ABENGOA

TDE Activity – Battery Management System

ESA Contract Nº 4000129433/19/NL/HK

ESR: Executive Summary Report

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1. Introduction

Battery-powered electronic devices have become ubiquitous in modern society. The recent rapid expansion of the use of portable devices (e.g. computers, personal data assistants, cellular phones, shavers, etc.) and hybrid electrical vehicles (EVs) creates a strong demand for fast deployment of battery technologies at an unprecedented rate.

To increase voltage in lithium-ion technology, series connection of cells is necessary due to the low-voltage behaviour of single cells. Applications for series-connected cells range from 1 cell in phones and laptops to hundreds of cells connected in series and parallel in big grid energy storage systems.

The electrical vehicle (EV) is the leading technology in the area of storage and management systems, and thus the main focus on terrestrial applications is on electrical vehicles and lithium-ion batteries, which are the most representative so far in EVs.

Lithium-ion batteries are the energy storage technology of choice in the automotive industry. This technology is very susceptible to overtemperatures, overvoltages (overcharge), undervoltages (deep discharge), and overcurrents, and can be damaged or can fail if exposed to these conditions. Additionally, lithium-ion batteries have a reduced efficiency at low temperatures, display a capacity fading effect, and an increase in internal resistance with use over time.

So, what is the BMS and which relation does it have with this? BMS is the acronym for Battery Management System, and is meant for any system responsible for the supervision, control, and protection of battery cells or systems. Its main responsibility is to ensure that all the lithium-ion cells of a battery are inside what is called the safe operation area, or SOA. In doing this, safety and reliability of battery systems are increased; individual cells and battery systems are protected from damage; battery energy usage efficiency is improved; and the battery lifetime is prolonged.

In particular, measuring the voltage, current and temperature of the battery becomes crucial for a BMS to do its work. These are used as input parameters for all the tasks performed by the BMS.

In terrestrial sectors (e.g. automotive), BMS technologies are used extensively for energy storage and are commercially available. They feature the measurement of all the cell voltages in a battery, as well as all or some selected temperatures in the battery. Individual cell currents may also have to be measured. Integrated circuits are needed for data processing and storage for calculating state variables like state of charge (SOC) or state of health (SOH).

There is currently already active battery management implemented in spacecraft power systems, but despite these widespread developments in the field of BMS in terrestrial sectors, the field of spacecraft BMS remains relatively unexplored. On ESA missions, the battery is reliably managed by the PCDU. The battery can be discharged at the desired current to achieve the necessary power and, as soon as solar power is available again, the battery is recharged until the adjustable voltage level is reached. At this voltage level, the battery current is regulated such that the battery voltage stays at the defined fixed end-of-charge voltage.

Space missions impose a wide range of stringent requirements on energy storage devices: from harsh environmental conditions to reliability, robustness, and safety throughout the mission life. Detecting and avoiding battery failure and extending battery lifetime altogether are primary concerns as missions increase in duration and distance from Earth.

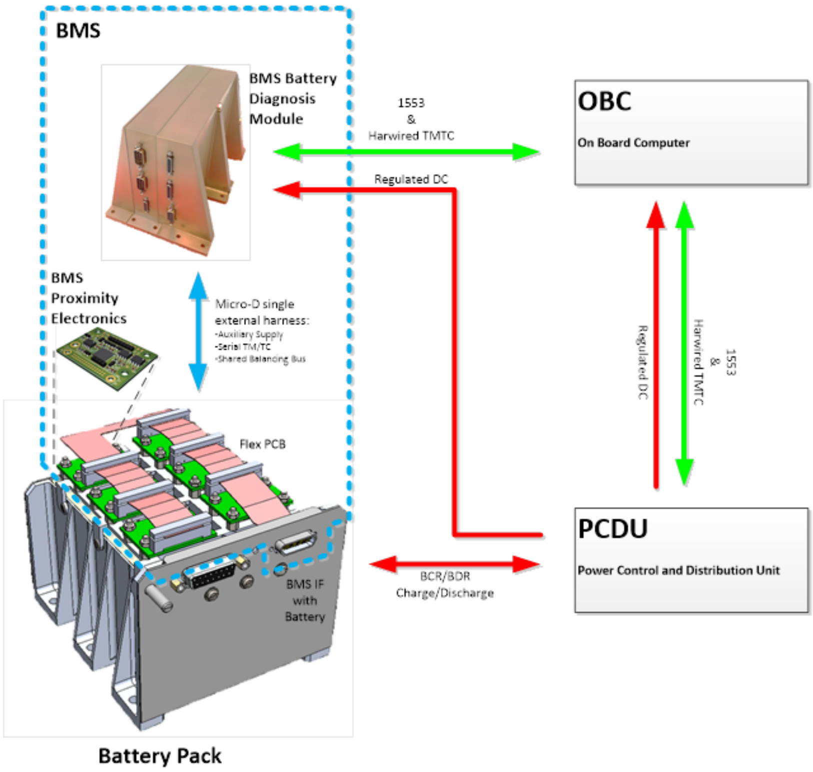
The quest to increase spacecraft payload capabilities and, thus, extend battery capacity over its lifetime inevitably leads to increasing the monitoring and control functions in spacecraft battery management systems. However, there are some particularities in spacecraft, as size and mass must be minimized, and a good combination of memory size, measurements and control channel bandwidth alongside the dimensional constraints has not been found. In other words, the data that can be obtained or even processed on board must be simplified.

This is very restrictive, and only in some cases, battery modules are built with a single cell monitoring and balancing feature. In contrast, in a terrestrial power plant, it is easy to increment sensing, monitoring and control signals to implement more advanced algorithms. Therefore, a compromise between complexity, data monitored for diagnostics and prognostics, and system robustness to increase safety and reliability shall be met.

2. This project's BMS

The TDE BMS project aims to design, produce and test an advanced, new approach of Battery Management System for spacecraft batteries, providing innovation beyond current state of the art, in order to enhance the battery performance and lifetime, allowing to resize the battery and save mass and cost. The BMS inherits concept and technologies from ground application but through a new architectural concept that meets with Space requirements.

The BMS is aimed as part of the spacecraft system in charge of power generation, storage and distribution, alongside the solar panel arrays, the lithium-ion battery and the power control and distribution unit (PCDU). The new concept keeps the charge and discharge of the battery in the PCDU, while the BMS is close to the battery and provides other functionalities.



The architecture of this BMS divides it in two parts, connected with each other: the Battery Diagnosis Unit (BDU), a module interfacing with the spacecraft's on-board computer; and the Proximity Electronics Unit (PEU), that spreads its functionality in several boards which are directly connected to the battery.

The main functionalities of this BMS include:

- Monitoring and measurements: The BMS is prepared to acquire cell and battery variables to be used by other modules or functionalities. Both BDU and PEU work in this: while PEU acquires cell voltage and temperature and string current, and conditions the signals, BDU is in charge of managing this acquisition process, as well as calibrating the measurements and software filtering. "String" refers to a set of cells connected in series.
- Cell and battery parameter calculation: The BMS is prepared to determine some parameters with the data obtained during the previous functionality. This is performed by the BDU, and is able to estimate the SOC and SOH of the cells and battery, as well as checking that cells are working in the safe operating area to detect any issues early.
- Cell balancing: The BMS is prepared to detect when cells are unbalanced (i.e. present a relevant voltage difference between each other or relative to the string mean value) and to start an active balancing process to keep them equalized. BDU uses the measurements from the first functionality to detect and identify the unbalanced cells, decides which balancing process to use (cell-to-cell or pack-to-cell) and start it. PEU connects the cells to the balancing sink or inject bus as per the BDU commands and an isolated DC-DC converter starts the equalization.
    - Cell-to-cell balancing is used when a cell is over the mean value of all cells and another is below it. This process transfers charge from the first cell to the second until the mean value is reached.
    - Pack-to-cell balancing is used when most cells are balanced but one of them is below the mean value. This process transfers charge from the whole battery (a bit from each cell, to keep them balanced) to the undercharged cell.

  Efficient balancing process are performed sequentially using shared buses aimed to decrease the need of external harness and reduce the mass and size impact of the harness itself and the associated magnetics of the multiple DC-DC converters needed for parallel balancing concept.
- Data handling: The BMS is prepared to manage the TM/TC interface with the spacecraft's electrical power system. BMS uses this to select the appropriate operational mode and transmit information about the status of both the battery and the BMS itself.
- Critical tasks: The BMS is prepared to manage high-priority functionalities as per hardwired commands from the spacecraft. This enables or disables the balancing process and the monitoring and measurements, and is based on a FPGA.

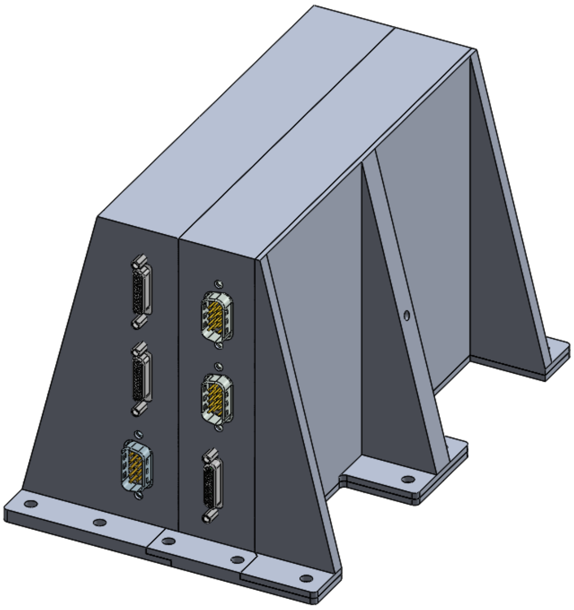
3. Design and manufacturing

The BMS system is divided in the following parts:

- A Battery Diagnosis Unit (BDU): this is a module which contains the core of the BMS functionalities: SOC and SOH calculation, cell balancing, provision of optimal charge current, alarms, interface with on-board computer.

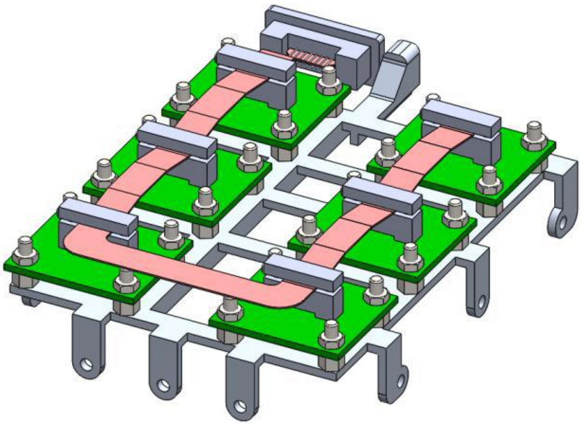
  The BDU comprises two electronic boards, which are located inside an enclosure and are internally connected:

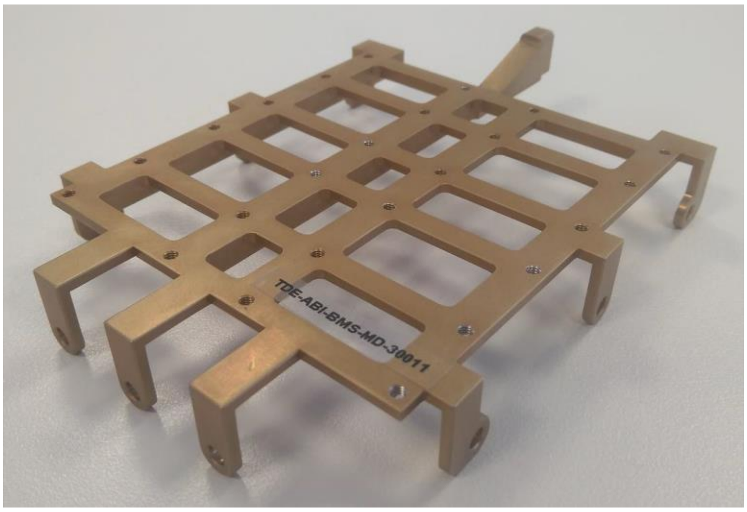
  - The Monitoring and Control Board collects the data from PEU and calculates the parameters needed to start the balancing processes. It is also in charge of transmitting information to the on-board computer.
  - The Power and Balancing Board generates the auxiliary supplies for PEU and is in charge of the balancing process.

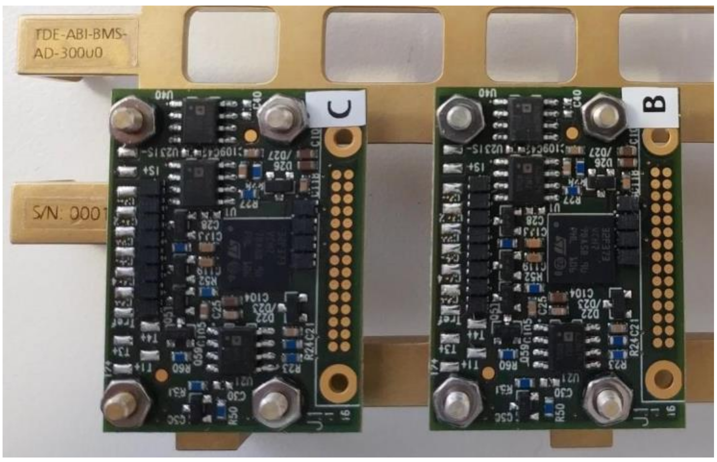


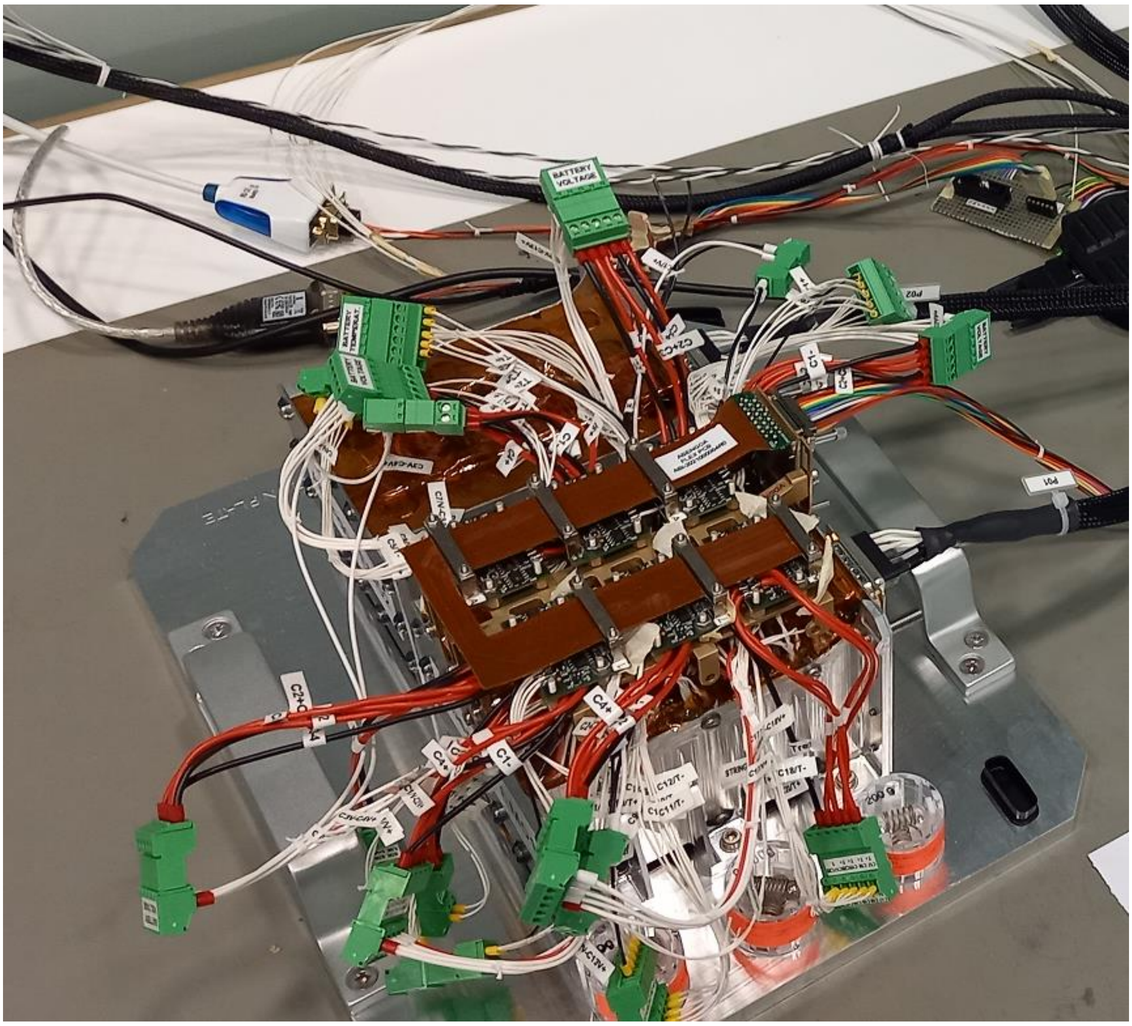
- A Proximity Electronics Unit (PEU): this is a module containing several boards which connect directly to the battery, providing auxiliary acquisition and control functions to support BDU functionalities. This includes cell monitoring (cell voltage, string current, cell temperature, pack current, pack bus voltage) and connection to the cell balancing system.

  The PEU system comprises six PEU Boards mounted on a plate directly on the battery, which are connected by means of an interconnection flexible board.





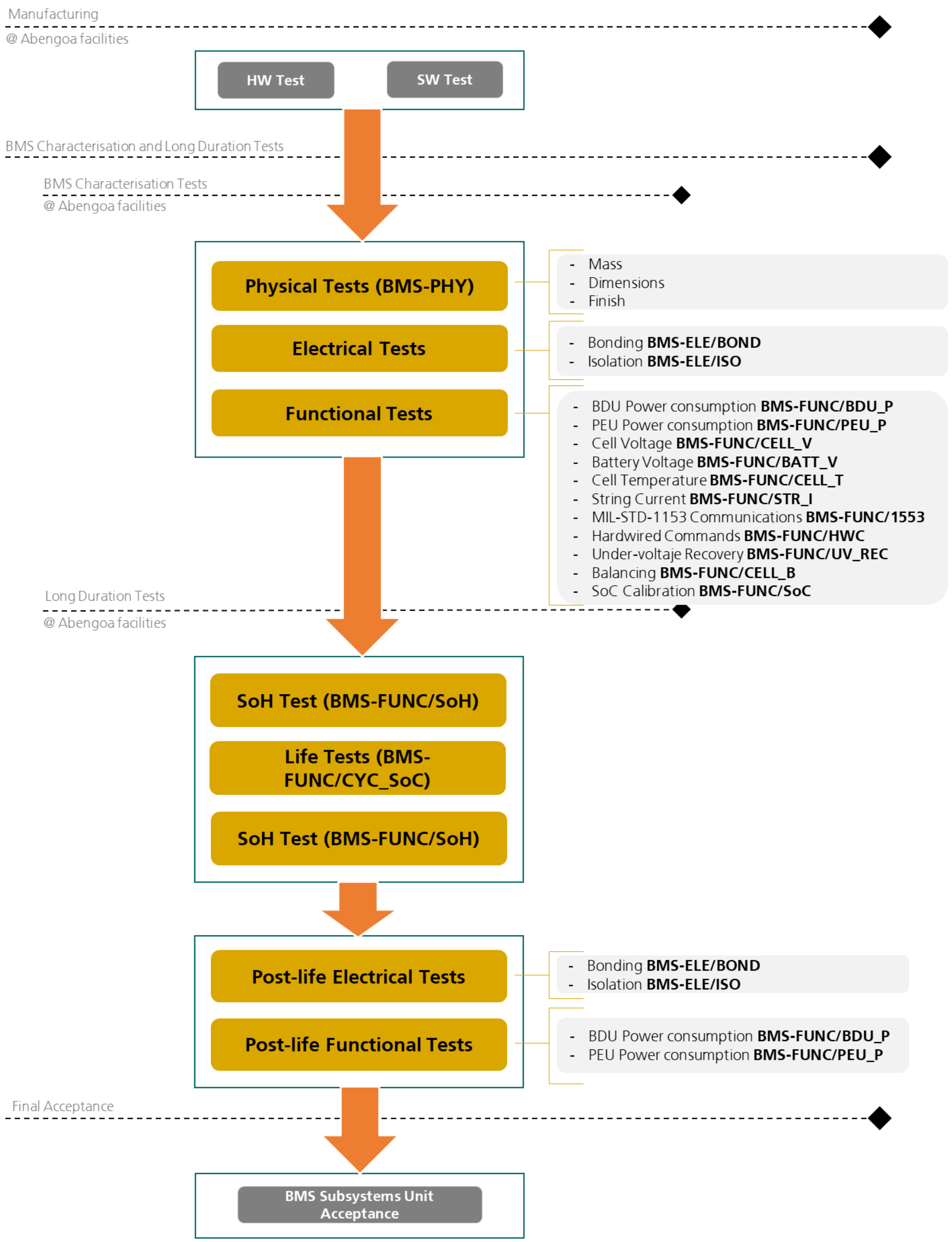




- The interface between BDU and PEU is a single and small external harness based on Micro-D connectors with several lines:
  - The auxiliary supply rail provides analogue and digital supply lines that PEU requires for operation. These supplies are generated at BDU.
  - The telemetry/telecommand (TM/TC) control bus is a communication bus used for controlling and monitoring PEU electronics. It treats BDU as the master system and PEU as the slave system.
  - The balancing sink bus is a power bus used during the balancing process. It connects the cell with extra charge to the BDU for charge extraction.
  - The balancing inject bus is a power bus used during the balancing process. It connects the cell with lack of charge to the BDU for charge injection.

The use of shared communication and balancing buses allow to significantly reduce the amount of external harness needed for the BMS application.

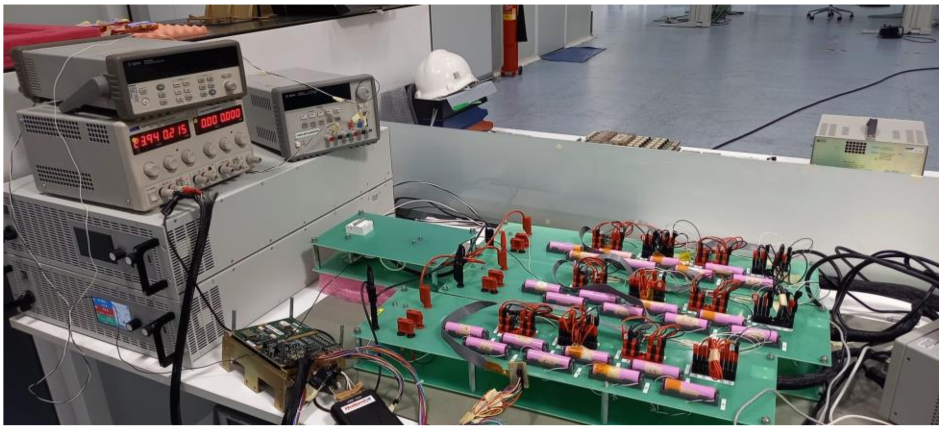
4. Tests



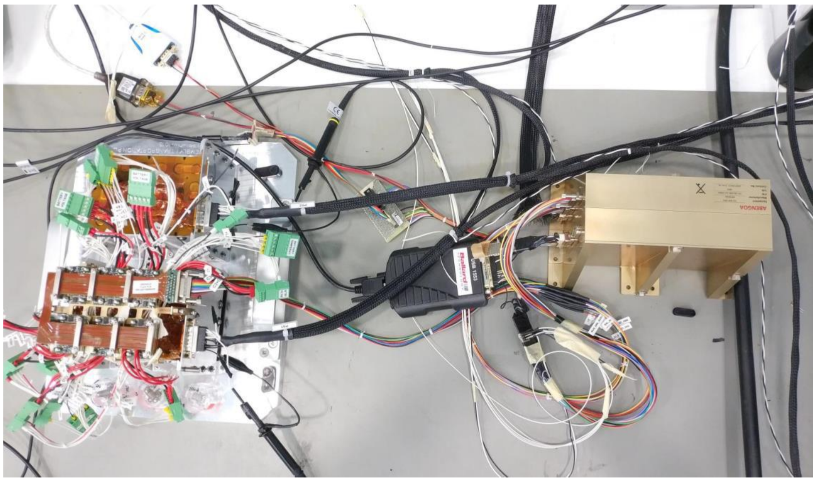
Manufacturing
@ Abengoa facilities
HW Test
SW Test
BMS Characterisation and Long Duration Tests
BMS Characterisation Tests
@ Abengoa facilities
Physical Tests (BMS-PHY)
Electrical Tests
Functional Tests
- Mass
- Dimensions
- Finish
- Bonding BMS-ELE/BOND
- Isolation BMS-ELE/ISO
- BDU Power consumption BMS-FUNC/BDU_P
- PEU Power consumption BMS-FUNC/PEU_P
- Cell Voltage BMS-FUNC/CELL_V
- Battery Voltage BMS-FUNC/BATT_V
- Cell Temperature BMS-FUNC/CELL_T
- String Current BMS-FUNC/STR_I
- MIL-STD-1153 Communications BMS-FUNC/1553
- Hardwired Commands BMS-FUNC/HWC
- Under-voltaje Recovery BMS-FUNC/UV_REC
- Balancing BMS-FUNC/CELL_B
- SoC Calibration BMS-FUNC/SoC
Long Duration Tests
@ Abengoa facilities
SoH Test (BMS-FUNC/SoH)
Life Tests (BMS-FUNC/CYC_SoC)
SoH Test (BMS-FUNC/SoH)
Post-life Electrical Tests
Post-life Functional Tests
- Bonding BMS-ELE/BOND
- Isolation BMS-ELE/ISO
- BDU Power consumption BMS-FUNC/BDU_P
- PEU Power consumption BMS-FUNC/PEU_P
Final Acceptance
BMS Subsystems Unit Acceptance

The test campaign can be divided in two stages:

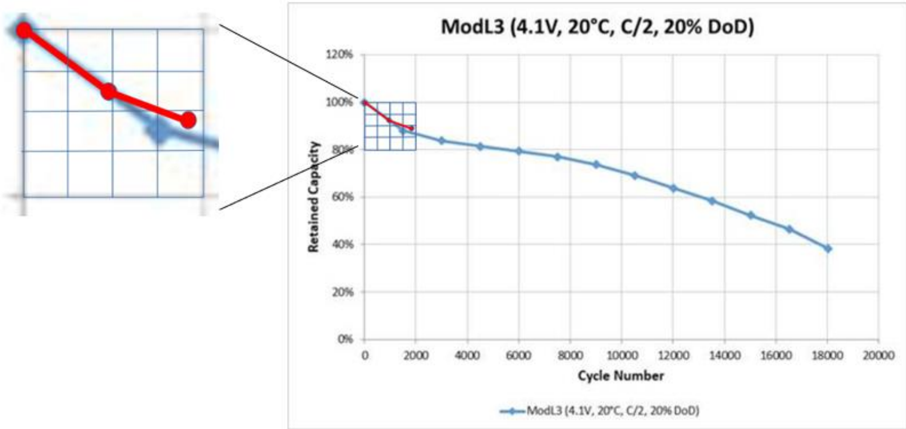
- BMS Characterization Tests: A customized battery mockup was used for this stage, replacing the real battery in order to be able to easily replace cells, provide test points and connect to an automated acquisition system. With this setup several functionalities were tested: power consumption; measurements of cell voltage, battery voltage, cell temperature and string current; communications with on-board computer; and hardwire commands; as well as other functionalities such as undervoltage recovery, balancing and SOC calibration.



- BMS Life Tests: These tests aim to demonstrate the benefits of the BMS application in a representative satellite environment during 1800 cycles (which translates to a period of approximately 3 months of uninterrupted, accelerated cycling). Now, a real battery provided by ABSL, with a 8s3p configuration, was used for the tests, on which the PEU system was installed. This battery was mounted on the same plate as a second battery, so that the results could be compared between a battery with BMS and a battery with no BMS. The objective of this test was to provide an estimation of the state of health (SOH) of the battery and its long-duration behaviour. In order to achieve this, the system was kept working for over 3 months of cycling and balancing processes, in a way to acceleratedly simulate the lifetime of a low Earth orbit (LEO) space mission.



After 1800 cycles applied to both batteries, the results show that the battery with BMS had a lower degradation than the battery without BMS, as per the estimated SOH. This can also be compared with curves provided by the battery manufacturer (ABSL) to show the improvements with BMS with respect to the theoretical evolution.



The results look promising and a trend towards improvement can be observed, even though 1800 cycles represent a low number of cycles overall and further testing may be needed for more certainty on the evolution.

As the activity has been based on a typical low Earth orbit (LEO) mission, these results show that BMS may bring benefit to space missions.

Additionally, the provision of telemetry for SOC and SOH is deemed very valuable for future applications.

5. Future

At the beginning of the activity, this was at TRL2. With the successful tests, it can be concluded that the project has reached its goal of TRL 3 and has even surpassed it to achieve TRL 4.

The main improvements in order to follow with the progress are in the optimization of electronics to facilitate the migration to space qualified components, the improvement of mechanical interfaces, and the addition of new features, such as a third balancing process method in cell-to-resistance, cell safety devices or passivation processes.