VL10ES Cell and Battery Status

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Space Power Workshop
Celebrating 40 Years of Space Power: Supporting mission success in an increasingly agile space domain
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Summary

1. Saft Satellite Battery Flight Heritage
2. VL10ES Cell Development
3. VL10ES 4S Pack Development
4. Conclusions

Saft Battery Flight Heritage

Saft Li-ion in orbit heritage and reliability

365 satellites in-orbit with Li-ion (GEO, MEO & LEO) : 341 operational

More than 2,5 Billion of cell hours in orbit with no failure or deviations

Total over 3,8 MWh in-orbit with 650 batteries and more than 45 000 cells in orbit

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

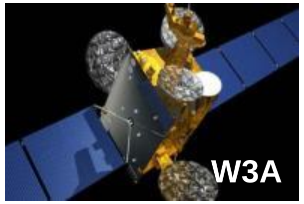
  2003 : Smart 1 has been able to reach Moon orbit thanks to ion thrusters' engines powered with Li-Ion battery

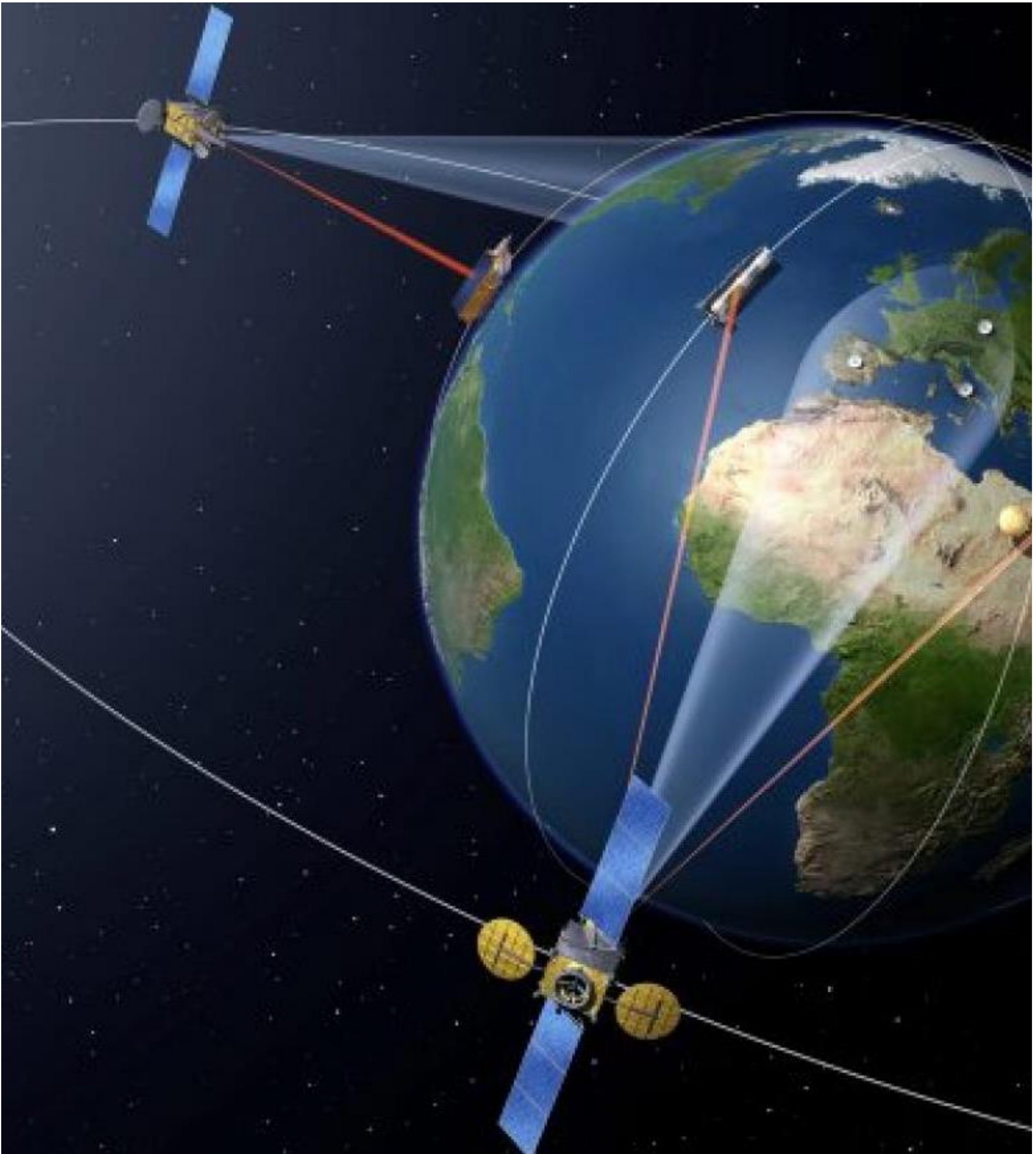
  1rst GEO Telecommunication satellite W3A launched 19 years ago (March 2004) with VES140 batteries

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

- **156 LEO satellites including** :

  75 first Iridium Next satellites with VES16 batteries





VL10ES Cell Development

VL10ES Performances objectives – compared with VES16

TotalEnergies

TECHNICAL PERFORMANCE

- Over 220 Wh/Kg to reduce battery weight
- High DOD cycling ranges: LEO 30% and GEO 70%
- Innovation on densification of electrodes
- Specific materials to preserve long life

SAFETY ENSURED

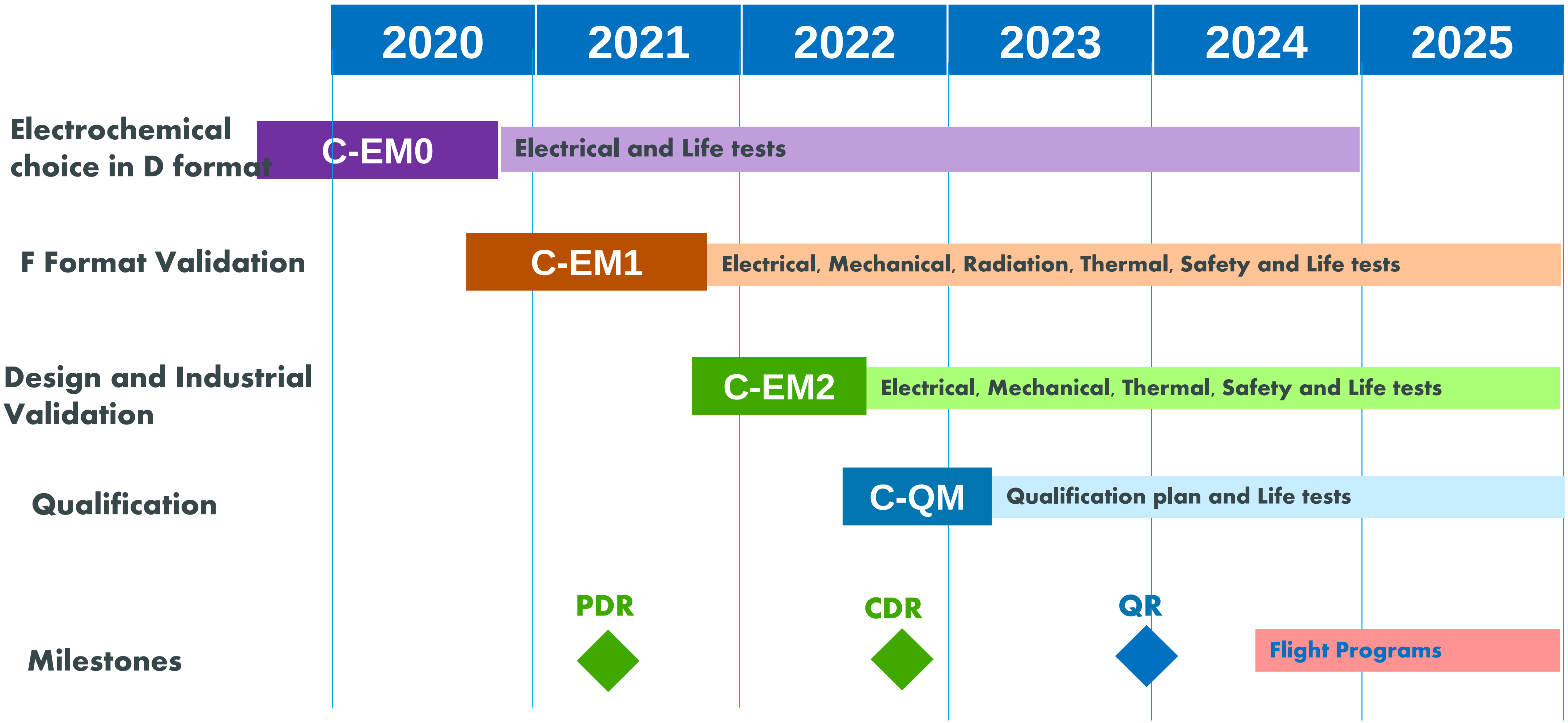
- Compatible with safety launch pad
- Robust stainless steel casing

PRICE REDUCTION

- Reduce the battery price
- Address LEO, GEO, MEO, constellation markets
- Less cells in large batteries

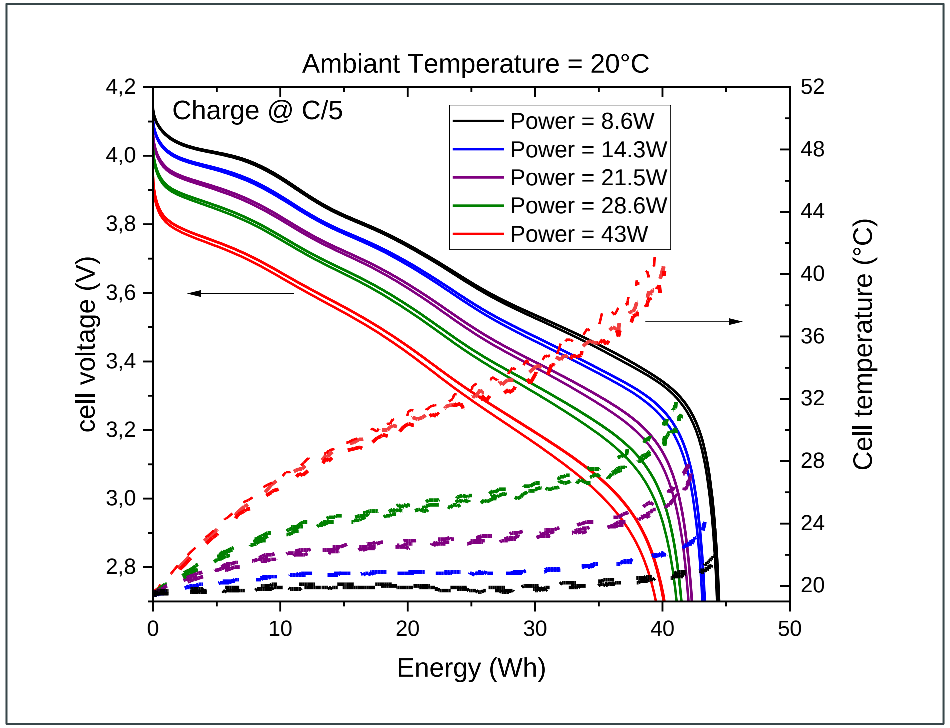
CELL TYPE	VES16 (D-size)	VL10ES (F-size)
Dimensions (Ø x H)	33 x 60 mm	**33 x** 103 mm
Weight	≤ 115 g	**210 g**
Volume	0.051 dm^3	0.086 dm^3
Voltage range	2.7 V - 4.1 V	2.7 V - 4.2 V
Nominal capacity	4.5 Ah @ 4.1V, 20°C	**> 12 Ah @ 4.2V, 20°C**
Nominal energy	16 Wh @ 4.1V, 20°C	**> 46 Wh @ 4.2V, 20°C**
Specific energy	> 140 Wh/kg	**> 220 Wh/kg**
Internal resistance	≤ 35 mΩ @ 20% DoD	≤ 22 mΩ @ 20% DoD / TBC
Operating temperature	+10°C / +40°C	+10°C / +40°C
Mechanical design margins	EWR & ECSS compliant	EWR & ECSS compliant

VL10ES Cell Development Plan

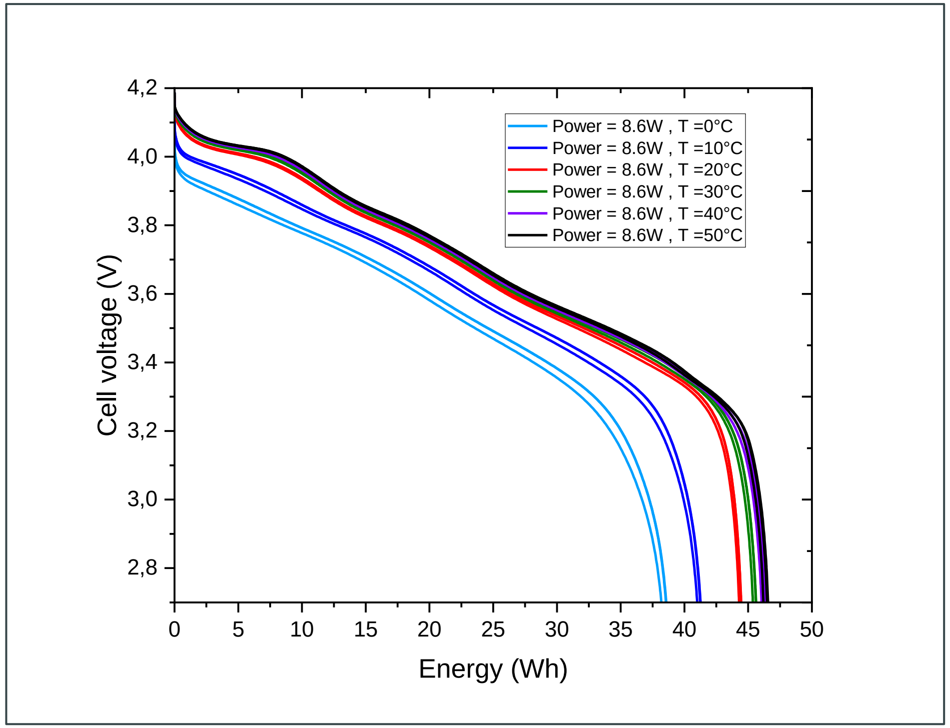


2. BOL Electrical performances EM2 Design: Constant power discharge versus temperature

Energy evolution vs Power at 20°C



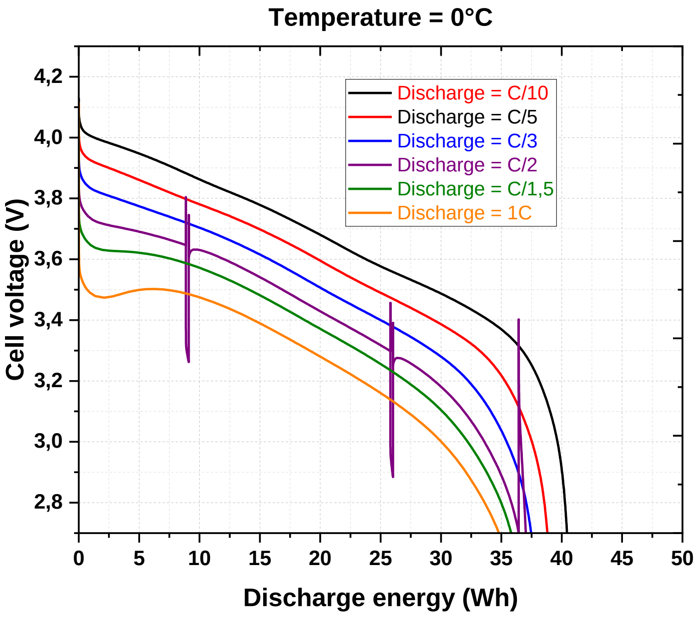
Energy evolution at constant Power vs Temperature



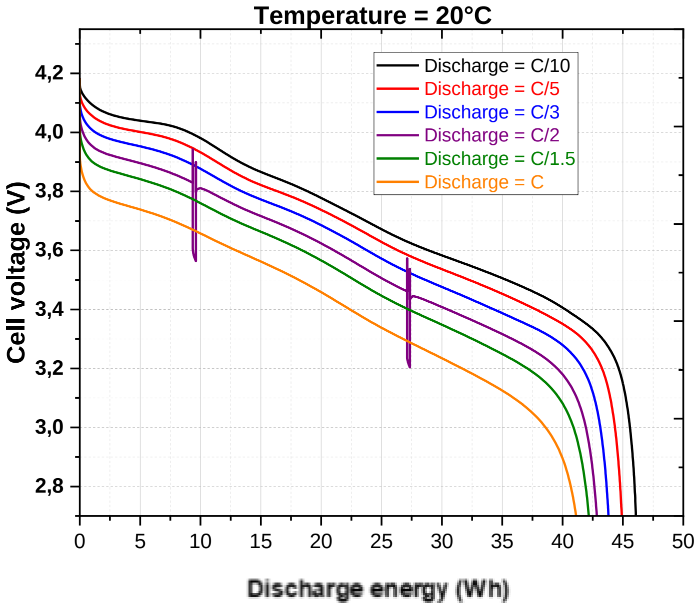
- Increasing discharge power leads to cell polarization together with a decrease in available energy and an increase in cell temperature.

BOL Electrical performances EM2 Design : discharge current versus temperature

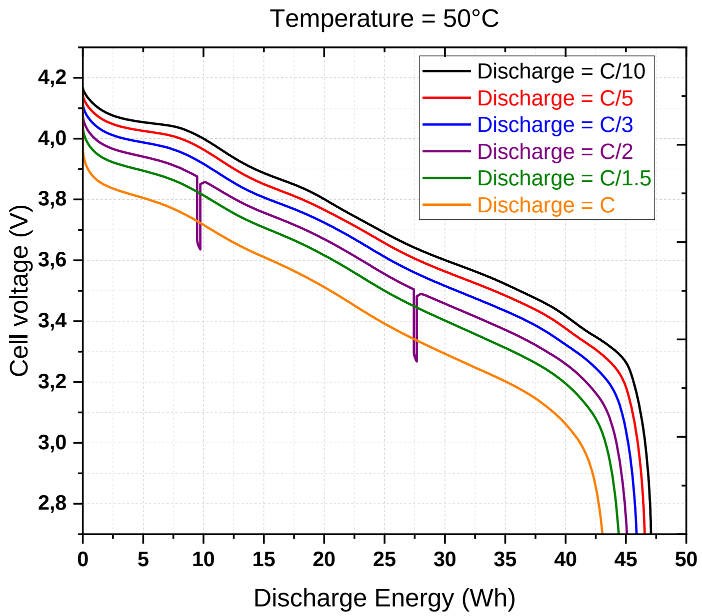
Energy evolution vs discharge rate at 0°C



Energy evolution vs discharge rate at 20°C



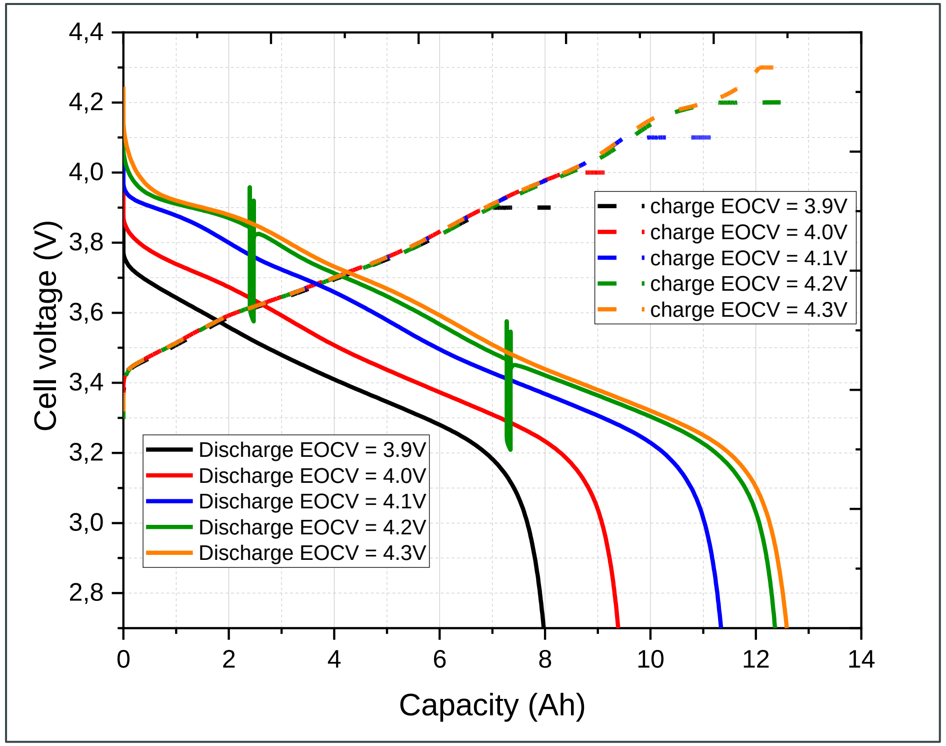
Energy evolution vs discharge rate at 50°C



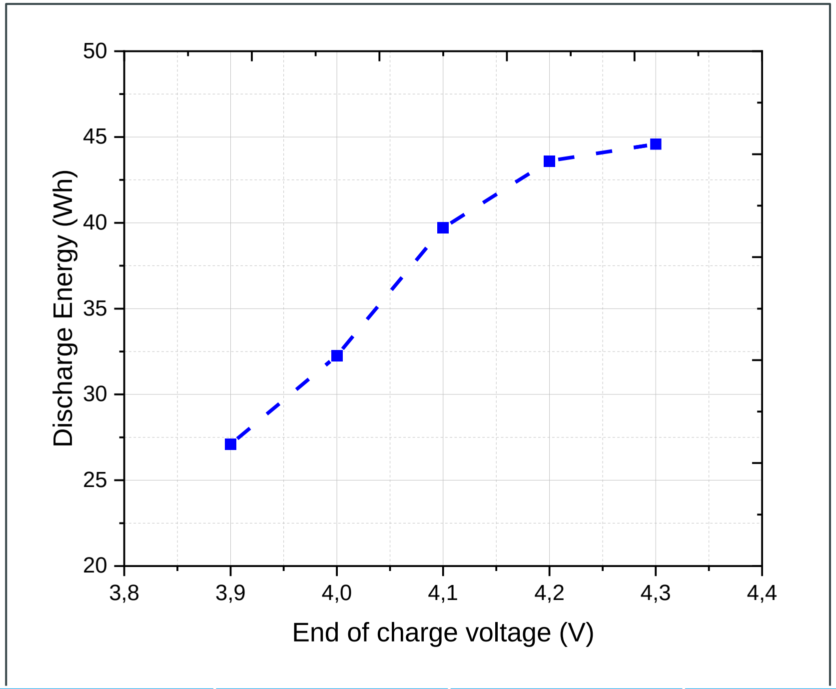
Average data	Temperature	0°C	20°C	50°C
Discharge energy	**Discharge = C/10**	40.3	**46.0**	46.9
	Discharge =C/5	38.7	44.9	46.4
	Discharge =C/3	37.3	43.7	45.7
	Discharge =C/2	36.2	**42.7**	44.8
	Discharge =C/1.5	35.5	42.0	44.3
	Discharge =C	34.4	40.9	42.9

BOL Electrical performances EM2 Design : Discharge energy/capacity versus EOCV

Capacity evolution vs EOCV at 20°C



Energy evolution vs EOCV at 20°C



	Estimated Energy C/2 @20°C (Wh)	Capacity C/2 @20°C (Ah)	Ratio
4.0 V	32.5	9.4	77 %
4.1 V	40.0	11.2	93 %
4.15 V	42	11.7	96.5 %
4.2 V	43.5	12.2	100 %

- Gain in capacity and energy is 2.5 % from 4.2 V to 4.3V

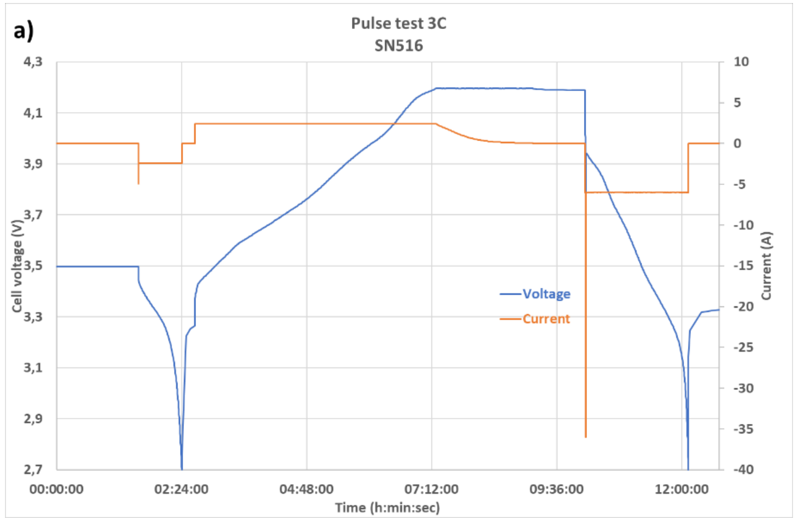
BOL Electrical performances EM2 Design: Pulse test

TotalEnergies

Pulse test : 3C 1second (current fault test)

Pulse test 1second	SN529	SN558	SN570
U (30% DOD)	3.138	3.135	3.141
T @ 30% DOD (°C)	21.5	22.0	22.0
U (80% DOD)	2.690	2.690	2.690
T@80%DOD (°C)	22.0	22.0	22.7

Pulse test : 3C 15 seconds (Radar test)



Pulse test	SN516	SN519	SN522
U (3C, 15 seconds)	3.272	3.290	3.280
T (°C)	20.5	20.2	20.7

As per EM1, EM2 Design cells are compliant with pulse current :
- 3C for 1 second starting from 30% DOD and 80% DOD,
- 3C for 15 seconds criteria.

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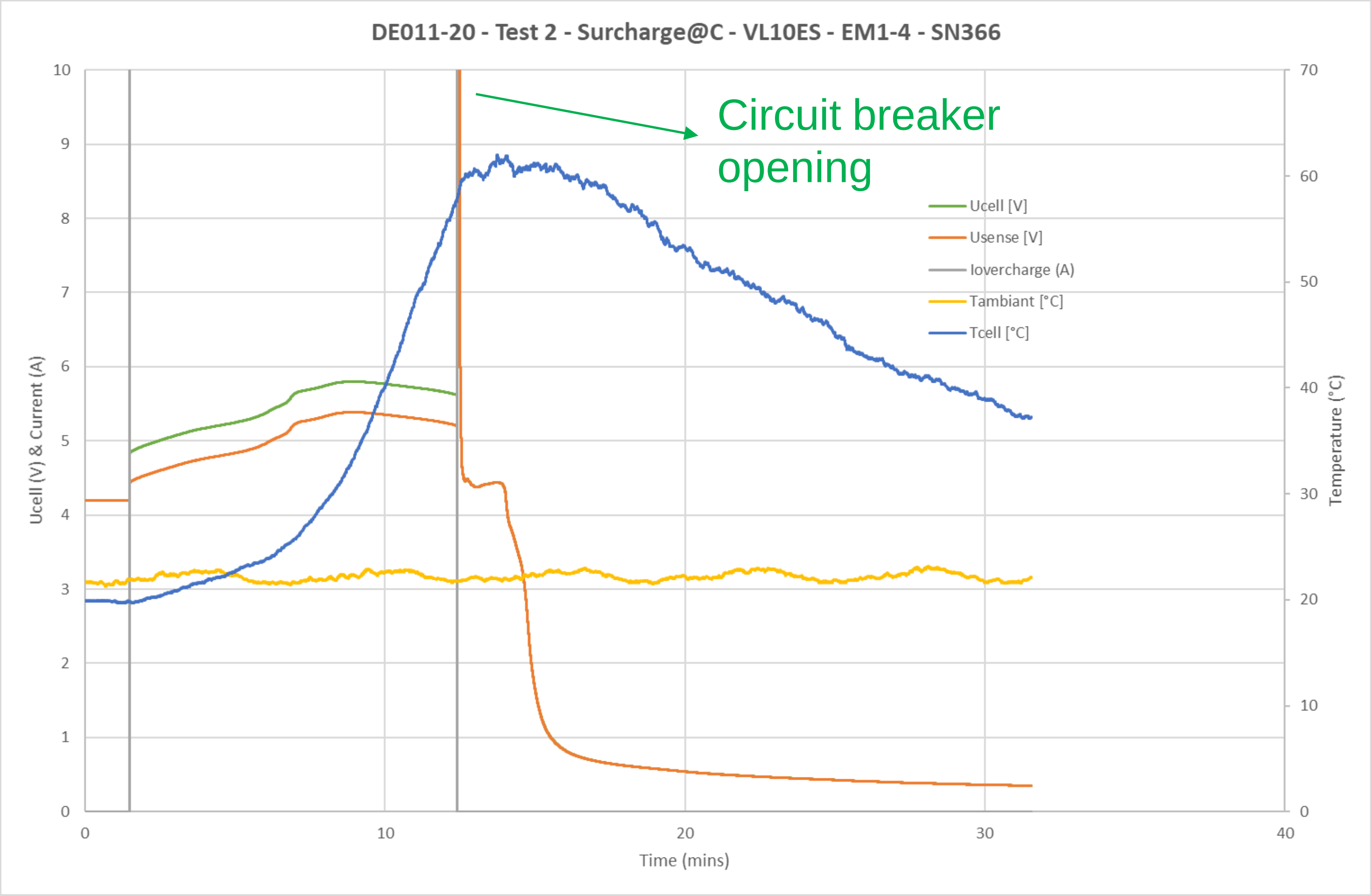
C-EM1/EM2 Safety Results

VL10ES safety as good as VES16 thanks to thick can, cover welding and 2 vents

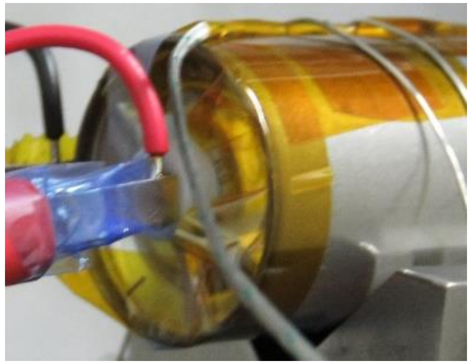
VL10ES	Crush test 50 & 100% SOC	C/3 & C over-charge	Impact test 100% SOC	Pin test 100%SOC	Pin test 50% SOC	Heating test	External-short 10mohm 100%SOC	Over-discharge	Drop test 100%SOC	ARC test 100%SOC	Nail test 100% SOC
C-EM1-4 C-EM2	100% SOC OK (2/2) EUCAR 2 50% SOC OK (2/2) EUCAR 2	C/3 OK (3/3) EUCAR 2 C OK (3/3) EUCAR 2	100% SOC OK (3/3) EUCAR 2 50% SOC OK (3/3) EUCAR 2	OK (3/3) EUCAR5	OK (3/3) EUCAR5	OK (3/3)	OK (2/2) EUCAR 3	(10/10 OK) in progress C/2 (10 cycles) at -0.5V	Ok (1/1) EUCAR 2	OK (1/1) EUCAR 5	OK (3/3) EUCAR 5

Tests results as good as VES16 : high level of safety

VL10ES EM1-4 : C over-charge



Before test



After test

T < 65°C EUCAR2

VL10ES C-EM1-4 : pin test 100% SOC – 4.2V

Before test

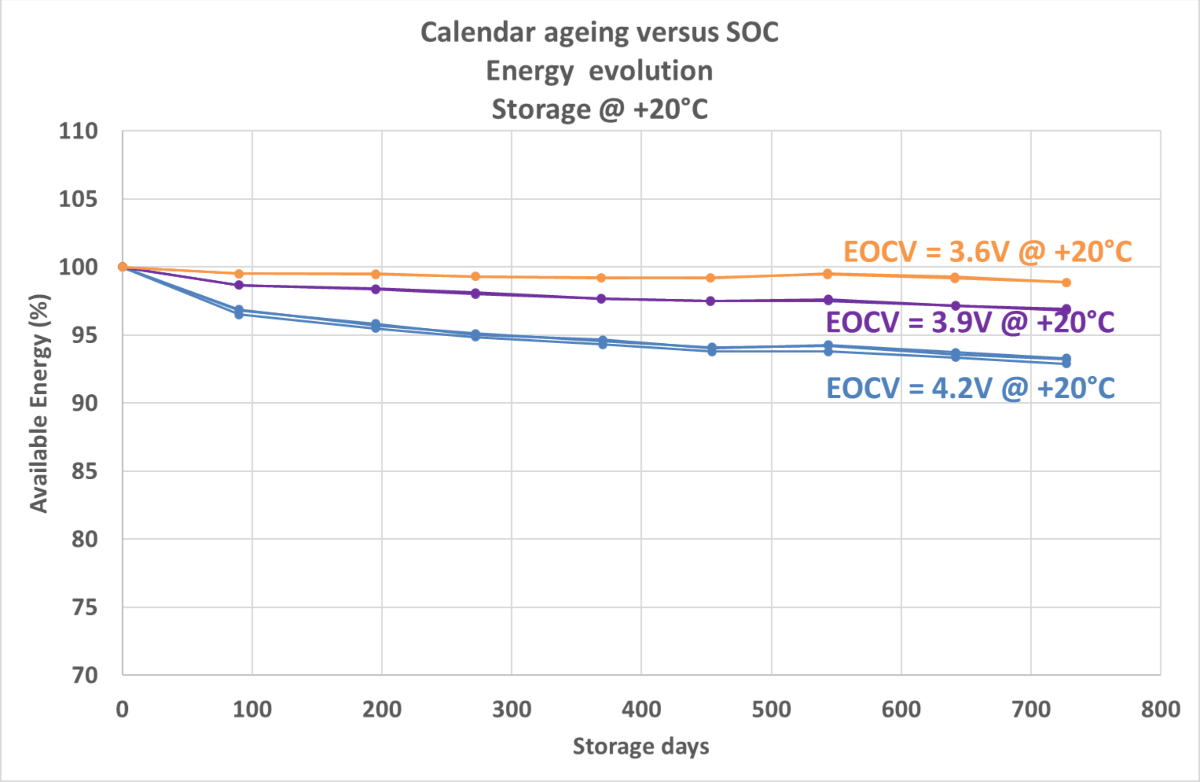
After test

EUCAR5
2 vents opening
No cover ejection
No explosion

Lifetests : Cell performances during Calendar test at different SOC and temperature

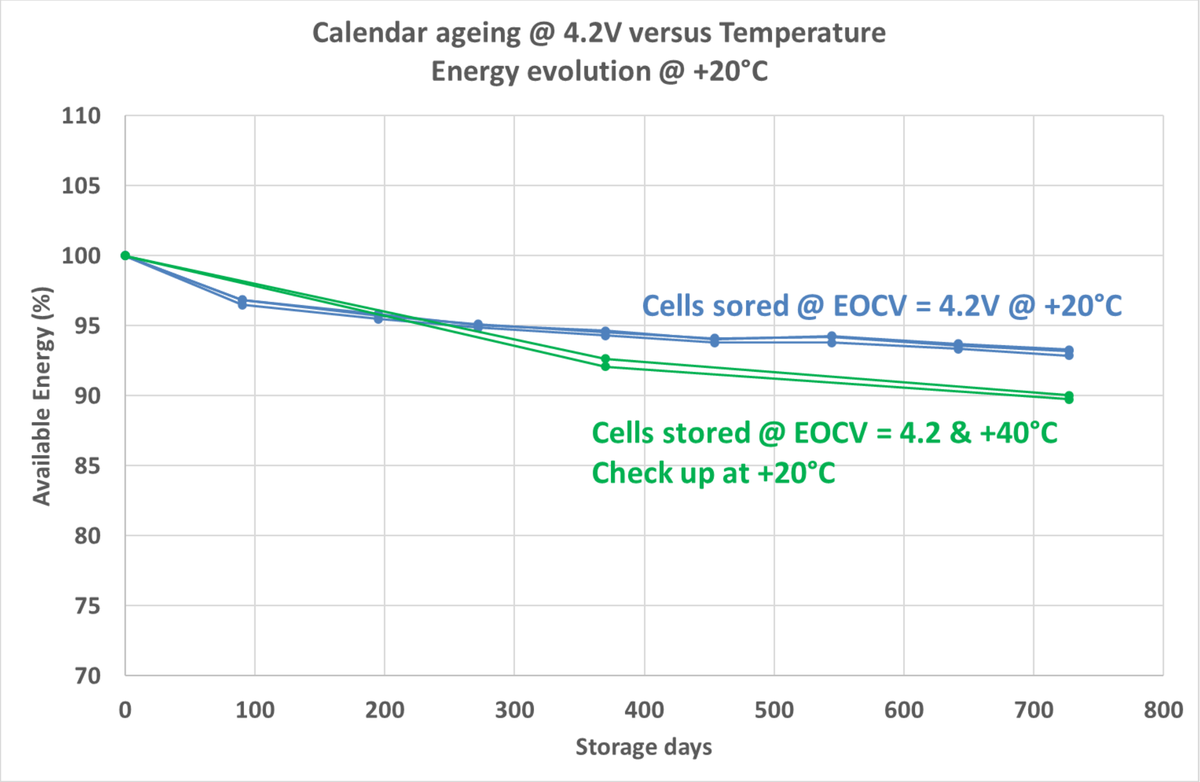
TotalEnergies

20 °C vs SOC



- Energy loss increases with SOC after 727 days :
  - 1.1% @ 3.6V
  - 3.1% at 3.9V
  - 7.1% at 4.2V,
- Stable internal resistance

4.2 V at 20 and 40 °C



Energy loss at full SOC increases with Temperature
After 2 year storage @ +40°C :
- Check up at +20°C : 10 % energy loss @ 727 days
- Check up at +40°C :10% energy loss @727 days

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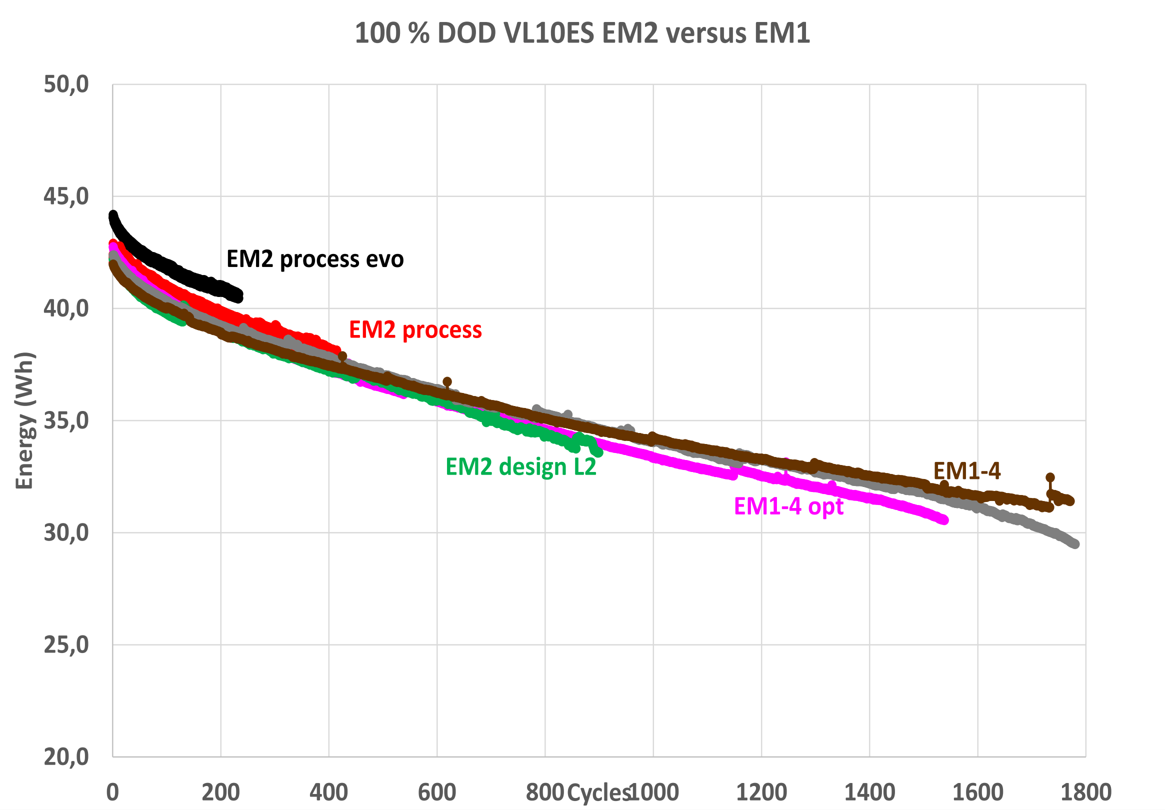
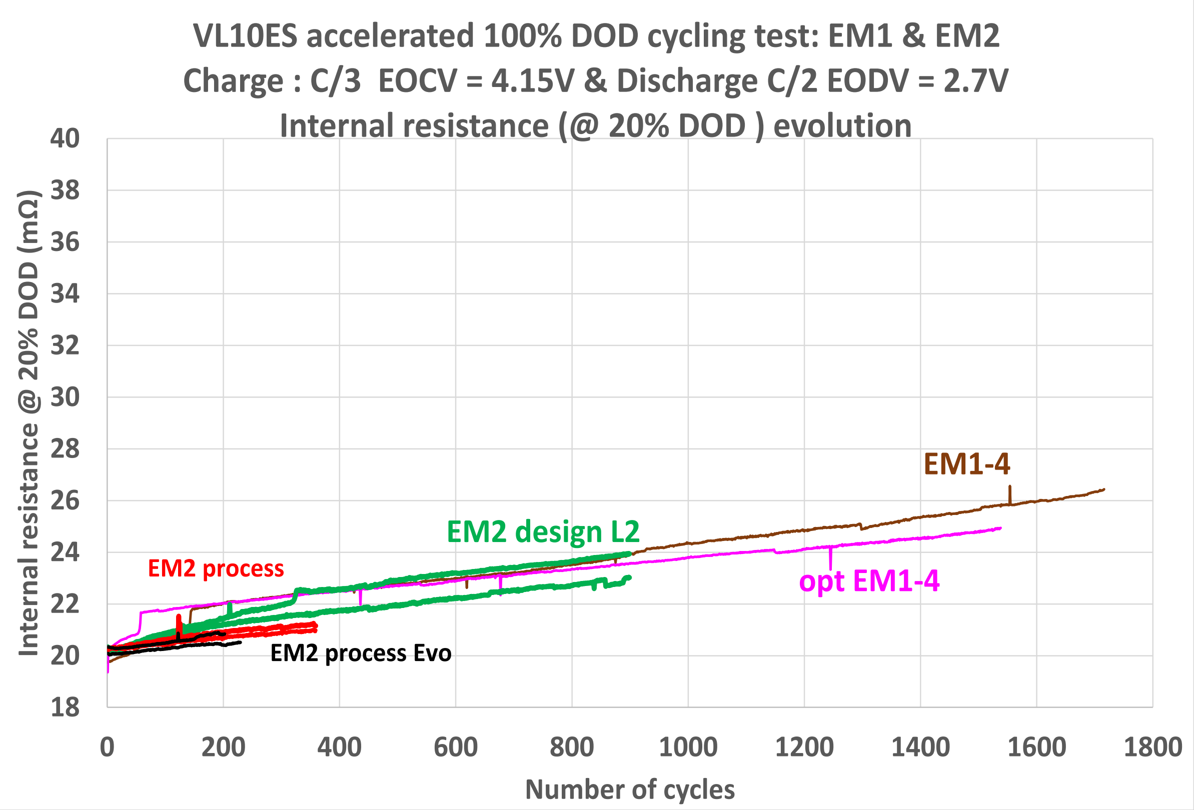
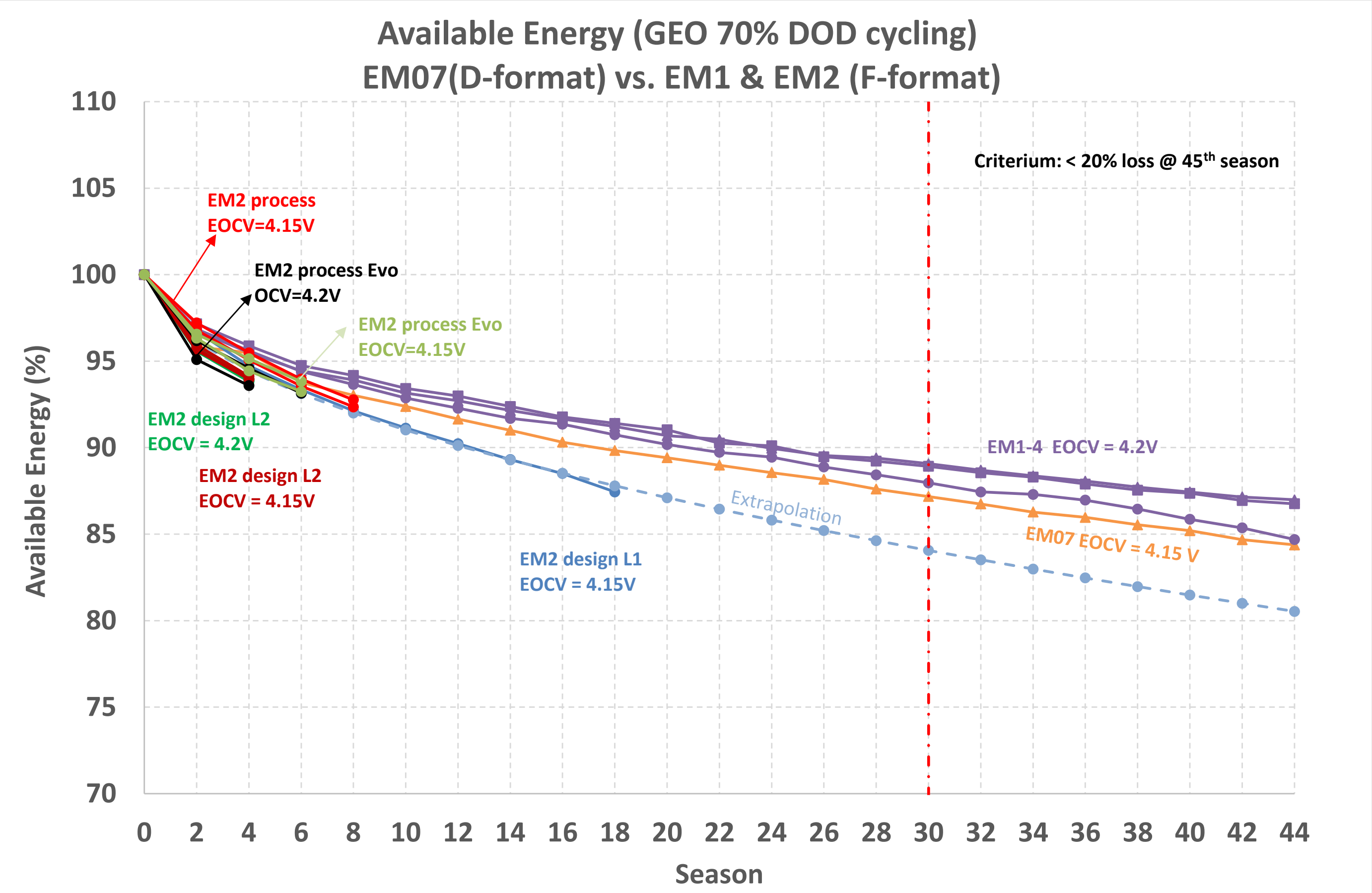
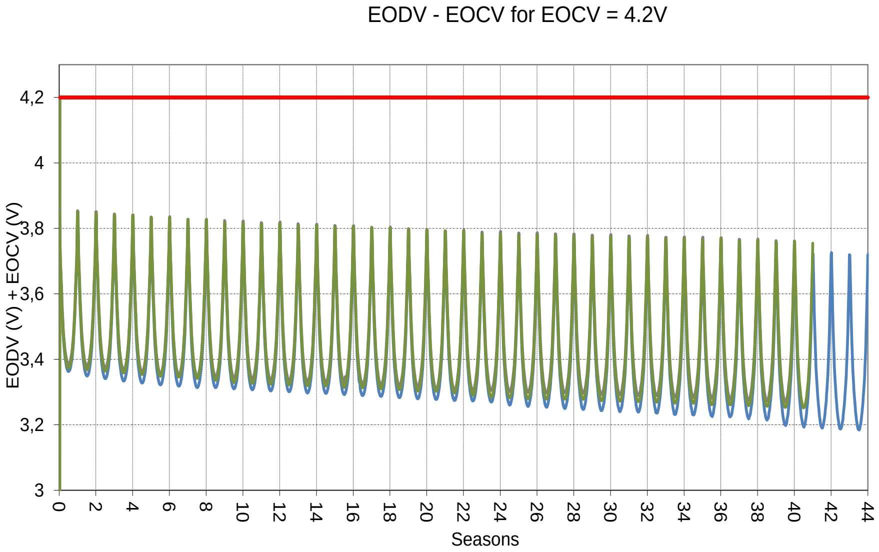
Accelerated 100%DOD cycling

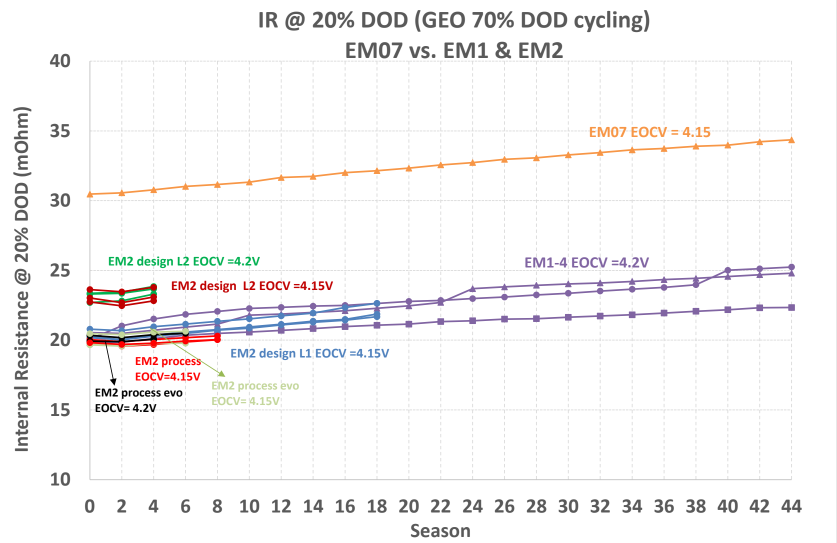




EM1-EM2 Cell 70 % GEO performances



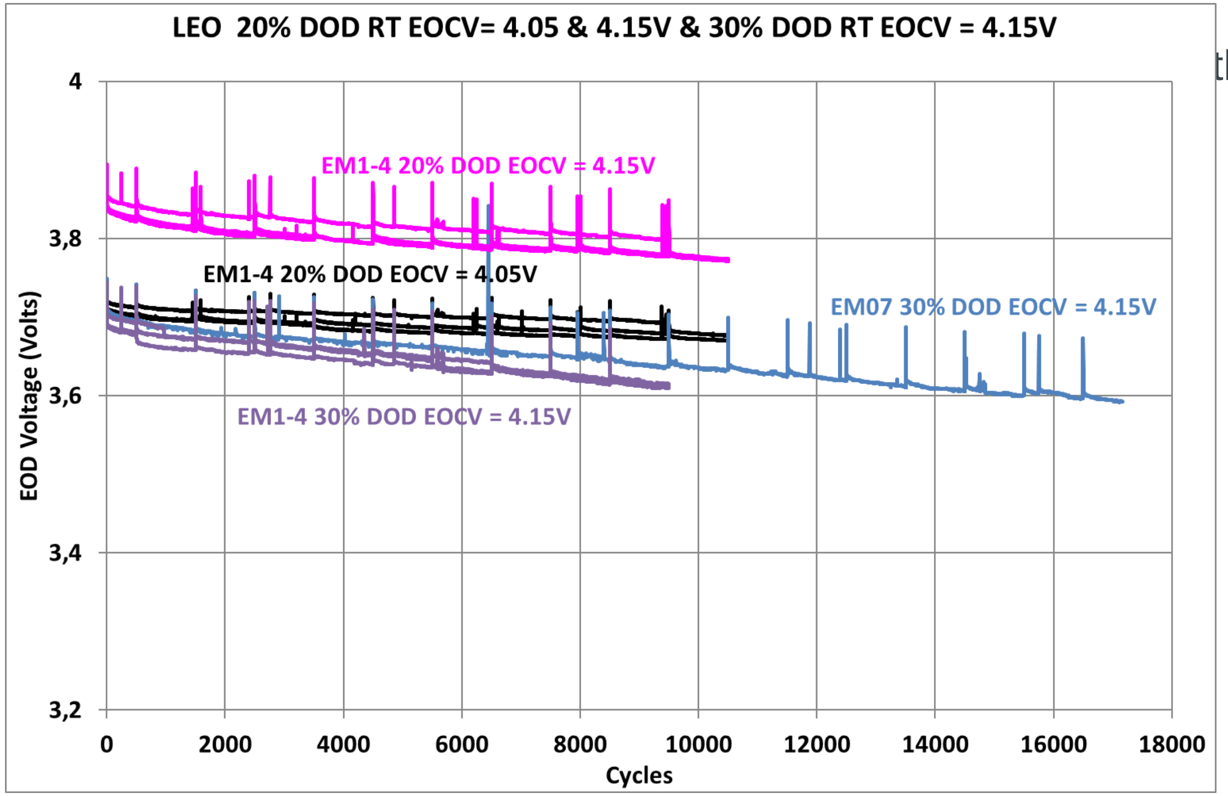




45 GEO seasons (equivalent to 22.5 years) successfully done on EM0 and EM1
EM2 life test are running

LEO cycling : C-EM1 Available capacity @ 20 and 30 % DOD

EODV and Energy



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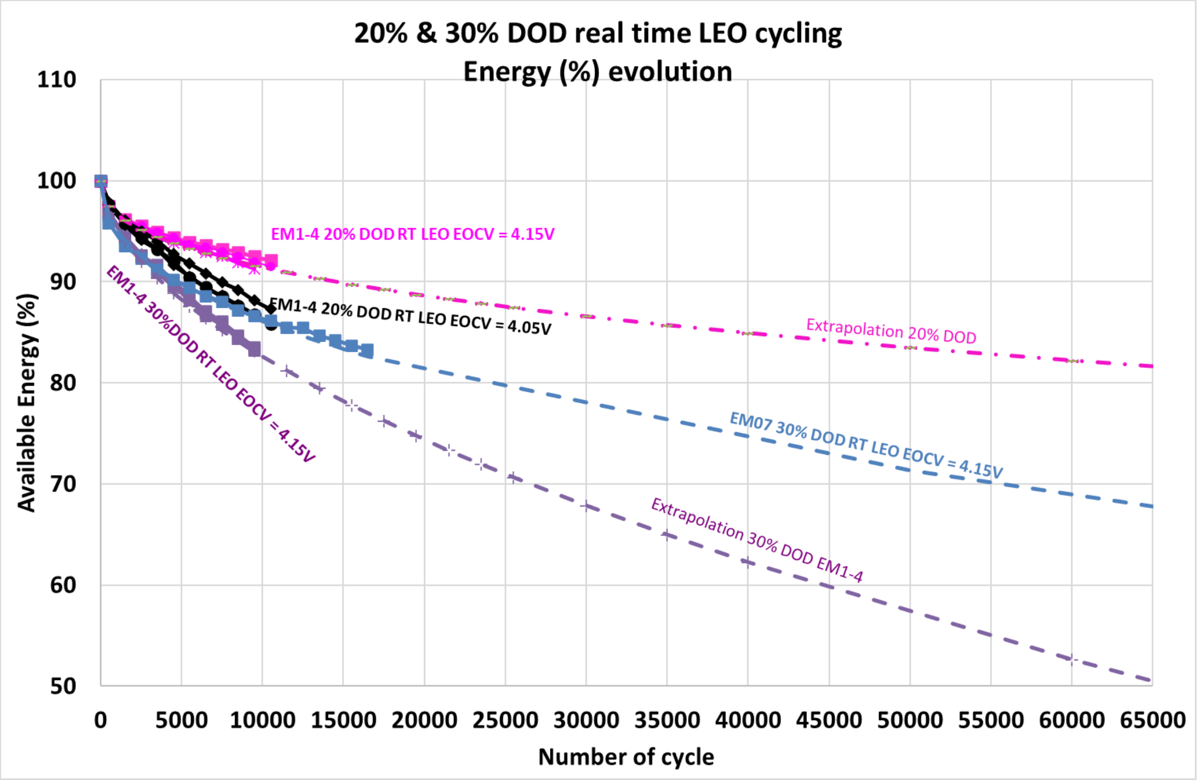
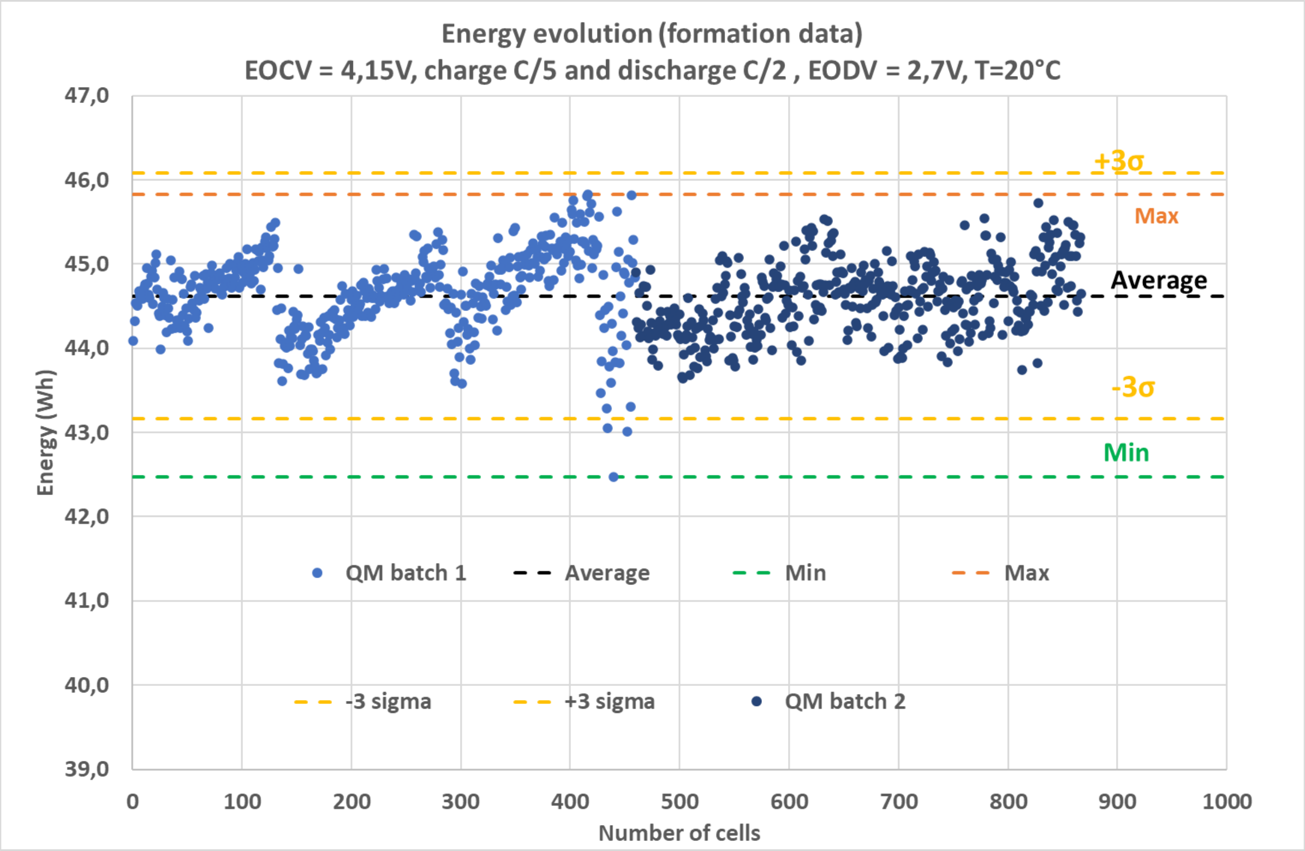


VL10ES QM cells

QM Cell performances



	Acceptance Energy (Wh) @ 4.2V & C/2 , T= 20°C
Average	45.4
Minimum	43.0
Maximum	46.5
Standard deviation	0.5

QM Cell average weight : 208.3 g

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 green color: Tests performed on EM1 and EM2 cells are already covering the Qual Test Plan

VL10ES Battery Qualification Status

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

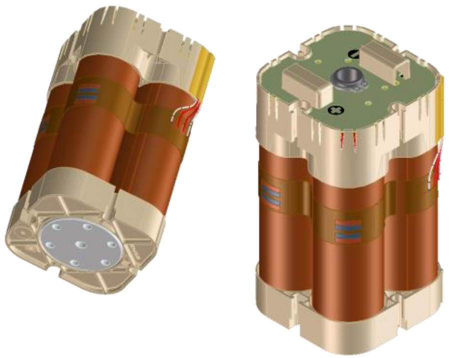
Autonomous electronics

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

Assembly innovation

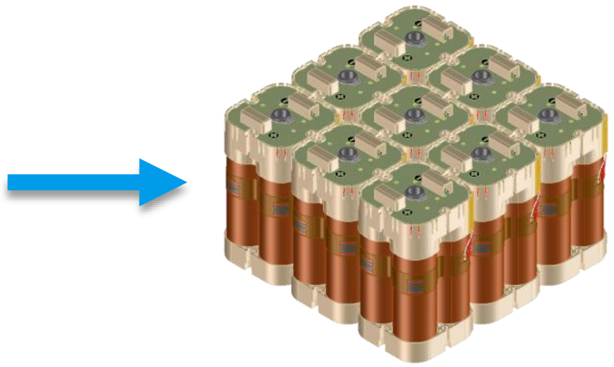
Each block is attached to the panel through a unique central screw.

4S1P block

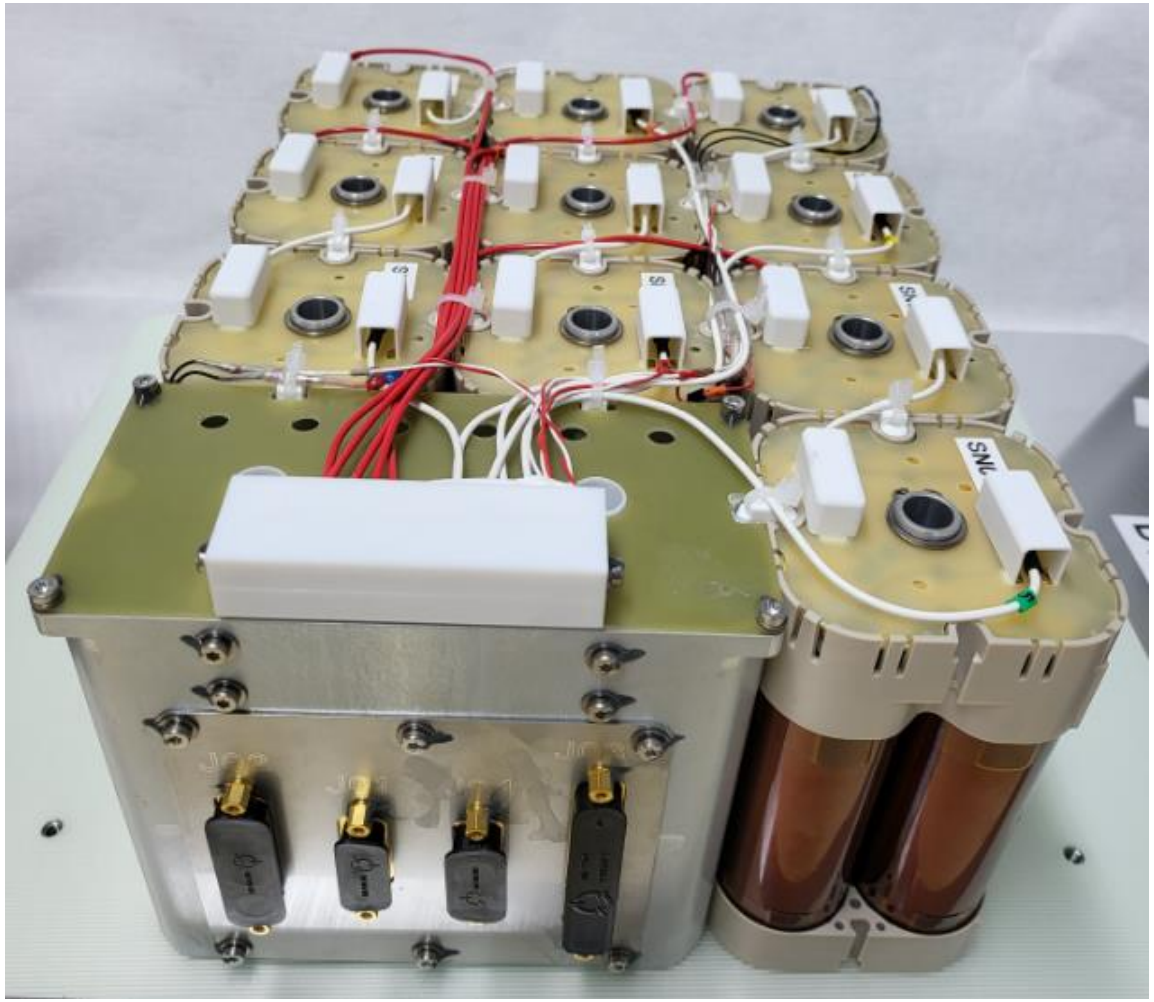


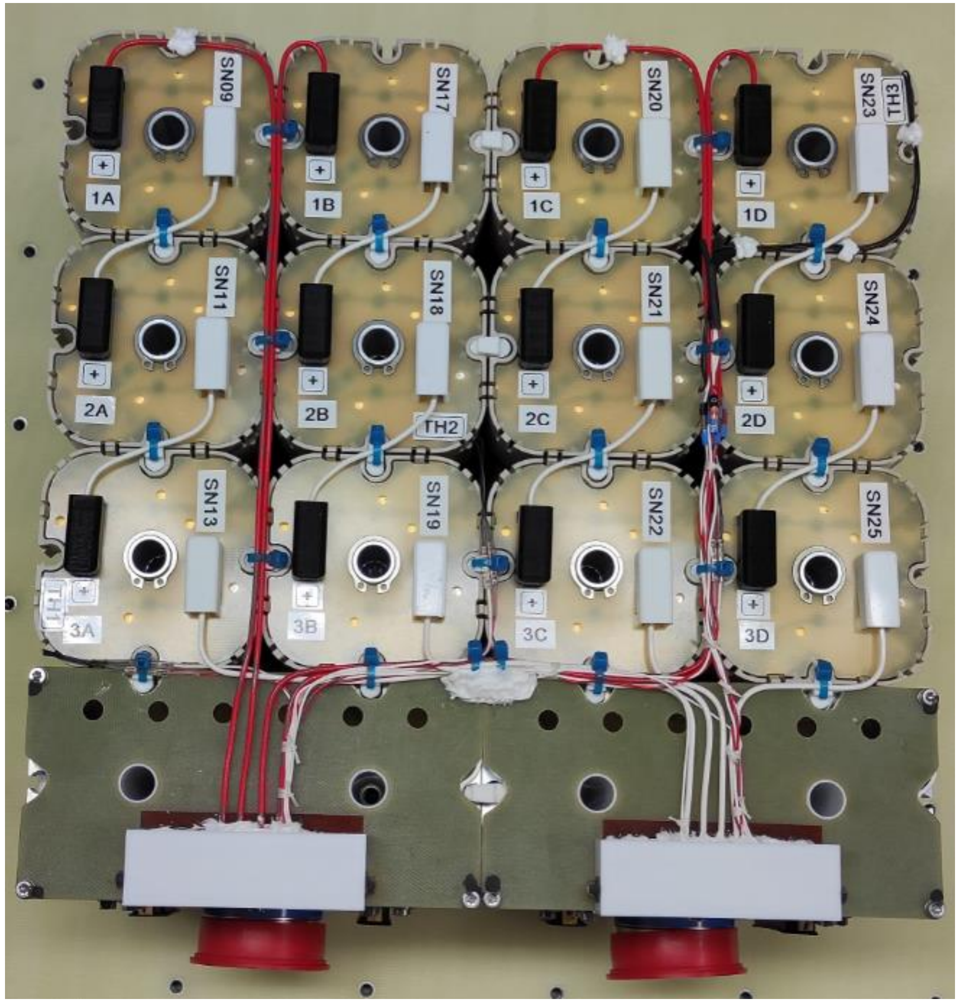
Individual Footprint
(mechanical / Thermal)

12S3P Example

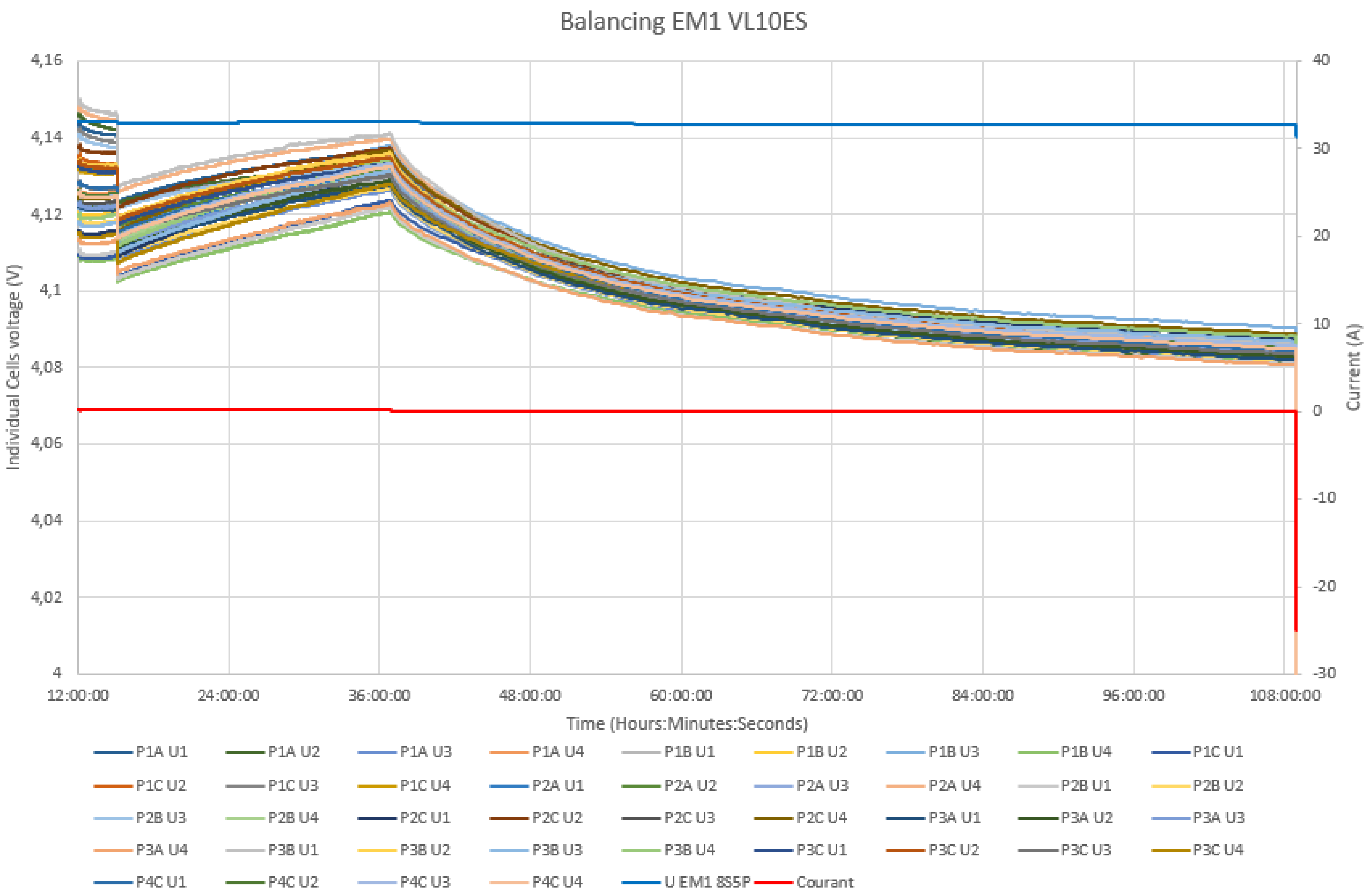


Bat-EM1 8S5P & Bat-EM2 12S4P





Bat-EM1/EM2 Test results – Balancing test in LEO Cycling



4S VL10ES Pack: Mechanical Environment tests

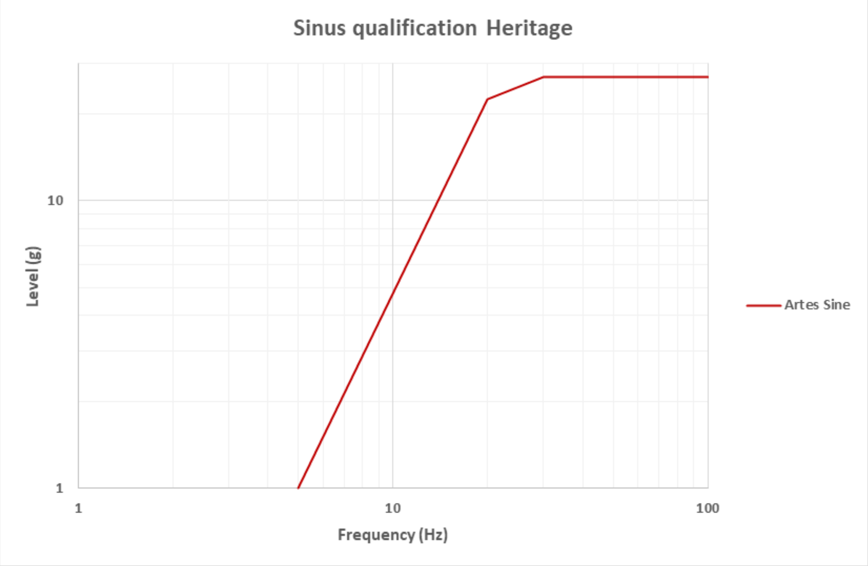
Sine high level

Sine	
Frequency (Hz)	Levels (g)
5	1
20	22,5
30	27
100	27

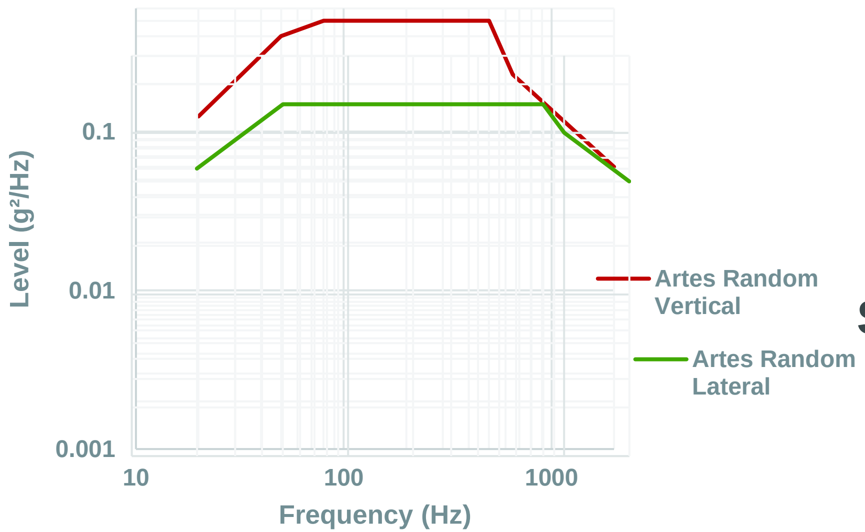
Random high level

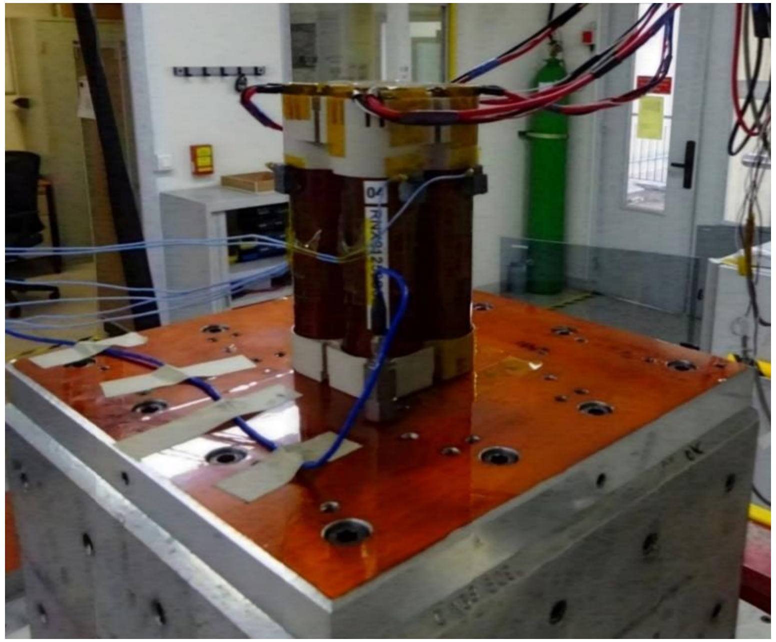
Random Vertical	
Frequency (Hz)	Levels (g²/Hz)
20	0,125
50	0,4
80	0,5
500	0,5
650	0,23
2000	0,06

Random Lateral	
Frequency (Hz)	Levels (g²/Hz)
20	0,06
50	0,15
800	0,15
1000	0,1
2000	0,05



Random Vertical qualification Heritage



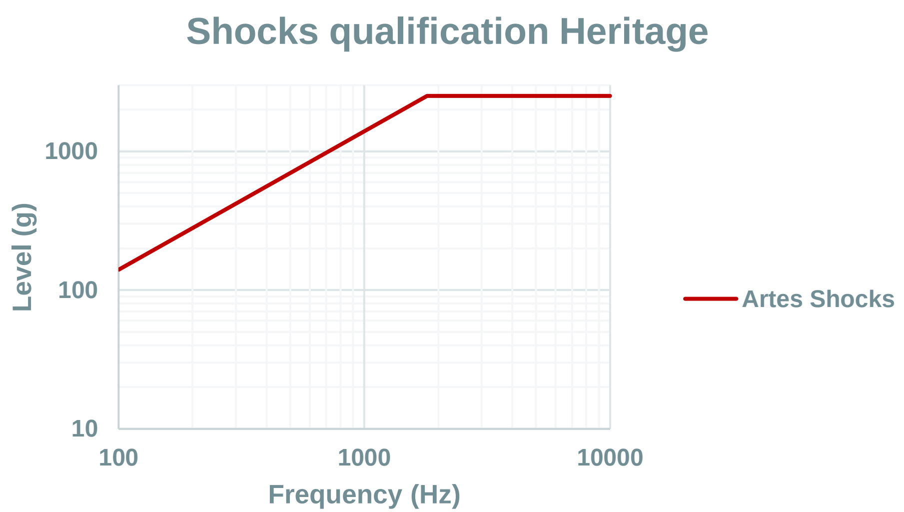


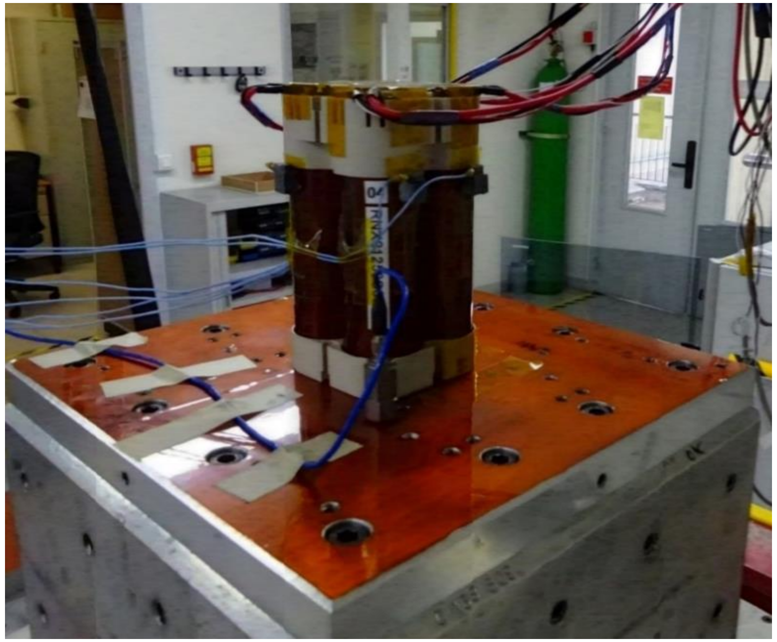
State of Charge between 3.95 & 4.2 Volts
taking into account a delay in launch

4S Pack Mechanical Environment tests

Shock level

Shock	
Frequency (Hz)	Levels (g)
100	140
1800	2500
10000	2500





State of Charge between 3.5 & 3.65 Volts taken into account the cell SOC at the end of the launch phase

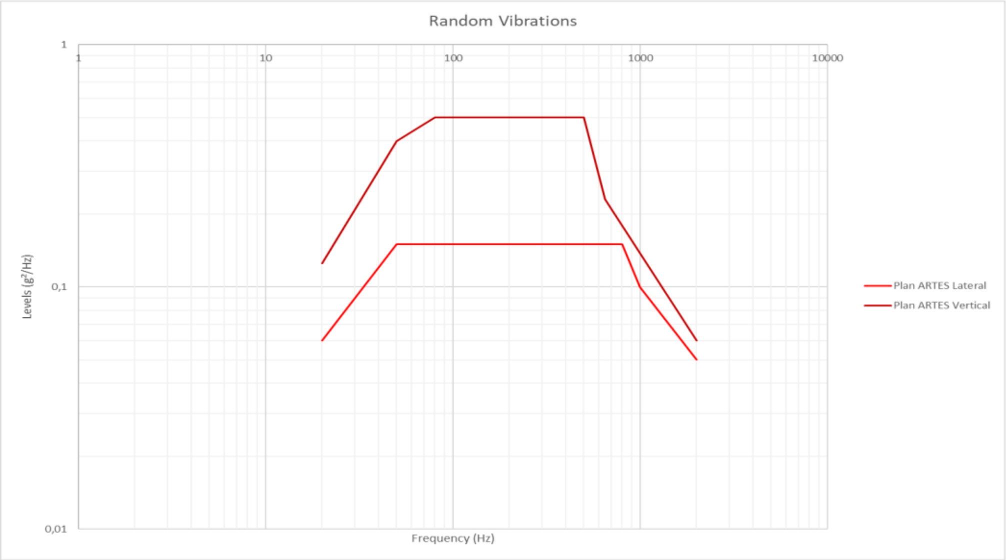
Energy/Capacity check : OK

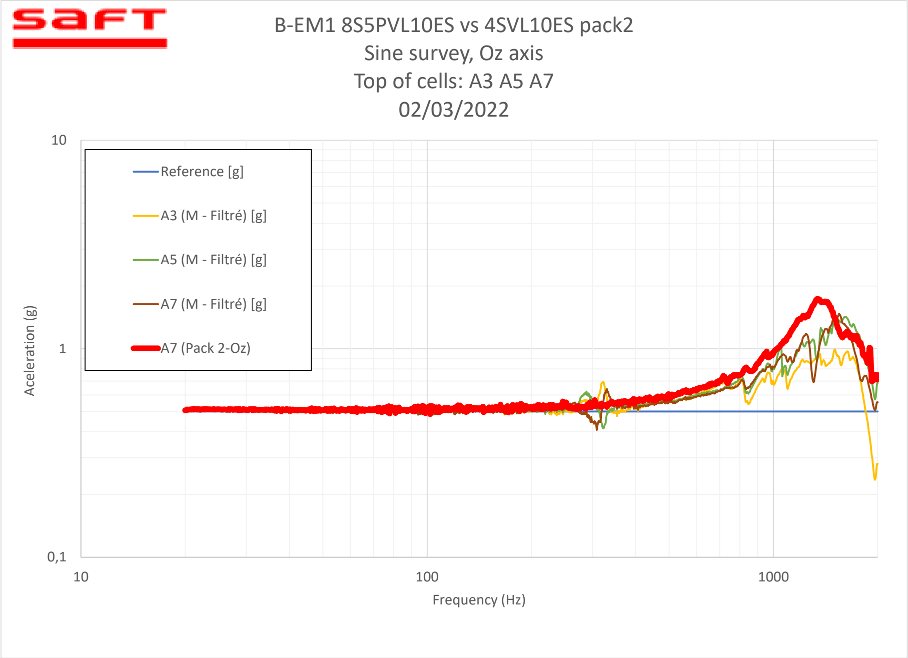
Internal resistance : OK

Bat-EM1 and 2 Test results – Sine/Random Vibrations

EM1 (8S5P)

EM2 (12S4P)





- Confirmation of result obtain at pack4S level, amplification lower (battery effect)

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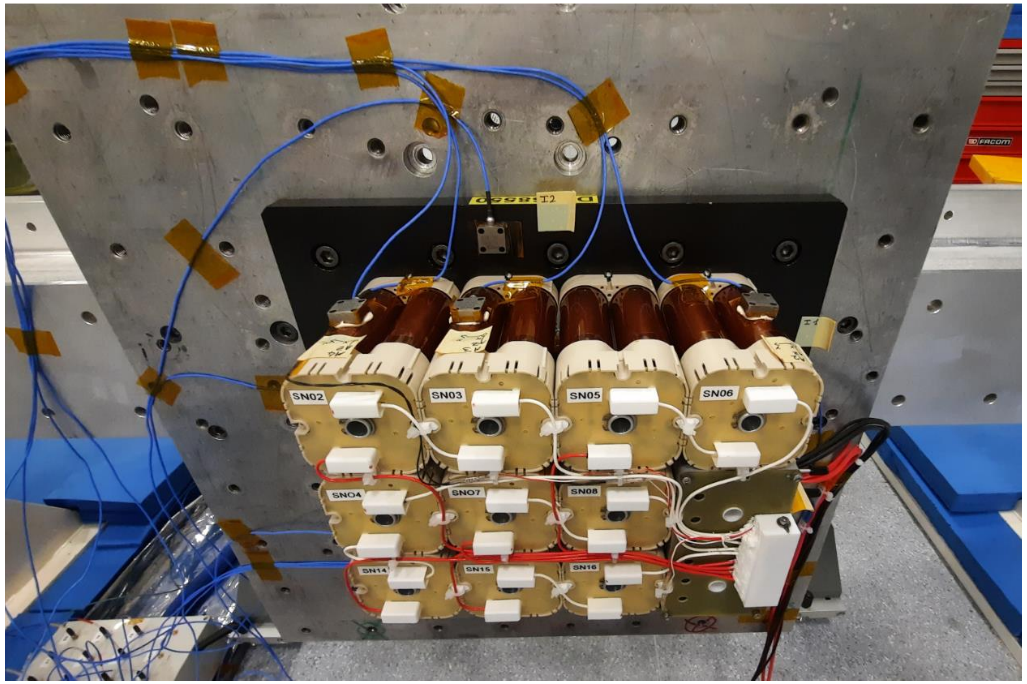
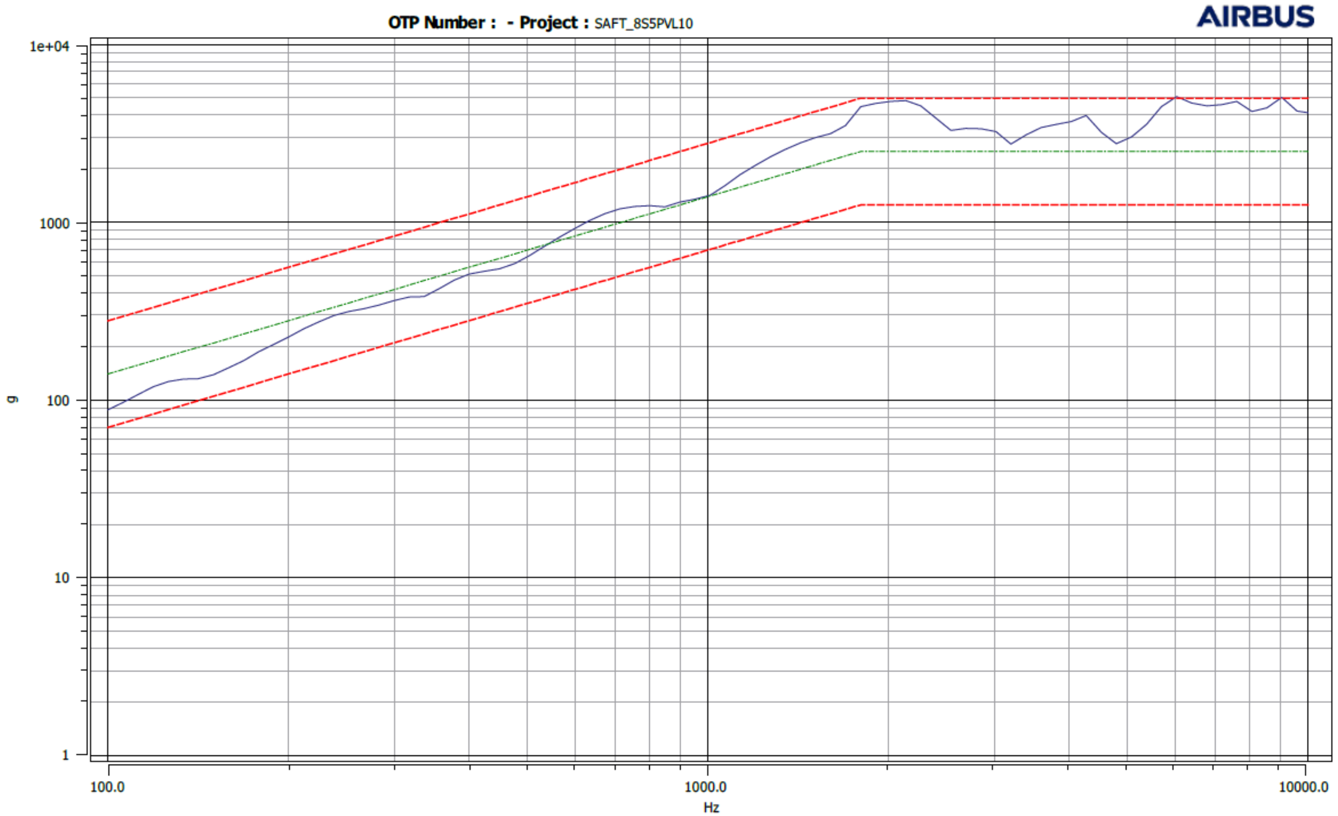
Bat-EM1 Test results – Shock tests

TotalEnergies

Shock	
Frequency (Hz)	Levels (g)
100	140
1800	2500
10000	2500





	Model	Test Name	Test Date	Type	Measurement Point	Maximum		Model	Test Name	Test Date	Type	Measurement Point	Maximum
—	B-EM1	Shock3_VL10_OZ	16/03/2022 15:55:22	SpectreDeChoc	I1_Z	5069	—		specificationXYZ				1253
--		specificationXYZ				1253	—		specificationXYZ				1253

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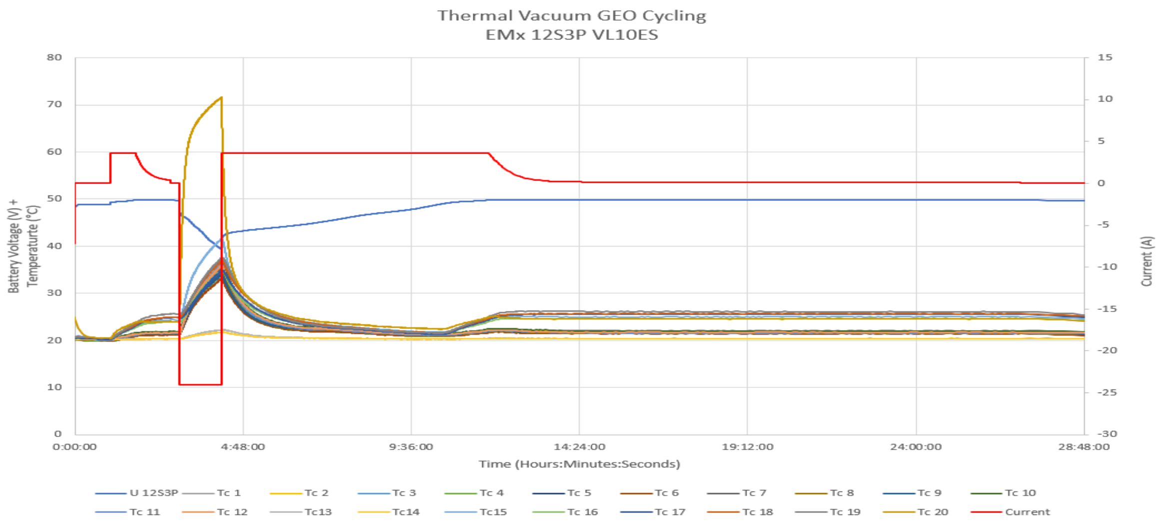
Bat-EM3 12S3P Thermal vacuum test

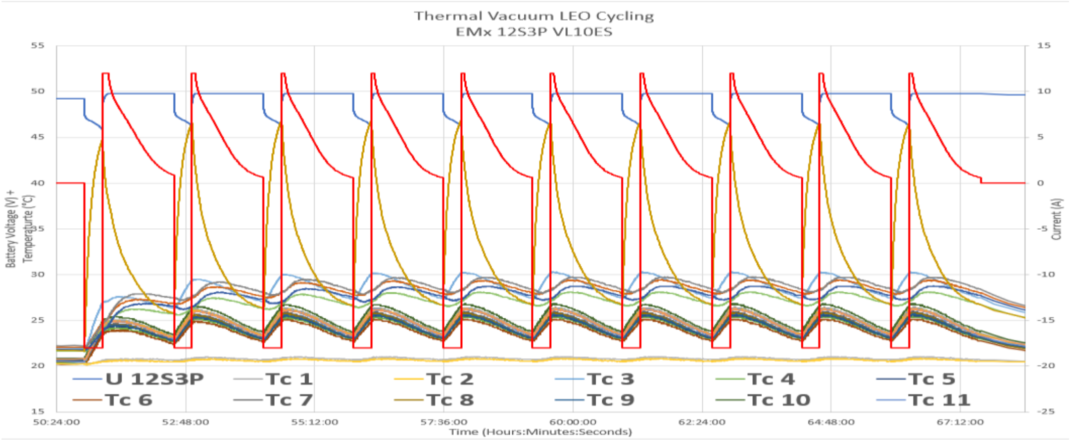
Thermal vacuum: GEO – 72mn discharge

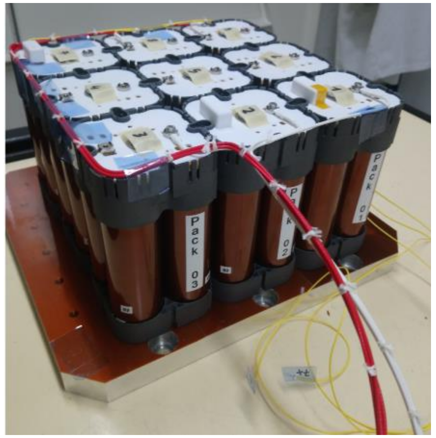
- 10°C increase of cell temperature at end of discharge



Thermal vacuum: LEO – C/3 charge / D/2 discharge

- Stabilisation at 5°C over the interface





Batt-EM3 12S3P

Bat-EM1/EM2 Test results

- Bat-EM's were successfully tested as per QM plan

  → Balancing system tests

  → Electrical Tests

  → Thermal tests

  → Environment tests : Vibration and Shock tests

  →Safety tests

All successful

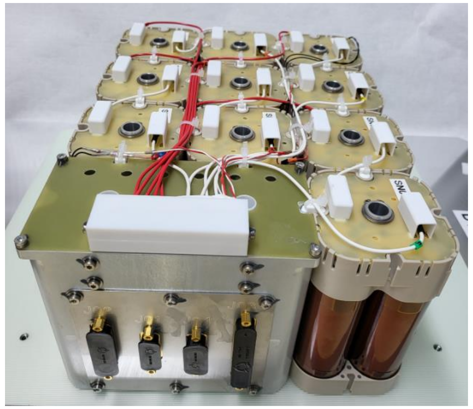
Battery Development plan

EM's Test plan **successfull**
- Batt-EM1 **8S5P**
- Batt-EM2 **12S4P**
- Batt-EM3 **12S3P**

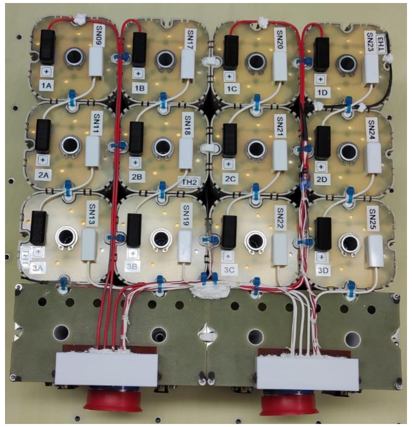
Electrical, Thermal, Mechanical (vibration, shocks), SBS tests
CDR held June 2022

Full Qualification test plan
- Batt-QM1 **8S5P**
- Batt-QM2 **11S6P**
- Batt-QM3 **3x12S4P**
- Batt-QM4 **12S20P**

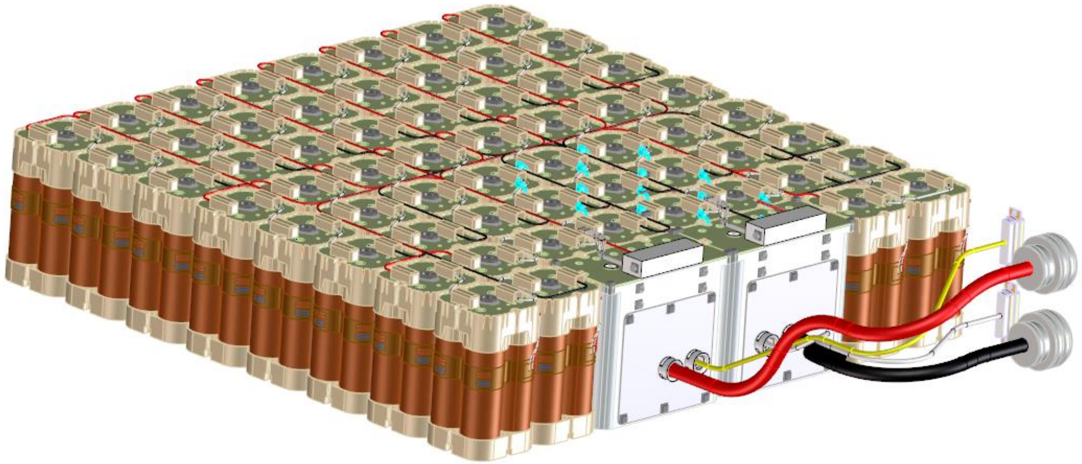
QR planned Q4 2023



Bat-EM1 8S5P



Bat-EM2 12S4P



Bat-QM4 12S20P VL10ES

Thank you