Energy Power System for Microsatellite μSAT-3: Generation and Storage Modules

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1. Introduction

The μSAT-3 is a 30Kg microsatellite developed by the Argentine Air Force. Its Power Plant is composed by four modules: energy generation and storage, battery management, power regulation, and distribution and protection. The present work describes the photovoltaic system, the battery system, and the module which controls the charging process.

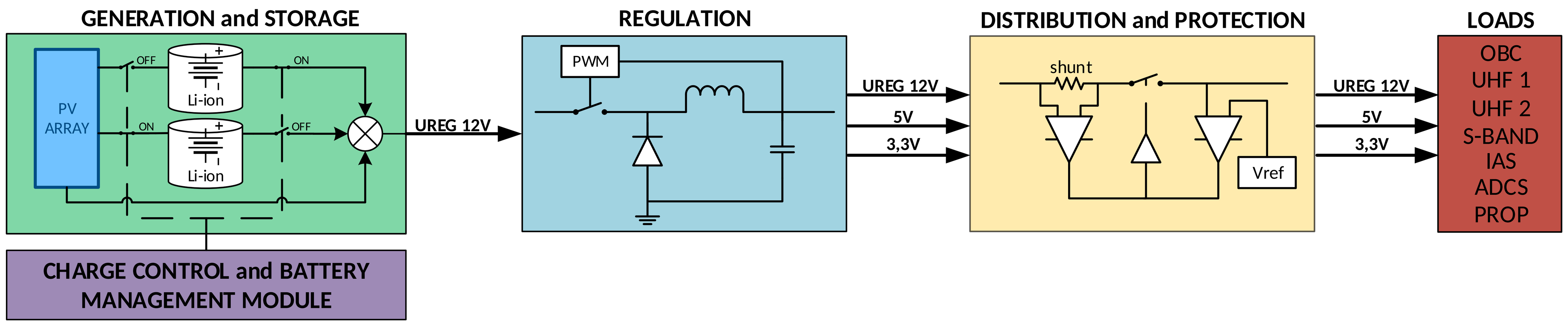

Fig. 1 – Block diagram of μSAT-3's Energy Power System.

2. Required Energy Estimation

In order to estimate the required energy by the μSAT-3, two operation sequences are proposed: taking pictures during the entire sunlit period of the orbit, and downloading data with the S-band transmitter, and taking pictures except during the satellite pass (Fig. 2).

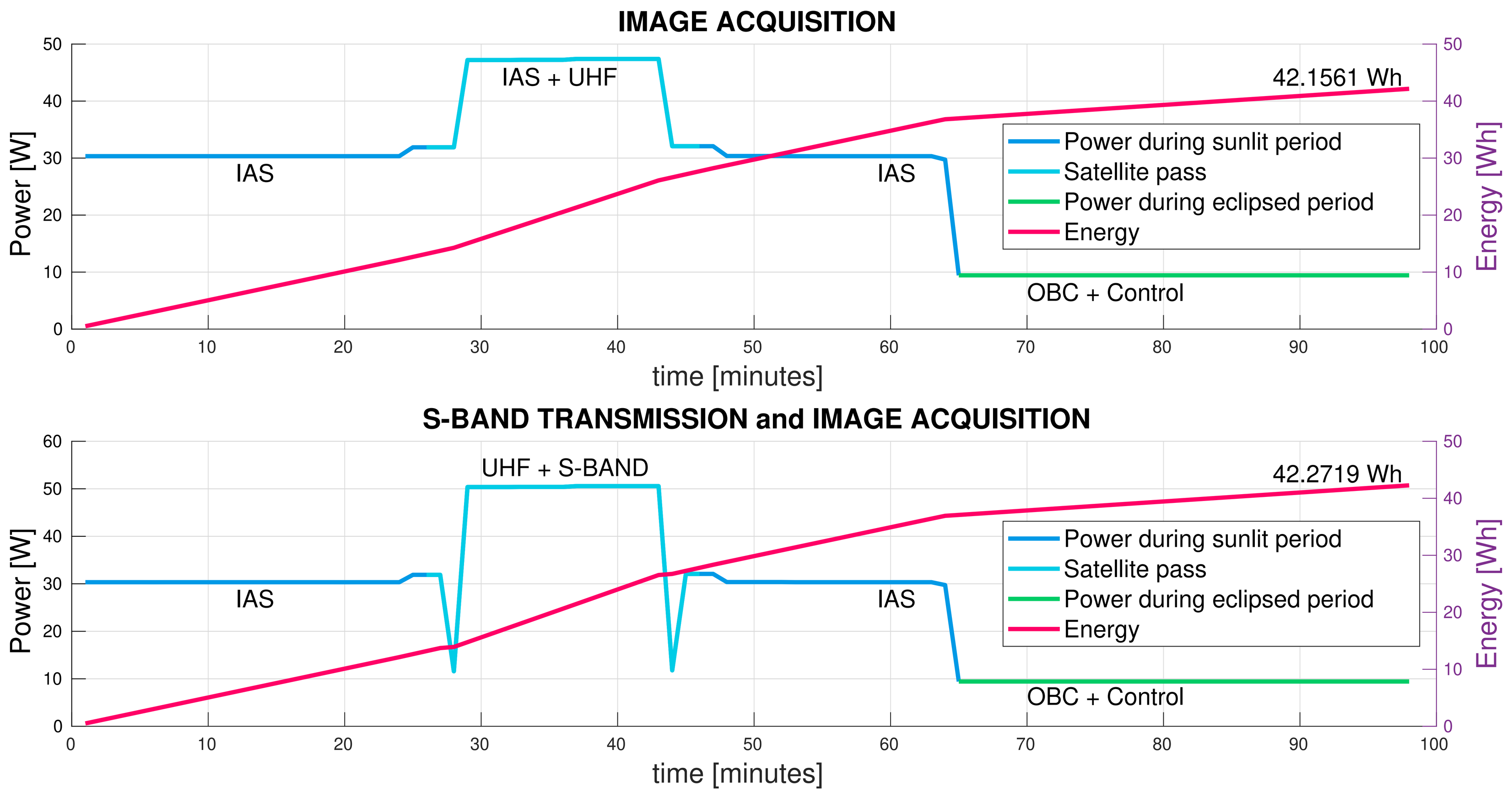

Fig. 2 – Power and energy consumption during one complete μSAT-3's orbit, for image acquisition (upper) and data transmission and image acquisition (lower) operation sequences. The maximum computed power is 50,6W, the average power is 25,8W, and the maximum current (@10,5V) is 4,8A.

The required energy for both types of operation sequences is 42,3Wh. This means that the batteries must deliver 126,9Wh (63,45Wh per battery) in three consecutive orbits (useful passes over the ground station).

5. Battery Charge Regulator (BCR)

The Battery Charge Regulator is a standalone unit, which regulates the voltage in order to charge the batteries keeping the ripple smaller than 1%.

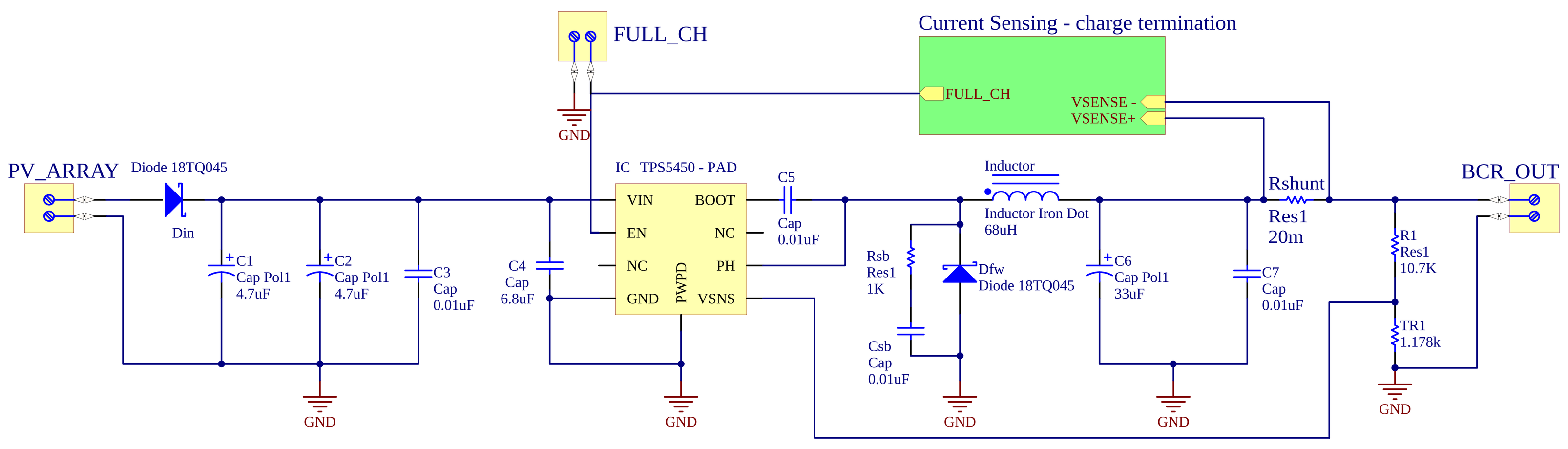

Fig. 5 – Schematic diagram of the Battery Charge Regulator.

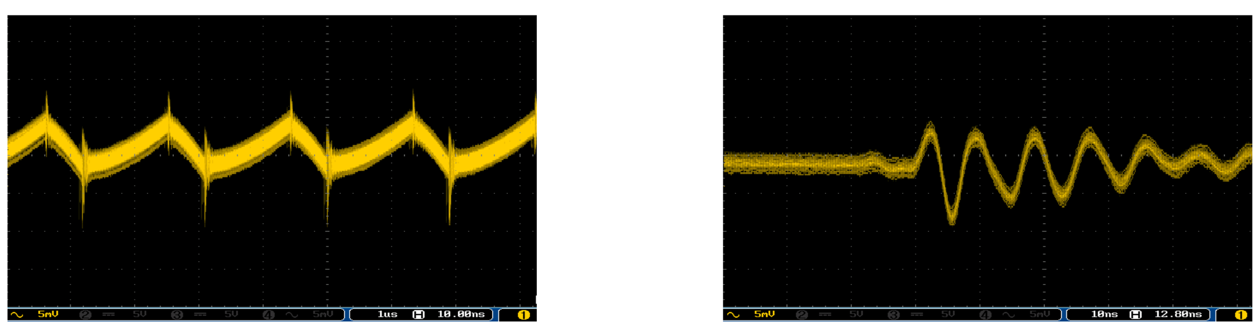

Fig. 6 – Ripple (left) and ringing spikes (right) measured in the BCR prototype. The obtained ripple is $10mV_{pp}$ (0,08%) and the ringing spikes are $15mV_{pp}$ (0,12%).

7. Conclusions

The general criteria was to design a simple, robust and durable system, with an autonomous functioning and no requirement of a microcontroller. In this sense, the battery cycling miss out the 40% of the total available energy in order to prolong its life cycle as long as possible. Besides, it is not necessary to include a current limiter module because the current capacity of the solar array does not exceed 4,5A (equivalent to 0,5C of each battery). In relation to the BCR circuit, the obtained results are as expected, but it can still be improved: the temperature reached during the test at maximum current was too high. Then, in order to improve the safety margin it is suggested to use another buck converter which presents a lesser $R_{DS}(on)$ and tolerates higher currents. To conclude, it is important to highlight that exhaustive tests to the system in a complete, joint working state are pending.

3. Photovoltaic System

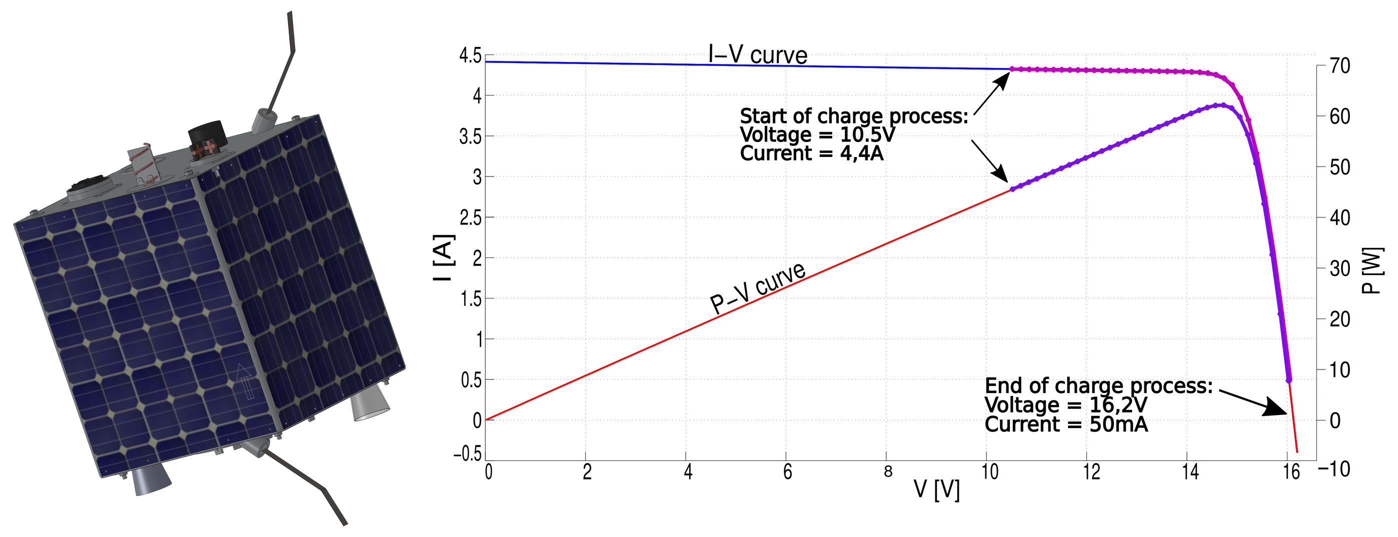

Fig. 3 – I vs. V and P vs. V curves simulated at 1365 W/m^2 of two μSAT-3's panels oriented in dihedral position to the Sun [1].

4. Charge Protocol and Battery Design

The μSAT-3 has twin Li-ion batteries composed by a s-p cell array: three cells in series in order to reach 12V on the UREG bus, and the parallel number is determined by the energy estimation (Fig. 2).

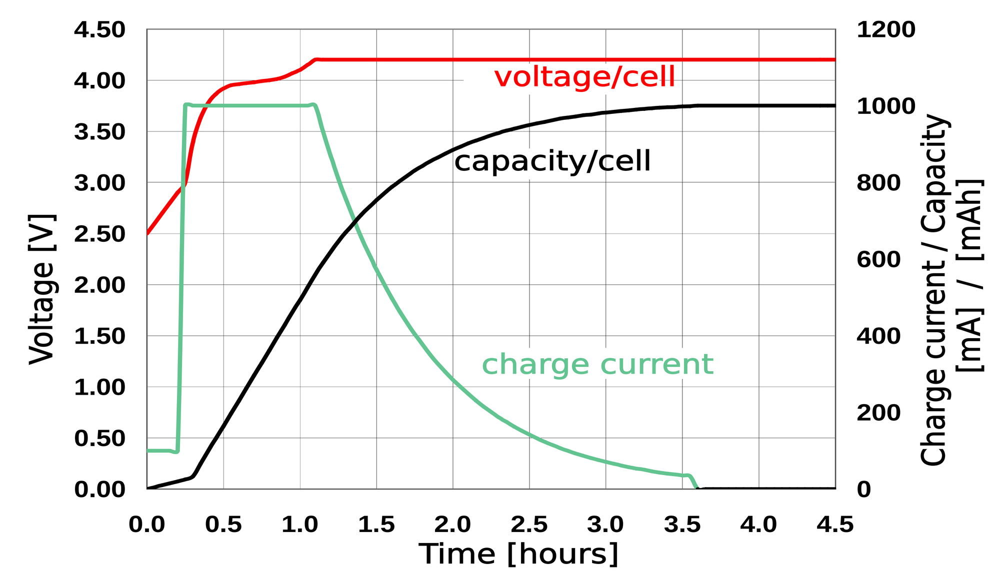

Fig. 4 – Typical charge curve of a Li-ion cell for CC/CV protocol.

Charge/Discharge Protocol Design:
Constant current stage @$4,4A$.
Constant voltage stage @$4,1V/cell \rightarrow$ SoC $\approx$ 80%.
Charge termination: when charge current drops to 0,01C.
Minimum discharge voltage: $3,5V \rightarrow$ DoD $\approx$ 80%.
Charge and discharge rate $<$ 1C.
(Percentage of usable energy: 60%) [2], [3].

Battery Design:
Nominal energy $= (63,45Wh \times 100)/60 = 106Wh$
$N°$ of cells $= E_{T_{bat}}/E_{cell} = 106Wh/5,4Wh \Rightarrow 21\ cells$
Configuration: $3s \times 7p$
Battery capacity $= 1,5Ah \times 7p = 10,5Ah$
Battery energy $= 5,4Wh \times 21\ cells = 113,4Wh$
Battery mass $= 42g \times 21\ cells = 882g$
Maximum charge rate (Figure 3): $4,4A \rightarrow 0,419C$.
Maximum discharge rate (Figure 2): $4,8A \rightarrow 0,459C$.
Charge termination current: $100mA$.

6. Battery Charge Manager (BCM)

In addition to the BCR, the designed battery charge protocol is executed by the BCM, which consist on a comparator that triggers digital signals according to the batteries voltage, and a logic unit that controls the driver unit to switch the batteries (when a battery is in service, the other is putting to charge).

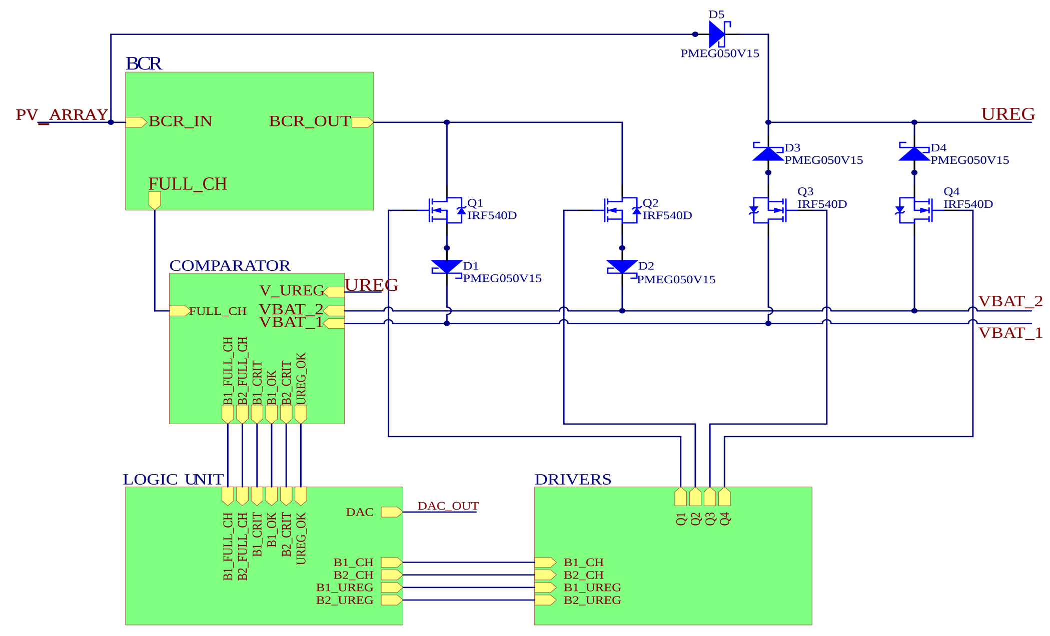

Fig. 7 – Schematic diagram of the Battery Charge Manager.

References

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