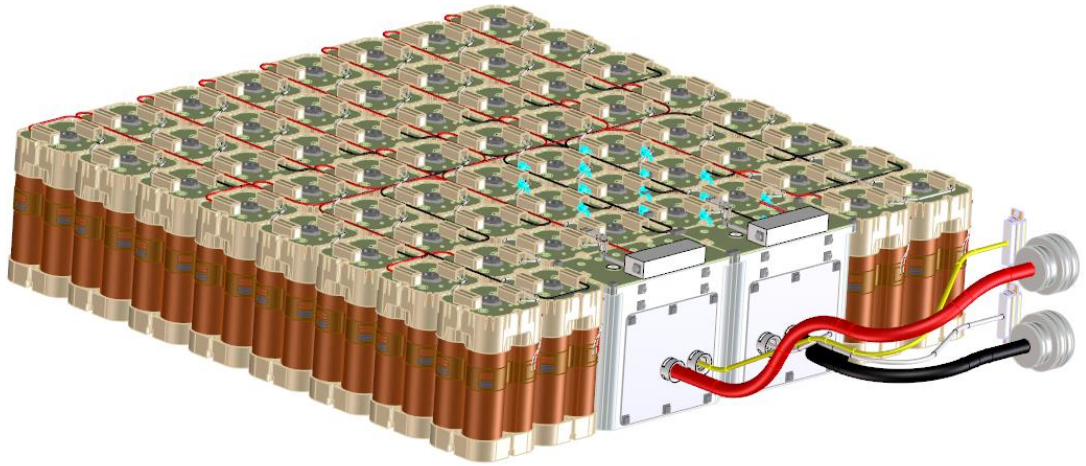
Full Qualification Test Plan running
- Batt-QM1 **8S5P**
- Batt-QM2 **11S6P**
- Batt-QM3 **3x12S4P**
- Batt-QM4 **12S20P**



Bat-EM1 8S5P



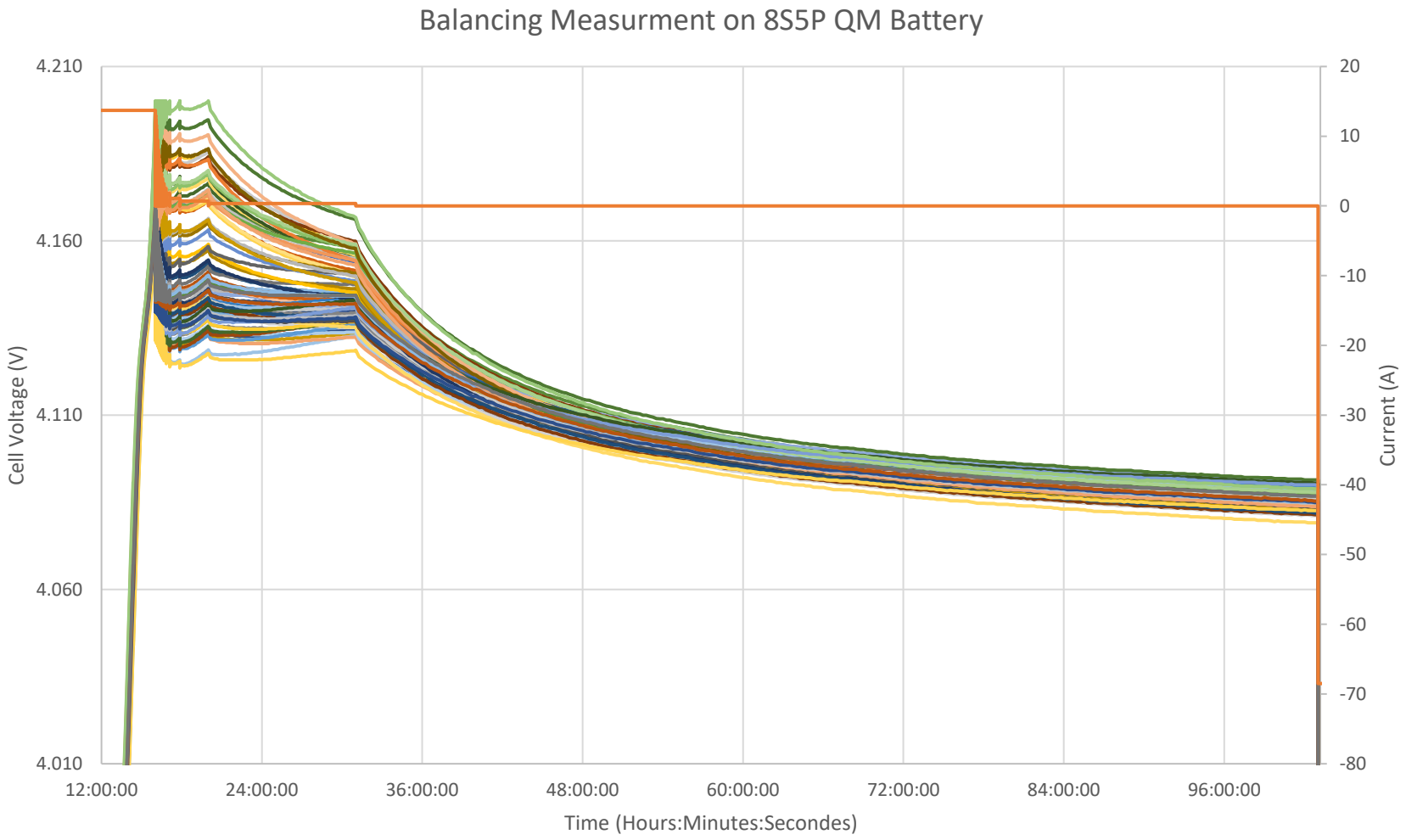
Bat-EM2 12S4P



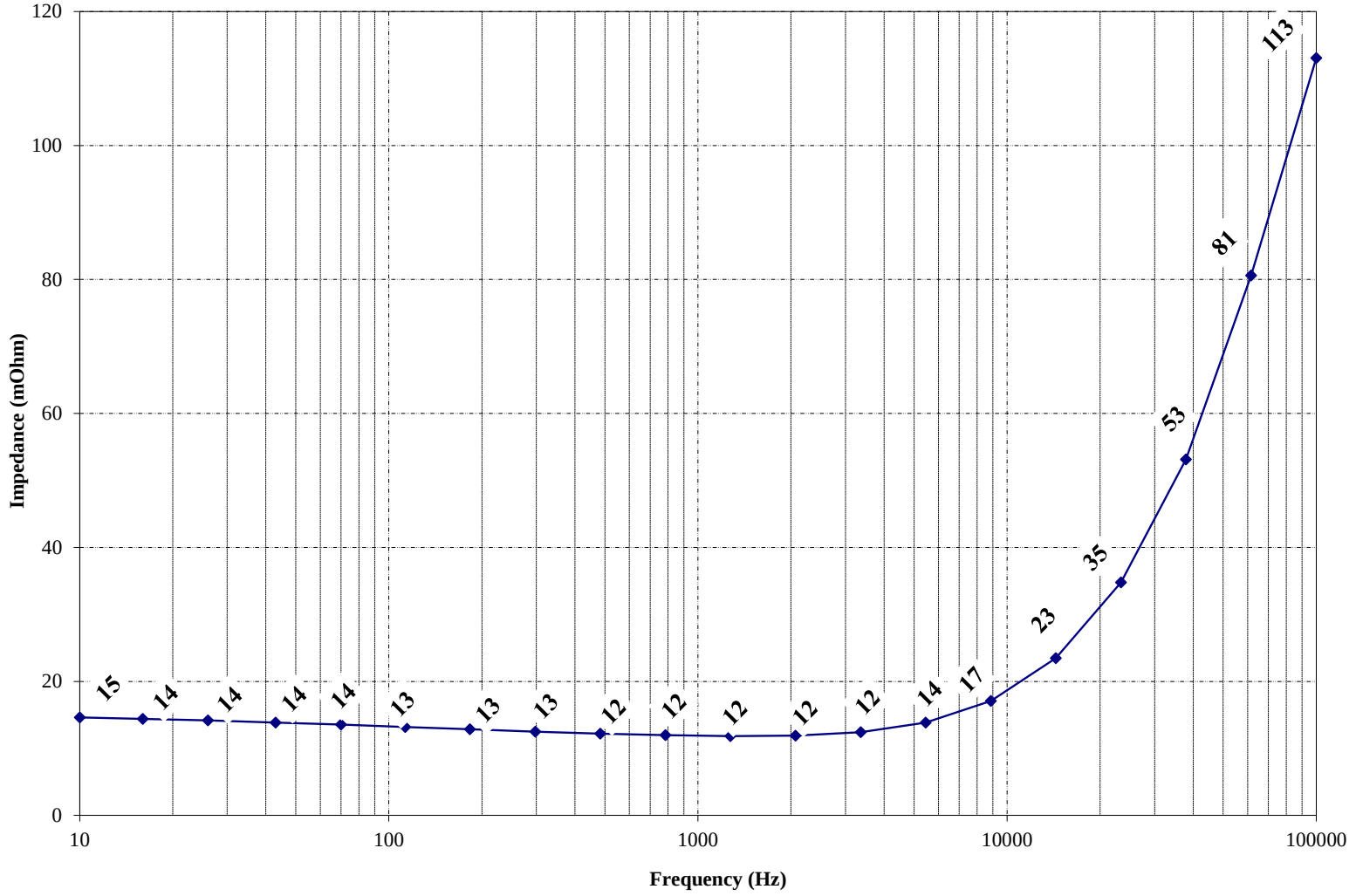
Bat-QM4 12S20P VL10ES

Balancing on 8S5P VL10ES QM

- 10 mV cell to cell spread obtained in 82 hours from 80 mV

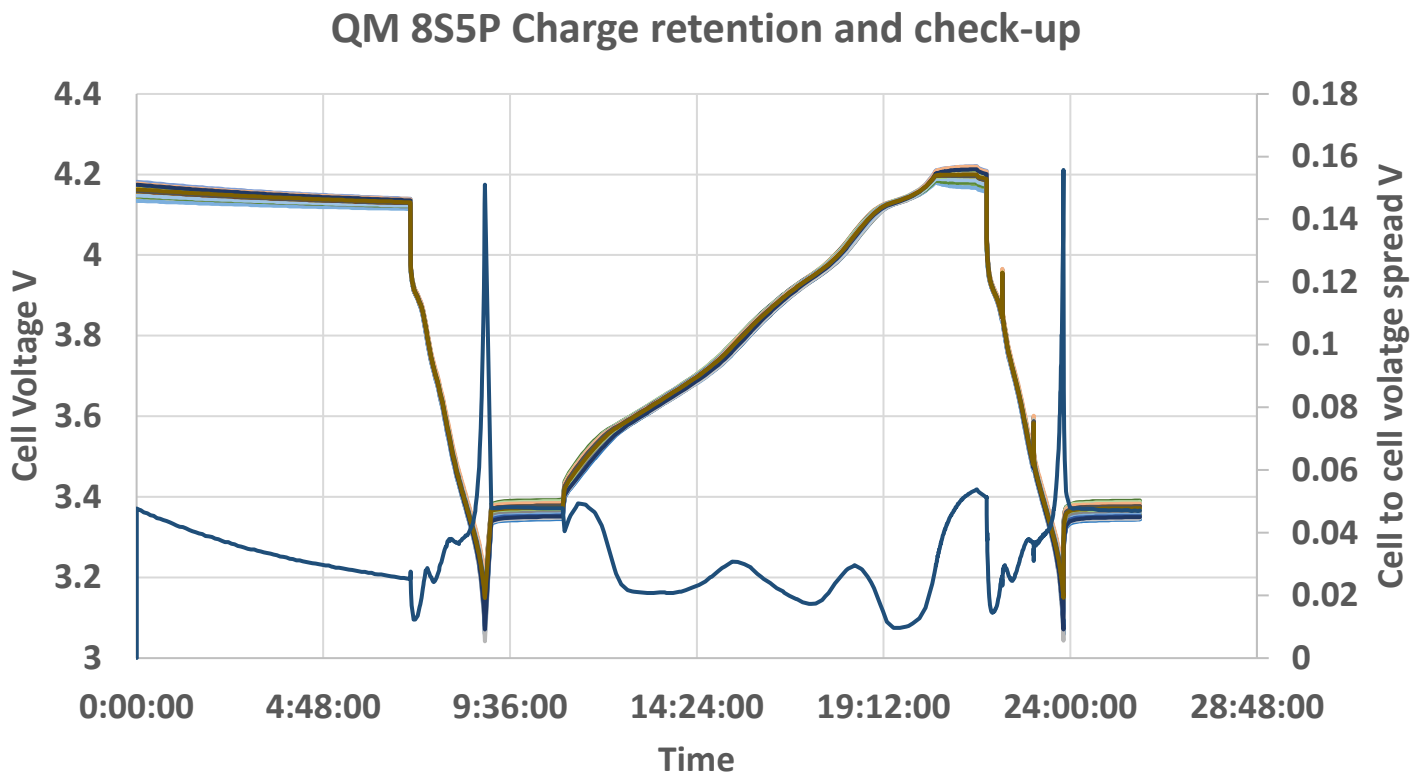


Impedance 8S5P VL10ES QM



Battery Charge Retention QM

- Cell to cell spread measurement during retention

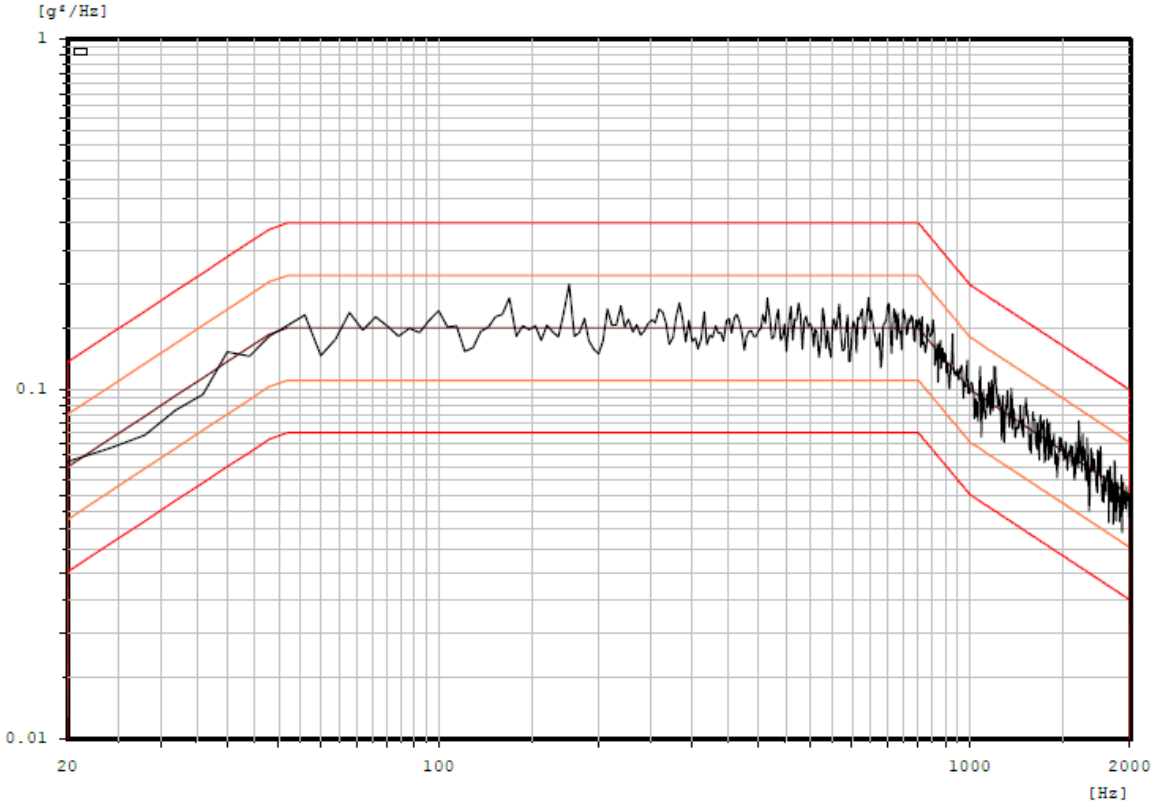


QM VL10ES Vibration Tests

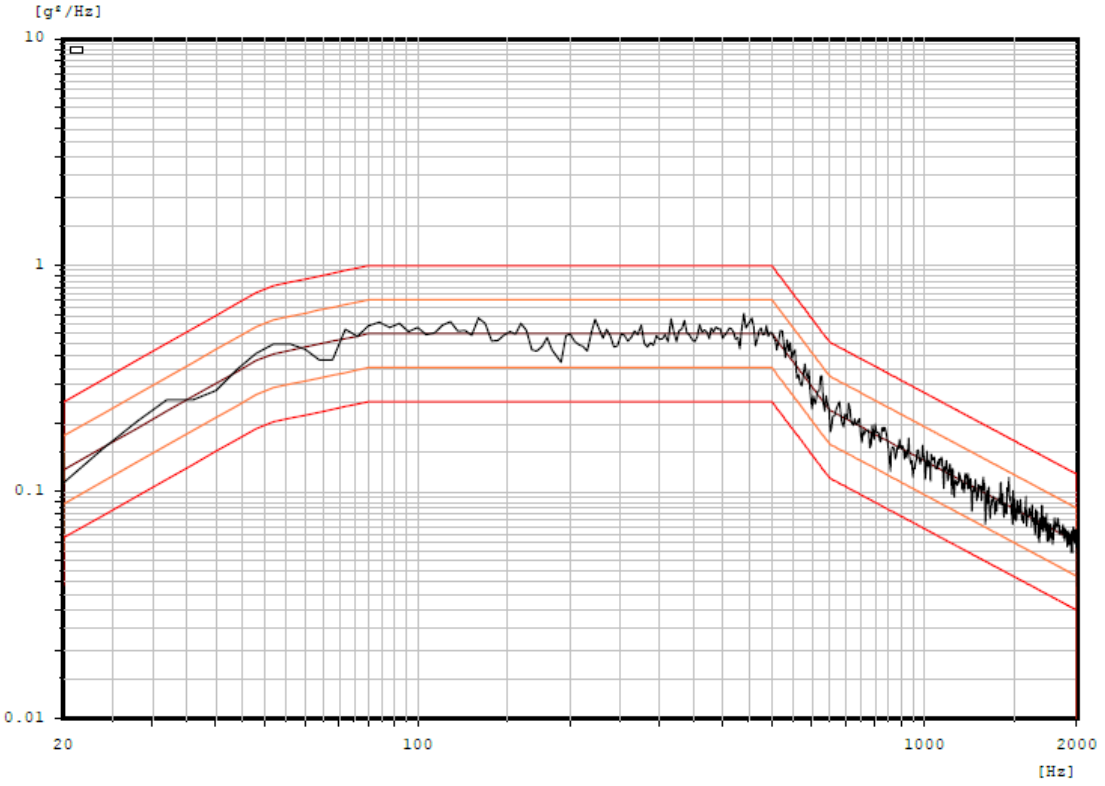
- Sequence :
  - Sine 3 axis
  - Random 3 axis
  - Sine with frequency search
  - Energy Check-up

Random Vibration X and Z axis

- X-axis

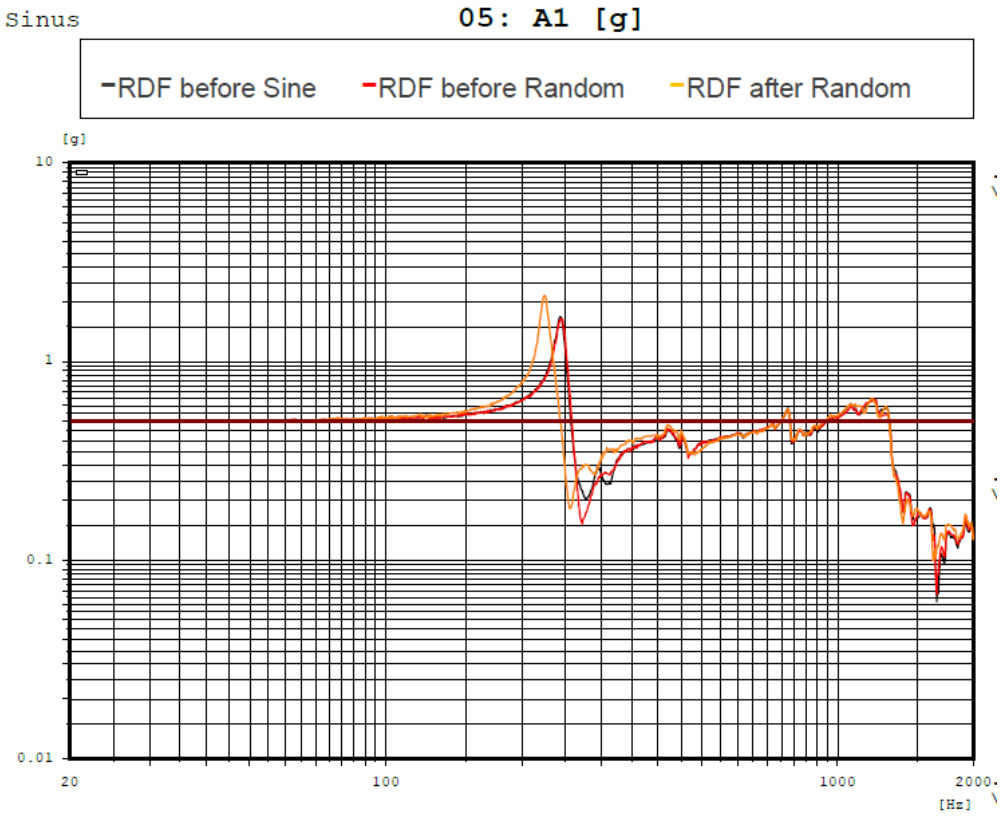


Z-Axis

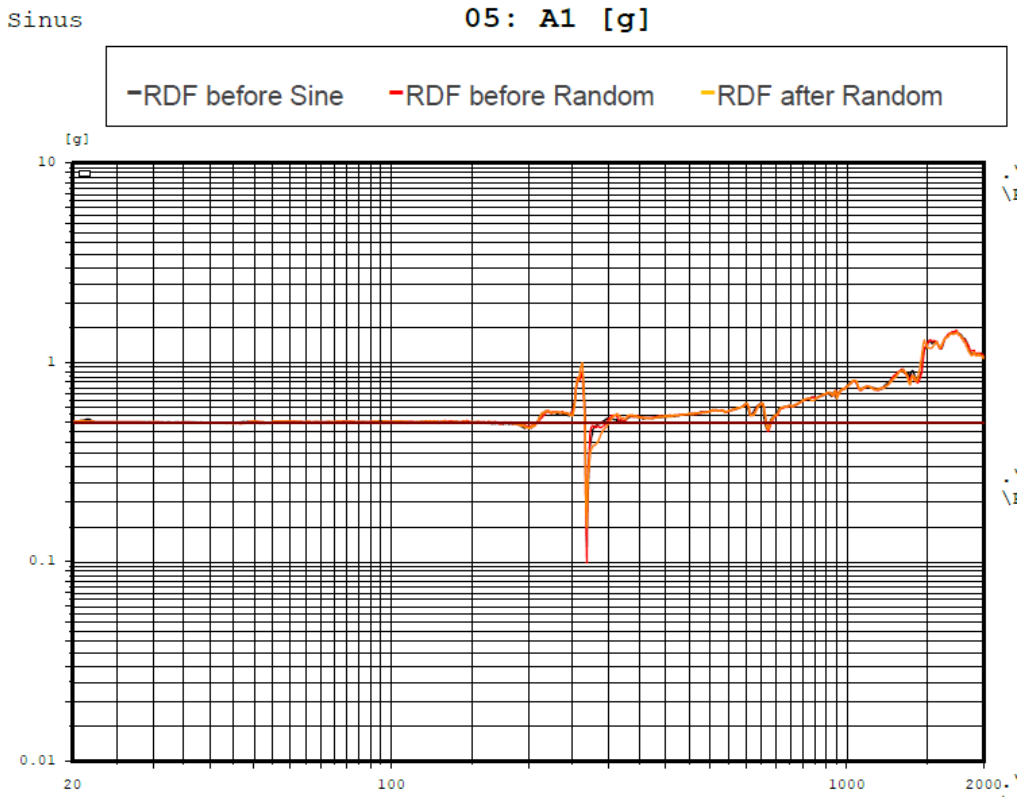


Sine before and after Random Vibration

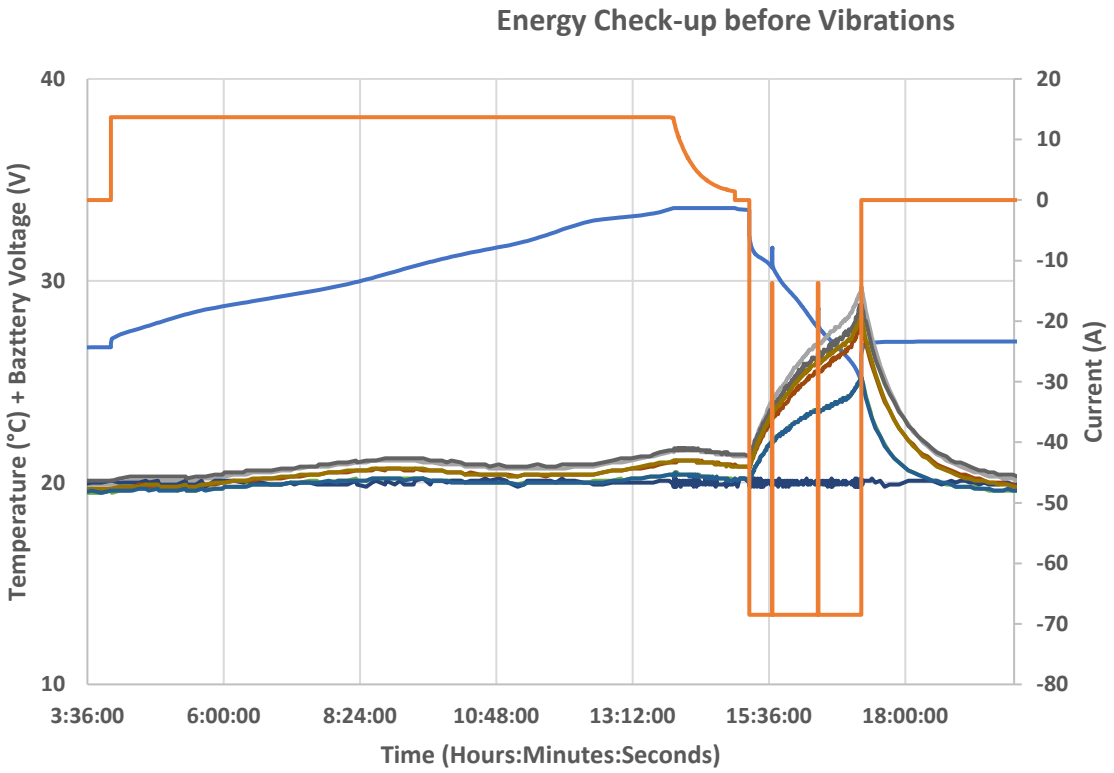
- X-axis

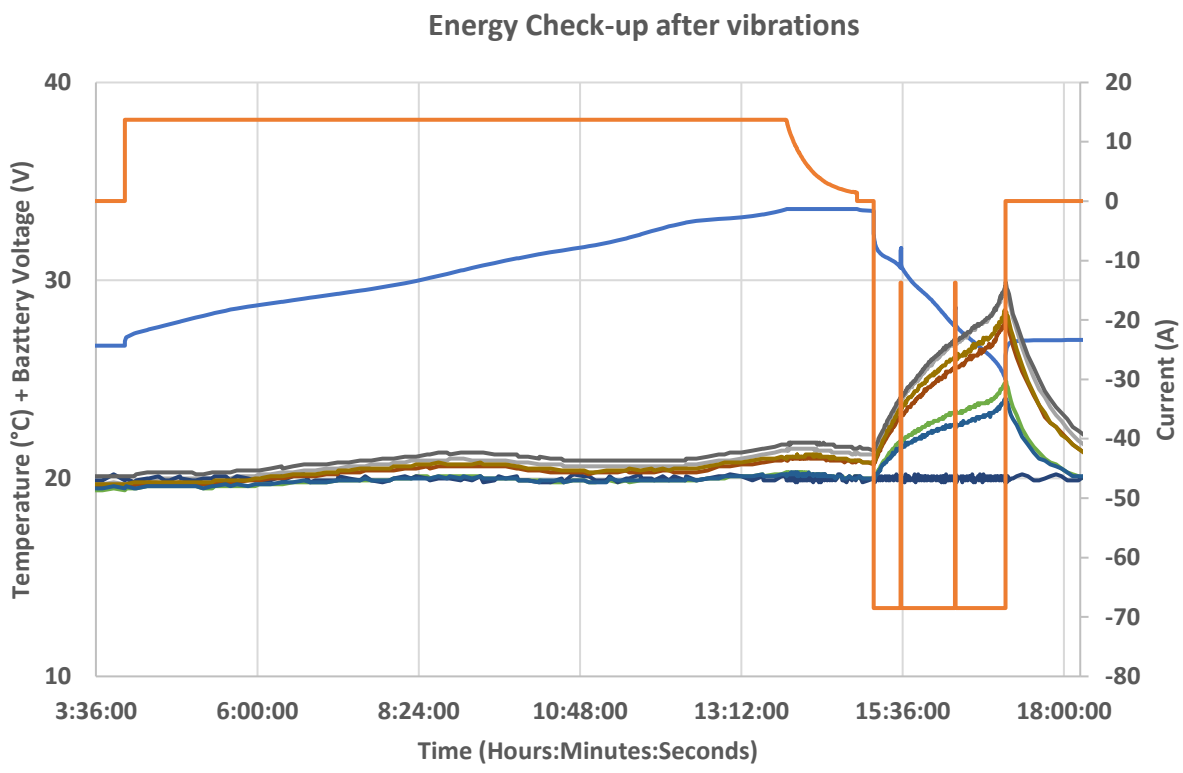


Z-axis



Energy Check before and after Random Vibrations





No energy or internal resistance evolution before and after mechanical tests

Conclusions

- VL10ES cell and battery development QR program is close to the end with QR planned at the end of the year.
  - The cell qualification tests have been already performed. Still some few are running.
  - Cell Life Tests are running : 30 seasons GEO already performed (15 years) and >20,000 LEO cycles
  - For battery qualification plan :
    - Electrical including performance in temperature, balancing
    - Environment tests
    - Safety tests

- First FM’ batteries have already been delivered to customers for satellite AIT

Acknowledgements

VL10ES cell and battery development is supported by :

- ESA (Dr Evelyne Simon, Aurore Carré)
- CNES (Christian Elisabelar and Diane Delbegue)

Thank you