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DESIGN AND TEST OF THE PAYLOAD ELECTRONICS & IN FLIGHT SEQUENCE DEVELOPMENT FOR THE CSUN CUBESAT1 LOW TEMPERATURE BATTERY EXPERIMENT

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Outline

- Motivation
- Technology
- CSUNSAT1
- Payload
- Payload Testing
- In Flight Sequences
- Integration & Test
- Conclusion and Future Work.
- Team Acknowledgement



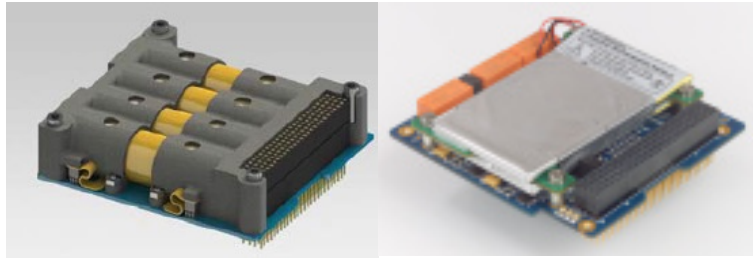
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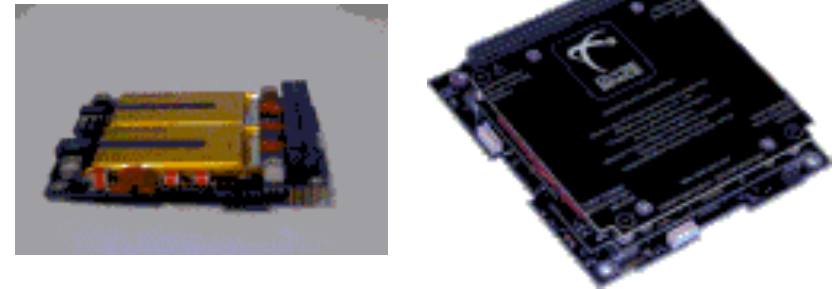
Motivation

Commercially available CubeSat Battery Systems

Cubesatkit/Pumpkin



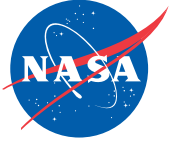
ClydeSpace



GOMSpace

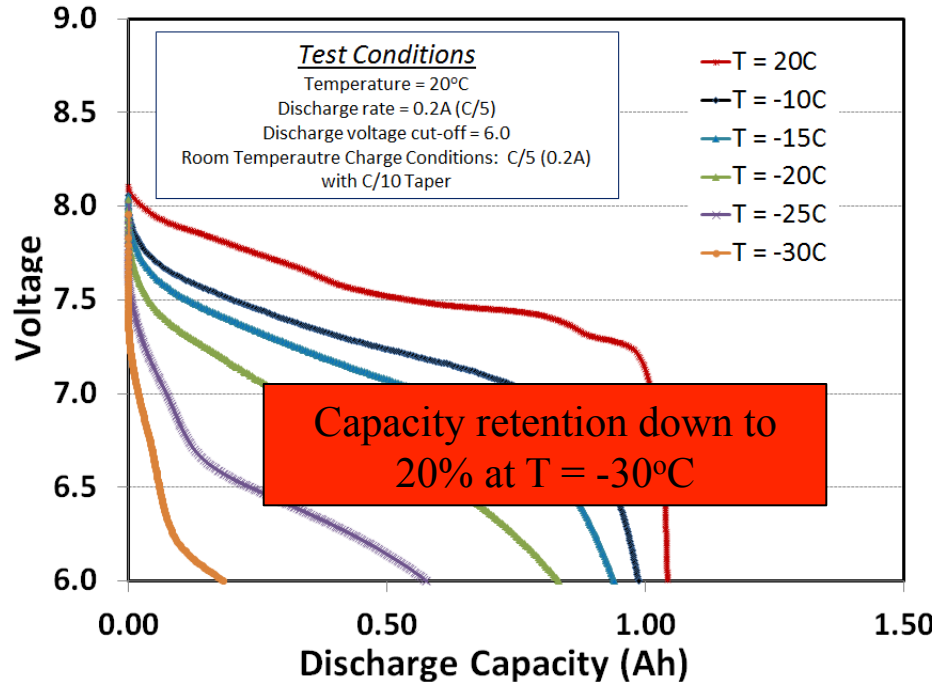


❖ Commercial Li-ion chemistries for CubeSat applications exhibit limited performance for high power and low temperatures $< -20^{\circ}\text{C}$.

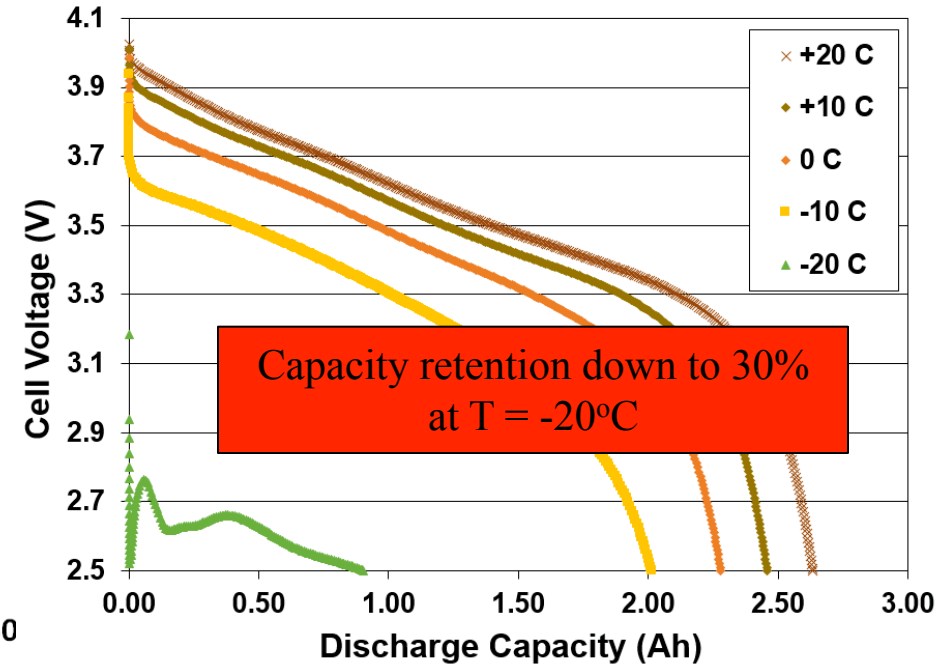


Commercial Li-ion Cell Performance

Li-Ion Polymer Cell



Li-Ion 18650 Cell



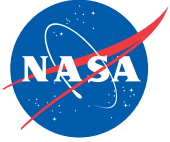
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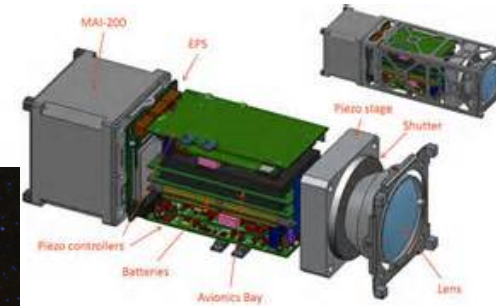
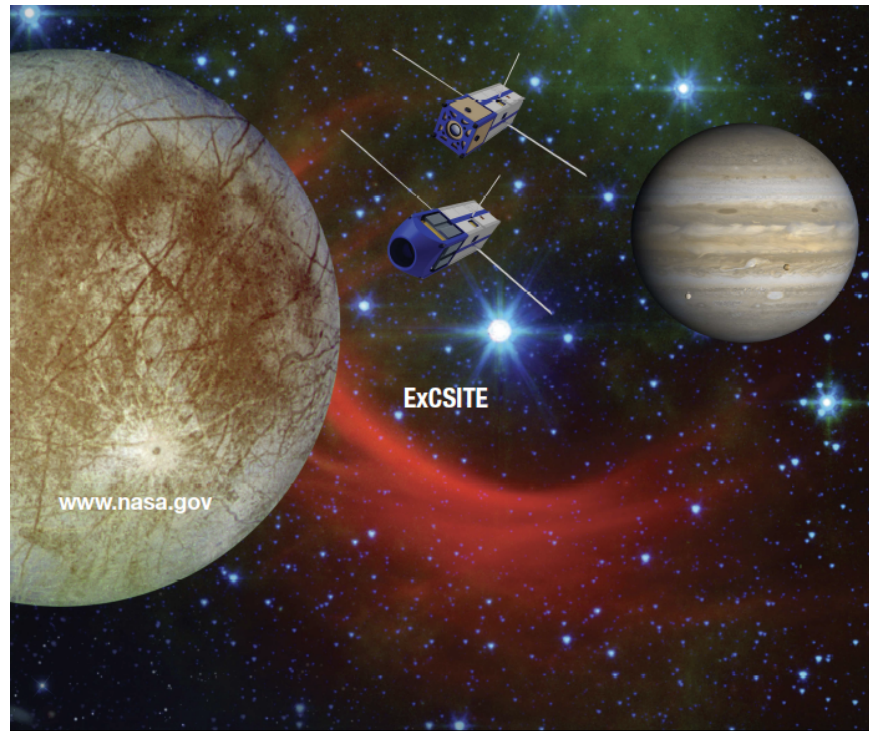
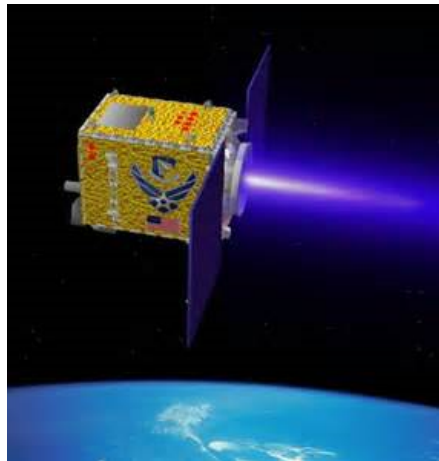
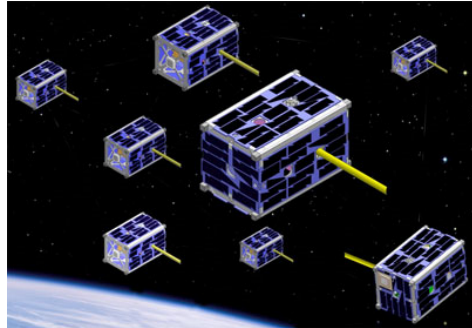
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Our Technology



NASA's Future SmallSat Missions



Small satellites beyond LEO orbits will require operation at lower temperatures. This leads to the need for a cold capable energy storage system.



Low Temperature Li-Ion, Supercapacitor Hybrid Energy Storage System

Challenge: Small spacecraft and in situ instruments require energy storage technology that can operate at low temperatures and provide power for high power payloads such as communication and propulsion.

Solution: JPL Hybrid Energy Storage System consisting of a new JPL electrolyte Li-ion chemistry coupled with high power super-capacitors to enable high discharge rate at low temperatures.



Capability	Current SOP	Proposed Tech
Operating Temperature	-20C to 20C	-50C to 20C
Discharge Rate	<1C	>10C
Battery Can Seal	Welded (expensive)	Crimped (COTS)



Benefits and Impact

- Benefits
 - Cold temperature operation eliminates energy for battery heating
 - High discharge rate enables high power operations such as communication and instrument operation normally not possible
- Relevance & Impact
 - Enables 3 classes of Missions:
 - Landers & in situ instruments
 - Europa Lander
 - Mars Sample Return
 - Sensor networks
 - Deep Space small spacecraft



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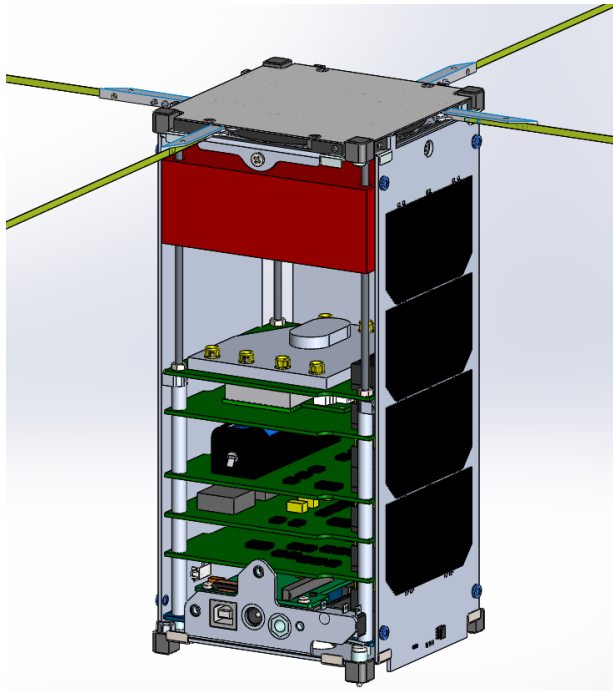
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CSUNSat1



CSUN/JPL CubeSat Collaboration Program

- Funded by NASA's 2013 Small Spacecraft Technology Program (1 FTE/yr for 2 yrs)
- Time frame: 11/1/2013 – 9/27/2015



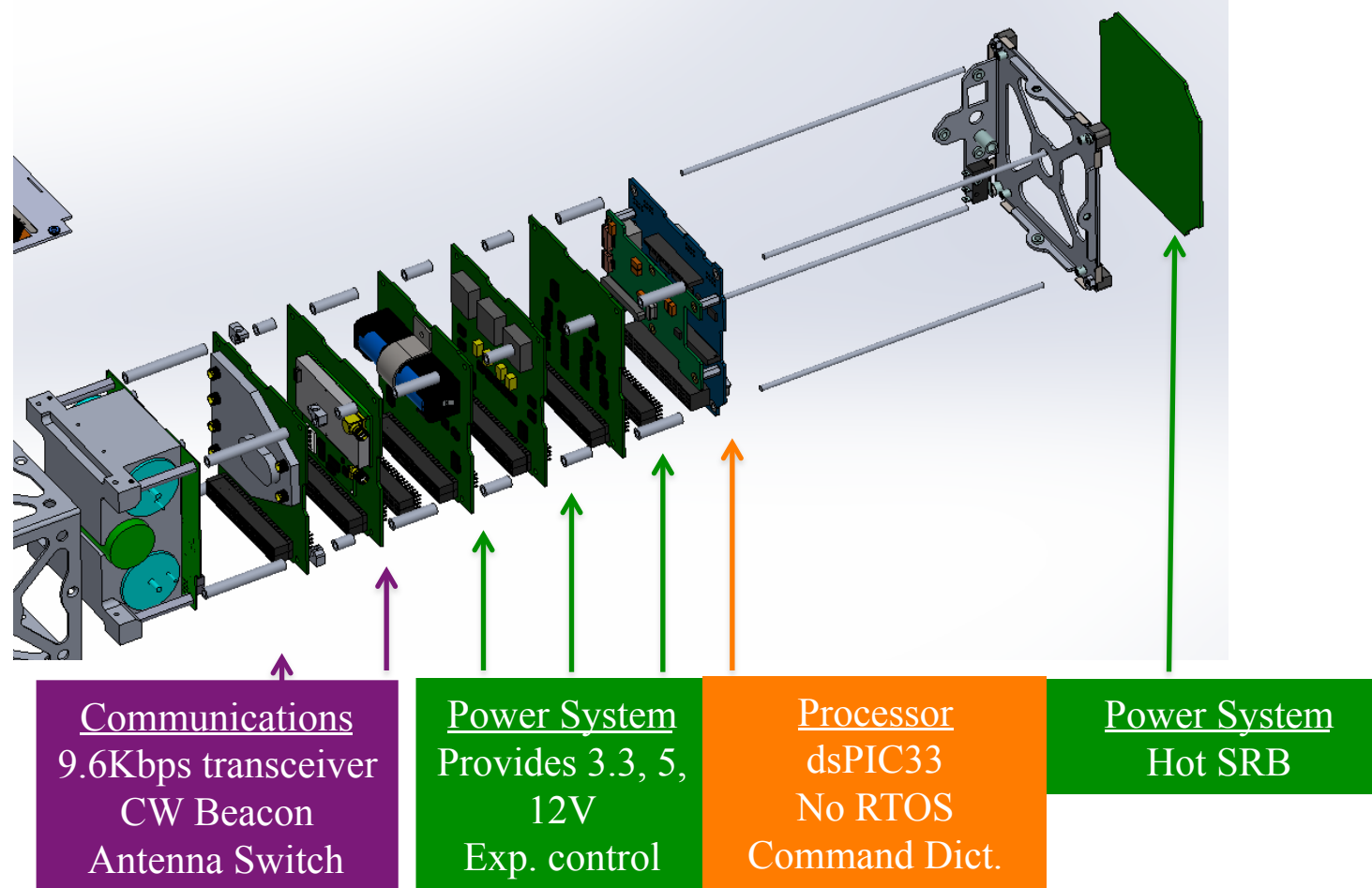
JPL Energy Storage Payload

CSUNSat1

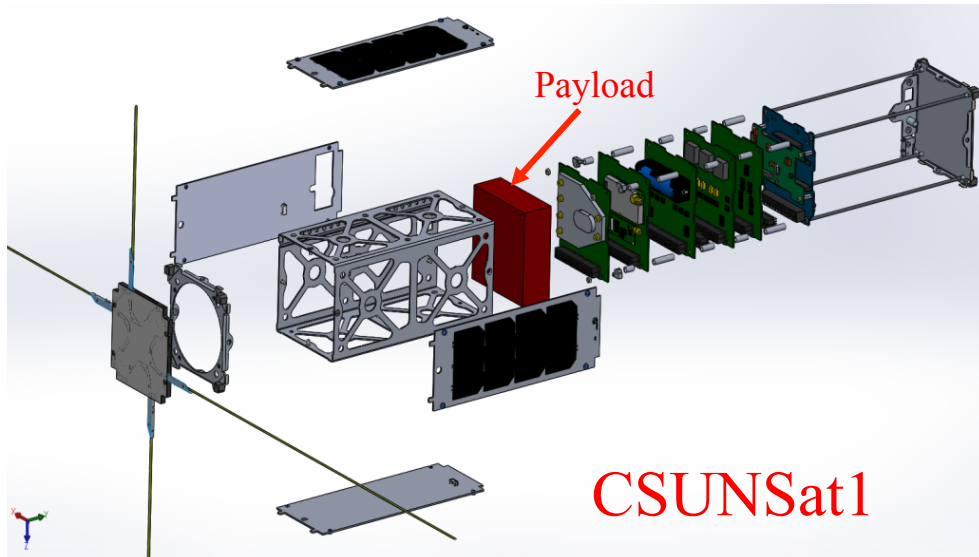
- 2U CubeSat
 - Processor
- Communications
- Power System



CSUNSAT1: Overview

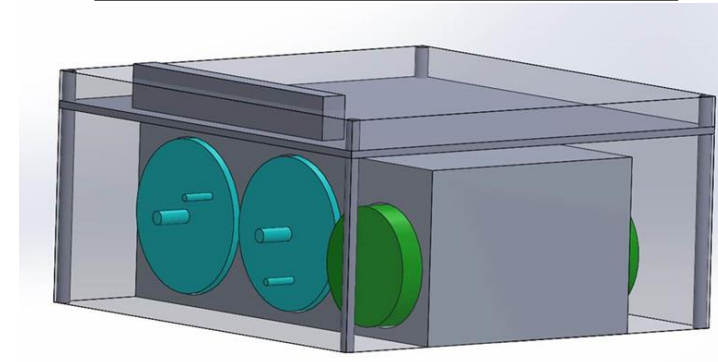


CSUNSat1/Payload System Overview



Payload Components:

1. Battery cell
2. Super-capacitors
3. Payload electronics



Payload Physical Parameters

Value

Total Mass (gm)	510.0
Width (cm)	9.0
Length (cm)	9.6
Thickness (cm)	4.7
Total Volume (cm ³)	483.8

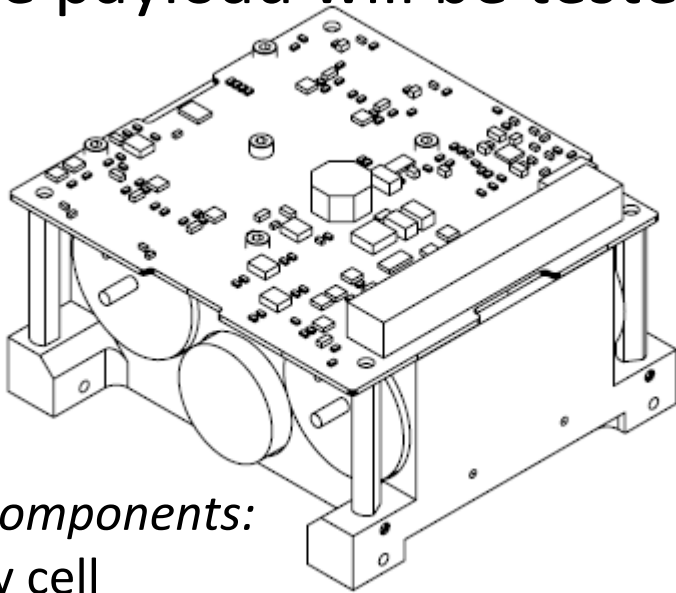


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Payload

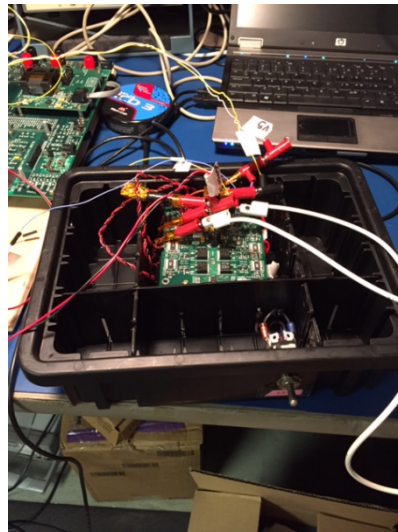
Payload Overview

- The payload consists of an electronics board, 2 supercapacitors and one low temperature Li-Ion Battery
- All interfaces with the CubeSat are through the cubesat connector
- The payload will be tested by JPL prior to delivery to CSUN



Payload Components:

1. Battery cell
2. Super-capacitors
3. Payload electronics



Payload EM2 integrated testing

Payload Physical Parameters	Value
Total Mass (gm)	510.0
Width (cm)	9.0
Length (cm)	9.6
Thickness (cm)	4.7
Total Volume (cm ³)	483.8



Payload Overview: Energy Storage



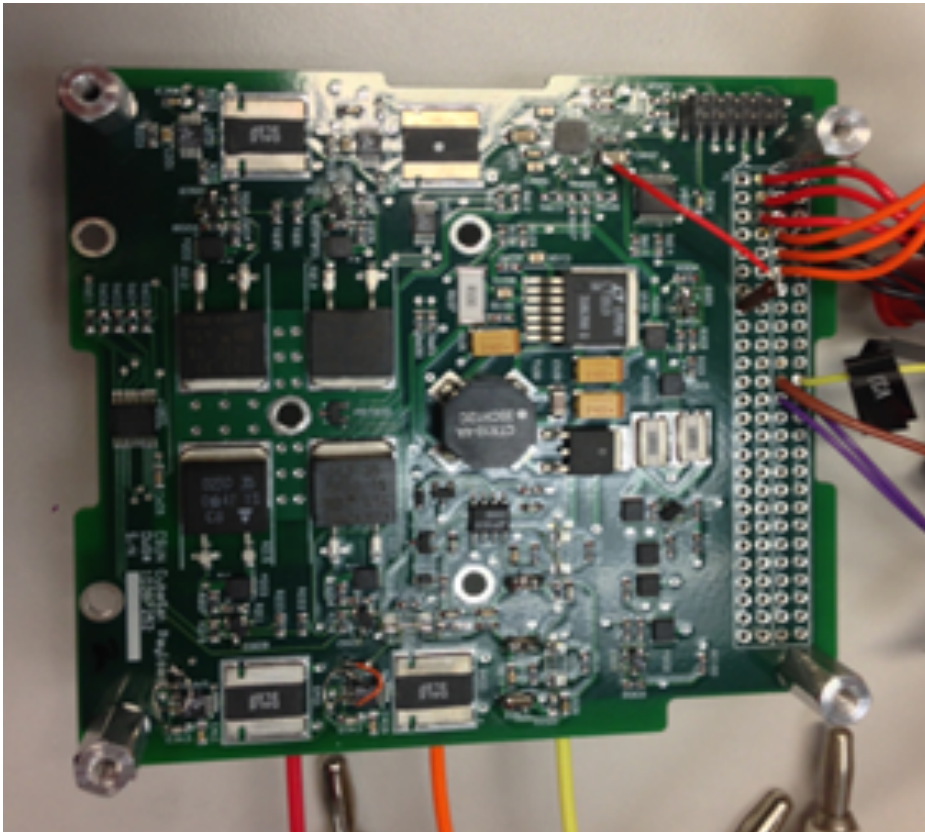
- **Battery**
 - 2.00V to 3.60V nominal operation.
 - ~ 2.20 Ah
 - [-40C - +20C] operating temperature range



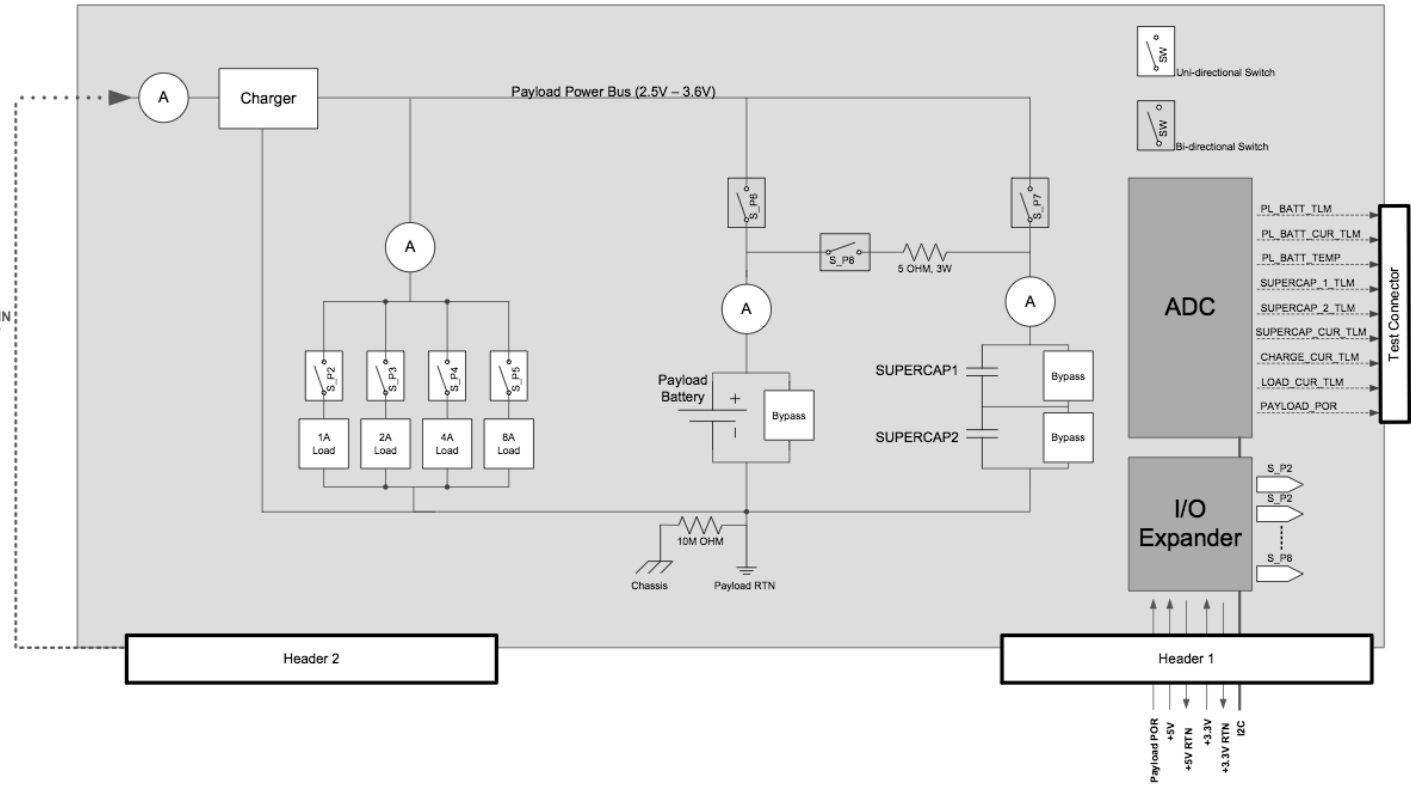
- **Supercapacitor (2 per payload)**
 - 350F each
 - [-40C - +20C] TBR temperature range



Payload Overview: Electronics



CHARGE_IN
V - 4.1V
2.5A





Payload Electronics

Key Features

- **Simple I2C Interface**
 - **Local ADC and port expander**
- **Telemetry**
 - **Battery and Capacitor Voltages and Currents**
 - **Battery Temperature**
 - **Charger and load currents**
- **Load Circuit**
 - **1-15A in 1A increments**
- **Hardware Fault Protection**



Payload Electronics Fault Protection

FP type	Fault Condition	Action	Detection	Cleared	Comments
Battery over voltage	>3.7V	Clamp Battery string	Clamp	Clamp unclamps	Battery is overcharged
Battery voltage	<1.95V	Disconnect discharge FET but not charge FET so battery can charge	Software	Software	Not a safety issue. Battery below min. capacity.
Battery Temperature	>40°C	Switch Off Battery – Switch off both charge and discharge FET	H/W	H/W < 38 °C no longer a safety issue	Potential shorted battery
Supercap cell voltage	>2.85V	Bypass charge current	H/W	H/W	Charge current bypasses the cell
Supercap cell voltage	<0V	Supercap offline	S/W	S/W	Vented?!
Deploy Switch	<0.5V	Ensure that payload battery and Super-capacitor are completely disconnected	H/W	H/W	This signal is to be kept low during launch.



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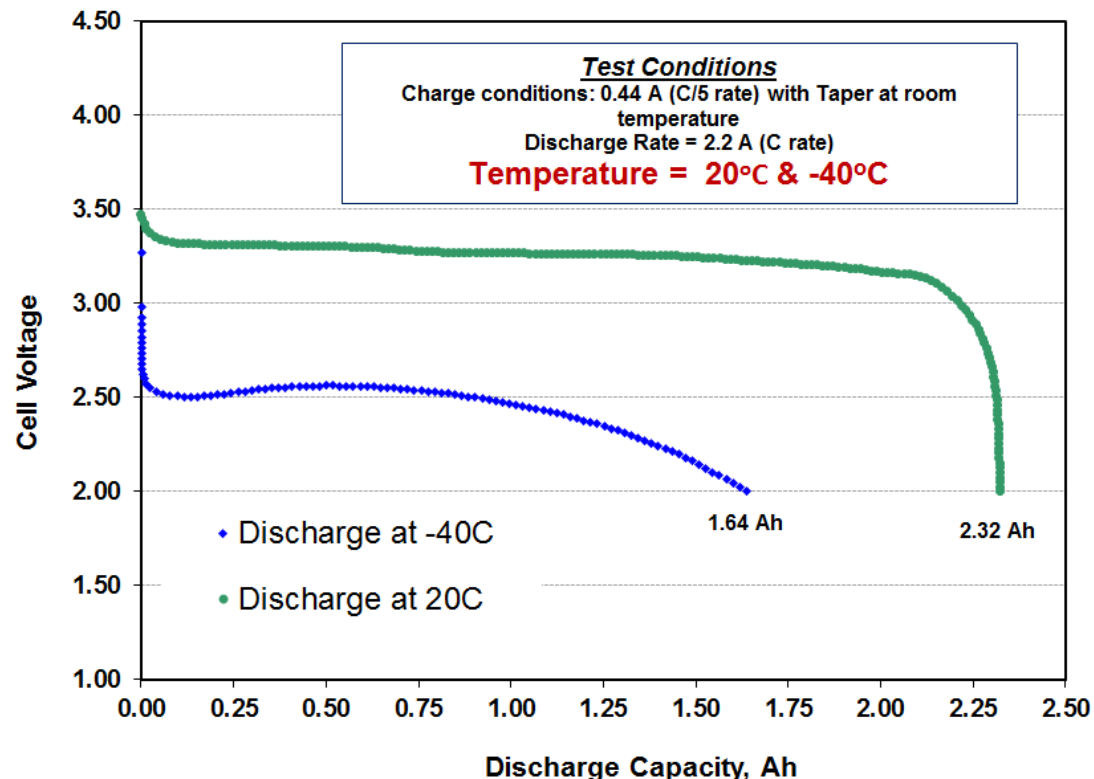
Payload Testing



Low Temperature Electrolyte Li-ion Cell

Navitas/A123 Li-Ion Cell (LiFePO_4)

JPL Electrolyte: 1.20M LiPF_6 in EC+EMC+MB (20:20:60 vol %) + 2% VC



Greater than 2x capacity in 26650-size cell (70 gm).

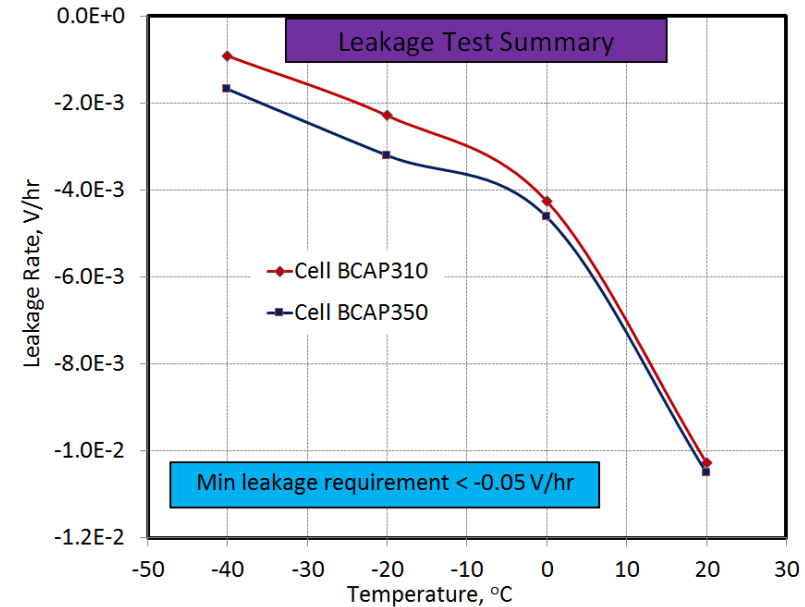
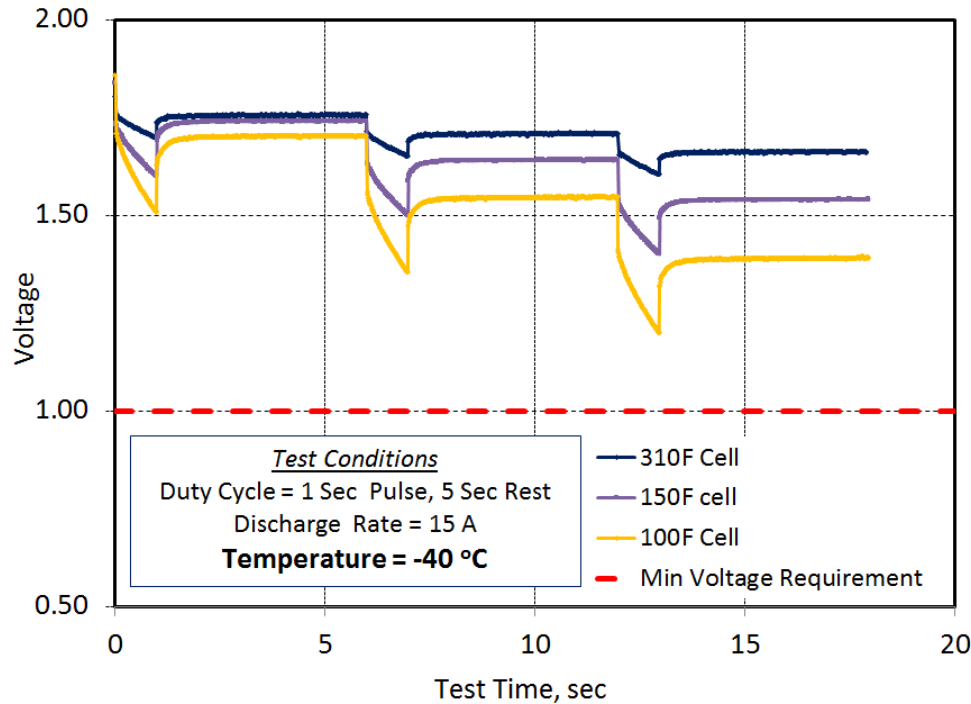
Greater than 70% of maximum capacity retention at -40°C.

Reference: M. C. Smart, B. V. Ratnakumar, K. B. Chin, L. D. Whitcanack, and S. Surampudi, "Performance Characteristics of Lithium-Ion Technology Under Extreme Environmental Conditions," *1st International Energy Conversion Engineering Conference, IECEC*, Portsmouth, VA, Aug. 17–21 2003.



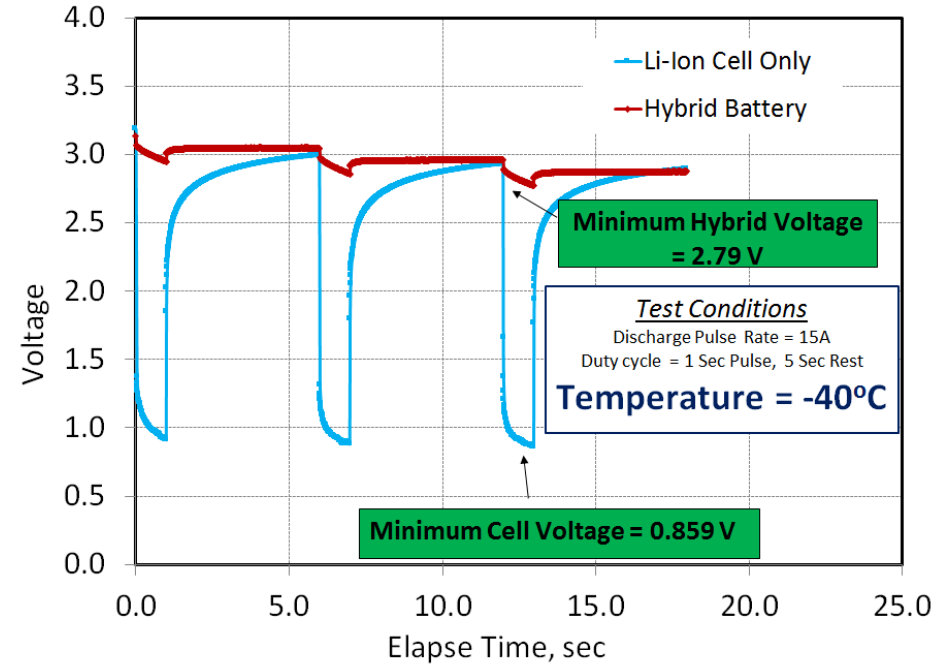
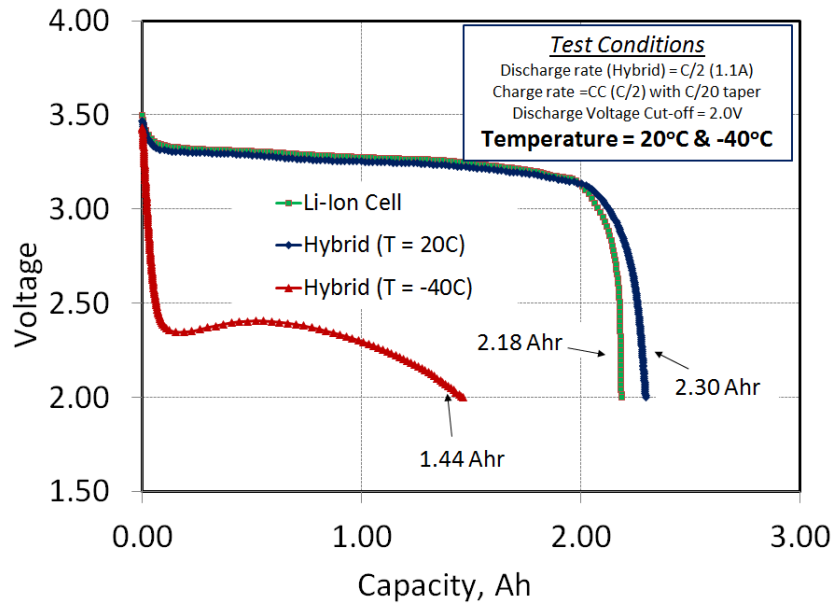
Super-capacitor Cell Test Performance

Maxwell Technologies – 100 to 310F Boostcaps



Super-capacitors greater than 100F will support worst-case 15A pulse loads down to -40°C.

Hybrid Performance



- Excellent capacity retention at -40°C.

- Substantial power improvements at low temperatures down to -40°C.
- Voltage drop improved by ~2.0V at 15A pulse when compared against low temperature Li-ion cell.



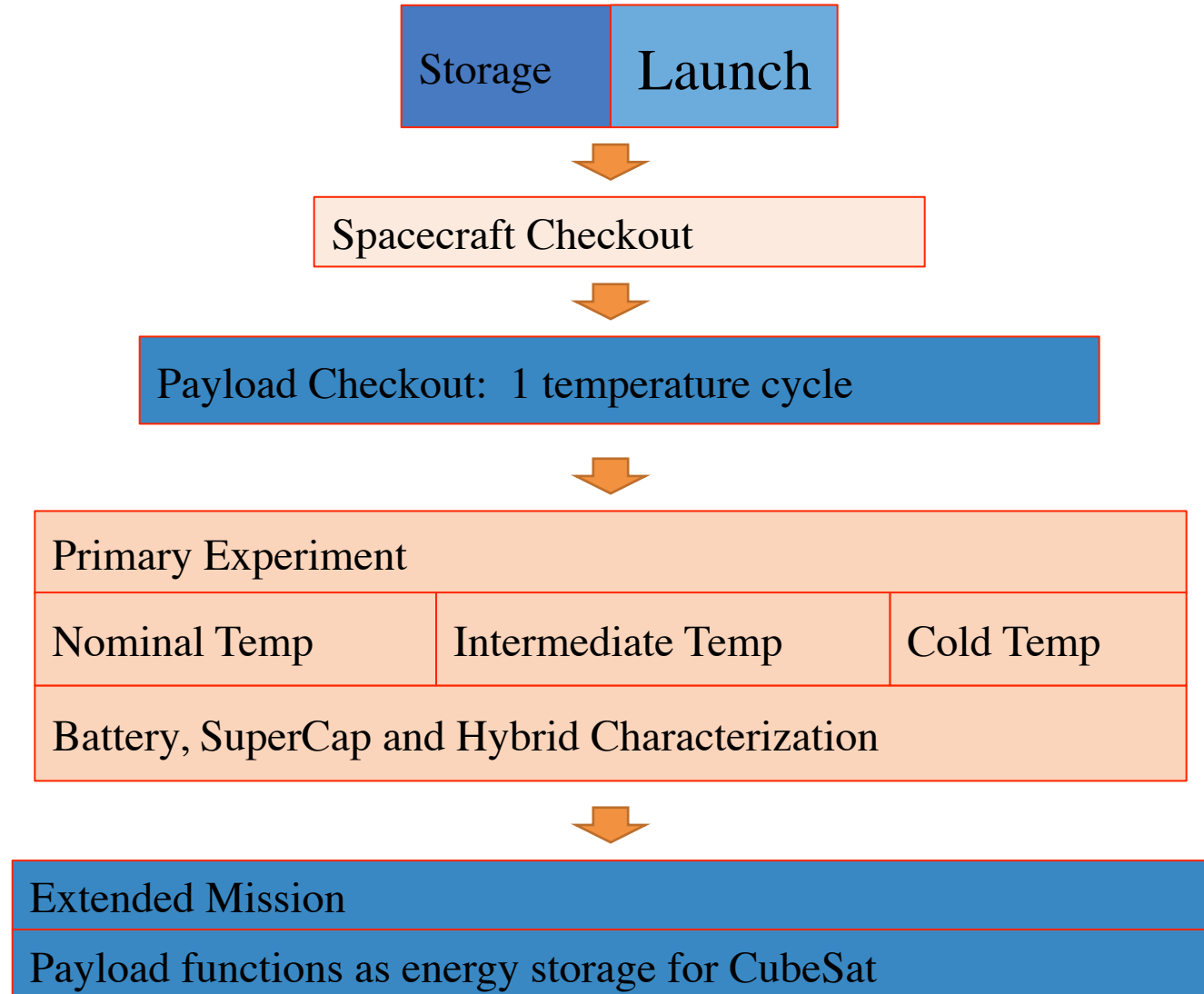
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In Flight Sequences



Concept of Operations: Overview





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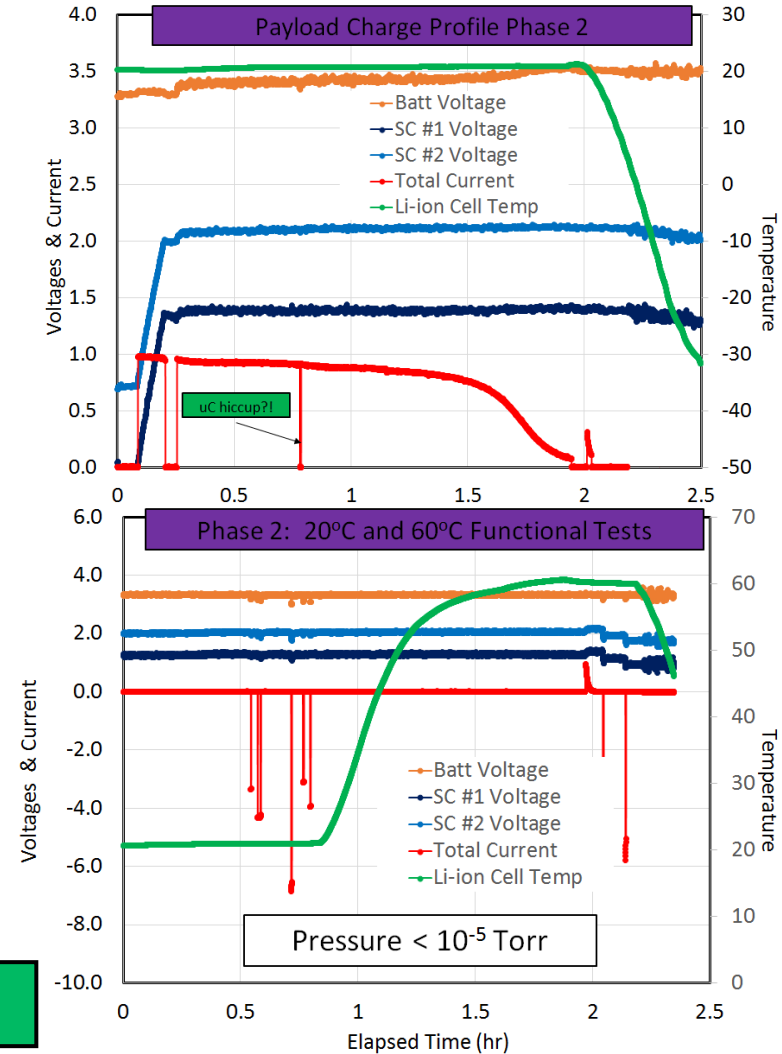
Integration and Test



JPL Environmental Testing

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Pressure < 10⁻⁵ torr



- No mass loss, no cell rupture under vacuum!

Payload Development & Assembly

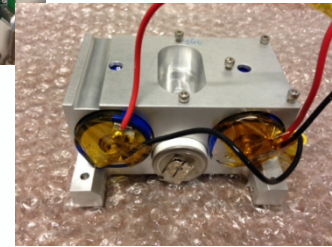
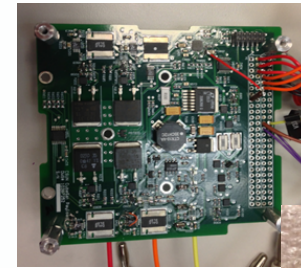


Cell Assembly



Flight Cells

Final Cell Selection



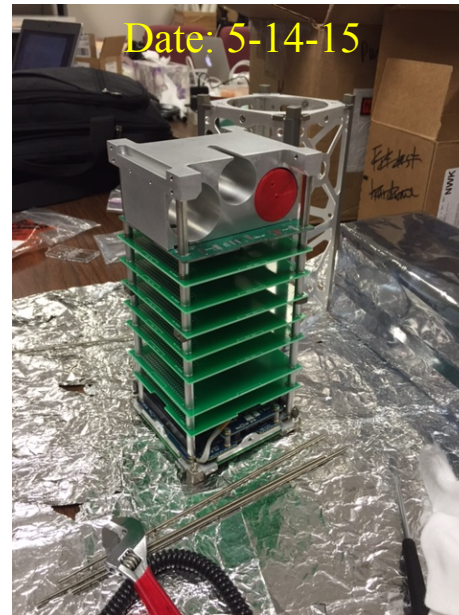
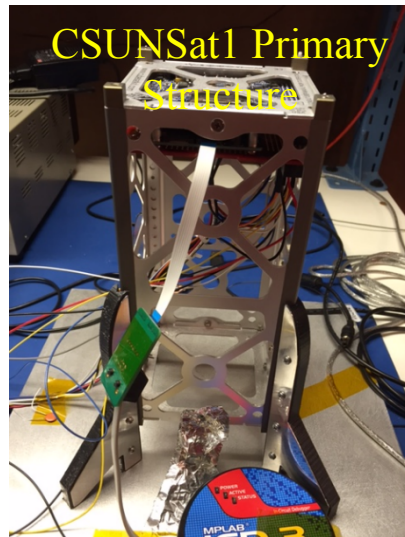
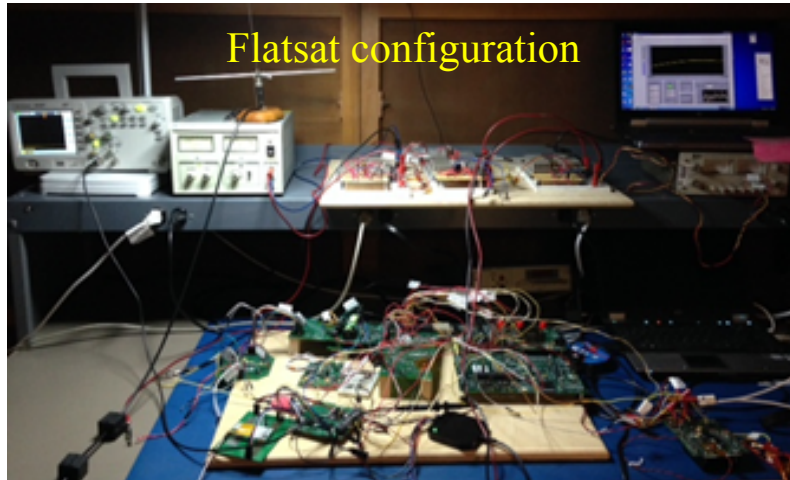
Flight Unit



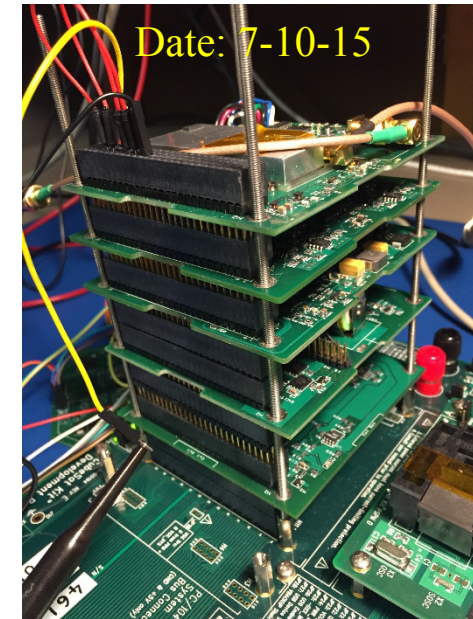
Final Integration



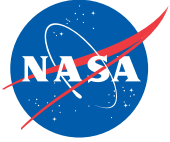
CSUNSat1 Systems Integration



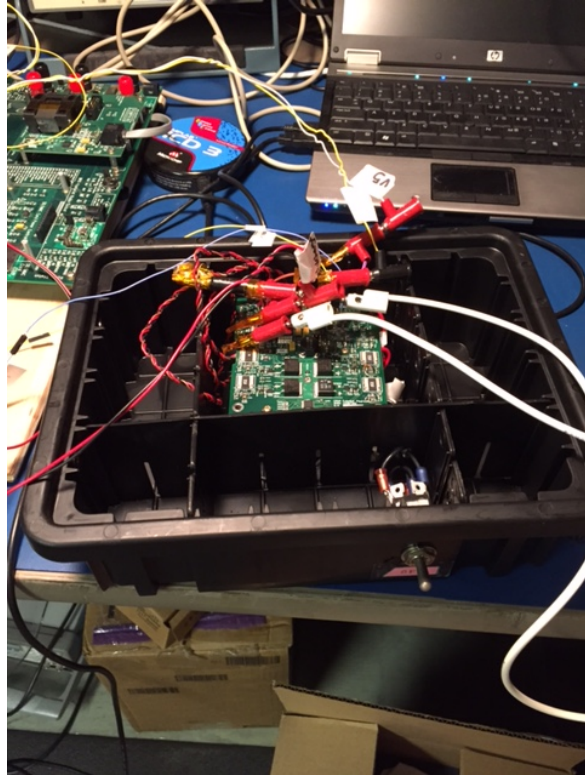
CSUNSat1 Fit
Check



CSUNSat1 Stack
Assembly



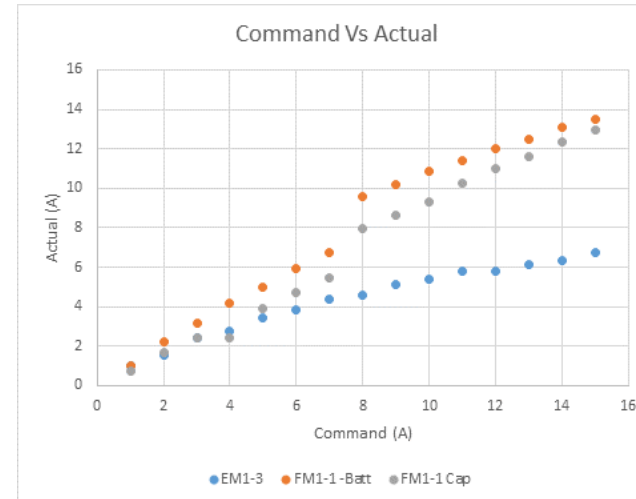
Flight Payload Testing - Successful

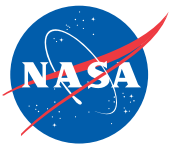


Payload FM Integrated Testing

Case E - 14A pulse

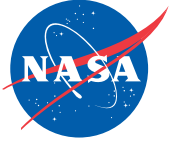
CH0 - PL_BATT_TLM is 1.48743 volts - Actual is 2.95958 volts
 CH1 - PL_BATT_CURR_TLM is 0.69763 volts - Actual is **-6.96005** amps
 CH2 - PL_BATT_TEMP is 0.33875 volts - Actual is 19.60039 C
 CH3 - SUPERCAP_1_TLM is 1.50574 volts - Actual is 2.98971 volts
 CH4 - SUPERCAP_2_TLM is 0.59265 volts - Actual is 1.10180 volts
 CH5 - SUPERCAP_CURR_TLM is 0.62927 volts - Actual is **-7.87281** amps
 CH6 - CHARGE_CURR_TLM is 0.00000 volts - Actual is -0.00260 amps
 CH7 - LOAD_CURR_TLM is 2.07458 volts - Actual is **14.85834** amps





Conclusions

- JPL Hybrid energy storage system exhibited excellent energy storage (>2x) and power (8C-rate) capabilities down to -40°C.
 - ❖ Capacity retention >70%.
 - Capacity retention for state of practice battery < 20%.
 - ❖ Supports >15A pulse current down to -40°C.
 - ❖ COTS cell design is functional in space environment.
 - ❖ **Potential applications:** radar systems, laser payloads, etc.
- Future work
 - ❖ Integrate payload to CSUNSat1.
 - ❖ Conduct experiments in the space environment.



CSUN Acknowledgement

- Dr. Sharlene Katz: Sharlene.katz@csun.edu
- Prof. James Fynn: James.flynn@csun.edu





JPL Acknowledgement

- Naomi Palmer - Team Leader/Manager
- Keith Chin – Energy Storage Lead
- JPL Energy Storage Team
 - Marshall Smart
 - Erik Brandon
 - Keith Chin



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