European Student Moon Orbiter
Electrical Power System (EPS) Team

www.esmo.co.uk

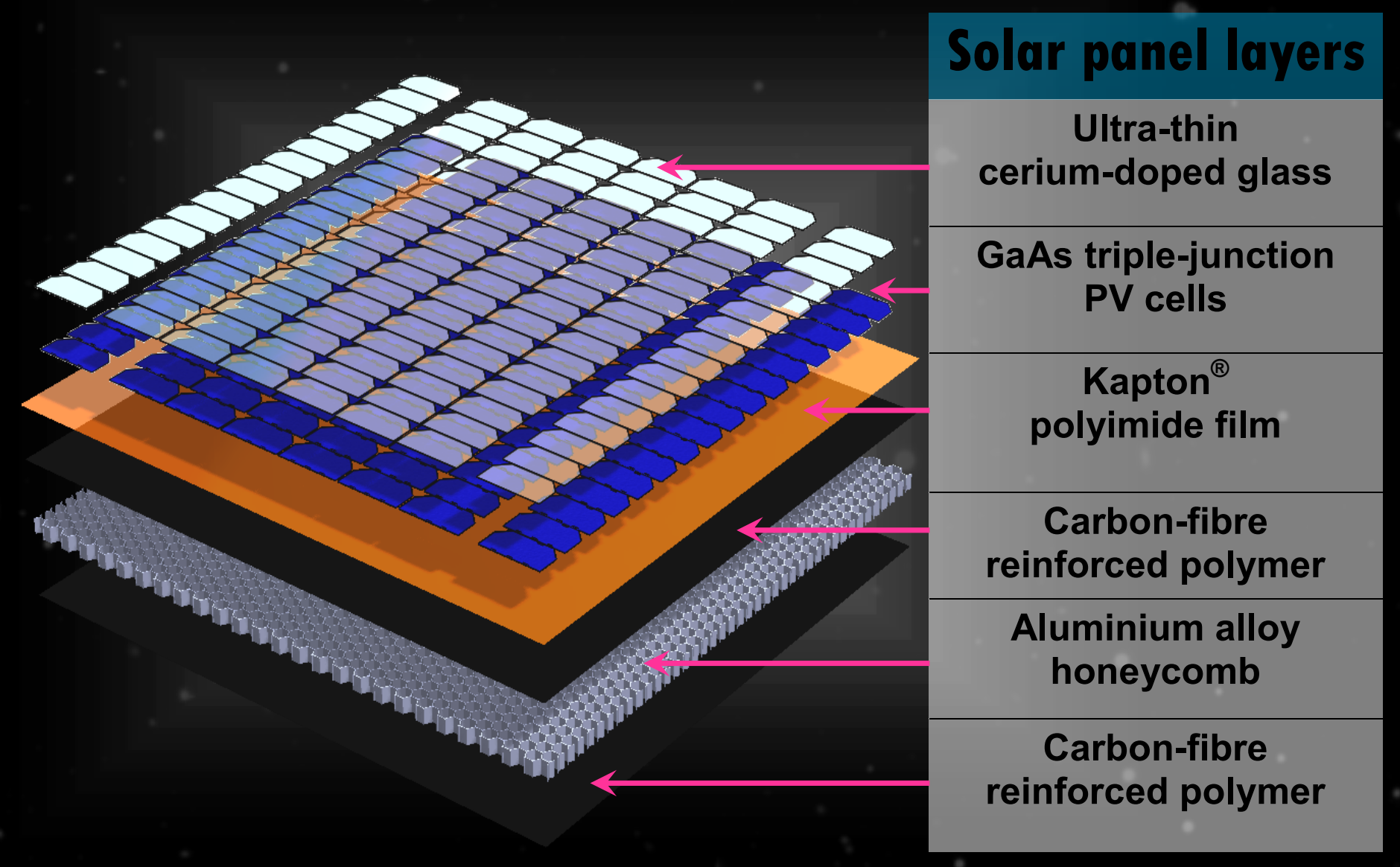
What is ESMO?

ESMO is a moon orbiting satellite that will be launched in 2014. It is the next space mission scheduled on the **European Space Agency**'s (ESA) calendar. ESA are the 'customer' with the project management under the control of **Surrey Satellite Technology Ltd.** (SSTL). The Warwick team are working alongside 23 other university groups across Europe, designing and building the system which will supply power reliably and continuously to the other subsystems throughout the mission.

PHASE			
B1	System Level Requirements	2009	
		2010	System Requirements Review (SRR)
B2	Preliminary Definition	2011	Preliminary Design Review (PDR)
C	Detailed Definition	2012	Critical Design Review (CDR)
			Qualification Review (QR)
D	Production and Qualification	2013	Final Acceptance Review (FAR)
E	Launch Campaign	2014	Launch Readiness Review (LRR)

Solar Arrays

The satellite will generate power using a pair of body-mounted solar arrays. Each array features 128 **photovoltaic cells**, arranged into 8 'strings', spaced so as to allow the panel to be fixed onto the spacecraft structure. The cells have an average **beginning-of-life efficiency** of 28%.



Solar array design considerations:

- The arrays must meet the **power demand** of the satellite throughout the mission (with the battery providing power during eclipse).
- The panel structure needs to be able to withstand the **stresses** and **vibration** associated with the satellite's launch.
- The materials in the panel must cope with **thermal stresses** as a result of the temperature gradient that will exist through the sunlit panel.

POWER

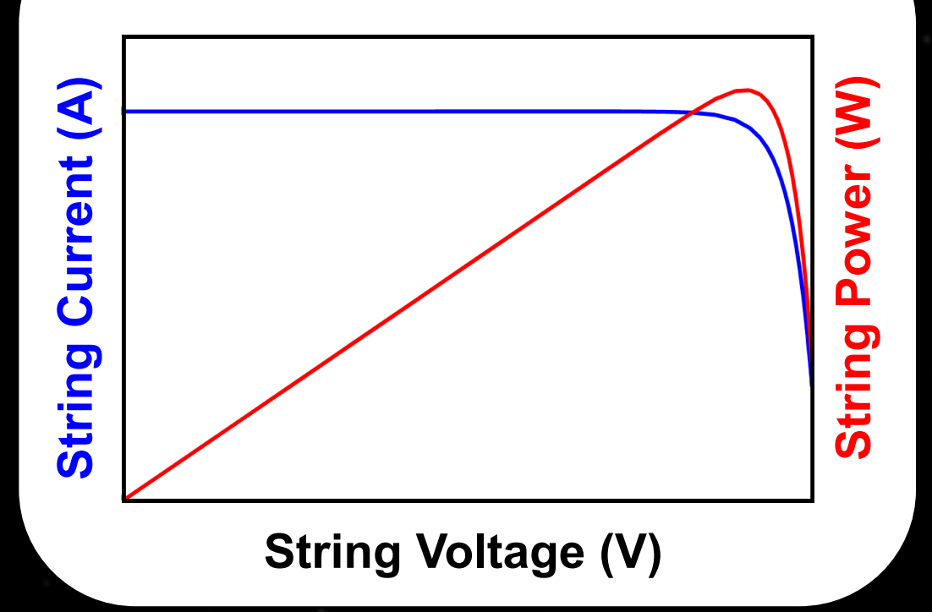
Thermal Modelling

- The efficiency of the solar cells is dependent on their **operating temperature** - so it is important to find out how the temperature of the solar cells varies with time.
- Upon leaving an eclipse, **radiation** from the sun incident on the solar arrays will cause the temperature to rise until outgoing radiation balances incoming, at which point the arrays are in a thermal **steady state**.
- A **lumped approach** thermal modelling exercise has shown that the solar panel structure takes around **27 minutes** to heat up from **-100°C** to **+100°C**, and that it reaches a maximum temperature of **113°C** after about **75 minutes**.

Power Characteristics

- The IV (current-voltage) and PV (power-voltage) characteristics of the solar cells are shown to the right, the maximum power which can be drawn is at the knee of the IV curve.
- The IV characteristics of the solar cells vary with **temperature** and **radiation spectrum** as well as exposure to damaging radiation such as ionising radiation.
- This has a large impact on the design of the solar array regulation in the Power Conditioning and Distribution Unit.

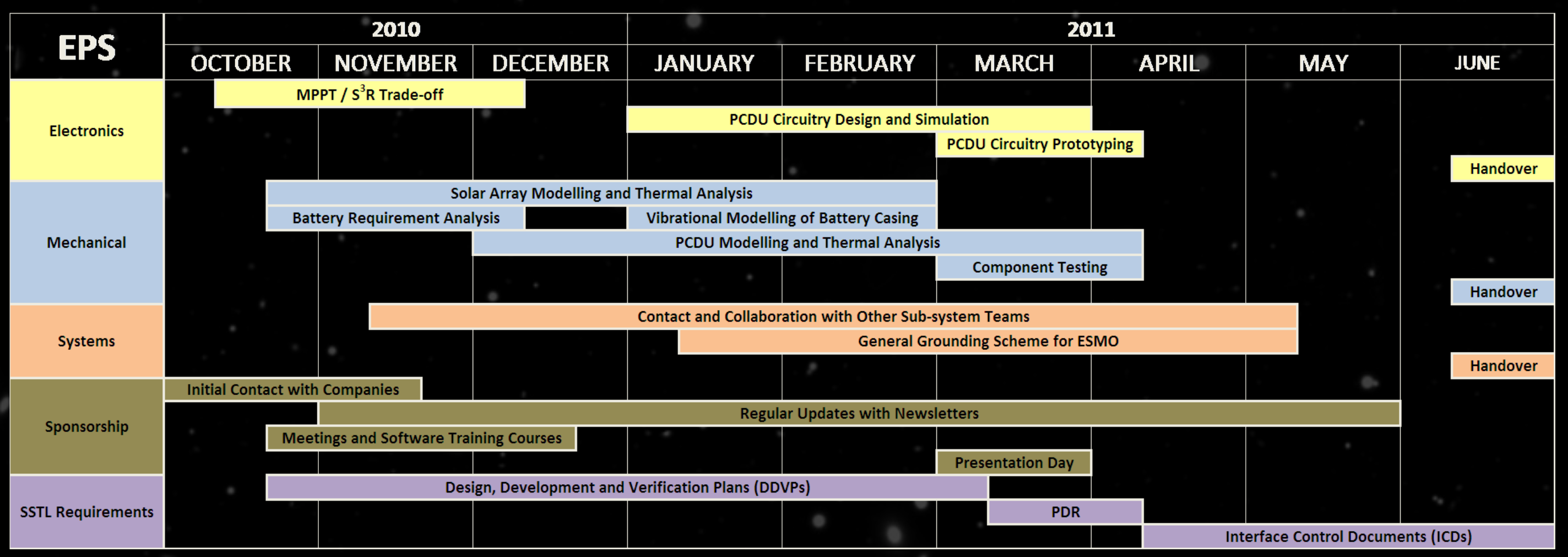
IV and PV Curves for a Solar Cell



Project Management

The project schedule is presented in a Gantt Chart. The technical work is divided into electrical and mechanical.

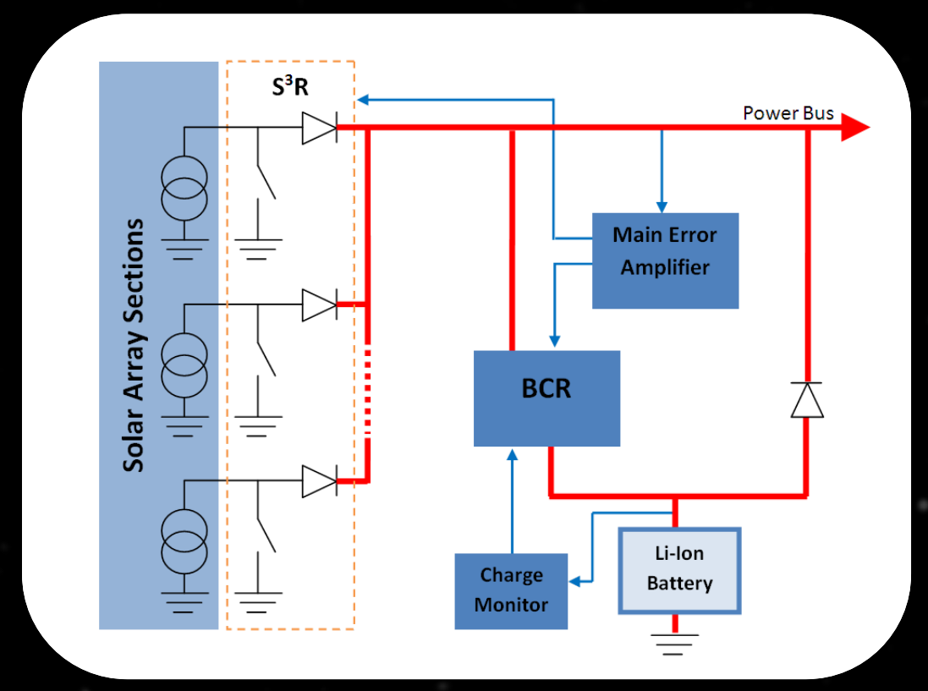
Team members have been assigned other responsibilities such as finance, sponsorship and communications.



Power Conditioning and Distribution Unit

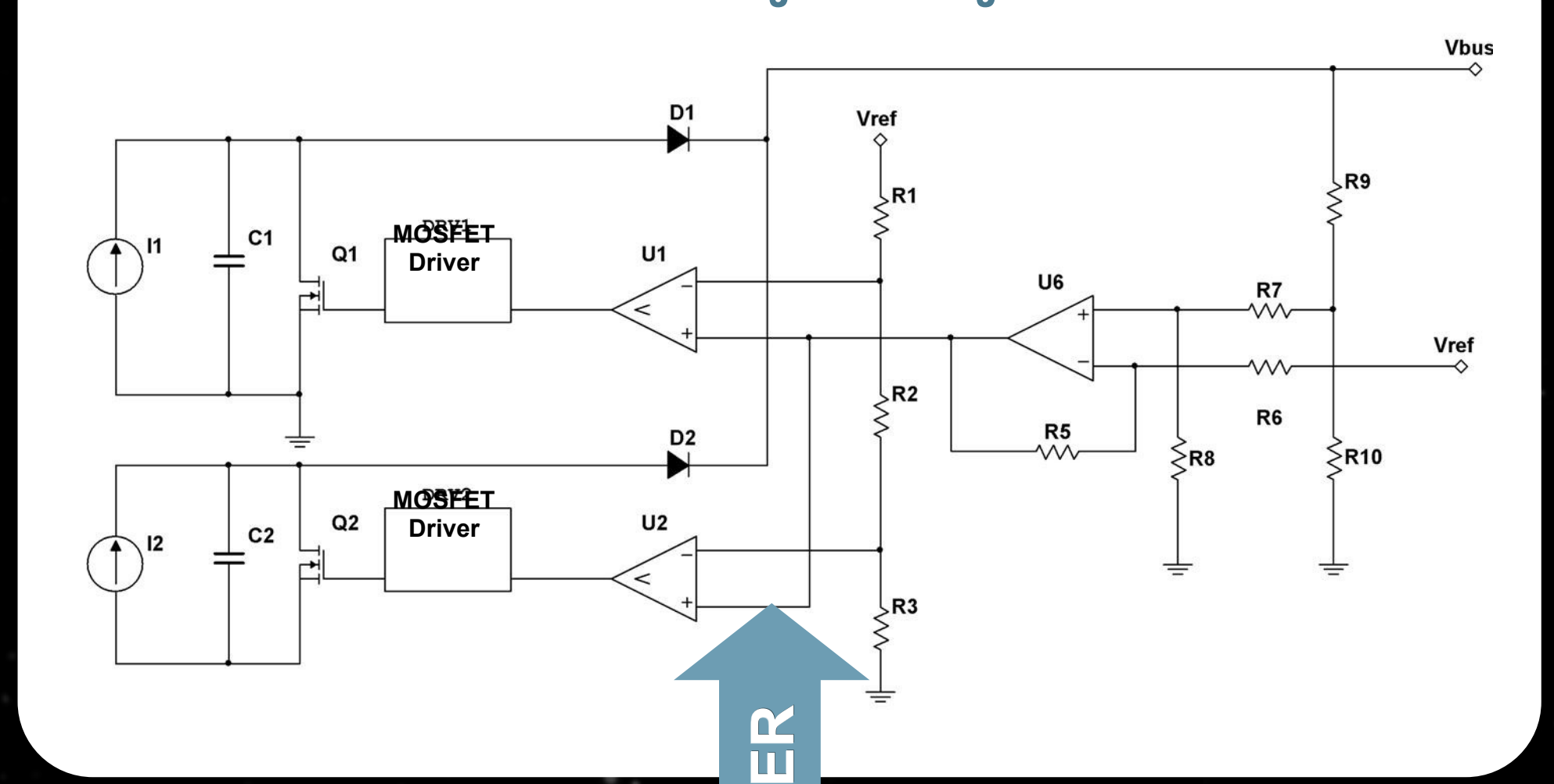
The **Power Conditioning and Distribution Unit** (PCDU) regulates the power produced by the solar arrays using either a **'Maximum Power Point Tracking'** (MPPT) system, or a **'Sequential Switching Shunt Regulator'** (S^3R). The power is used to supply the satellite's sub-systems, and to charge the battery for periods of eclipse.

Sequential Switching Shunt Regulator



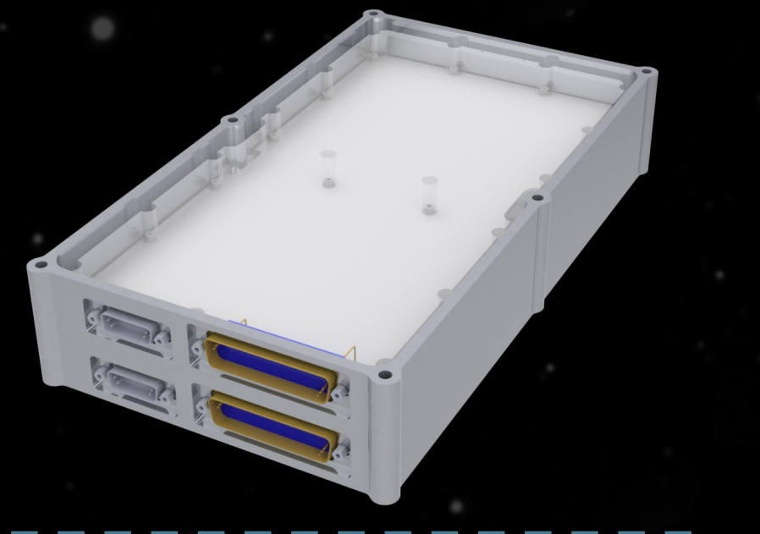
- An S^3R system is regulated while the satellite is in sunlight and unregulated while it is in eclipse (**sun-regulated**).
- The bus voltage is compared by the **Main Error Amplifier** (MEA), U6 in the circuit diagram, with a reference voltage (V_{REF}).
- One input of the comparators is fixed by the resistor ladder R1, R2 and R3. The other input is fed by the output of the MEA.
- As the error signal increases, the input to the comparators U1 and U2 increases. This turns on the MOSFETs which reduces the error on the bus by shunting excess current to ground.
- In a full implementation the resistor ladder would be extended so that there are more switching sections. The MEA also controls the **battery charge regulator** (BCR), this is known as **two domain control**.

S³R Circuit Design including MEA

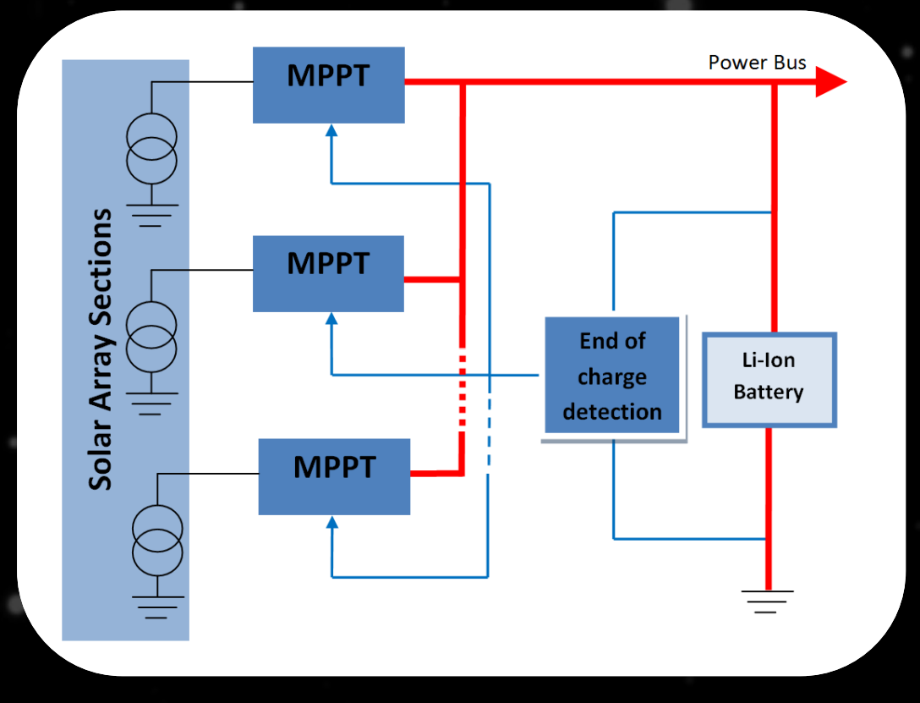


PCDU Casing

The PCDU casing will provide mechanical protection and a thermal heat sink for the internal circuitry. This will protect the PCDU and keep it in its safe operating range.

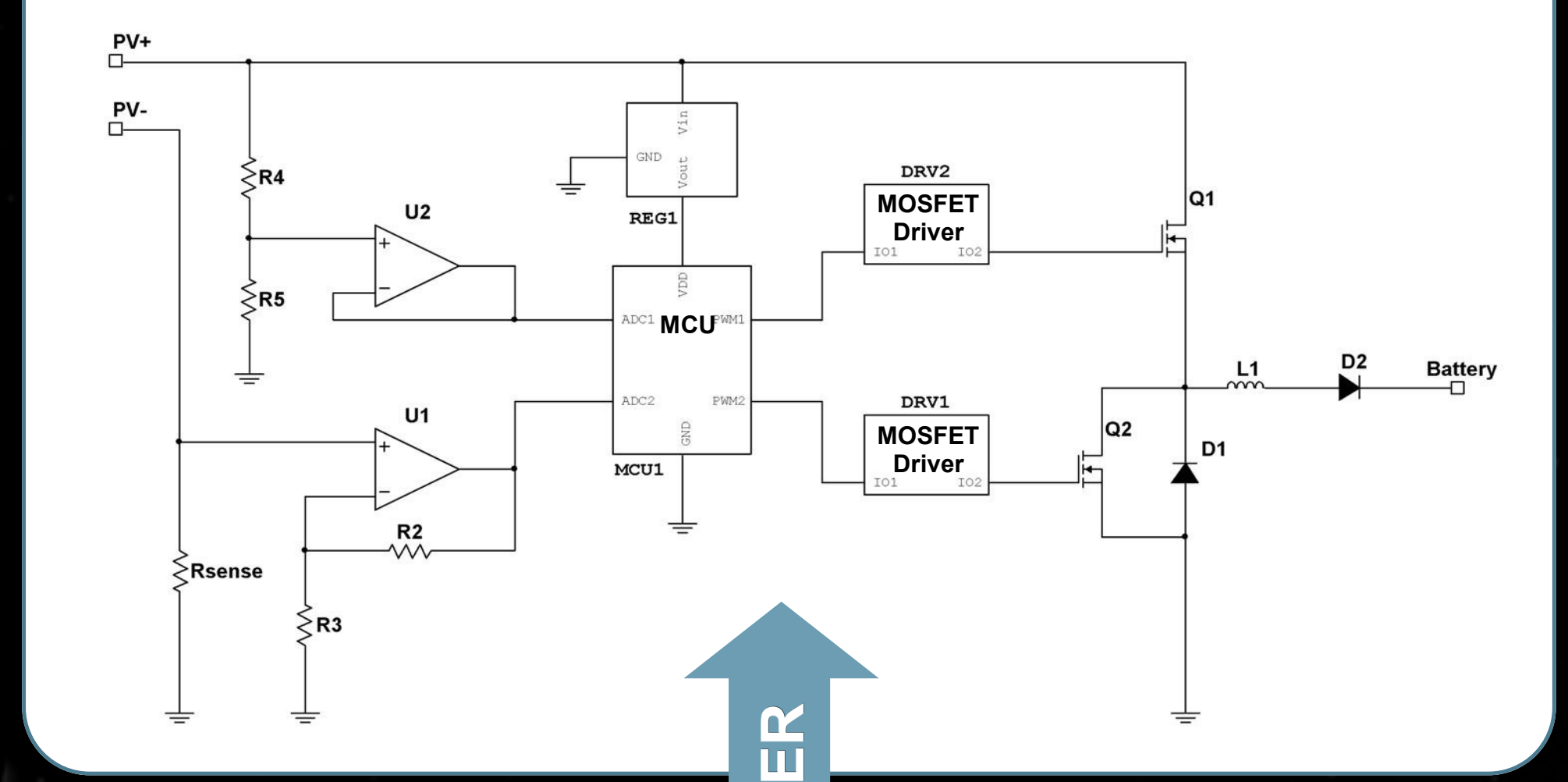


Maximum Power Point Tracking



- An MPPT uses a power bus directly connected to the battery. It is therefore **unregulated**. A single unit operates similarly to a switching regulator.
- The units modify their own input voltage to maximise the power drawn from the solar arrays.
- The circuit diagram below shows a potential implementation of a single MPPT unit using a **"perturb and observe"** algorithm. The microcontroller unit (MCU) modifies the duty cycle and calculates the power produced by the solar array. If the power has increased from the previous calculation, the duty cycle is changed in the same direction. Otherwise, the direction is reversed.
- The circuit below shows a buck converter however, a boost configuration could also be used.
- The diode D2 protects the battery in the case of a fault in the MPPT unit.

Single MPPT Circuit Design



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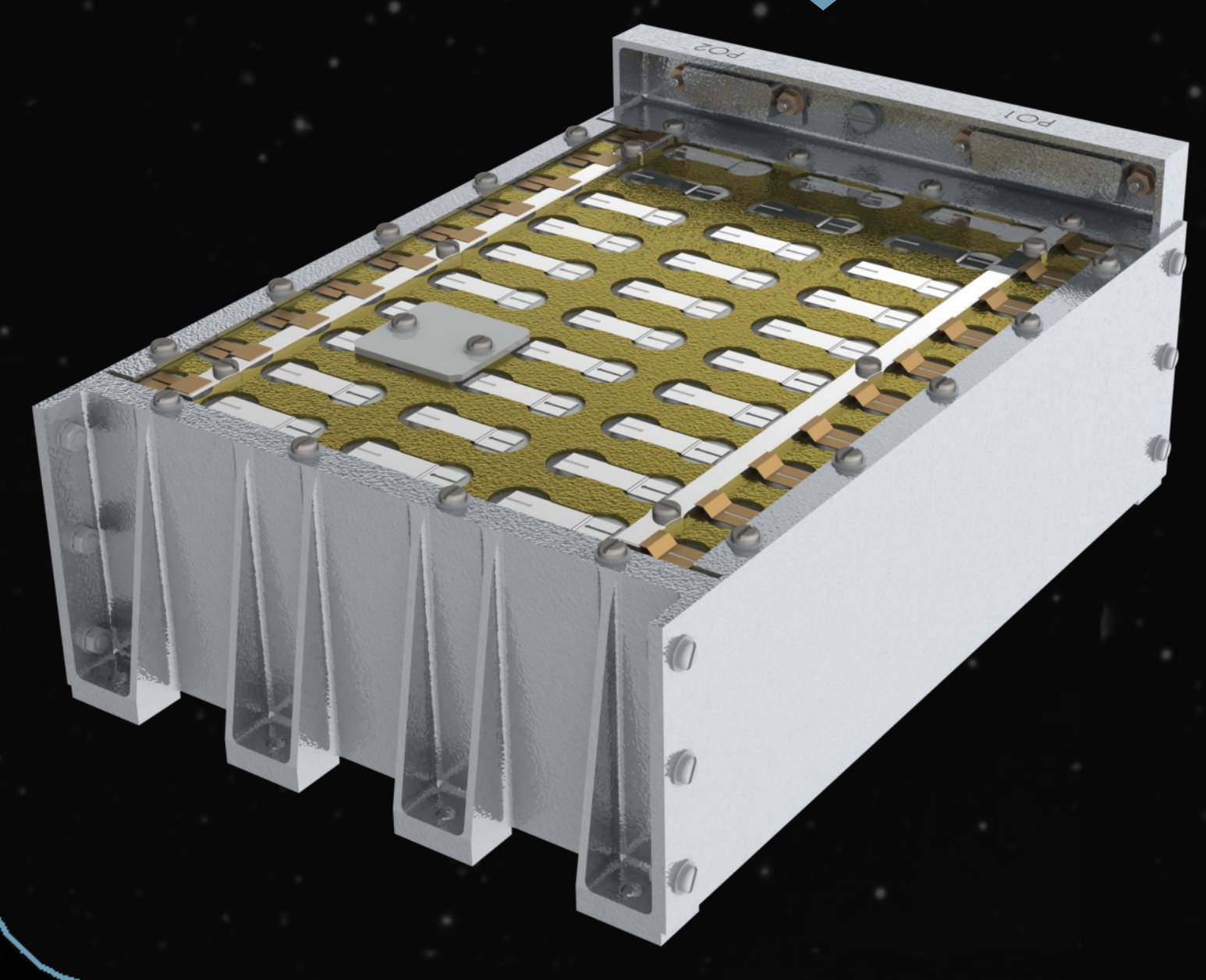
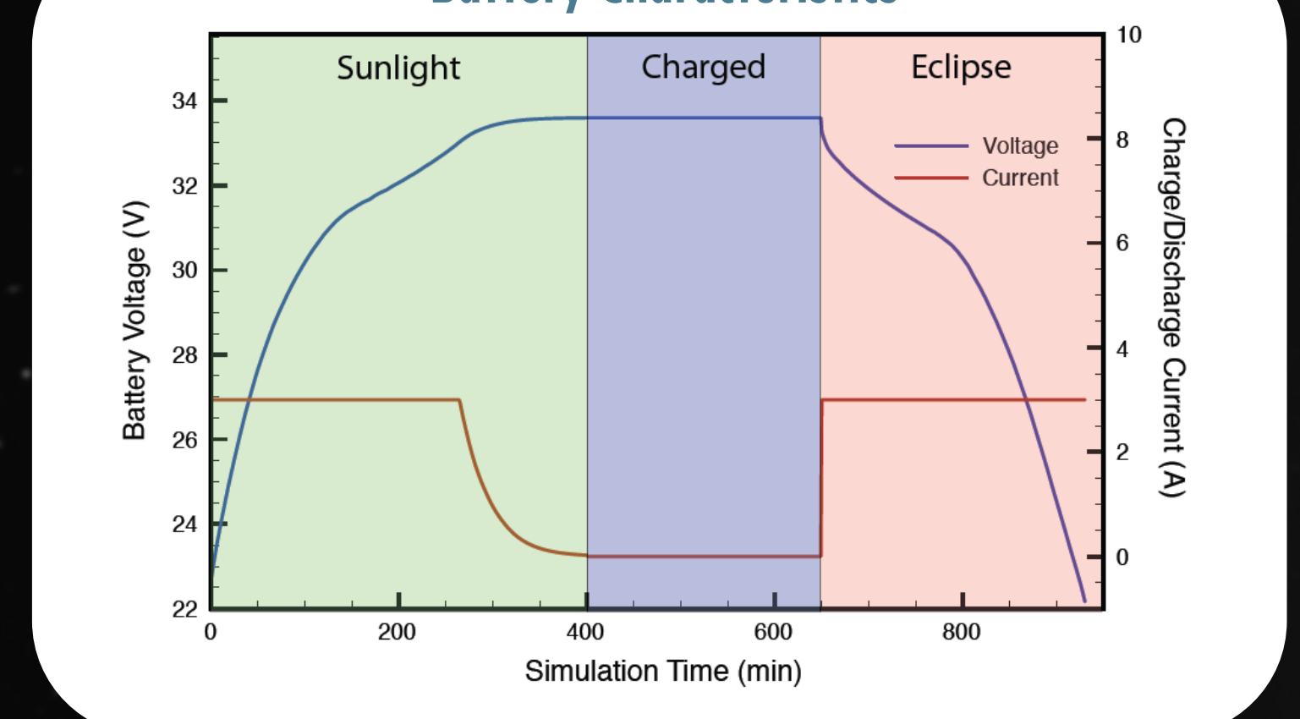
Battery



- Provides the satellite with power during eclipse periods.
- Whilst in sunlight, the battery is charged from the excess power produced by the solar arrays.
- The **15Ah battery**, provided by ABSL, stores energy using **ABSL 18650HC lithium-ion cells** arranged in an **8s10p configuration**. This means that the battery is connected with 8 cells in series and 10 in parallel, giving a **maximum voltage of 33.6V**.
- Lithium-ion batteries have an optimal operating temperature range. The battery will therefore include a heater to ensure that the temperature does not drop below this range.

Battery Characteristics

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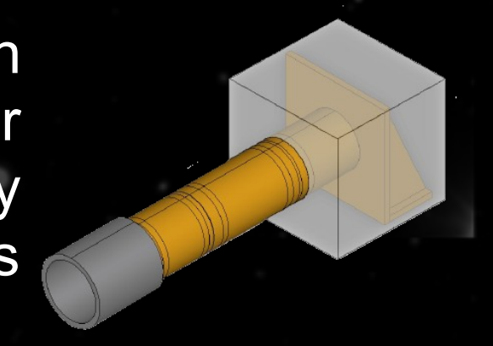
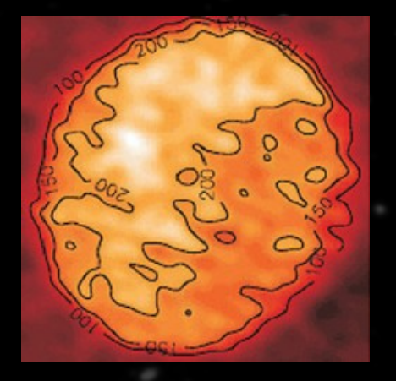
Payloads

ESMO will carry a range of scientific and educational payloads, including:

- A **Narrow-Angle Camera** which will capture images of the lunar surface, at locations suggested by schools engaged with ESA's educational outreach programme.



- A **Microwave Radiometric Sounder** will take measurements that will yield data about the thermal conditions, depth and structure of the lunar soil (regolith) that cannot be gathered from optical measurements.



- Equipment to establish **LunaNet**, an internet-like data communication network between spacecraft orbiting the moon.

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Other subsystems

The EPS must supply power to several other subsystems which are critical to the mission:

- A chemical **propulsion system** to accelerate the spacecraft into and out of its proposed orbits.
- The **On Board Data Handler** (OBDH) which is ESMO's central computer.
- **Reaction wheels** and **attitude thrusters** to orientate the spacecraft (e.g. to point the solar arrays at the sun, or the camera at the moon).
- The **communications system** which will receive commands and relay data back to Earth.