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OPEN TECHNOLOGY FOR SPACE

Open Source "All Parallel" EPS for CubeSats

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Batteries Over Time

- Battery (and EPS) technology has evolved along with spacecraft
- Drivers are
  - Smaller spacecraft
  - Larger area solar cells
  - Higher voltage solar cells
  - Different battery chemistries
  - Lower voltage electronics

Lithium Ion (Li+) vs. NiCd

- Significant differences between chemistries
- NiCd/NimH:
  - Reach a plateau voltage
  - Extra power turned into heat
  - Often used to terminate charging
- Li+:
  - Keep storing charge
  - Eventually may fail
  - So-called “venting with flame”

Li+ Fact Sheet 1

- Cells must not be charged above 4.3V absolute maximum.
- Cells must not be discharged below about 3V.
- Typically if they are floated, it occurs around 4.05-4.1V for full ratings.
- If a cell is fully charged and left for a while, it "relaxes" to around 3.9V.
- When discharge commences, the cell voltage is about 3.6V average.
- There is no penalty for running the cells below their rated Ah. They don't "forget" their original rating.

Li+ Fact Sheet 2

- Cycle life goes up at lower voltages, the equation is roughly Ef (Vch)= 2^[10*(4.2-Vch)] where Ef is the enhanced life cycle factor (Ef = 2 would mean that the battery will survive twice as many charge-discharge cycles as Ef = 1), and Vch is the charge voltage. (Not sure where this equation comes from).
- They must not be charged below 0C, but can be discharged at much lower temperatures.
- UL cells are protected by an electronic circuit which prevents over charging, over discharging and over current. This is the primary protection.
- UL cells have secondary protection in the form of a self-resetting fuse.

Li+ Fact Sheet 3

- The self-resetting fuse is latching and the current through it must be reduced to zero for several seconds to allow it to cool.
- When it resets, the fuse is at a higher resistance than it was before. This can persist for months.
- Cells also have a pressure disconnect and a vent.
- Defects in a cell (metal particles) can cause a short, causing the cell to "vent with flame". This can cause an adjacent cell to then fail, causing a cascade effect. Barriers are often placed between cells in a pack to prevent this.
- Battery manufacturers typically ship a cell at 40% state of charge.

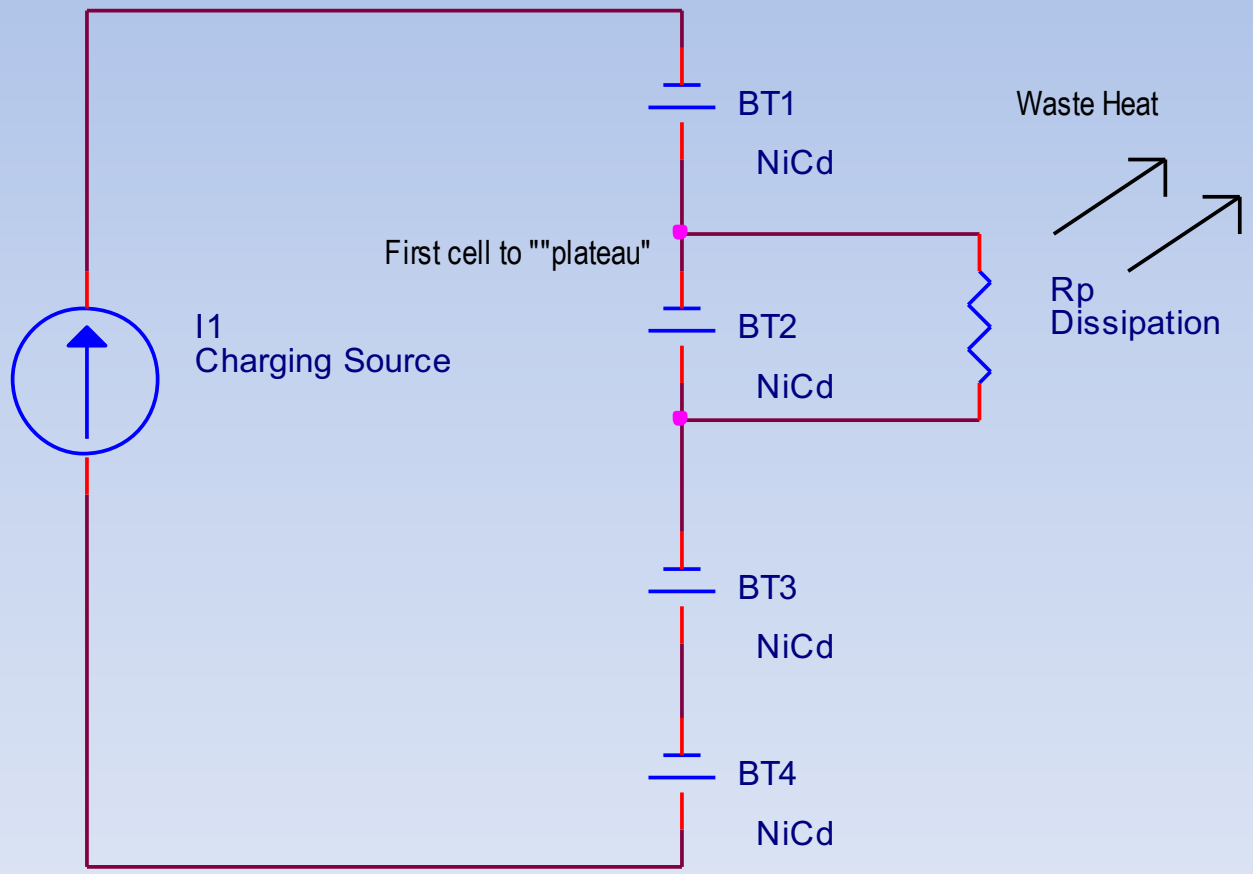
Li+ Fact Sheet 4

- Reducing EOCV (End of Charging Voltage) from 4.05 to 3.85V reduces capacity fade from 70% to 50%. See: <http://www.che.sc.edu/faculty/popov/drbnp/website/publications_pdfs/web8.pdf>
- Simulation (see above paper) indicates that only DoD of 20% or less and EOCV in the range 3.85-4.05V meet the requirements for a 5 year LEO mission.
- In a series battery, each cell must have its voltage monitored, and some form of active balancing carried out.
- Balancing must be done while charging, but can have benefits if done while discharging.
- Cells parallel well, and can be treated as a single cell for charge/discharge termination if they are approximately at the same temperature.

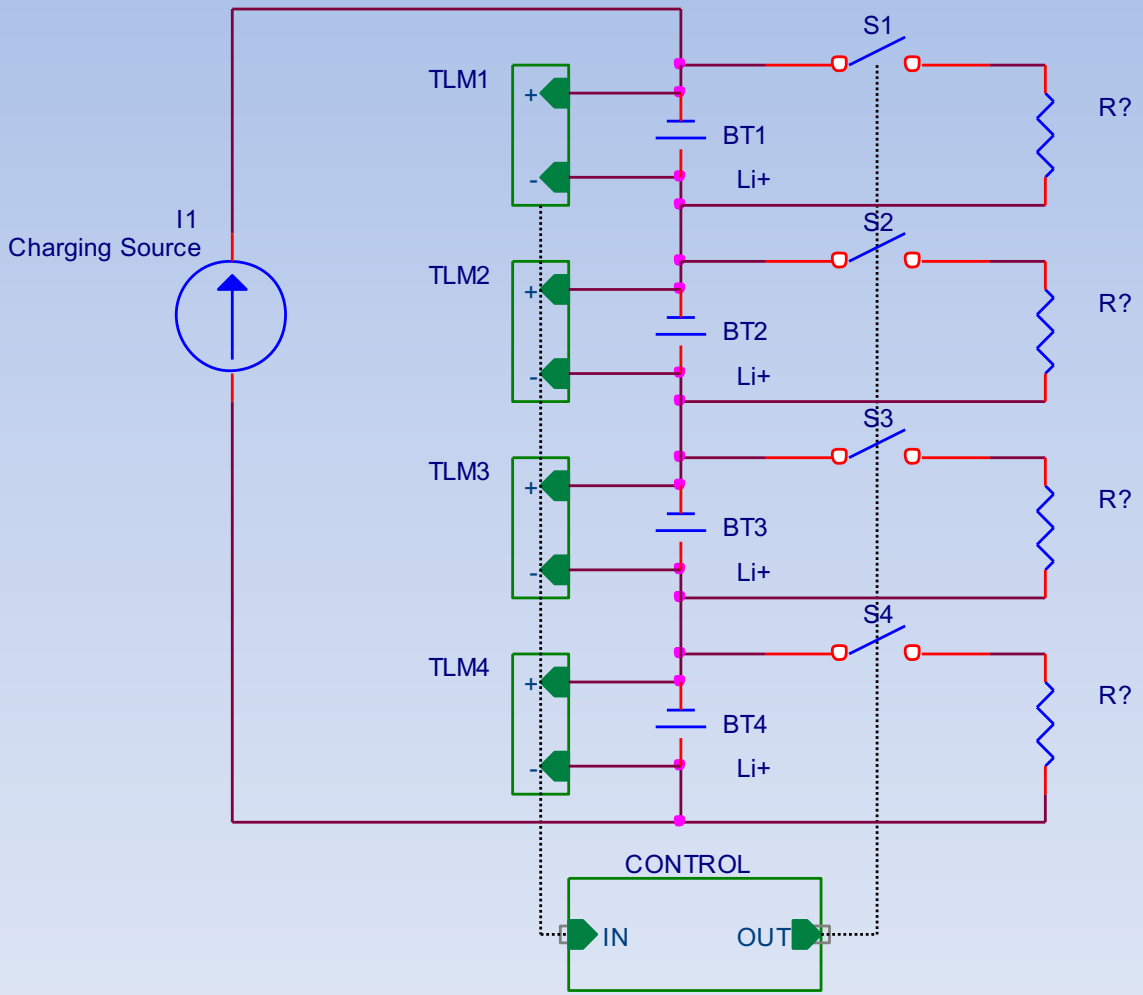
Cell Balancing

- From **CubeSat Design Specification Rev. 13**
- **The CubeSat Program, Cal Poly SLO**
  - 3.3.8 CubeSats shall incorporate battery circuit protection for charging/discharging to avoid unbalanced cell conditions.

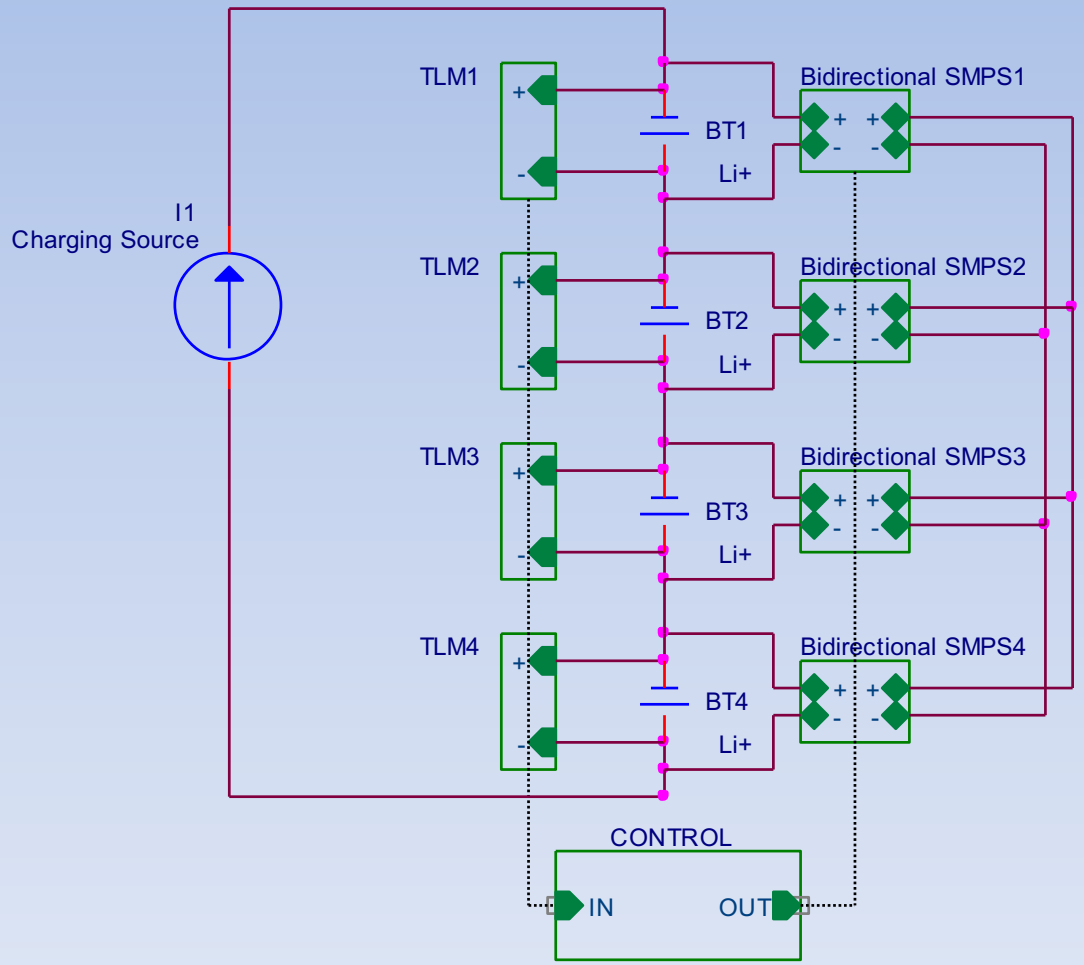
NiCd Battery is Self Balancing



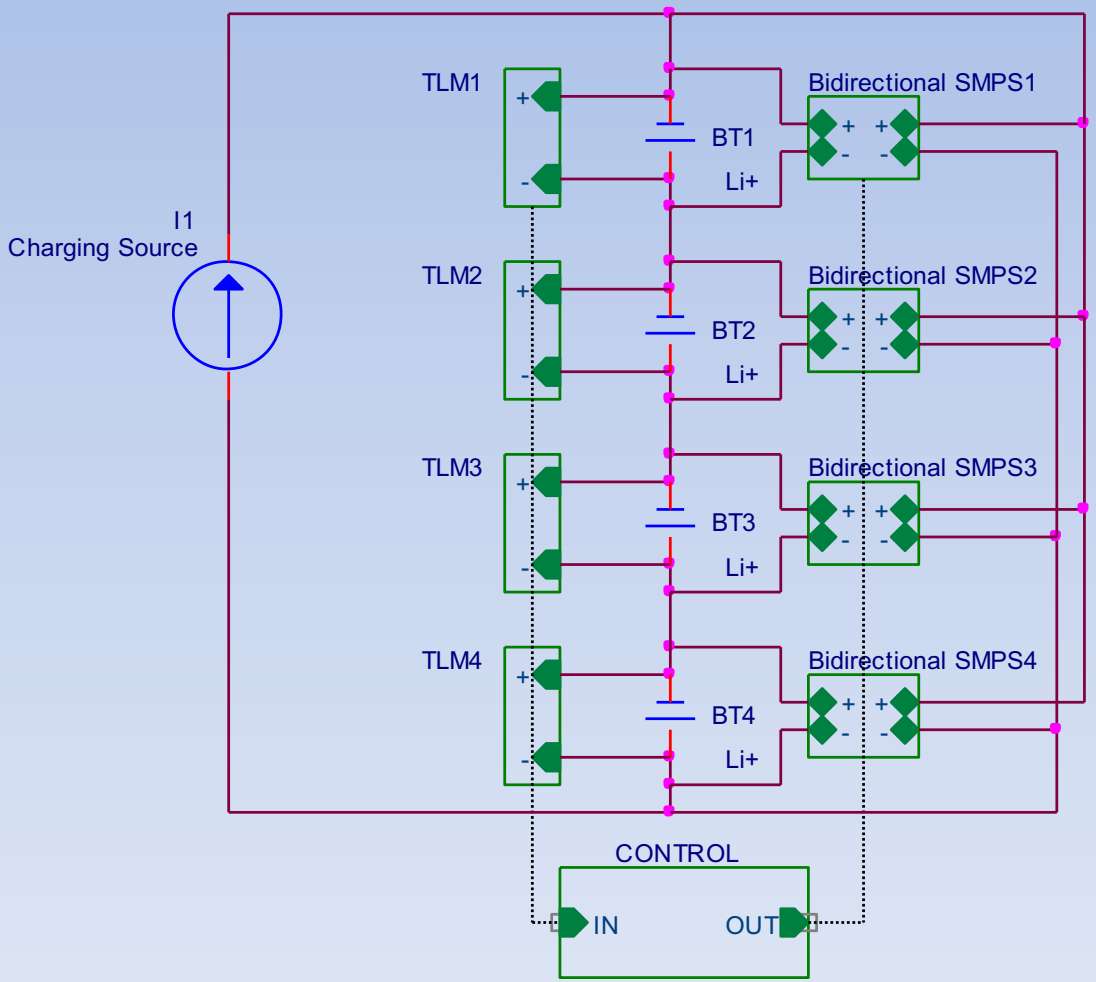
Li+ Must be Actively Balanced -Dissipative Balancing



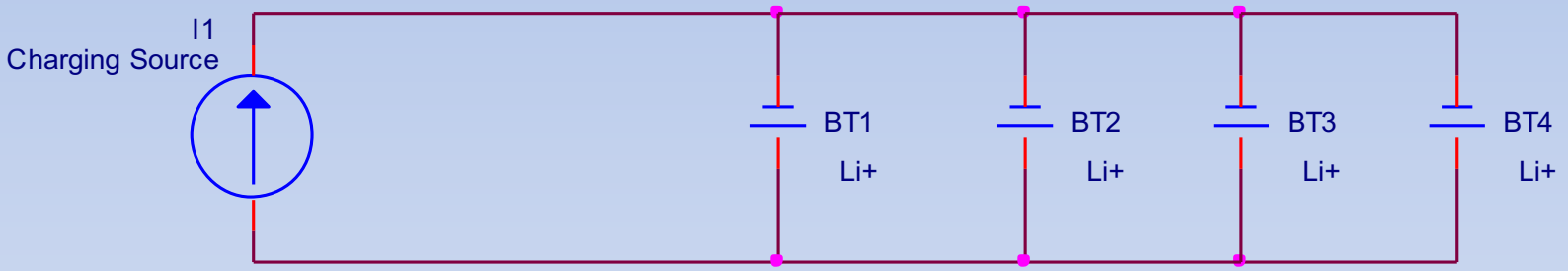
Li+ Must be Actively Balanced -Sharing Bus Balancing



Li+ Must be Actively Balanced -Battery Terminal Balancing



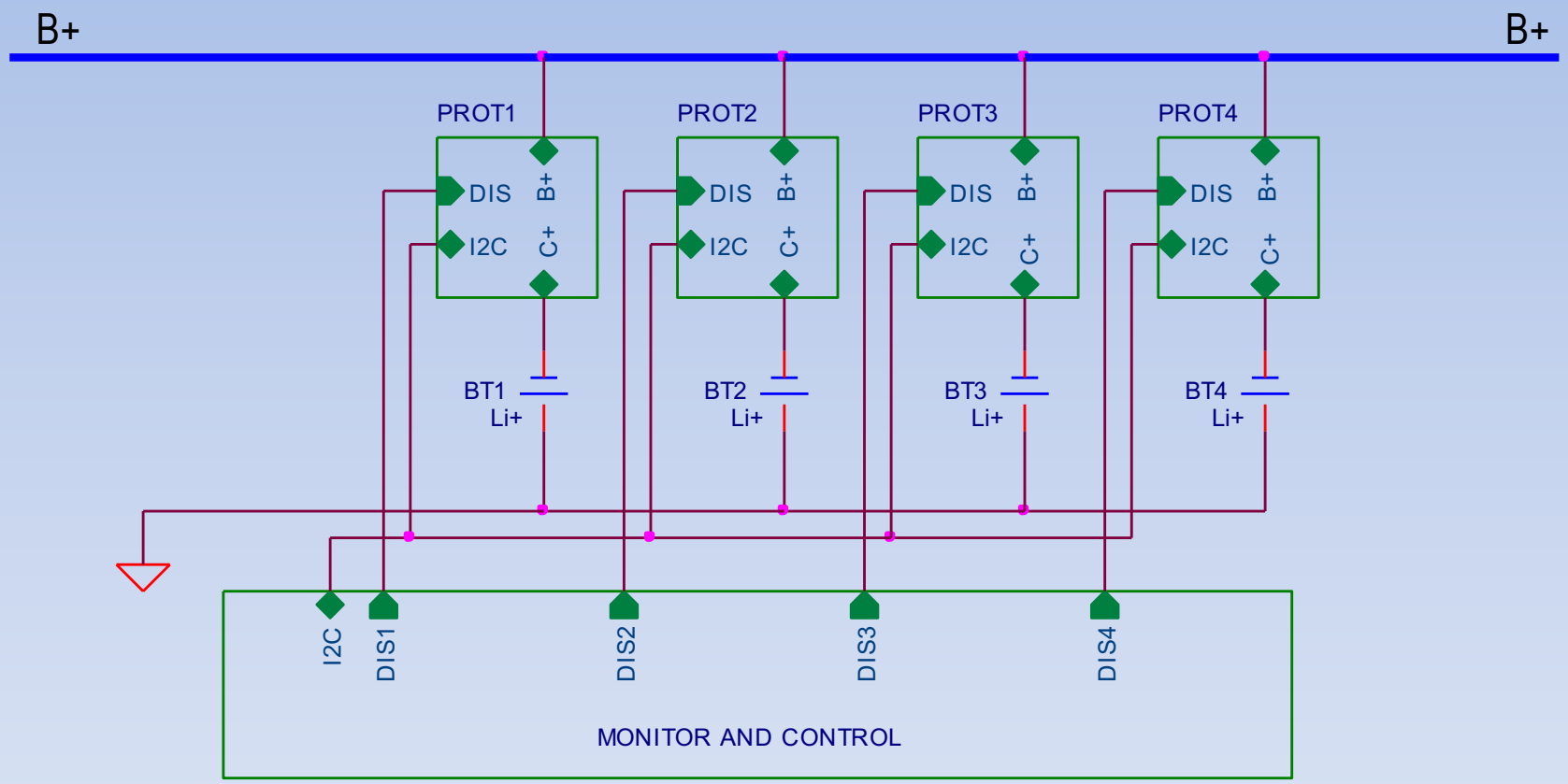
Parallel Battery is Always Balanced



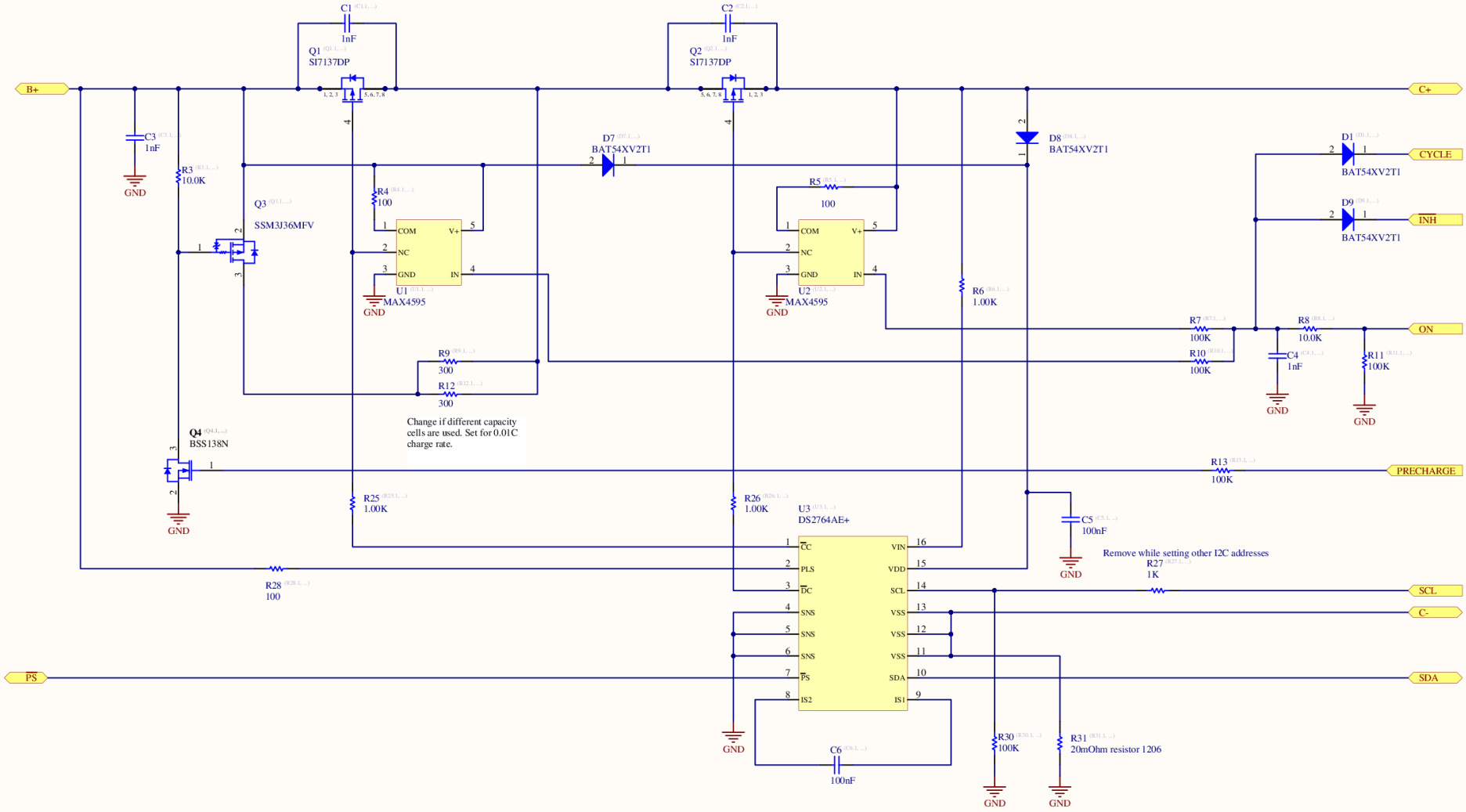
Parallel Advantages

- No charge balancing required
  - More efficient and reliable
- Can add cells incrementally
- Single cell failure only reduces capacity by one cell

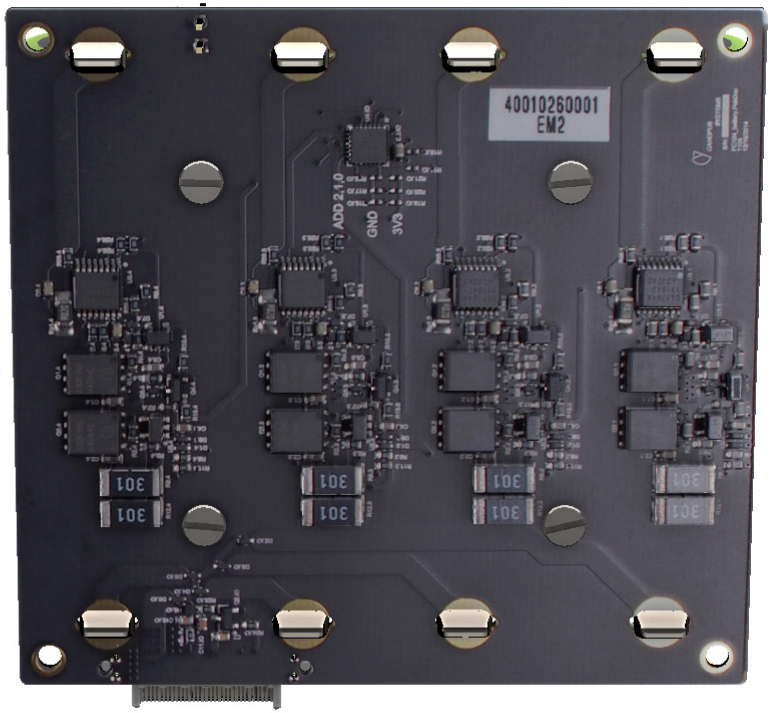
Battery Topology Showing Protection and Disconnect



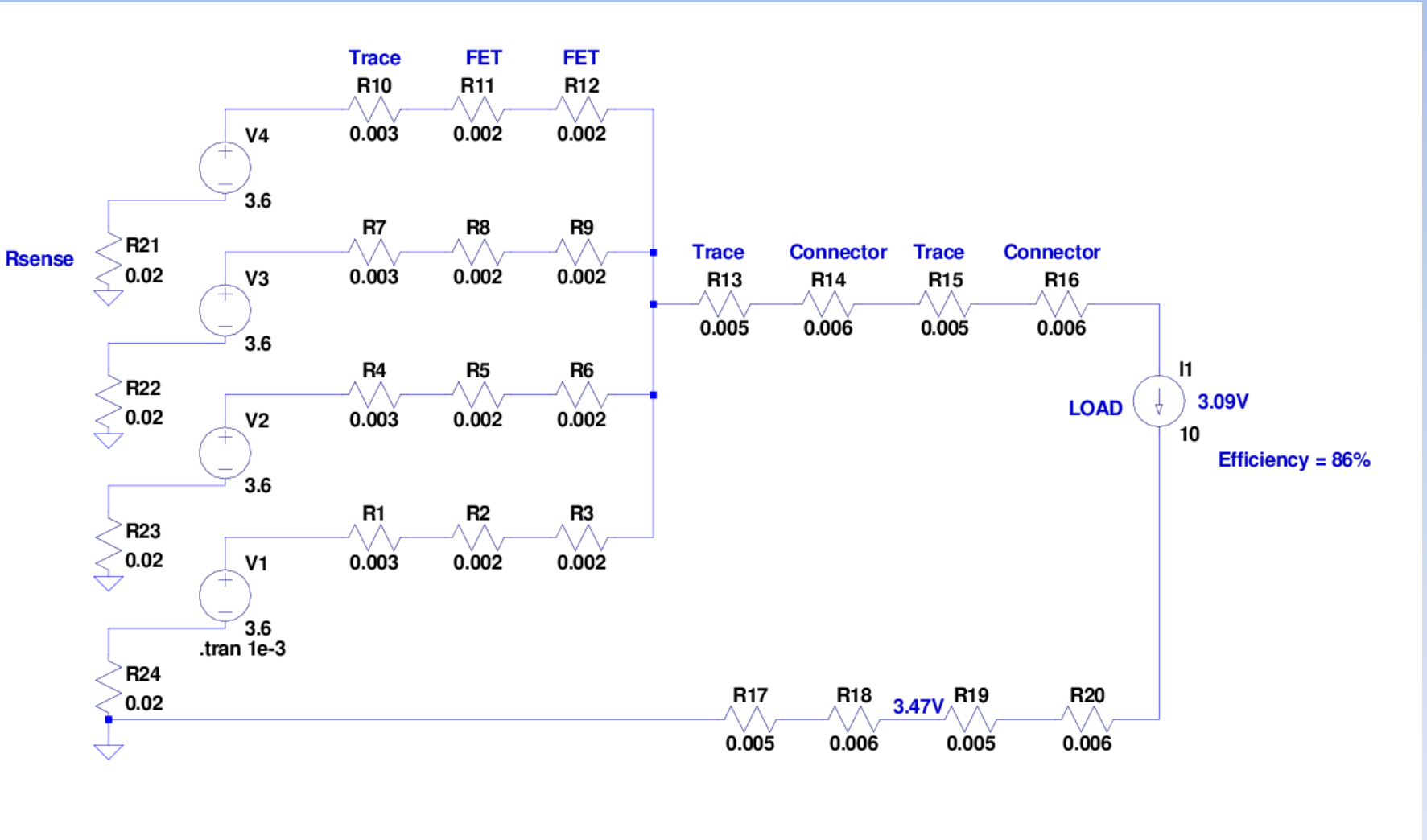
Protection Schematic



Corvus BC Battery Board



Is There a Down Side?



Different Classes of Loss

- Fixed losses
  - E.g. EPS control micro
- Losses that scale linearly
  - E.g. solar arrays and PVCs
- Losses that scale as the square
  - E.g. linear POL regulators
- Losses that scale as the cube of power
  - E.g. Fixed power output SMPS

Scaling to High Powers is Challenging

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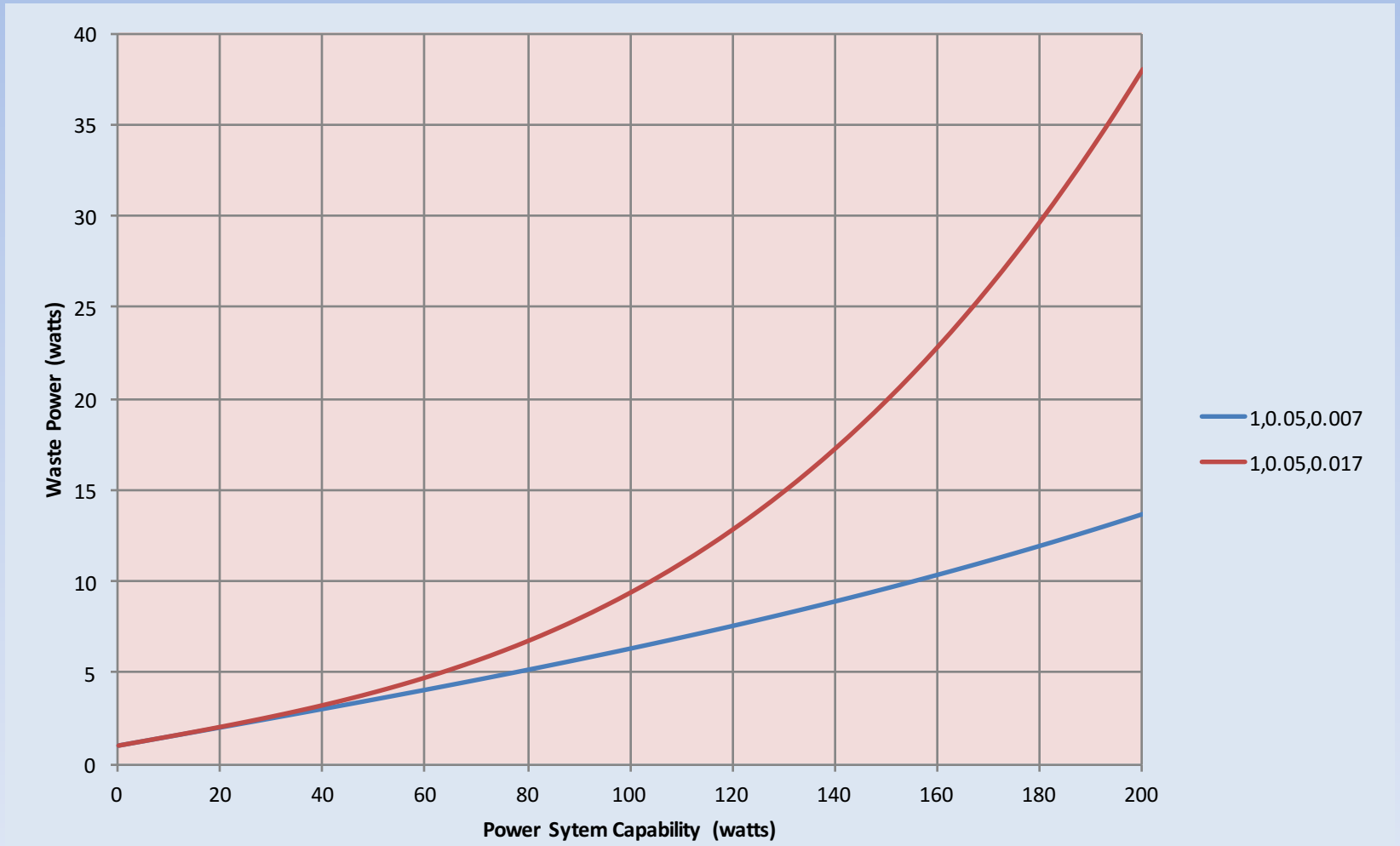
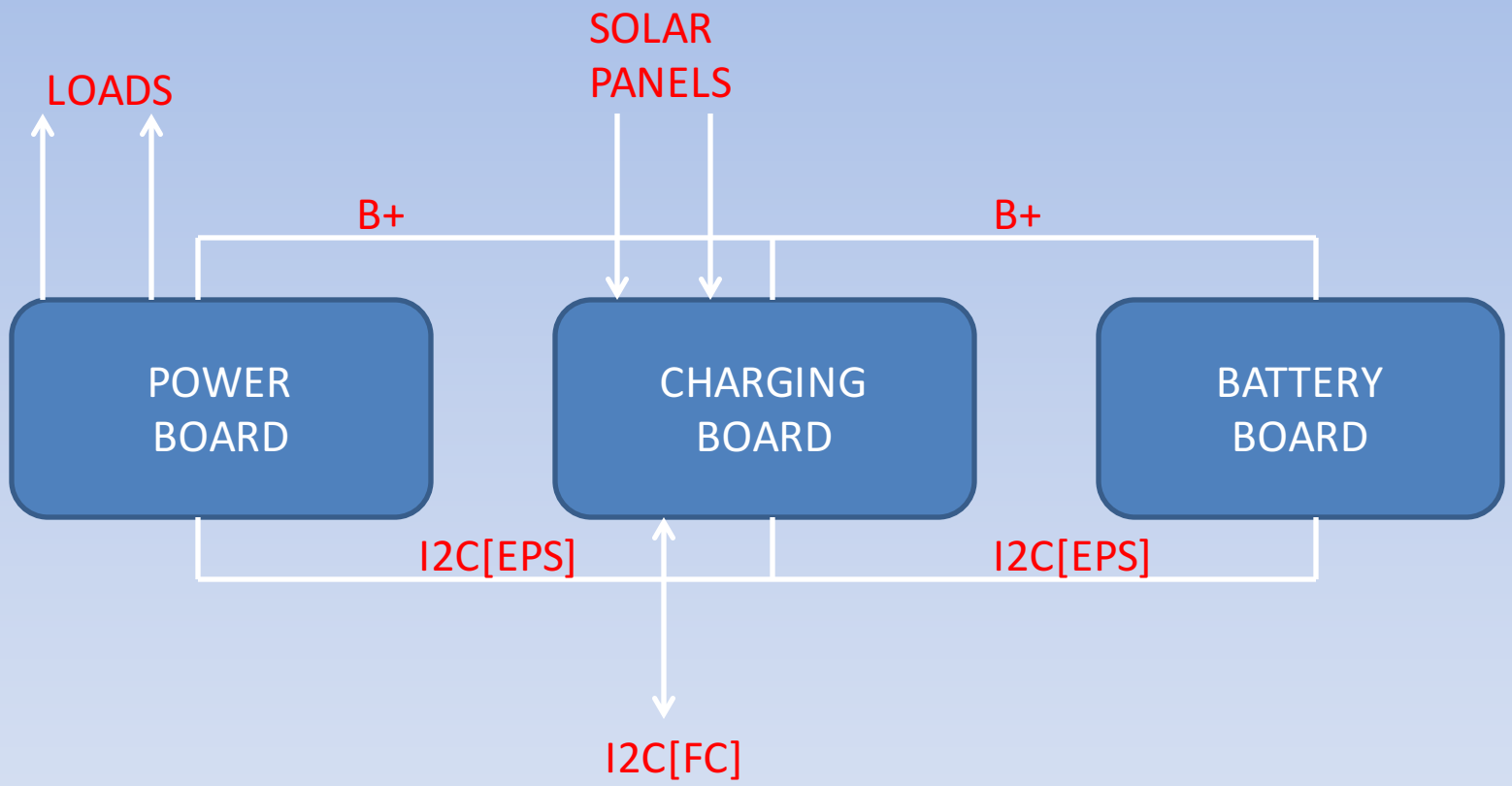


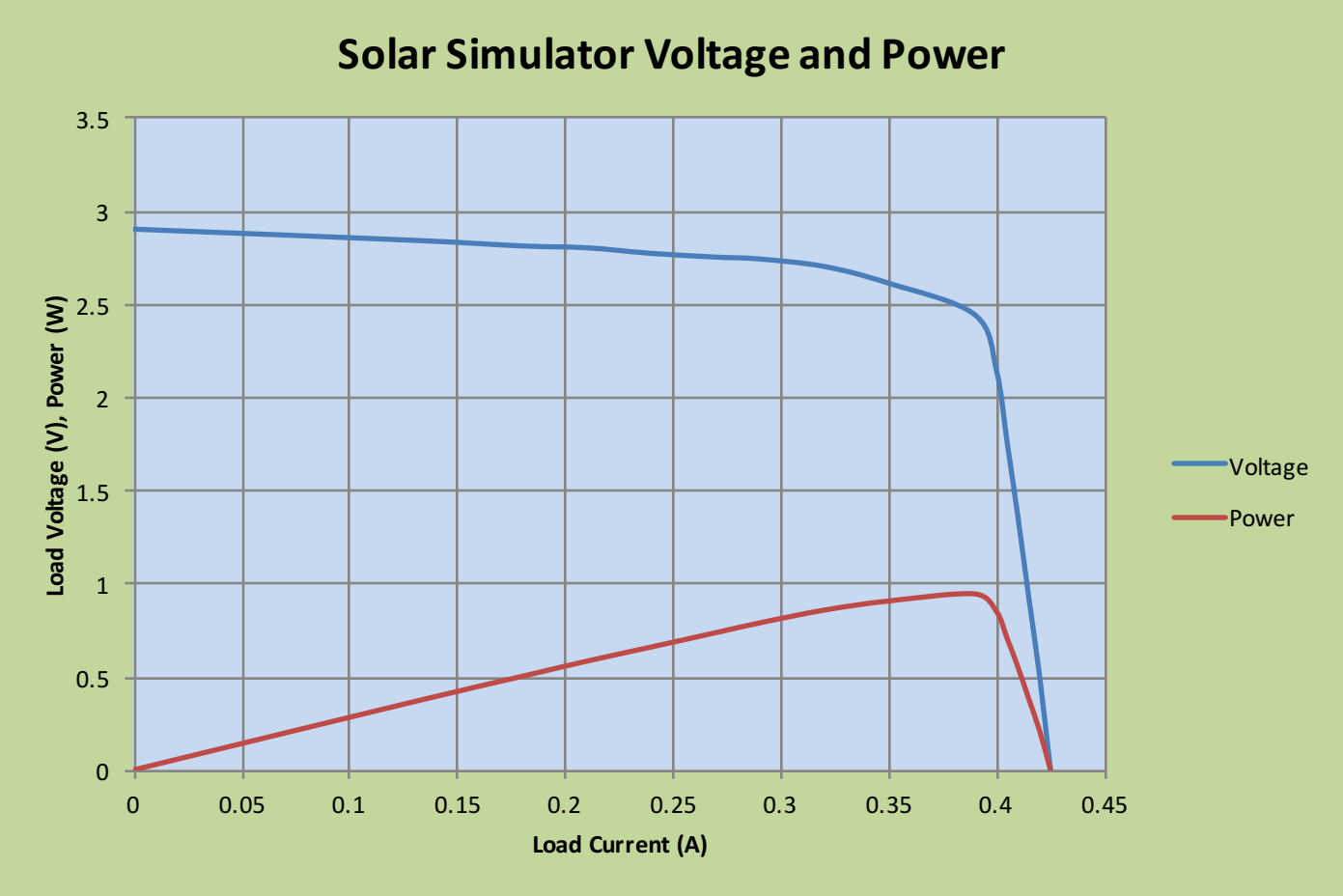
EPS Functional Blocks



Charging Board Functions

- Convert PV array voltage to charge B+
- Track MPP of cells
- Controller
  - Runs MicroPython
  - I2C Master for EPS
  - I2C slave from Flight Computer
  - Consolidates EPS telemetry

Maximum Power Point
UTJ Cell



Maximum Power Point Tracking

- Adjusts input voltage when output is current limiting
- Keeps output voltage constant at full charge
  - Can operate with entirely dead battery
  - In sunlight only
  - “OSCAR 7” mode
- MPPT Can run in either of two modes
  - Temperature programmed
  - Perturb-and-observe

Power Board Functions

- Convert B+ to other voltages
  - +5V
  - +8V
  - +12V
- Switch outputs
- Monitor current/voltage
- Protect against shorts
- Current drive for melt wires

Transition to Distributed EPS

- B+ voltage is around 3.4 to 4.0 volts
- Many circuits run from 3.3V
- LDO regulators with 0.08V drop available
- Efficiency at 3.6V is 92%
  - As efficient as SMPS
  - But simpler and more reliable
- Encourage use as POL regulators

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Thank You

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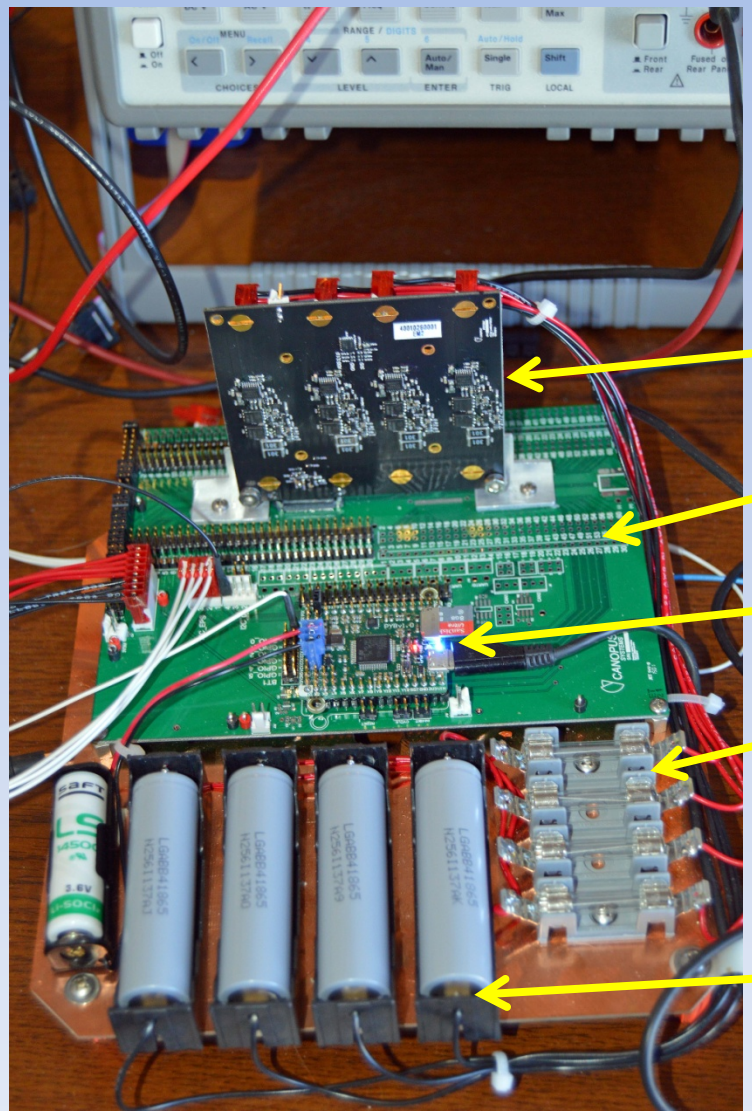
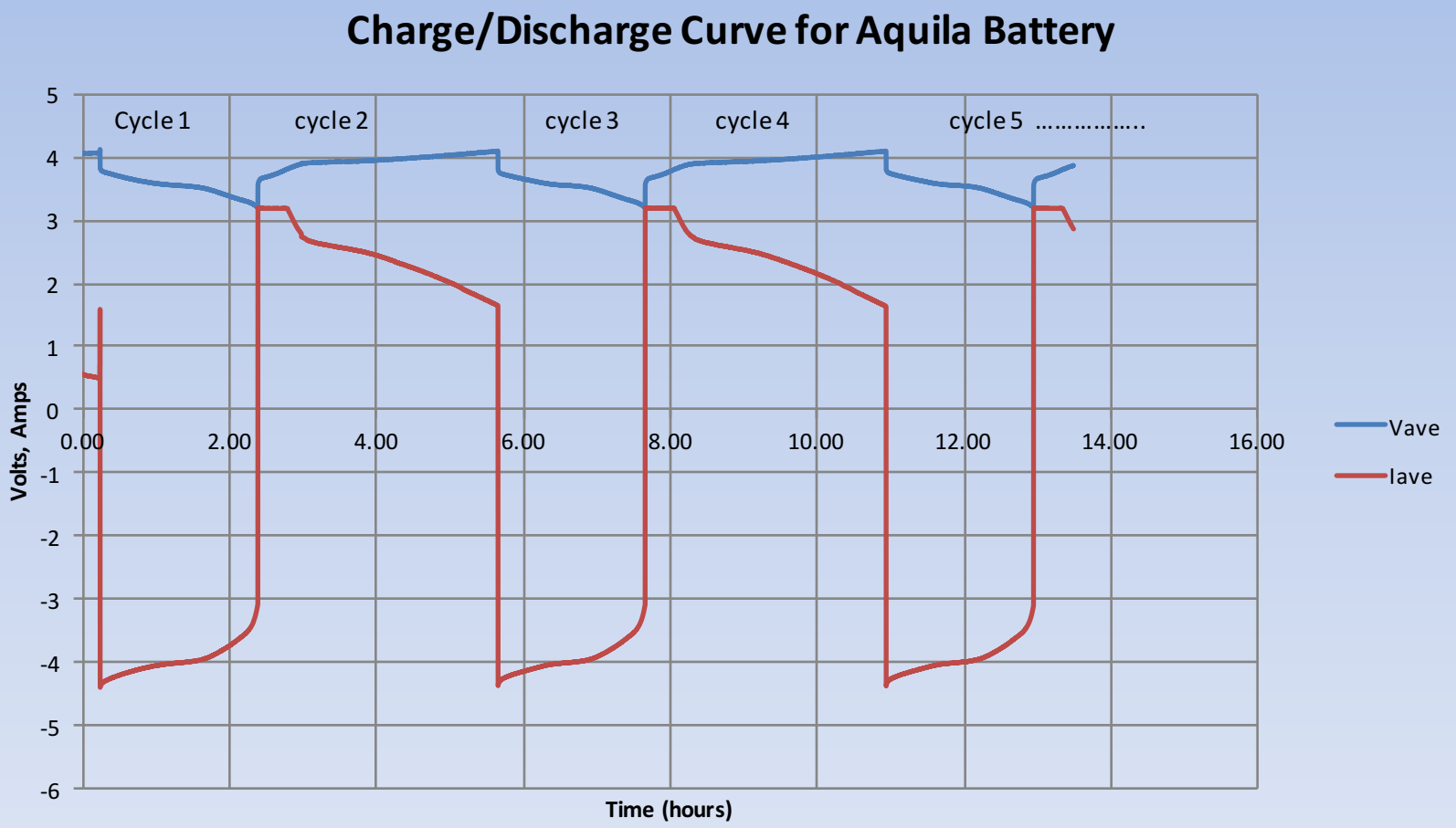
Backup Slides

Test Setup



Charge/Discharge Cycles



Cells Compared

	Pack	Cell 1	Cell 2	Cell 3	Cell 4
Tenergy	-8.11094	-2.04613	-2.08146	-2.01762	-1.96567
	-7.97426	-2.02348	-2.05464	-1.96896	-1.92724
	-7.98956	-2.02849	-2.05389	-1.97717	-1.93008
Panasonic	-9.80782	-2.41693	-2.52244	-2.38997	-2.47849
	-8.77776	-2.15888	-2.32316	-2.03024	-2.26544
	-8.81995	-2.17718	-2.33769	-2.0295	-2.27559
LG	-4.47749	-1.44799	-1.46576	0.002465	-1.56617
	-3.34138	-1.02646	-1.10735	0.001726	-1.20932
	-3.33702	-1.03286	-1.10623	0.001726	-1.19968

Corvus BC Battery Board

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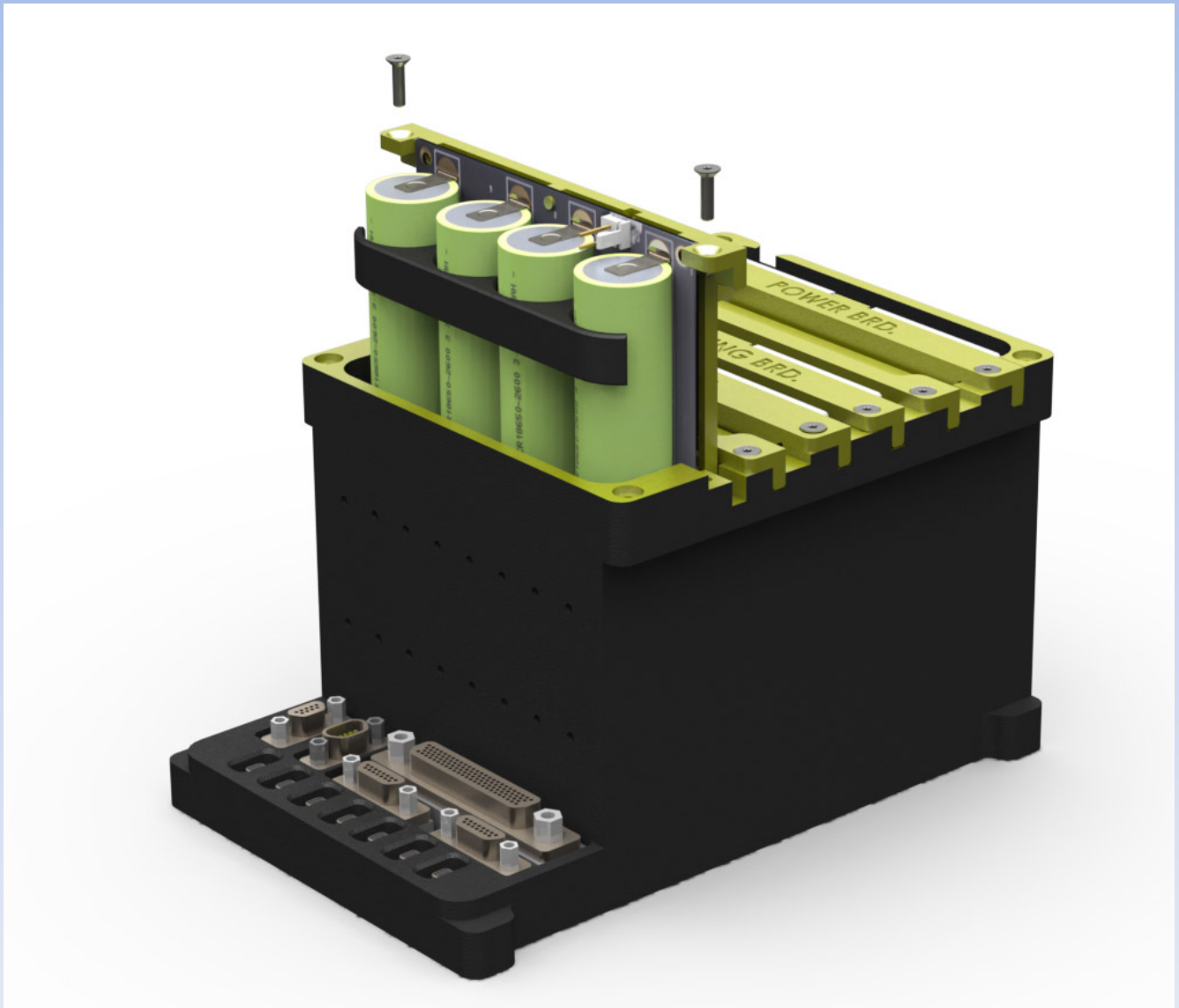
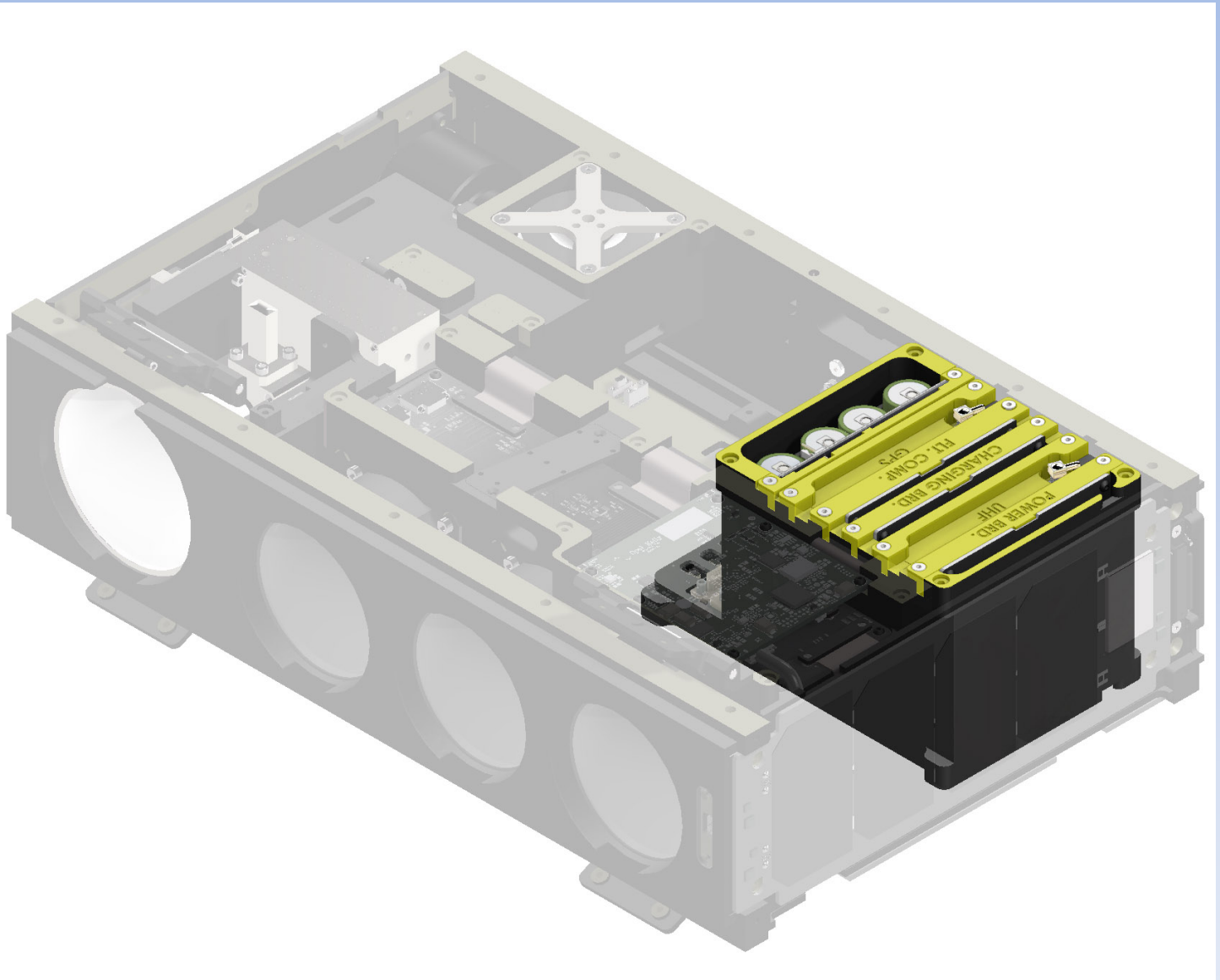
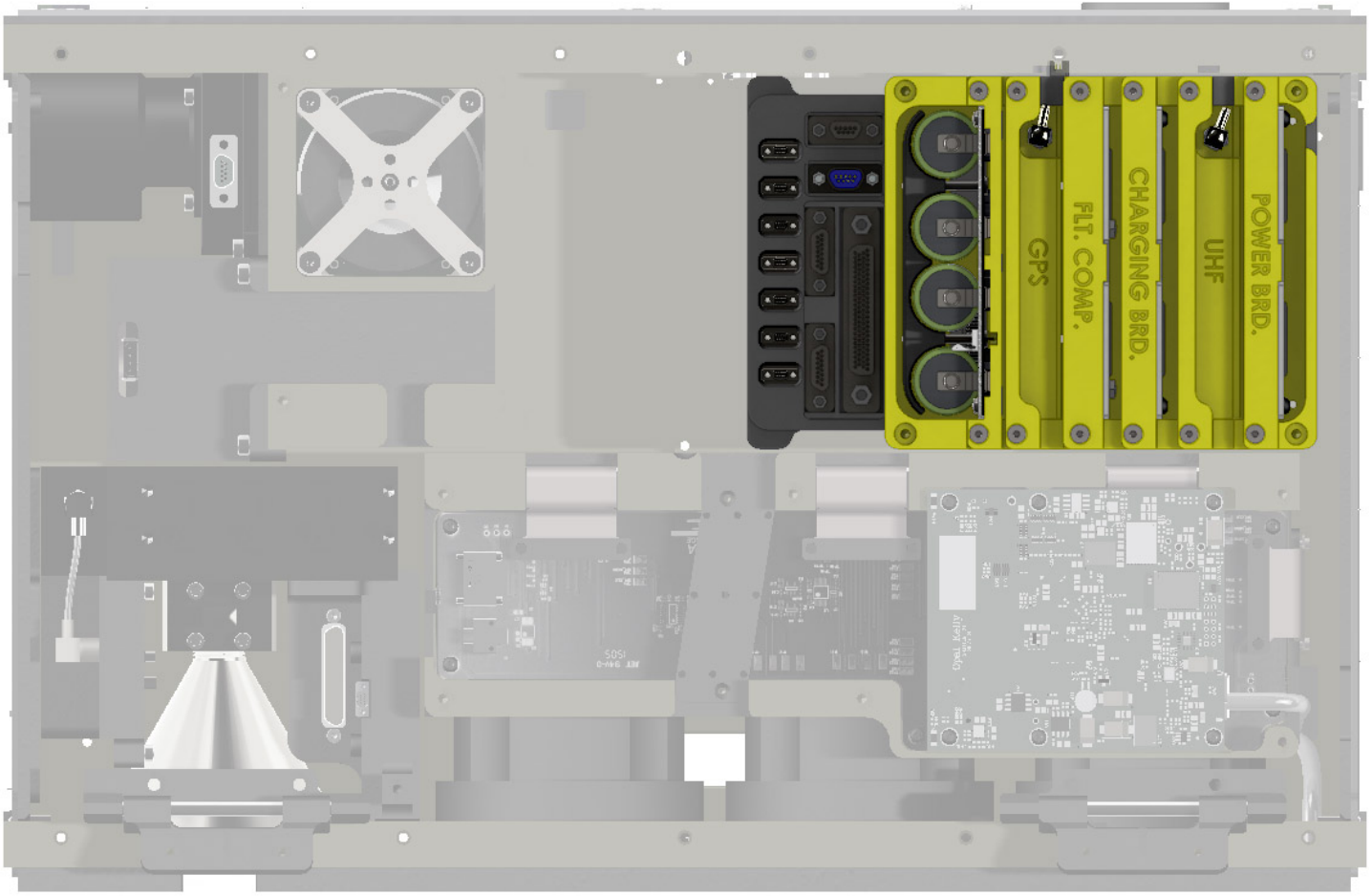
Battery Board in PDM



PDM in Corvus BC Bus



PDM in Corvus BC Bus



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Corvus PDM Section