

# Modular battery for LEO small-SAT applications

## Abstract

This paper presents a way to decrease the cost of energy storage devices for LEO (Low Earth Orbits) small satellites applications. Two key factors will be analyzed in order to develop cheap and versatile spacecraft battery unit: “Modularity” and “Qualification of Li-Ion cells not specifically developed for space applications”. It will shown that through the modularity it is possible: to avoid lot’s of the recurring costs related to development of a space hardware; and to satisfy a large range of spacecraft energy demands simply adding or removing elementary battery “modules”. Furthermore, it will explained the delta-qualification needed for Li-Ion cells designed for automotive in order to use them in space applications. In this context, S.A.B. Aerospace acquired a strong flight heritage through the development of a modular battery for LARES (Laser Relativity Satellite) mission launched with the maiden flight of VEGA Launcher. Based on this heritage SAB is improving design of the modular battery, in order to make it suitable for longer missions. Given its many advantages, SAB battery has been selected for a LEO satellite project (carried out by the Italian National Agency), in order to store and provide electrical energy for a mini-satellite, which shall be operative for 3 years and requires about 1100 Wh, with discharge power peak up to 2 KW.

**Keywords:** battery, modularity, LEO, small-satellites, Li-Ion, qualification, power, storage

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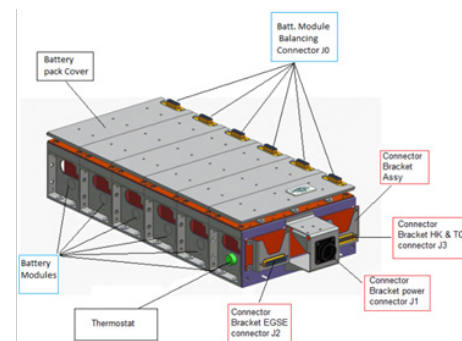
## Introduction

LEO small satellites for Earth Observation (EO) are becoming more and more popular for their lower weight and price. One of the most expensive spacecraft sub-system is the EPS and in particular the battery unit.<sup>1</sup> It is worth noting that there are not two identical spacecraft batteries, because the suppliers work closely with satellite manufacturers to customize the energy storage devices in order to meet the requirements set by the customer as function of the mission. Therefore, decreasing of battery unit costs and development times is a very interesting challenge. SAB battery modularity permits to satisfy a large amount of energy demands for a lot of LEO satellites configurations, depending on the number of integrated modules. Thus, modularity translates in an increase of versatility and in a decrease of development times and costs. Furthermore, SAB battery is equipped with Li-Ion cells designed for automotive applications, having a lower cost with respect to Li-Ion cells specifically designed for spacecrafts. In order to make them suitable for space applications an easy delta-qualification can be performed through which space environment resistance and compliance to mission requirements will be demonstrate. Such qualification foreseen simple model philosophy and test campaign which will be described and explained into this paper.

## Battery overview

The SAB Battery Pack is based on the recurring design of the Battery Pack of LARES, space qualified in VEGA Maiden Flight. It is represented by a Li-ion rechargeable modular battery able to supply electrical power to all the satellite equipment during ground operations, launch, eclipse periods, peak power demands, and safe mode. The battery is modular in the sense that it can satisfy a large number of power requirements for different satellite configurations by

simply adding or removing basic elements named “modules” (Figure 1).



**Figure 1** SAB battery pack overview.

Each battery module is able to achieve XSYP (series in parallel) battery configurations and integrates Voltage balancing components. The main standard I/F with the satellite and EGSE is a connector support named “Connector Bracket Assembly”.

## Elementary cells

SAB Modular Battery is equipped with Lithium-Cobalt Li-Ion cells.<sup>2</sup> Such cells were not designed specifically for spacecraft applications, but given their great performances they have been used in several satellite batteries. Main characteristics of the cells have been reported into Table 1.

## Module assembly

The SAB Battery modules are self-standing electro-mechanical assembly including:

**Table 1** Elementary cells main characteristics

Voltage range:	2.7- 4.1V
Average voltage:	3.65 V
Nominal Capacity:	5.8 Ah
Internal resistance:	40 mOhm
Max Stored energy:	21.2 Wh
Capacity loss after 12500 cycles (C/3 charge rate and 20% DOD):	12.27%
Capacity loss after one year of storage (EOCV : 4.1V):	< 4%
Mass:	0.15 Kg
Dimensions:	60 mm X 65 mm X 18 mm

- N Li-ion cells (i.e. N = cells in series)
- Several mechanical parts
- An equipped PCB with balancing connector (J0) (Figure 2).

**Figure 2** SAB battery single module.

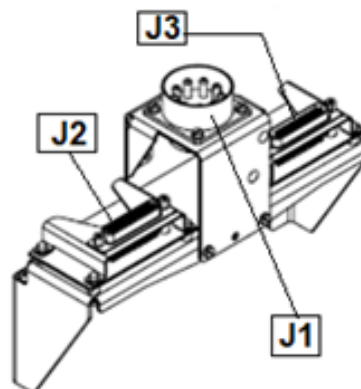
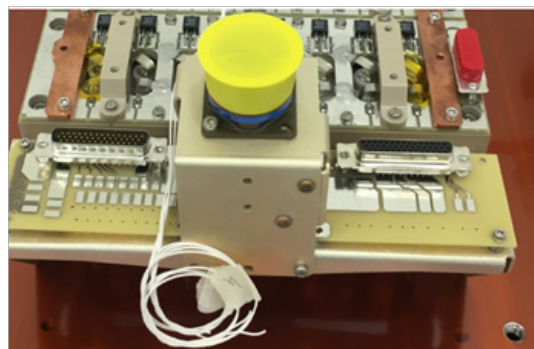
Number of cells connected in series depends on required Spacecraft Bus Voltage. For a 28 V Bus it is necessary to use 8 Lithium cells per string, each one having nominal voltage around 3.6 V. A dedicated Module PCB allows cells voltage balancing. Battery configuration adopts a passive balancing approach. Passive balancing is carried out, at module level, by integrating passive components on module PCB. Passive balancing allows the stack to look like every cell has the same capacity as the weakest cell. Using a relatively low current, it drains a small amount of energy from high SoC cells during the charging cycle, so that all cells charge to their maximum SoC. This is accomplished by using a switch and bleed resistor in parallel with each battery cell switching

### Connector bracket

The battery/satellite electrical interface, for power, housekeeping, EGSE, and thermal control, is provided by the Connector Bracket assy. Such electromechanical assembly is composed of:

- Several mechanical parts
- An equipped PCB with two HD-sub 44 pin connectors:
  - housekeeping/thermal control (J3)
  - EGSE connector (J2)
- A circular main power connector (J1) (Figure 3).

From a functional point of view, connector bracket PCB is an intermediate step in the connection of battery components (i.e. battery module terminals and heater-thermocouple circuits) with connectors (i.e. housekeeping/thermal control connector and EGSE connector) (Figure 4).

**Figure 3** Connector bracket assembly.**Figure 4** Connector bracket.

### Thermal control system

SAB Battery Pack is also equipped with its own thermal control system composed of the following elements:

- Main, Redundant, and Test Heaters
- Main and Redundant Thermostats (if needed)
- Temperature Sensors

The activation/deactivation of flight Heaters lines is nominally managed via S/W, at OBDH/PCDU level, and in case of S/W failure via Thermostats (see Figure 5 below).

It is worth noting that in case of failure in short circuit of the Thermostat, a dedicated PCDU Switch 3, controlled by the OBDH S/W, can disable the related function. This implementation allows to not redund, at Battery Pack level, the Thermostat device.

### Model philosophy and test campaign

Developing of SAB Modular Battery foresees the following model philosophy.

- # 1 EM Engineering Model
- # 1 EQM Engineering Qualification Model
- # 1 PFM Proto-Flight Model

A dedicated test campaign has been planned in order to verify the suitability of SAB battery for satellites applications. For the actual project following test campaign has been taken into account:

- a) Visual Inspection
- b) Physical Properties
- c) Electrical Functional Test
- d) Accelerated Life Cycle Test
- e) Nominal Life Cycle Test
- f) Mechanical Vibration
- g) Thermal Vacuum Testing

Electrical functional and Life Cycle tests have been performed with the following Battery Test System (Figure 6).

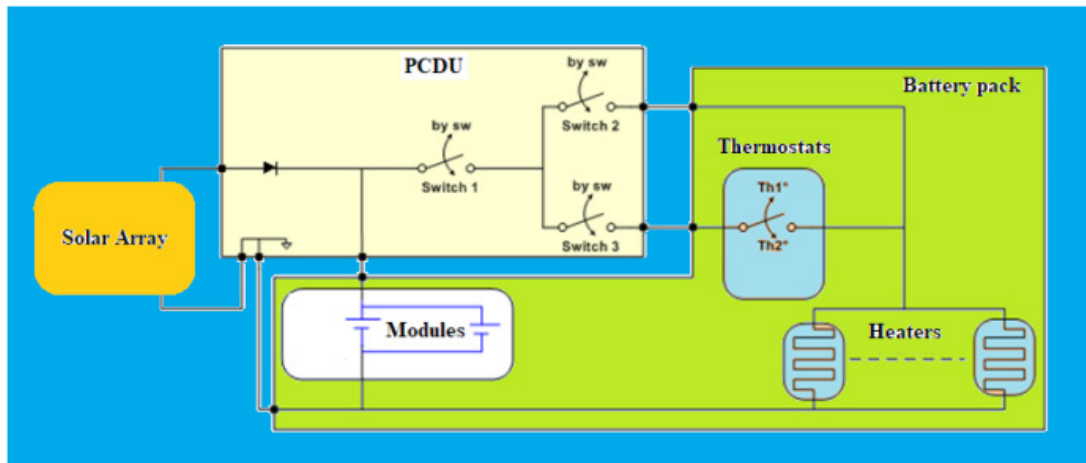


Figure 5 Thermal control system block diagram.

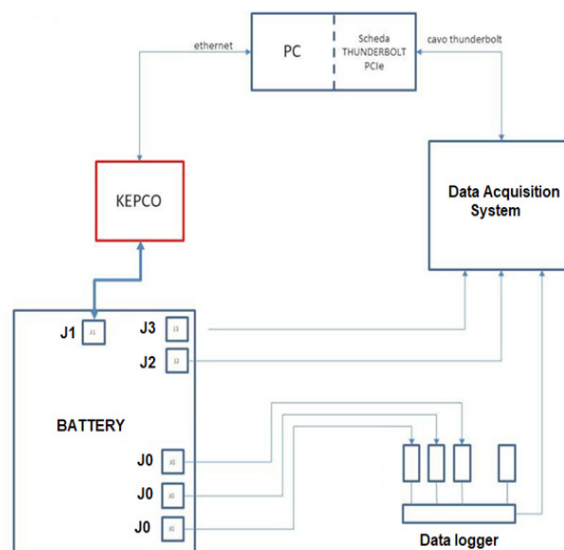


Figure 6 Battery test system.

### Accelerated lifecycle test

SAB battery flight heritage is based on a model developed for a launcher, not for satellites applications. For this reason analysis and tests have been performed to study Battery Pack capacity fading in order to guarantee its functionality during overall spacecraft lifetime.<sup>3</sup> Therefore an accelerated life test has to be performed. Considering the destructive nature of Accelerated Lifecycle Test, it is performed on an Engineering Model (EM) designed in 8S3P configuration (No.3 modules connected in parallel) (Table 2).

Anyway, at the end of Accelerated Lifecycle Test the EM will not be destroyed, because the test will be stopped before effective Li-Ion cells EoL. Therefore, there will be the possibility to perform other test on the battery.

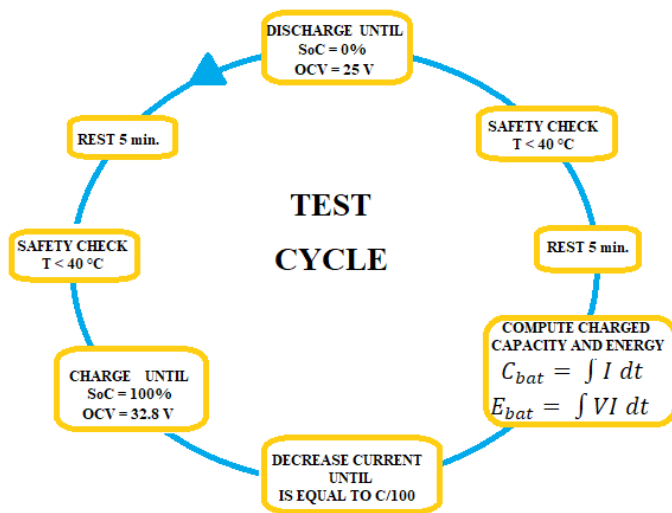
Thus, an innovative and accurate method to predict the available EoL (End of Life) capacity has been defined to show the suitability to the specific applications. Such method is based on the correlation between data collected from an Accelerated Life-cycle Test and mathematical method solutions. In this way, it is possible to set-up a

test performing about 20% of duty cycles carried out from the battery during its overall lifetime, using maximum allowable charge/discharge rate to accelerate the capacity fading rather than a thermal chamber. In this way it is possible to demonstrate the compliance with customer requirements in terms of energy demands during overall mission with low costs and times. At the end of Accelerated Lifecycle Test the EM will not be destroy, because the test will be stopped before effective Li-Ion cells EoL. Therefore, there is the possibility to perform others test on the same model, advancing the state of development by exploiting an hardware that in other types of accelerated life tests would have been destroyed.<sup>4</sup>

**Table 2** 8S3P Engineering Model (EM) performances

8S3P BATTERY CHARACTERISTICS	
Weight (kg)	< 7
Nominal EM Voltage (V)	29.2
Minimum EM Voltage (V)	21.6
Maximum EM Voltage (V)	32.8
Maximum EM Capacity (Ah)	17.4
Maximum EM Stored Energy (Wh)	572.13

Following figure shows test cycle for capacity and stored energy computation during the Accelerated Lifecycle test (Figure 7).

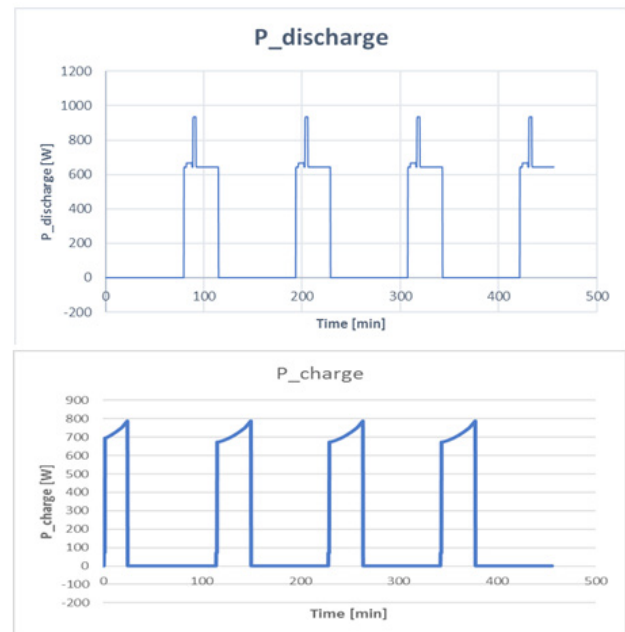


**Figure 7** Test cycle for capacity and energy calculation.

### Nominal lifecycle test

Once Accelerated Lifecycle test is over, a Nominal Lifecycle test is performed on EM, with the aim to study the effects of capacity fading with respect to the real mission power profile.<sup>5</sup> When this test starts, SAB battery has performed 3000 duty cycles and it is arrived to 17% of its overall lifetime. Hereafter the process for Nominal Lifecycle Test DoD calculation is explained, starting from a model of mission power profiles. Figure 8 shows the worst case scenario, which is taken into account for Test DoD calculation.

As shown in Figure 8, it is possible to model the discharge phase essentially in two time intervals as follow:



**Figure 8** Worst case mission power profile.

- a. load 650W, duration 30 minutes
- b. load 950W, duration 3 minutes

Since three modules will be used for testing EM, starting from power profiles shown in figure, half load has been taken into account for this test. Nominal Lifecycle test technical parameters have been summarized into Table 3.

**Table 3** Nominal Lifecycle test technical parameters

Nominal load	325 W for 32 min.
Peak load	475 W for 3 min.
Charge rate	2C/3
Discharge rate	2C/3
DoD	32%
Cycle duration	115 min.
Whole test duration	1 months i.e. 376 cycles

### Conclusion

Given its many advantages, SAB battery has been selected for a LEO satellite project (carried out by the Italian National Agency), in order to store and provide electrical energy for a mini-satellite, which shall be operative for 3 years and requires about 1100 Wh, with discharge power peak up to 2 KW. For this project SAB battery pack is in 8S6P configuration and it is characterized by the following characteristics (Table 4).

Adoption of innovative Li-Ion cells is being studied with the purpose of being used on this battery in the near future, in order to increase even more performances and life time. With the adoption of new elementary cells SAB battery in 8S6P configuration can achieve following performances (Table 5).

New cells are already qualified and their marketing is now in progress. The increase in terms of stored energy is due to the increase of elementary cells capacity density. Such increasing will permit to increase also power peaks and life time of the battery.

**Table 4** Actual SAB Battery performance

<b>8S6P BATTERY CHARACTERISTICS</b>	
Weight (kg)	< 13
Nominal Voltage (V)	29.2
Minimum Voltage (V)	21.6
Maximum Voltage (V)	32.8
Maximum Capacity (Ah)	34.8
Maximum Stored Energy (Wh)	1144.26

**Table 5** Near future SAB battery performance

<b>8S6P BATTERY (with new cells) CHARACTERISTICS</b>	
Weight (kg)	< 13
Nominal Voltage (V)	29.2
Minimum Voltage (V)	20
Maximum Voltage (V)	33.6
Maximum Capacity (Ah)	40.8
Maximum Stored Energy (Wh)	1370.88

## Acknowledgements

None.

## Conflicts of interest

The authors declare that there is no conflict of interest.

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