A New Electrical Power System Architecture For Delfi-PQ

Uludag, Sevket; Speretta, Stefano; Gill, Eberhard; Bouwmeester, Jasper; Pérez Soriano, T.

Publication date
2017

Document Version
Submitted manuscript

Published in
University Satellite Missions and Cubesat Workshop, 2017

Citation (APA)
Uludag, S., Speretta, S., Gill, E., Bouwmeester, J., & Pérez Soriano, T. (2017). A New Electrical Power System Architecture For Delfi-PQ. In F. Graziani (Ed.), *University Satellite Missions and Cubesat Workshop, 2017* (Vol. 163, pp. 511-522). Article IAA-AAS-CU-17 -07-03 Univelt Inc..

A NEW ELECTRICAL POWER SYSTEM ARCHITECTURE FOR DELFI-PQ

M.S. Uludag[*], **S. Speretta**[†], **J. Bouwmeester**[‡], **E. Gill**[§] **and T. PerezSoriano**[¶]

Due to strict constraint regarding the volume of a PocketQube (50x50x50 mm) it is crucial to reduce the space that is consumed by the satellite bus subsystems. This paper focuses on a new architecture for the electrical subsystem in order to reduce its volume and increase the usage of empty surfaces inside the satellite. This increment in volume efficiency is going to be achieved by splitting the electrical power system on different surfaces and reducing the number of required voltage regulators. This modular approach is going to be realized by two main steps. First, removing the regulated bus from the satellite and delivering an unregulated bus to the subsystems. This will also give flexibility to other subsystems to use a voltage level which are more suitable for their requirements. Secondly, the internal side of the solar panels are going to be used for MPPT (maximum power point tracking) circuits, actually achieving a distributed power generation system, similar to ground-based solar power generation systems. The battery board is going to be a separate board with its dedicated communication lines and will also act as an interface between the solar panels and power distribution board via simple spring loaded connectors. This latter solution helps reducing dramatically the number of cables in the satellite,thus simplifying integration. The main objective of this work is turning the EPS(electrical power system) into a more flexible, scalable and volume-efficient system by a physical relocation of its components and a lean approach. The new EPS will be functionally and environmentally tested in a flight representative satellite model with the aim to verify its simplification in integration, assess its true performance as well as its reliability during launch vibration which especially includes spring-loaded connectors.

INTRODUCTION

PocketQubes are femtosatellites with dimensions of 5 cubic centimeters. While 10 cubic cm of CubeSat is called 1U, for a pocketqube 5 cubic cm is called 1P. Internal board dimension is 42x42 mm due to spacing between solar panels. Since 5 cm is the outer dimension, when taking 2 solar panels on the sides into account with at least 1.6 mm of thickness and 2 mm of margin for internal routing per each side, boards can only be 42x42 mm. PocketQubes derive from CubeSats with the goal of pushing miniaturization even further and reduce the volume by a factor of 8. This decrement in volume also causes a decrement in mass and thus, subsequently in cost. The work presented here is part of the Delfi-PQ project.[1] Even though Delfi-PQ is a PocketQube, it is not using the more common PQ60[2] standard but a different one: PQ9.[3] After describing Delfi-PQ, the following sections will deal with power generation architectures, power storage and distribution

---

[*] Electronics Engineer, Faculty of Aerospace Engineering, Delft University of Technology, m.s.uludag@tudelft.nl.

[†] Researcher Dr., Faculty of Aerospace Engineering, Delft University of Technology, s.speretta@tudelft.nl.

[‡] Researcher, Faculty of Aerospace Engineering, Delft University of Technology, jasper.bouwmeester@tudelft.nl.

[§] Prof., Faculty of Aerospace Engineering, Delft University of Technology, E.K.A.Gill@tudelft.nl.

[¶] Electronics Engineer, Faculty of Aerospace Engineering, Delft University of Technology.

architectures, commercial of the shelf CubeSat power systems and architectures and proposed solution. Future work to characterize the performances of the system and ensure it would survive the space environment will be explained.

DELFI-PQ

Del-PQ is a PocketQube currently being developed at TU Delft using an agile approach, contrary to the typical V-model design. Shorter life cycle development benefits students, allowing them to get more involved in every iteration. The reduction in cost and development cycle increases the launch frequency. Incremental engineering becomes fundamental, also providing benefits on the reliability side because flight experience becomes more frequent than when following traditional development strategies. End-to-end development motivates students and provides them with a better insight into real-world engineering opportunities and training experiences. With this strategy, technical and educational objectives are more aligned, and the integration of such a project in the curriculum is facilitated.

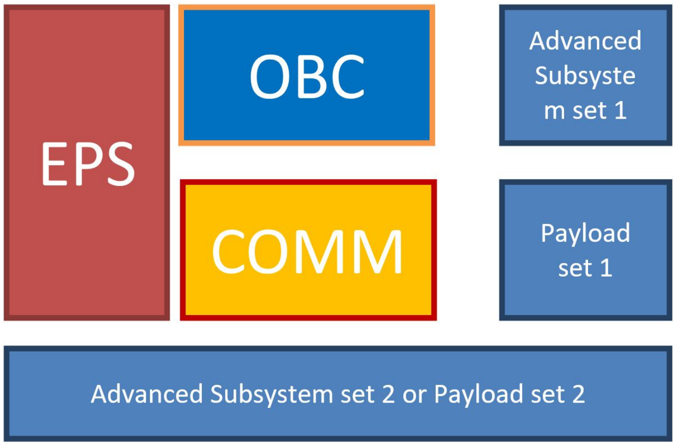

Figure 1. Spacecraft architecture supported by PQ9

Figure 1 shows the structure of the satellite, showing the different sub-systems. The core sub-systems (EPS, COMM and OBC) are highlighted on the top-left corner of the picture, while the remaining space in the satellite is allocated for more advanced sub-systems or for a payload.

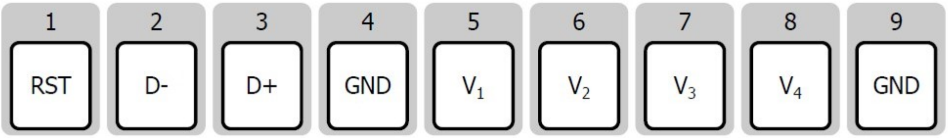

Figure 2. PQ9 connector form factor on Delfi-PQ PCB[?]

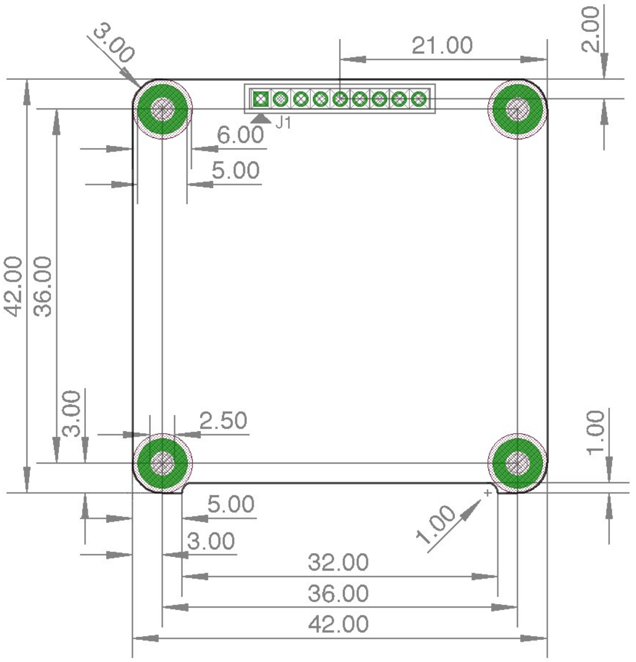

Figure 3. PQ9 connector form factor on Delfi-PQ PCB[3]

Table 1. Signal Functions of PQ9

Pin	Signal	Function
1	RESET	System reset when pulled high
2	D-	RS-485 inverting signal (a.k.a.B)
3	D+	RS-485 non-inverting signal (a.k.a.A)
4	GND	Ground
5	V1	Unregulated Bus-1(recommended: OBC & Radio)
6	V2	Unregulated Bus-2(recommended: ADCS, GNC, ISL & ISR)
7	V3	Unregulated Bus-3(recommended: Propulsion)
8	V4	Unregulated Bus-4(recommended: Payloads)
9	GND	Ground

A lean 9-pin bus interface has been designed and developed to minimize the bus size and save space for the rest of the sub-systems. The PQ9 connector configuration is shown in Figure 2. Table 1 maps the connector pins with the signal functionality. The satellite bus design was open-sourced from the beginning and design files have been publicly shared to facilitate the growth of a community of PocketQube designers and users (see Figure 3 with the board template PCB layout[3]).

POWER GENERATION ARCHITECTURES

Power generation in a satellite is usually achieved with solar cells. Depending on the spacecraft operational environment (Low-Earth orbit, geostationary orbit or interplanetary orbits), several solar panels and power conversion configurations have been developed. The two most common ones are S3R (Sequential Switching Shunt Regulator)[7] or MPPT (Maximum Power Point Tracker). S3R regulators show a much higher efficiency with respect to MPPTs because they are only composed by power switched connecting different sections of the solar array to the power bus. This can be done effectively in case the power bus voltage is matched to the solar array voltage and this voltage is stable throughout the mission (constant illumination and temperature conditions on the solar arrays, like in geostationary satellites). When instead, the illumination conditions vary, the solar array voltage will vary and this can limit efficient power transfer to the loads. In this case an MPPT is used to control a switching regulator that adapts the solar array voltage to the spacecraft power bus voltage, ensuring maximum power is harvested from the solar cells. Since Delfi-PQ is intended to fly in LEO and it is also expected, due to its limited mass,[8] to experience big temperature variations on board, the MPPT architecture is the most suited one. Moreover, Delfi-PQ is intended to perform experiments in orbit, so flexibility was maximised during the design phase: this prevented matching the solar array design (body mounted cells) to the internal power bus, actually requiring a switching converter for power conversion.

POWER STORAGE AND DISTRIBUTION ARCHITECTURES

Most of electrical power systems for satellites has BCR and BDR modules. BCRs are Battery Charge Regulators where the panel output values are regulated in order to charge and protect the battery voltage during charging. These are placed on EPS, where they consume space and cause loss of efficiency. In addition to BCRs, there are BDRs which are battery discharge regulators. These regulators are there in order to protect the batteries from over discharge and regulate their outputs before distribution. In Delfi-PQ, unregulated buses are being used, which are specified in Figure 2 and Table 1. This has been developed due to lack of volume. Owing to the limited volume, it cannot host more than 8 systems and thus there is no need for additional power or communications buses. As a result of this 9 pins bus connector is sufficient. By introducing unregulated bus voltages, every subsystem can have its dedicated supply voltage with better efficiency, since each regulator is optimized for its specific requirements. With respect to BCR and BDR, unregulated buses are more efficient since there are less voltage regulators/converters on the power line.

COTS CUBESAT POWER SYSTEMS AND ARCHITECTURES

As seen in Figure 4, Figure 5 and Figure 6 electrical power systems consists of multiple modules which are consuming space on PCB. The usual power generation architecture employed is the MPPT because the spacecrafts are usually used in LEO with heavily varying solar array temperature and illumination conditions. Since these systems are also hosting BCR, BDR on them these modules also cause extra power losses.

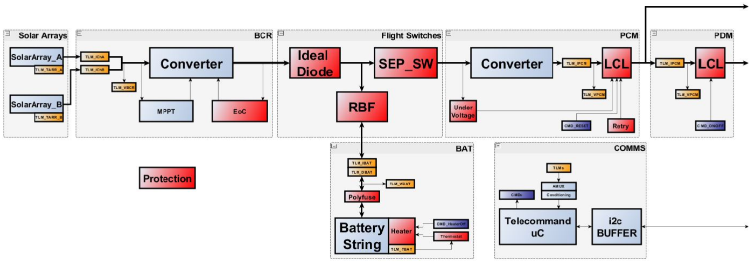

Figure 4. Clyde Space EPS Diagram[4]

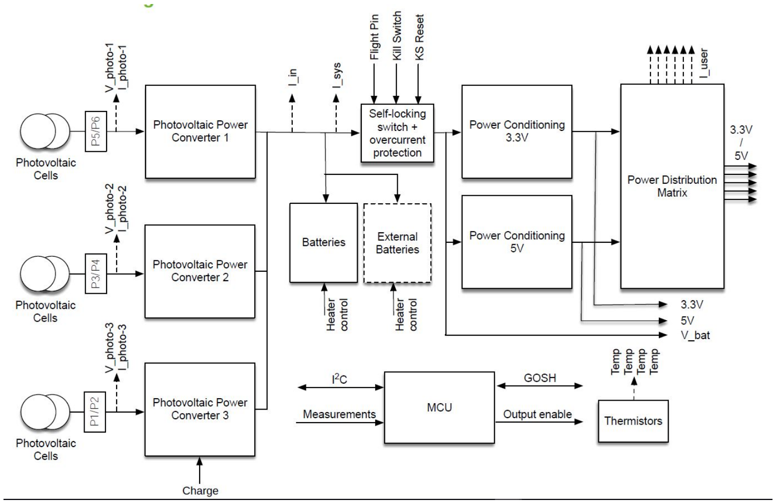

Figure 5. GOM Space EPS Diagram[5]

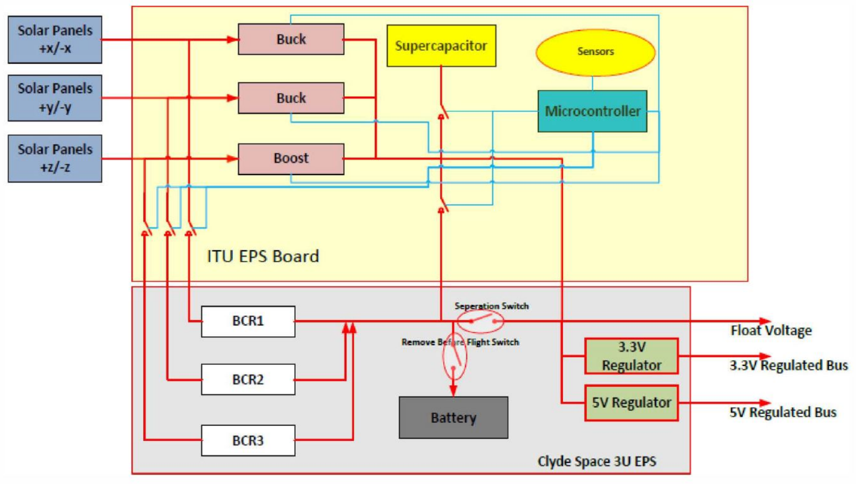

Figure 6. ITU EPS Diagram with Clyde Space EPS Diagram[6]

The power distribution architecture is usually a regulated bus to eliminate the need for a dedicated converter on each sub-system. This solution limits the size of the subsystems but increases the complexity of the power system. Moreover, the overall power conversion efficiency of the system is limited due to the use of a single converter to service different loads. Power regulators consumes same amount of power even if they work at full capacity or not. But since power consumption varies, efficiency losses of converters limit the efficiency.

PROPOSED SOLUTION

Due to lack of space and necessary functions of the power system, electrical power system of Delfi-PQ consists of 3 main subsystems, seen in Figure 7. These subsystems are solar panels with their dedicated power regulation, main power board which contains protection and distribution circuits and battery board which has dedicated battery protection, charge and discharge circuits. Besides having MPPT circuits on each panel individually, this power system only has unregulated bus voltages which are the direct output values of the batteries (battery-regulated power distribution bus).This unregulated bus line is being used for power distribution and battery charging. The miniaturization of components for mobile phones has a great impact for this design architecture. As a result of this miniaturization, ultra thin coils can be placed on the internal side of solar panels. Current design includes coils with a height of 1.7 mm.

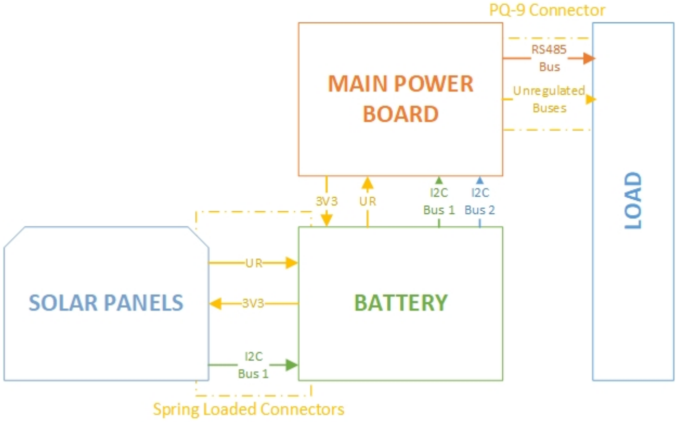

Figure 7. Power System Block Diagram

Solar Panels

There are 4 solar panels on the satellite similar to Figure 8. As shown in Figure 9 each solar panel consists of its own MPPT which regulates the voltage directly to main unregulated bus line and 2 solar cells which are connected in parallel. Advantages of having a dedicated MPPT on each panel makes it easier to connect as many panels necessary in parallel configuration. It needs to be taken into account that this is possible with a main board which can handle all the current with respect to solar panel configuration.

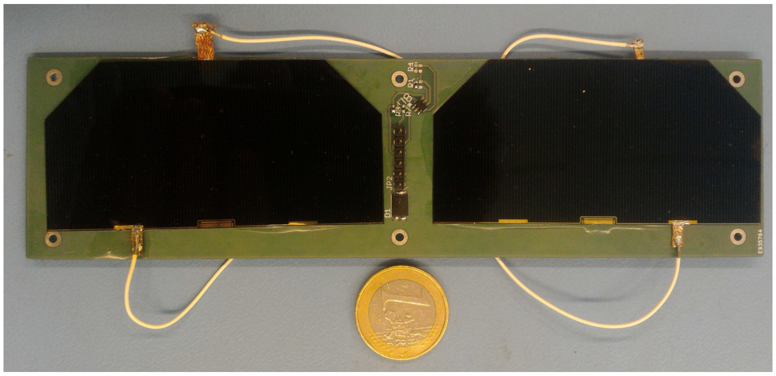

Figure 8. Solar Panel Table Top Model

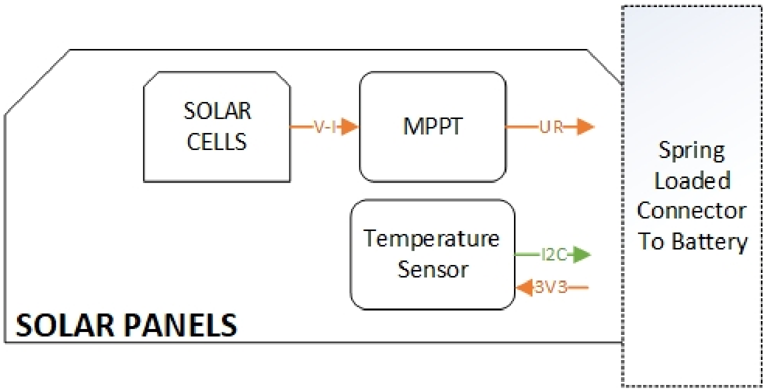

Figure 9. Solar Panel Block Diagram

Main Power Board

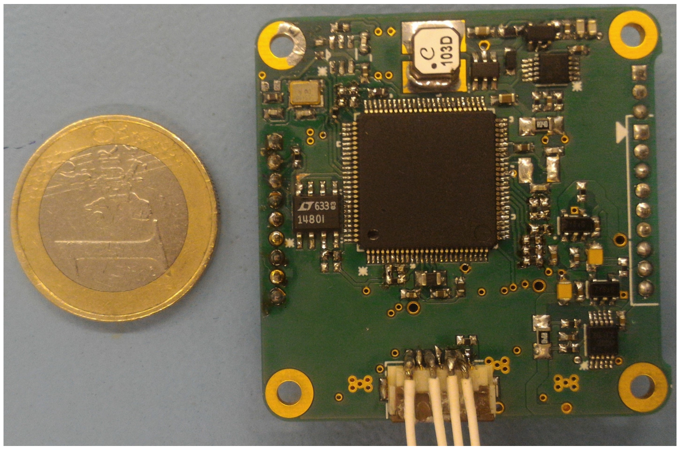

Figure 10. Delfi PQ Main Power Board

The system consists of general protection, monitoring and power distribution circuits. System uses RS485 in order to communicate with OBC (on-board computer). RS485 IC can be seen in the left side of Figure 10 with a termination resistor of 3.3 kohms. Generated power is being distributed into 4 unregulated bus lines shown in Figure 11. These lines have the voltage value between 3 V to 4.1 V due to the selection of the battery (the system employs a battery-regulated bus with a single cell Li-Ion battery). When the voltage level reaches a threshold discharge level, the main board will cut the power to other subsystems with respect to their importance. Each line will supply approximately a maximum of 4.5 W of power. This means that if there are multiple subsystems connected to same bus, either one of them will be on stand by or their total power consumption cannot exceed the maximum value. Voltage and current monitoring circuits on each line measures and send the data to MCU in case of an short circuit or exceed usage of power. The main power board also contains a direct reset function which allows communication subsystem to reset the whole satellite via command from the ground station. Besides the protection circuits, the main board has 2 inhibit switches which allow system to be connected to separation/deployment switch or an RBF (Remove Before Flight). There is an 3.3 V regulator on the main board in order to supply the internal elements and solar panel elements. On the board itself this line supplies power to RS485, voltage/current monitors and MCU while on solar panels it is only used to supply voltage to temperature sensors in order to create temperature data even in eclipse. This line is also being monitored and has a reset capability for the system itself.

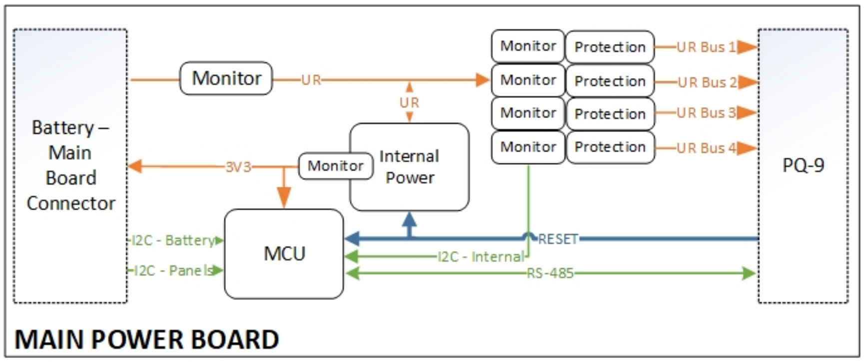

Figure 11. Main Power Board Block Diagram

Battery Board

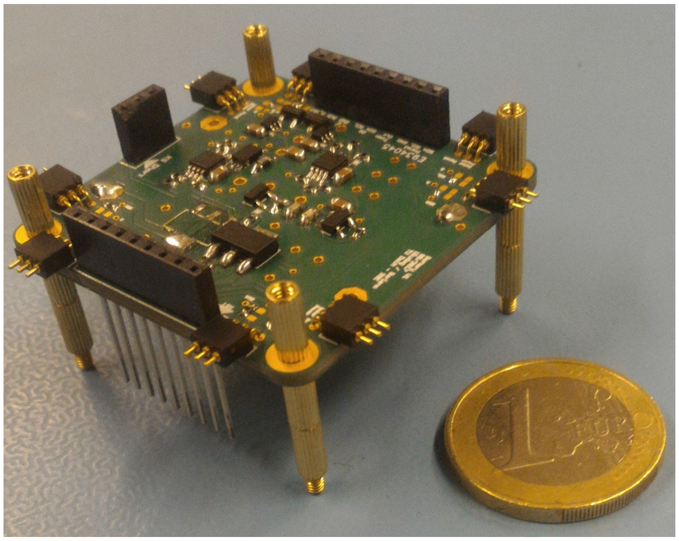

Figure 12. Battery Board with its stand offs, connectors and RBF connection

The battery board is responsible for battery protection from overcharge, discharge and temperature range of 5 to 40 ^{o}C. All the protection elements are directly powered via the battery voltage which allows the systems to be self sufficient. In case of overcharge and discharge, the system is capable of interrupting charge or discharge power lines. The first discharge protection is located on main board: when the voltage goes down to 3 V, the system stops supplying power to the unregulated bus lines. When a critical power level (2.7 V is reached) battery system even stops supplying power to main board. With its direct connection to solar panels seen in Figure 12, it can be recharged without the main board control. The battery board also acts as a carrier for I2C line and 3.3 V supply voltage between the solar panels and the main power board. Overall basic functionality has been shown in Figure 14. In addition to these functionalities, battery board has the capability to be able the launched from the ISS. Since ISS launches are considered as manned missions, they require 3 inhibit switches[9] where the switch locations can be seen in Figure 13. Battery board hosts 2 inhibit switches which can be connected to separation/deployment switches or RBF.

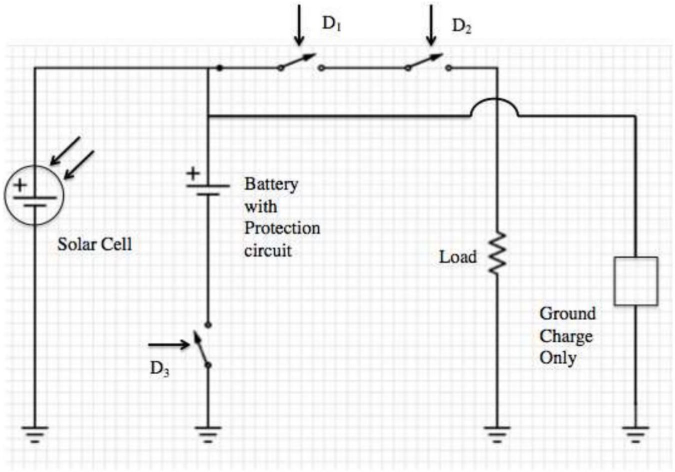

Figure 13. Inhibit Switch Requirement for ISS launches[9]

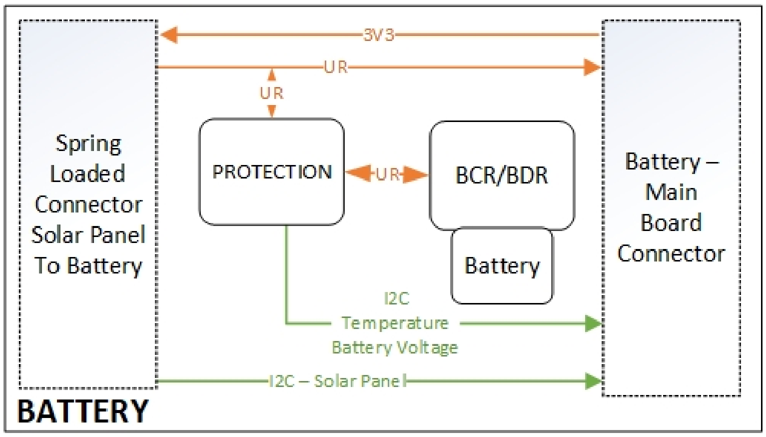

Figure 14. Battery Board Block Diagram

Interfaces

As a result of dividing the power system in to different modules, connectivity between them is deemed a priority. From power generation to consumption, interfaces begin with the solar panels. In order to simplify the integration and get rid of the cables, spring loaded connectors have been used between the solar panels and the battery board. Solar panels are directly connected to battery board so that batteries can be charged without any control from the main power board and to save space on the main board. The solar panels output is also connected to the battery board via a dedicated connector between the battery board and main power board. The location of spring loaded connectors on the battery board can be seen in Figure 12. In Figure 15 mating pads for the spring loaded connectors on the solar panels are located on the left. The overall system connectivity is shown in Figure 16.

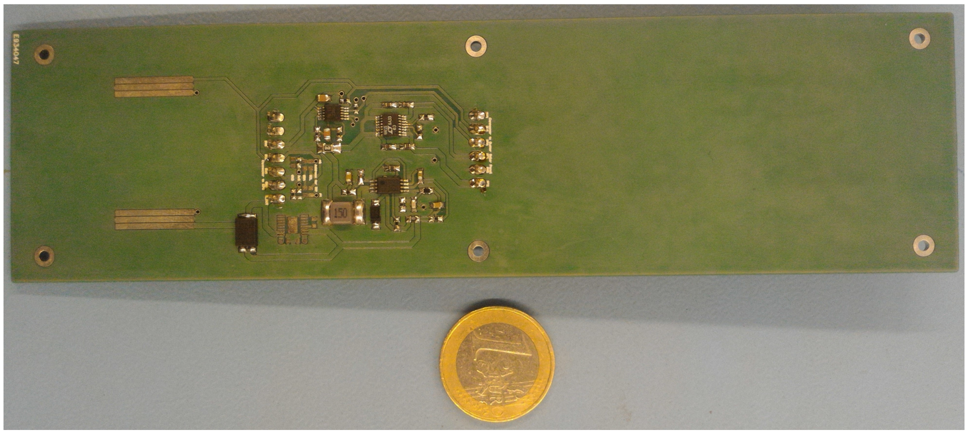

Figure 15. Spring Loaded Connector connection on Panels

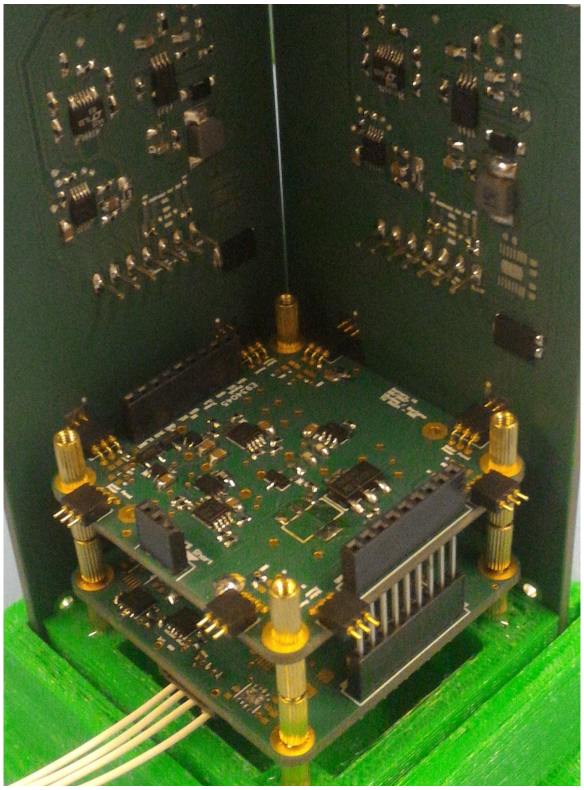

Figure 16. Power System Connectivity

Power System Functional Test

In order to create independent test setups, a ground support equipment has been developed to allow assembling all the sub-systems in a flatsat configuration. In Figure 17, an example connection and placement on the flatsat can be seen. In the Figure, there is a battery board, a main power board, a solar panel and a subsystem to consume additional power from unregulated buses. Via USB, monitored values can be displayed on a PC and, by using the test points on the board, real time monitoring can be done with an oscilloscope. Due to lack of sun simulator we were not able to provide irradiance to solar panel therefore could not measure overall system efficiency.

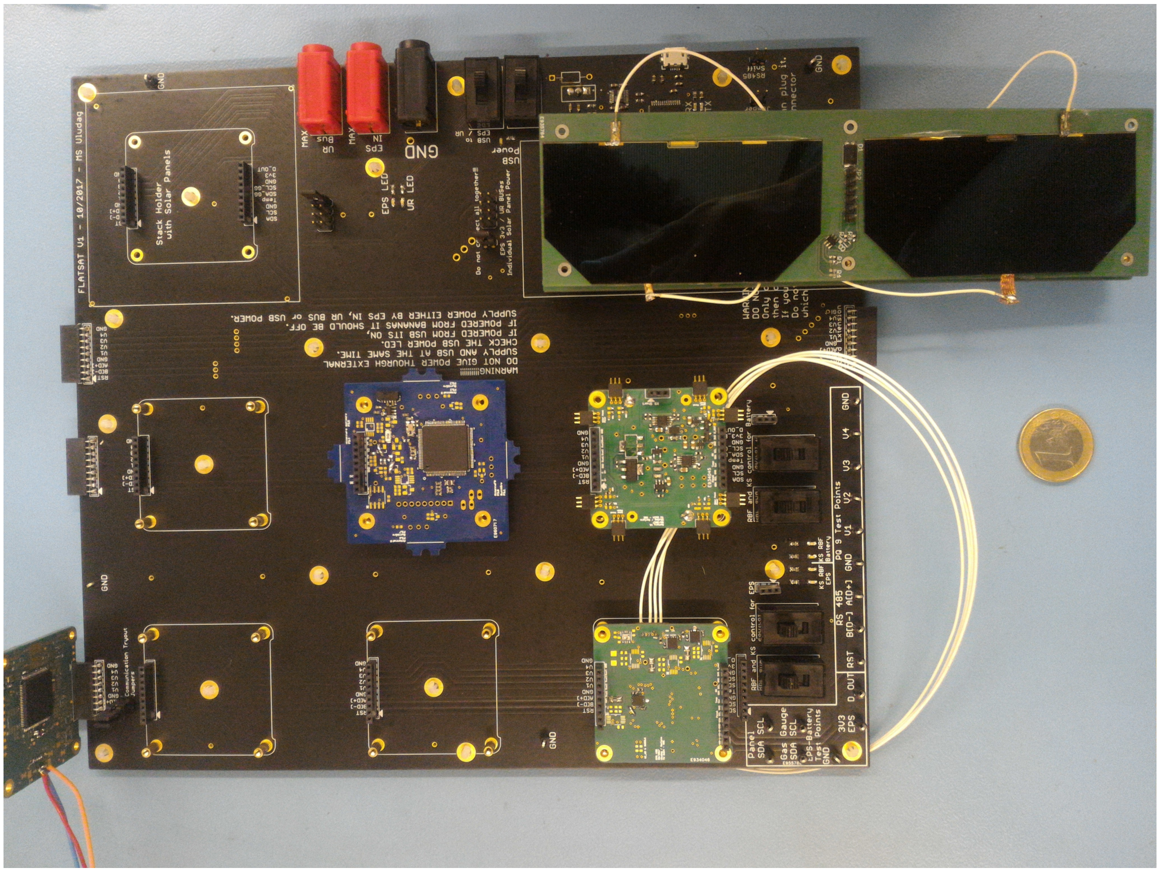

Figure 17. Test Setup Placement

FUTURE WORK

The system will be fully assembled and qualified for space. The qualification process will include thermo-vacuum tests and vibration tests. In order to prevent misassembly, the battery connector is going to be replaced to eliminate possible confusion with the main bus connector. RBFs and separation/deployment switches are going to be connected to a single connector so that number of cables will be reduced. Even tough MPPT is currently done by a dedicated integrated circuit, a dedicated MPPT circuit will be implemented, tested and compared with the current version in order to increase its flexibility and efficiency. Stand alone latch up protection will be implemented for internal voltage supply lines.

CONCLUSION

In this paper we described the existing architectures for a power system and presented a new architecture specifically suited for very small satellites. The goal of this new architecture was to improve the efficiency and simplify the assembly, given that there are no more cables between the solar panels and main electrical power board . Further analysis and tests are necessary to ensure that the system requirements are met.

REFERENCES

[1] `www.delfispace.nl`

[2] `http://www.pq60.info/`

[3] `https://github.com/DelfiSpace`

[4] Clyde Space, March 2014, *User Manual:3rd Generation EPS (3UA)*, Document No.:USM-25-01311.

[5] GOM Space, November 2017, *NanoPower P31u/P31uX Datasheet*. Retrieved from `https://gomspace.com/UserFiles/Subsystems/datasheet/gs-ds-nanopower-p31u-20.pdf`

[6] A. R. Aslan, et.al., "Development of a LEO Communication CubeSat," 6th International Conference on Recent Advances in Space Technologies (RAST), June 2013.

[7] A. M. Kamel, A. S. ElWakeel and U. R. AbouZayed, "Sequential Switching Shunt Regulator for Satellite Power Control System," *IOSR Journal of Electrical and Electronics Engineering*, Vol. 12, No. 3, 2017, pp. 78–83.

[8] S. Speretta et al, CubeSats To PocketQubes: Opportunities and Challanges, Proceedings of the 67th International Astronautical Congress (IAC), Guadalajara, Mexico 2016

[9] Nanoracks, December 2013, *NanoRacks CubeSat Deployer (NRCSD) Interface Control Document*. Retrieved from `http://nanoracks.com/wp-content/uploads/NanoRacks-CubeSat-Interface-Control-Document-CubeSat-Guide.pdf`