# THE LEO PCDU EVO - A MODULAR AND FLEXIBLE CONCEPT FOR LOW TO MEDIUM POWER LEO & SCIENTIFIC MISSIONS

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## ABSTRACT

After a successful AS250 LEO PCDU product life [1], with more than 12 FMs manufactured (4 of them currently in orbit), and 10 years in the market, an evolution is required in the product to make available a new PCDU for Low Earth Orbit, scientific, interplanetary and export missions in line with evolving customer needs.

Market trend towards volume & mass reduction, plus new required capabilities (in particular End of Life Passivation and Launch Off to support multiple launch) justify the need for a new LEO PCDU EVO generation. This paper will deal with a simple question with no immediate answer: how to save 20% PCDU mass and volume while keeping or improving existing performances.

## 1 MOTIVATION

The targeted unit is intended to satisfy the needs of LEO and scientific spacecraft with a design and construction optimized for small missions, but covering also medium power range units up to 3kW. The proposed concept is also applicable to the distribution part of the 28V regulated buses classical of interplanetary missions like the PCDU for JUICE. A novel approach has been developed for that, on which the interface with the solar array (DET function) and the battery is scalable to the total solar array and battery energy to be managed.

## 2 PCDU ARCHITECTURE

Figure 1 is an image of the LEO PCDU EVO EM as built for the Merlyn flight mission.

A brief summary will be provided on unit capabilities, in order to have an overall view in advance to implementation aspects, see table 1 hereafter.

| | Configuration capabilities | |
|---|---|---|
| **Module Type** | **Minimum** | **Maximum** |
| DHS I/F | 1 | 1 |
| DET | 1 | 2 |
| BATT/MEA | 1 | 2 |
| DISTRIBUTION | 0 | 6 |
| DEPLOYMENT | 0 | 2 |
| **TOTAL** | 3 | 13 |

*Table 1. LEO PCDU EVO modularity vs. configuration*

*Figure 1. LEO PCDU EVO EM during integration in the configuration for Merlyn mission*

A single Data Handling Interface module is required regardless the unit configuration selected, since the master FPGA (either nominal or redundant) contained on it already encloses all the required VHDL code to govern any PCDU configuration from maximum to minimum one.

In general terms the PCDU is built with a number of modules of catalogue of existing ones. No modifications are required on the building blocks to configure the PCDU for a given mission. Automatic software tools have been developed to configure the distribution modules to the particular needs for LCL classes and types of a specific application case.

Table 2 below shows the different functionalities available for the LEO PCDU EVO and their most relevant performances.

## 3 HOW TO DO THE SAME (OR EVEN MORE) IN LESS VOLUME

Mass & volume reduction while adding new performances was identified as the design target for this PCDU evolution. Packaging optimization, proper selection of the modularity and functionality integration are the key drives to achieve these targets. This must be

| Function | LEO PCDU EVO Performance Parameter | |
|---|---|---|
| **DHS I/F** Data Handling Subsystem Interface Module | Number of Mil-1553 Bus Interfaces | 2 (each N+R) |
| | Number of APS | 1xN + 1xR |
| | Number of SOL Inputs | 1xN + 1xR |
| | DOC (Direct On Command) Lines available | YES, N+R |
| | TM/TC Control | Parallel for Conditioning Serial for Distribution |
| **DET** Direct Energy Transfer (S3R) | Reliable sections | YES M+1 concept |
| | Maximum section current | 9.5A |
| | Efficiency | >98,5% |
| **BATT/MEA** Battery Interface & Main Error Amplifier | Max. Charge / Discharge Current | 50A/65A per BAT Module |
| | Number of EOCV Levels | Up to 16 |
| | Number of Charge Current Lim. Levels | Up to 16 |
| | EoL Passivation | YES |
| | Launch Off Capability | YES |
| Distribution Capabilities | Max. Number of CL Outlets | Up to 104 |
| | Max. Number of PO-LCL | Up to 16 |
| | Max. Number of Heater Outlets | Up to 192 |
| | Types of Limiters available | SO-LCL, PO-CL, LCL |
| | Classes of Current Limiters available | 0.5A, 1A, 2A, 3, 4A, 5A, 6A, 8A, 10A |
| | Classes of PO-CL available | 0,5A, 1A, 2A, 3A, 7A |
| Deployment Devices | Supported Actuator Types | EED & LSRU |
| | Safety Deployment Strap | YES |
| | Max. Number of Deployment Outlets | 24+24 |

*Table 2. LEO PCDU EVO Module and functionality*

achieved in both Power Conditioning and Power Distribution parts of the whole PCDU. These two parts of the PCDU will be discussed now separately.

### 3.1 Power Conditioning

When the same implementation of a concept is used for a wide power range, normally the lower power application cases are penalised in mass, and/or the higher power application cases are penalised in efficiency. Implementations for high current paths do not use to be light in terms of weight.

The innovative idea used in this LEO PCDU EVO is based on making totally modular the PCDU Power Conditioning part. The higher the power, the higher the number of “power slides” to be used. This modular approach is extended to the EPS implementation. This modularity applies to the Battery module and to the DET module.

The Power Conditioning modularity concept is reflected in Figure 2. Several design aspects have been also optimized in order to achieve not only a more optimum use of the available volume, but also an easier manufacturing:

- Sub-D connectors for battery I/F instead of bulky circular ones,
- Solid state-based battery switch,
- Flex connections for power devices, and
- Exhaustive use of commercial space grade inductors SMT type.

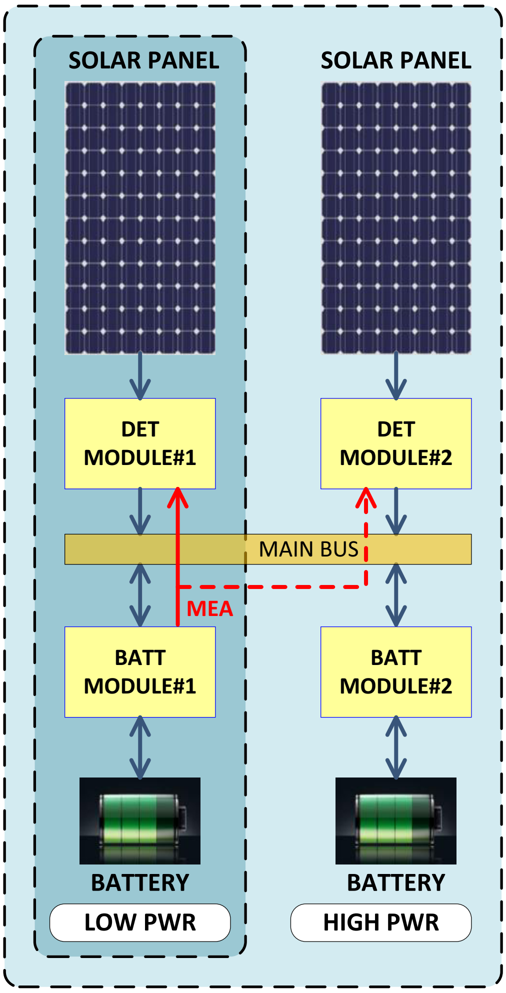


*Figure 2. LEO PCDU EVO Conditioning modularity*

DOI: 10.1051/e3sconf/20171618009

New packaging solutions are also considered, enabling pitch reduction on all modules, e.g. using SMT capacitors of better volumetric efficiency for main bus capacitor. Deep analysis on component type minimization was also run. Figure 3 shows the EM module of DET function.

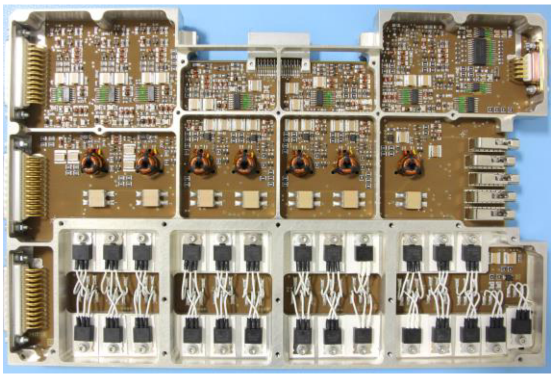

*Figure 3. DET Conditioning Module EM*

It is to be highlighted that LEO PCDU EVO mass and volume reduction was not made thanks to performances reduction. All functionalities of previous product were maintained if not improved.

In particular it is to be highlighted that DET S3R cells are reliable by design (one failure tolerant) with respect to the loss of the power available from any solar array section.

DET implements the M+1 concept (one extra section) with two main functionalities under MEA control, see figure 4 for reference:

- To feed the bus with the power coming from a section whose S3R cell failed in open circuit in the power path to the main bus, or
- To handle the power from a solar array section whose S3R cell failed in open circuit in the shunt power path, in case the instantaneous bus consumption is below the power provided by this section.

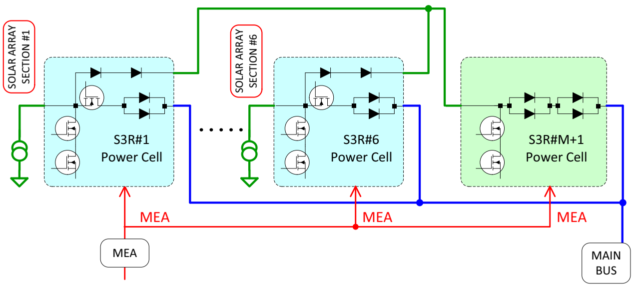


*Figure 4. DET Module failure tolerance concept w.r.t. Solar Array available energy*

Nominal sections are connected to M+1 section by a couple of power diodes in series as can be seen on figure 4.

In addition, there are new functionalities in line with market trends and customer requirements regarding green space regulations. In this sense, the LEO PCDU EVO implements electronics to passivate the solar array once the end of mission was reached [4].

The same diodes mentioned before that are connecting every S3R cell to the M+1 cell, are used to connect the S3R cells to the electronics in charge of passivating the solar array, refer to Figure 5.

Passivation is exercised by a pair of electromechanical power relays in series (to be one failure tolerant w.r.t. a failure leading to the contacts of one relay stuck to on position).

Moreover, passivation command is executed in two steps, Arming + Firing, and passivation action is reversible as long as there are energy enough available in the spacecraft battery.

Power Conditioning modularity as shown on Figure 4 is also applied to passivation function: the passivation relays are physically implemented in the BAT/MEA module to optimize the use of the available volume in the unit and to provide the same solution regardless the power range.

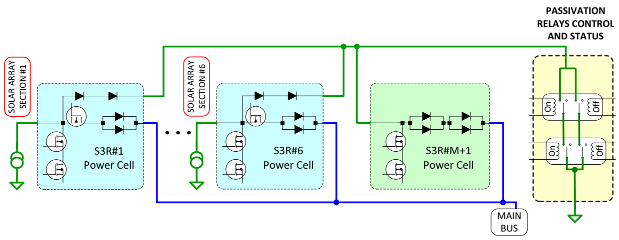


*Figure 5. EOL Solar Array Passivation*

Another performance added to PCDU design is the launch off capability for multiple launch scenarios. It is based on a couple of series redundant separation straps.

Opening one of the straps is enough to start up the PCDU in a controlled manner. A parallel control of the PCDU status through an interface with EGSE is also possible while on ground via two switches in series. This feature – in conjunction with the solid state-based battery switch - easies the handling of the PCDU on ground while spacecraft integration is taking place.

The scheme for the launch off interface (and EGSE interface) implementation is shown on Figure 6 hereafter.

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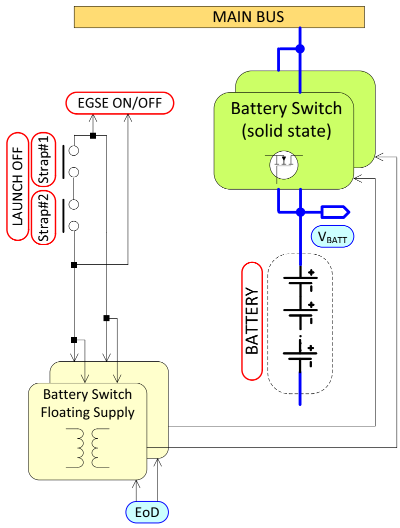


*Figure 6. Launch off Interface implementation*

### 3.2 Power Distribution

Power Distribution Modules are normally the most numerous ones in a PCDU. Any effort oriented to their optimum implementation has a multiplicative effect and – at the end - may drive the physical characteristics (mass and dimensions) of the PCDU. A relevant integration effort has been conducted to optimize the implementation of the Power Distribution Modules, using the heritage coming from previous GEO and interplanetary missions. Design drivers can be summarised in the key aspects that follow.

Internal Communications

Distribution Modules implement as much outlets as possible to reach the maximum achievable degree of integration. As consequence, the number of individual telecommands and telemetries to be handled is proportionally high. Any module size and mass optimization passes through local TM/TC control function integration.

A Digital ASIC (**SECOIA** – **SE**rial **CO**mmunication **I**nterface **A**SIC) performs this task operating as slave of the master FPGA in the DHS Module, see Figure 7.

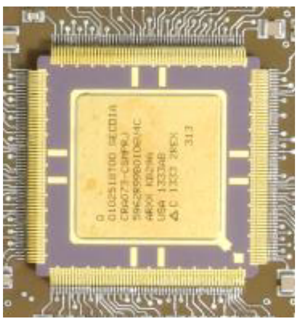

*Figure 7. **SECOIA** – **SE**rial **CO**mmunication **I**nterface ASIC*

This product is the evolution of many FPGA based serial link designs used in the past, in particular the PCDUs for BEPI Colombo MPO and Solar Orbiter mission.

Distribution Modularity

The use of SECOIA opens the door to an increase in the number of distribution items that can be implemented in a single board. In fact the limitation per module now comes from the number of pins available in the module output connectors that can be implemented in the unit's front panel to be compatible with the targeted box height.

Second step of optimization was to select the adequate number of Distribution items to configure the standard multi-mission Distribution board. Several different configurations were challenged in the scenarios provided by previous real flight mission cases. From that analysis, an optimum configuration was selected, while still feasible in terms of electronics packaging surface budget. In fact, the use of this modularity meant the reduction of one board less in all mission cases studied. Again, the proposed modularity is possible thanks to the savings in Distribution Module local TM/TC control part surface budget due to SECOIA use. Figure 8 shows the EM of the Distribution Module implementation.

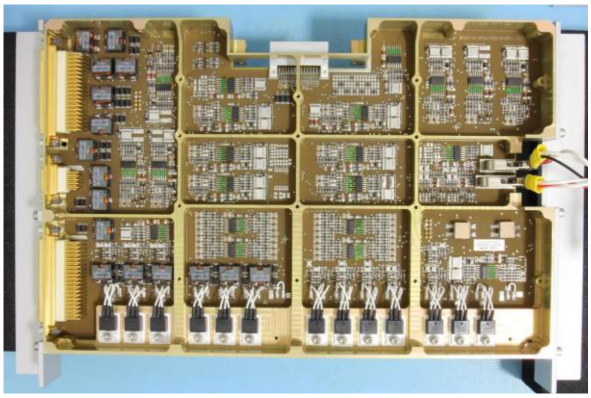

*Figure 8. Distribution Module EM*

The distribution concept flexibility is such that:

- All heater group LCLs can be used as "pure" LCLs if needed.
- 2 Current Limiters per module are configurable as Re-armable protection devices.
- 4 Current Limiters per module are configurable as high current outlets (up to 10A).
- 4 Current Limiters per module are configurable as "Safe Off" device, i.e. with a second switch in series.

DOI: 10.1051/e3sconf/20171618009

Current Limiter Control

The implementation of the control elements of the function is also responsible for the high degree of integration achieved. In particular:

- Current Limiters undervoltage protection is centralised. Three levels, for essential, non-essential and permanent loads, are selectable for every Current Limiter. Every protection threshold detector is triple redundant and majority voted to be one failure tolerant.
- LCL control electronics is supplied from the OR-ing of one secondary voltage from every APS, N & R, plus a linear regulated power source located in MEA module. In this way the status and control of every LCL is kept whatever the status of the TM/TC I/Fs and their potential switching in time from nominal to redundant or vice versa.
- Current Limiters control loop and current telemetry is based on dual bipolar transistors, easily replaceable in case of future eventual obsolescence.

Deployment module architecture

Regarding the deployment function, number of safety barriers and architecture are the classical ones with Firing + Arming + Selection stages. A total of 24 deployment channels are available.

Every deployment channel is able to handle either EED or LSRU devices, thanks to a firing device based on a step-down buck converter able to work in two operational modes:

- Current source, with a current level intended for classical pyrotechnic devices, and
- Voltage source (current limited) for non-explosive actuators.

FMEA and dedicated thermal analyses in failure case have been run to demonstrate that no electrical and/or thermal failure propagation will take place from the distribution function to the deployment function. See figure 9.

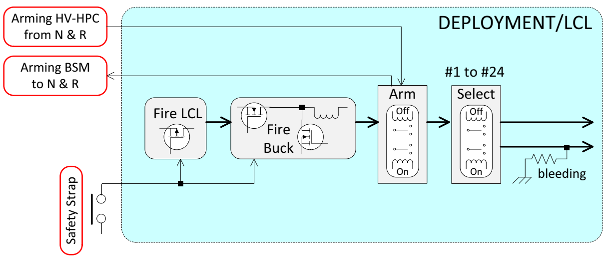


*Figure 9. Deployment architecture*

Arming function is nominally controlled by SHP commands, while the rest of the function is governed by 1553 I/F. Safety strap is also provided to inhibit firing function on ground. Figure 10 shows the EM of Deployment module for Merlyn flight mission.

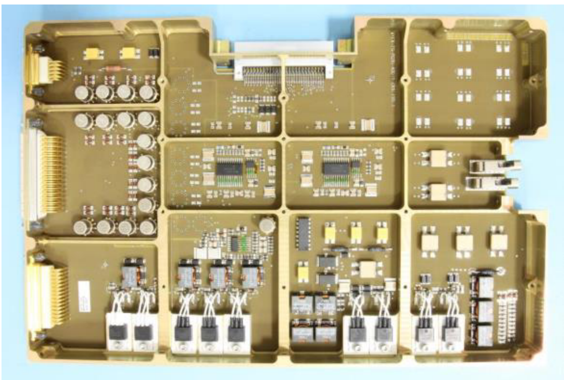

*Figure 10. Deploy/LCL module EM*

## 4 ACHIEVEMENTS

It was said at the beginning of the paper that main targets were to save 20% mass and volume while keeping or improving existing performances, and adding at the same time new functionalities in line with new requirements.

Previous chapters highlighted the most relevant electrical and functional aspects of the new design. Now attention will be focused on PCDU physical properties, mass & dimensions.

### 4.1 Dimensions

Unit dimensions are: 292mm x 302mm x 210mm w.o. mounting feet & connectors protrusions, lenght x depth x height. Depth is 350mm with protrusions.

This represents a 23% saving in volume for the same modularity and some added functionalities w.r.t. previous AS250 PCDU concept. It is remarkable the reduction in height of 12,5% for improved compatibility with the existing platforms from different primes.

### 4.2 Mass

PCDU mass is <16,5kg for a configuration as to satisfy the needs of the previous typical AS250 mission. This represents a 15% saving in mass for the same modularity and some added functionalities.

## 5 CONCLUSIONS

Staring from an existing LEO PCDU product, with more than 12 FMs manufactured, strategies have been presented for product optimization and mass & volume reduction, while adding new features in line with

DOI: 10.1051/e3sconf/20171618009

emerging customer requirements.

The activity carried out is intended for unregulated bus LEO missions, but is directly applicable to science missions and to the PCDU distribution part of the 28V regulated buses classical of interplanetary missions, as is the case of the PCDU for JUICE. Merlyn spacecraft will be the first LEO flight application case of this new concept, being FM expected by beginning 2017.

Moreover, the use of this concept for JUICE will bring to the product new building blocks developed in the frame of this interplanetary mission, developed to be compatible in size and performances with the LEO PCDU. This will complement the product portfolio of available functionalities for 28V buses (either belonging to the category of regulated or battery follower).

Main achievements are:

- ✓ Multi-mission configurable PCDU intended to cover the user power range from ≤500W up to 3kW.
- ✓ Distributions module flexibility to be used in the distribution part of 28V regulated bus PCDUs for interplanetary missions.
- ✓ Optimized height and width for full compatibility with most platforms currently on the market.
- ✓ Relevant mass reduction w.r.t. previous LEO PCDU product.
- ✓ Built-in EOL passivation in line with new 'green space' regulations.
- ✓ Built-in Launch-off capability for multiple launch.
- ✓ Compatible to drive the deployment devices existing in the market with the same design.
- ✓ Reliable S3R cell design:
  - ✓ No power loss after a single failure, and
  - ✓ Power in the bus from solar array interface can be regulated down to 0 Watts after a single failure.
- ✓ Solid state based battery switch.
- ✓ Very high LCL configuration capabilities:
  - ✓ Wide range of classes available from 0.5A to 10A.
  - ✓ Three different types of LCL available.
    - ✓ PO-LCL: Limiter that is permanently On, also called R-LCL (R standing for "Re-armable")
    - ✓ SO-LCL: Safe Off Limiter, with a second switch in series with independent control, and
    - ✓ Normal LCL.

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