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

G.S. Bolotin* K.B. Chin, M.C. Smart, E.J. Brandon, N.K. Palmer

Jet Propulsion Laboratory, California Institute of Technology

4800 Oak Grove Drive, Pasadena, CA 91109

*gary.s.bolotin@jpl.nasa.gov

S. Katz, J.A. Flynn

California State University, Northridge

Dept. of Electrical and Computer Engineering

Northridge, CA 91330-8346

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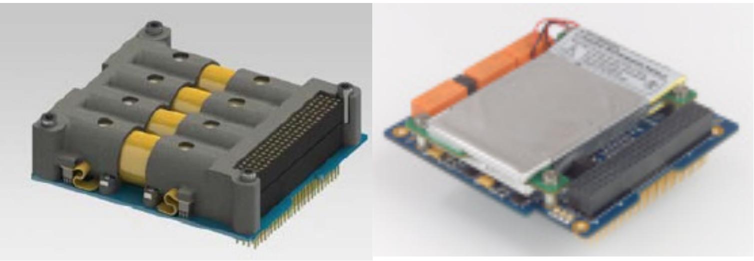
Outline

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

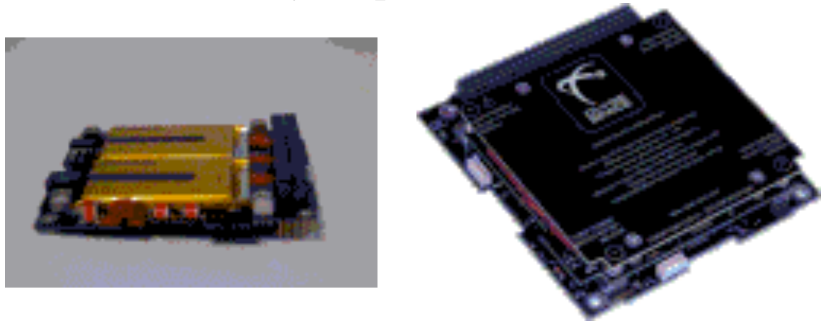
Motivation

Commercially available CubeSat Battery Systems

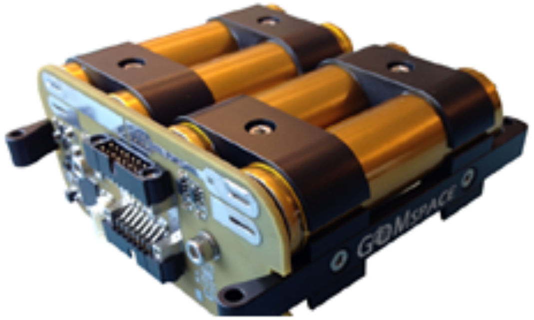
Cubesatkit/Pumpkin



ClydeSpace



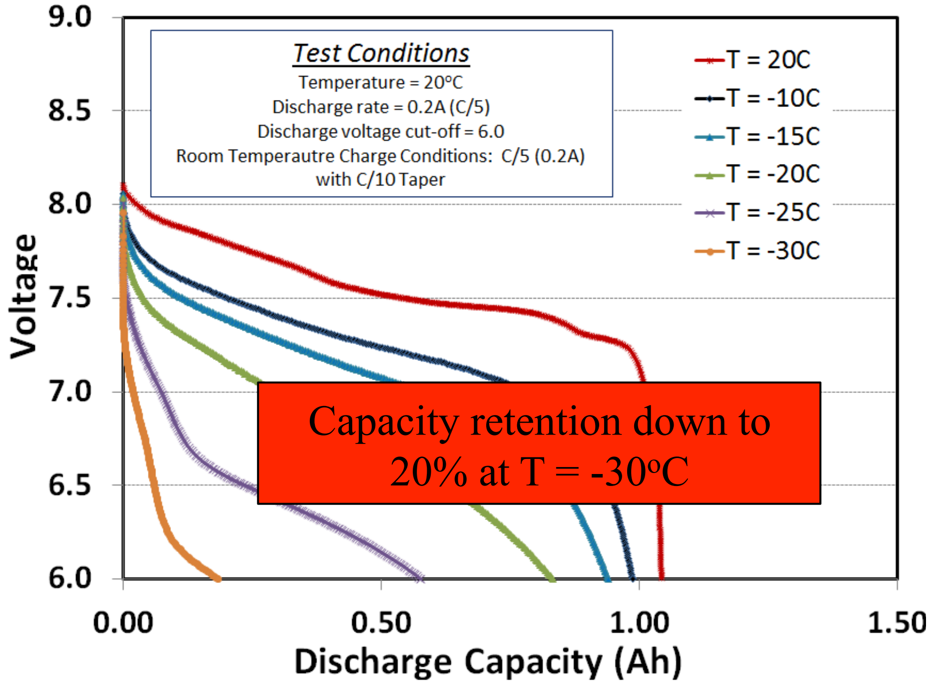
GOMSpace



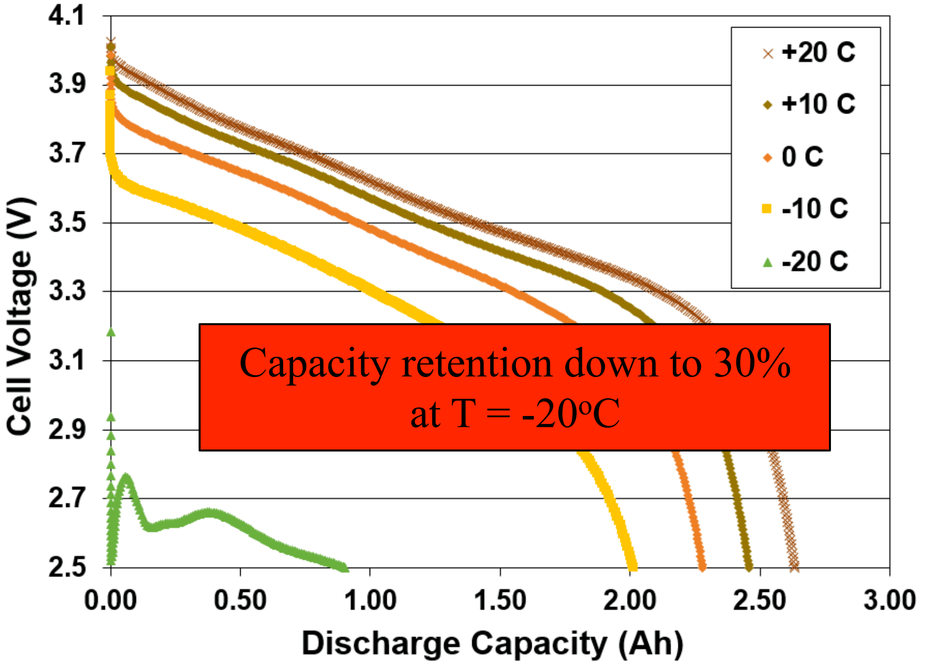
❖ Commercial Li-ion chemistries for CubeSat applications exhibit limited performance for high power and low temperatures < -20^{o}C.

Commercial Li-ion Cell Performance

Li-Ion Polymer Cell



Li-Ion 18650 Cell



- ❖ Commercial Li-ion chemistries for CubeSat applications exhibit limited performance for high power and low temperatures < -20°C.

Our Technology

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NASA's Future SmallSat Missions

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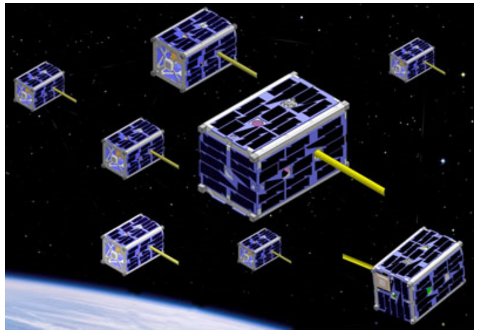
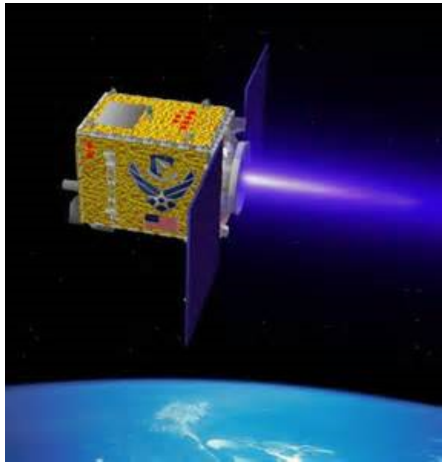
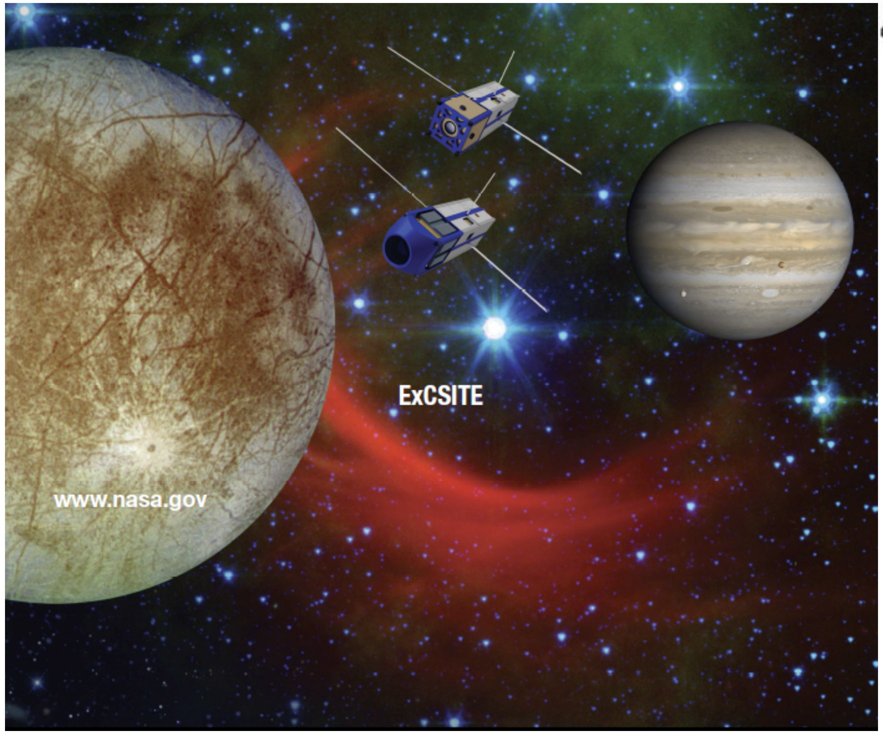
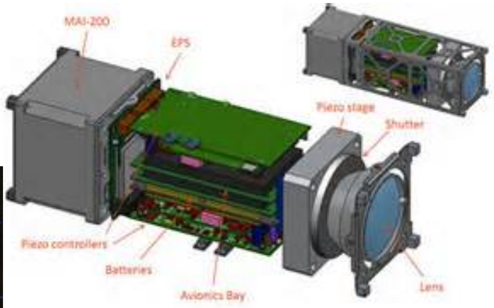






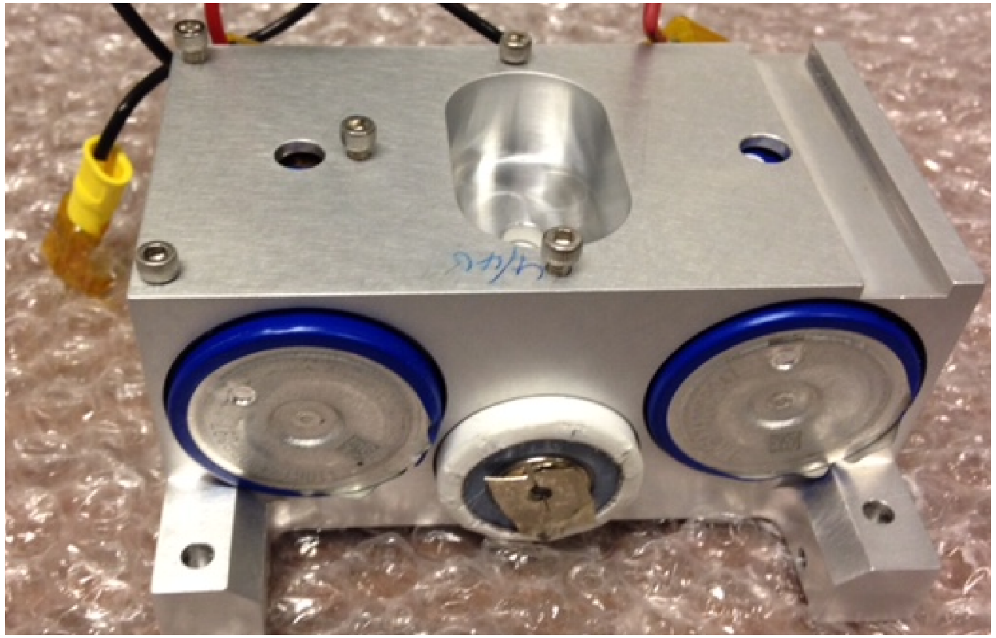


Small satellites beyond LEO orbits will require operation at lower temperatures.
This leads to the need for a cold capable energy storage system.

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)

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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

CSUNSat1

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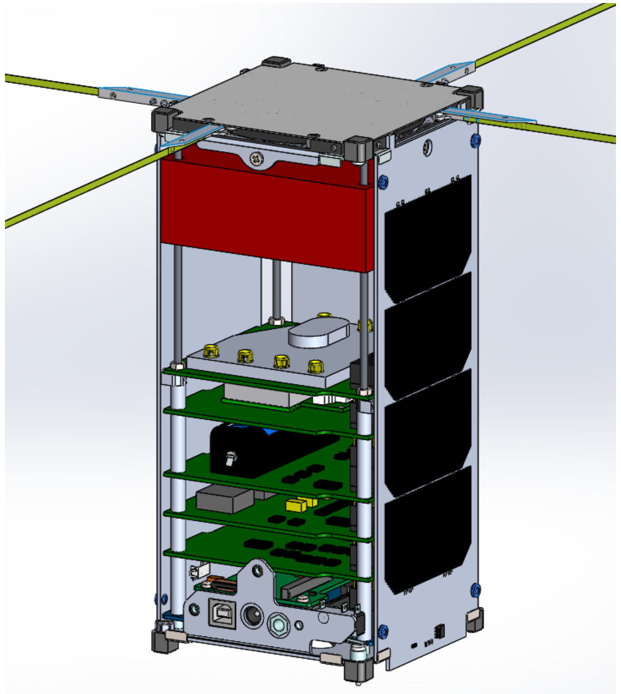
CSUN/JPL CubeSat Collaboration Program

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

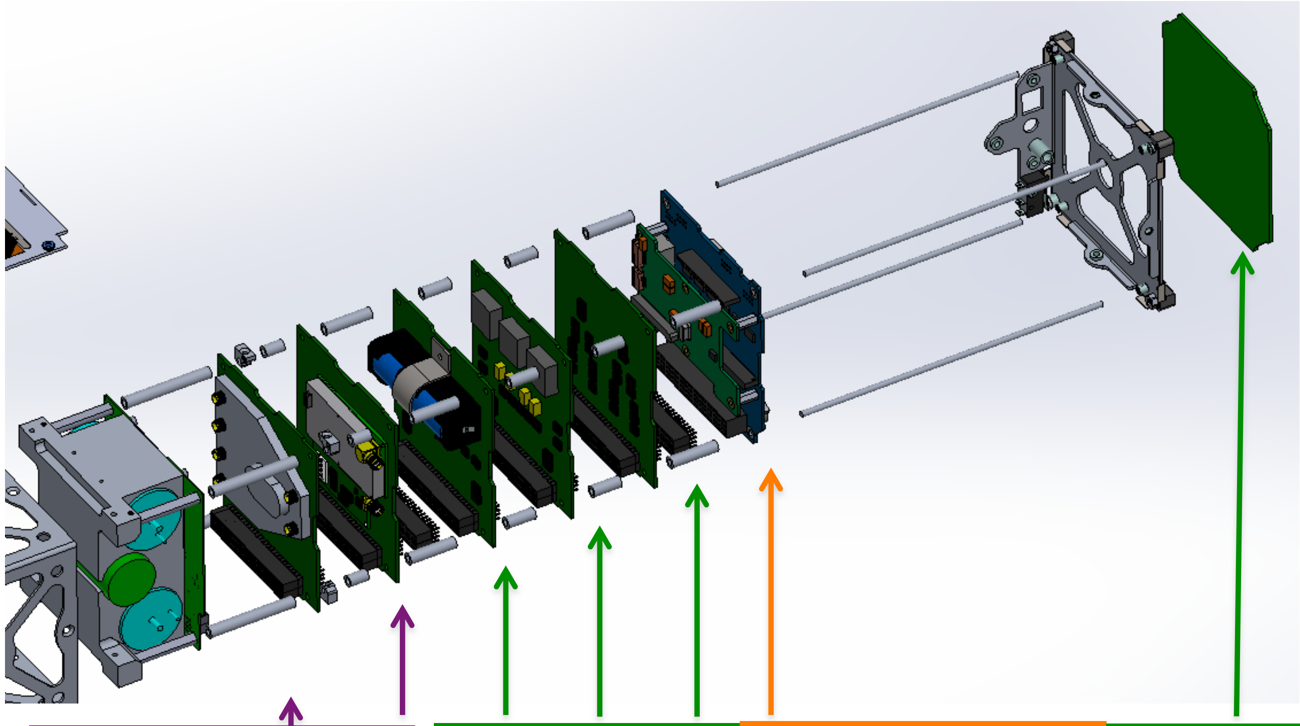


JPL Energy Storage Payload

CSUNSat1

- 2U CubeSat
- Processor
- Communications
- Power System

CSUNSAT1: Overview



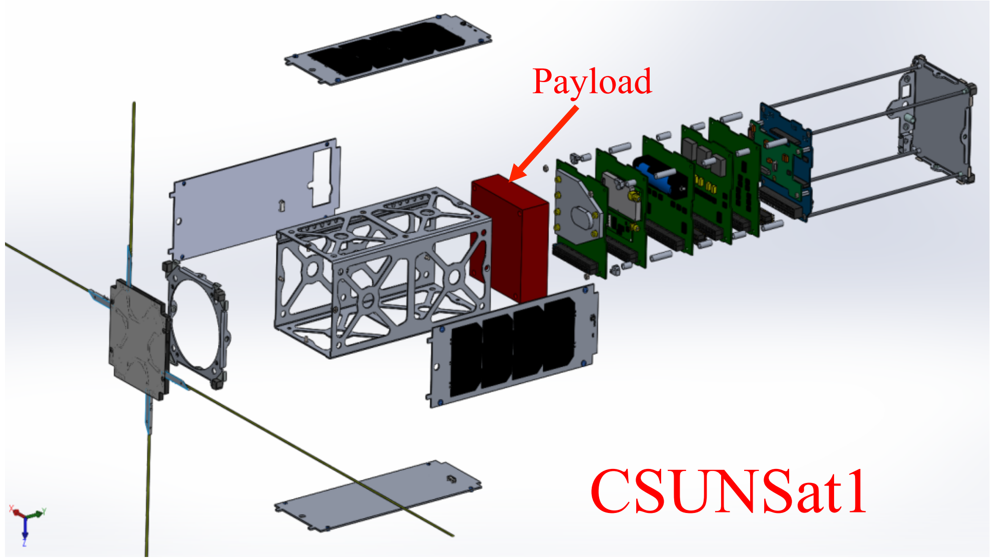
Communications
9.6Kbps transceiver
CW Beacon
Antenna Switch

Power System
Provides 3.3, 5, 12V
Exp. control

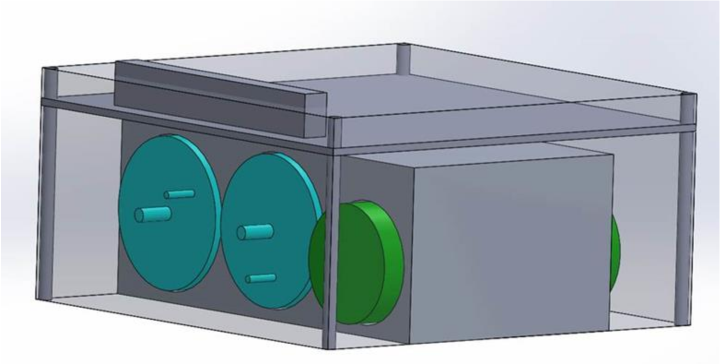
Processor
dsPIC33
No RTOS
Command Dict.

Power System
Hot SRB

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

Payload

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Payload Overview

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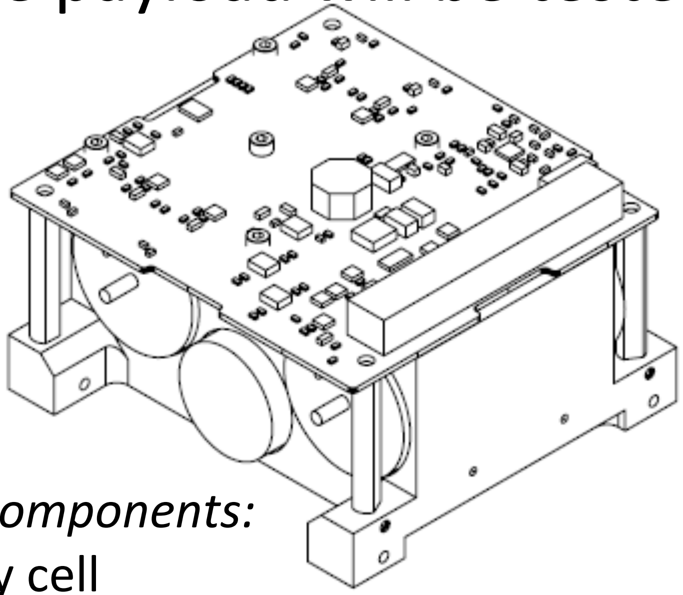
- The payload consists of an electronics board, 2 supercapacitors and one low temperature Li-Ion Battery
- All interfaces with the CubeSat are through the cubesat connector
- The payload will be tested by JPL prior to delivery to CSUN



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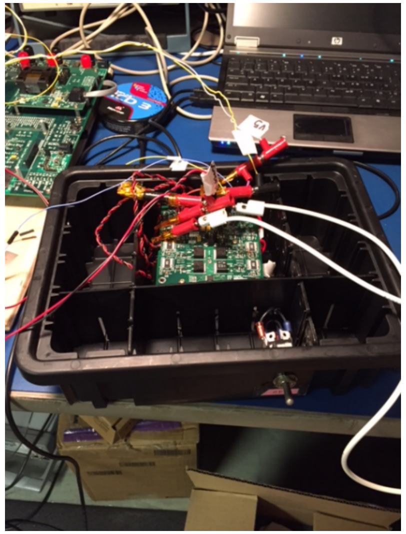

Payload EM2 integrated testing

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

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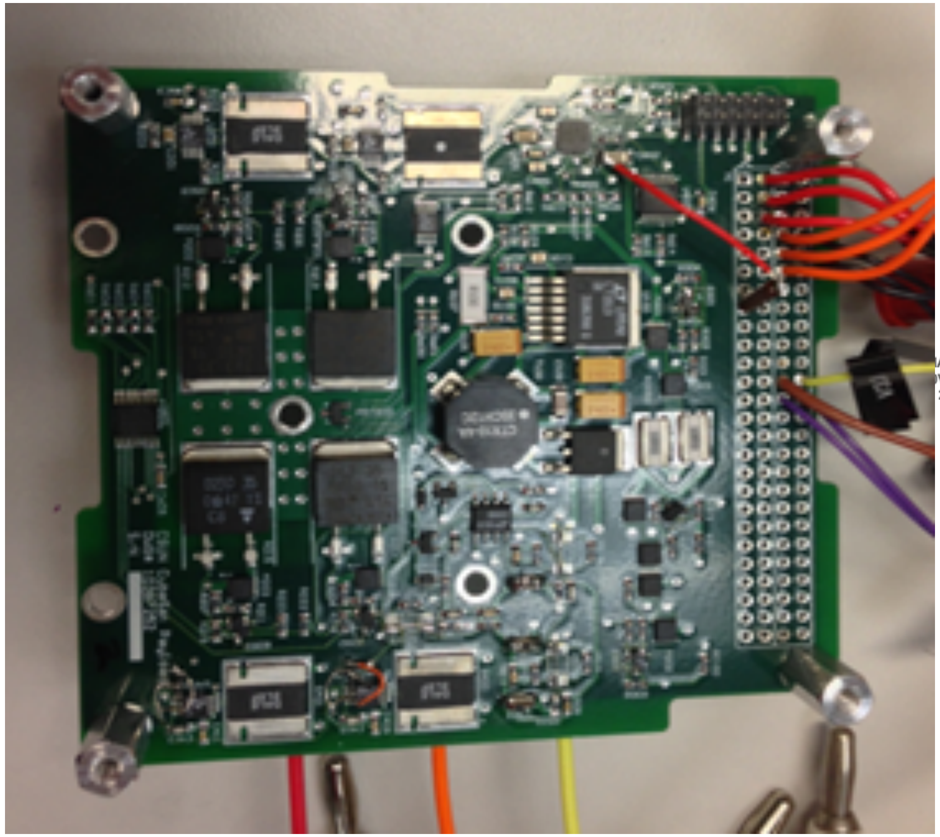

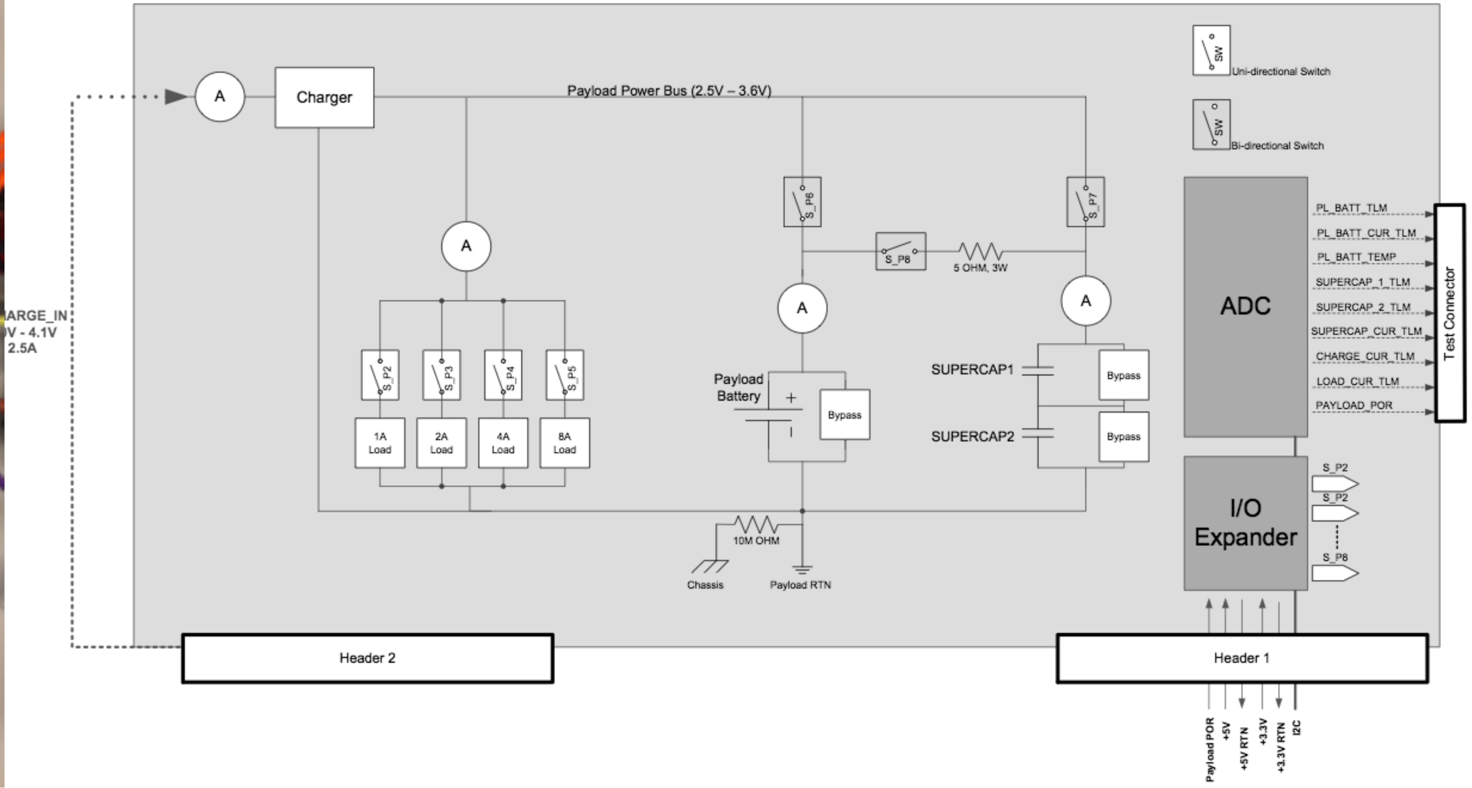

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Payload Electronics
Key Features

- **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**

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Payload Electronics Fault Protection

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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.

Payload Testing

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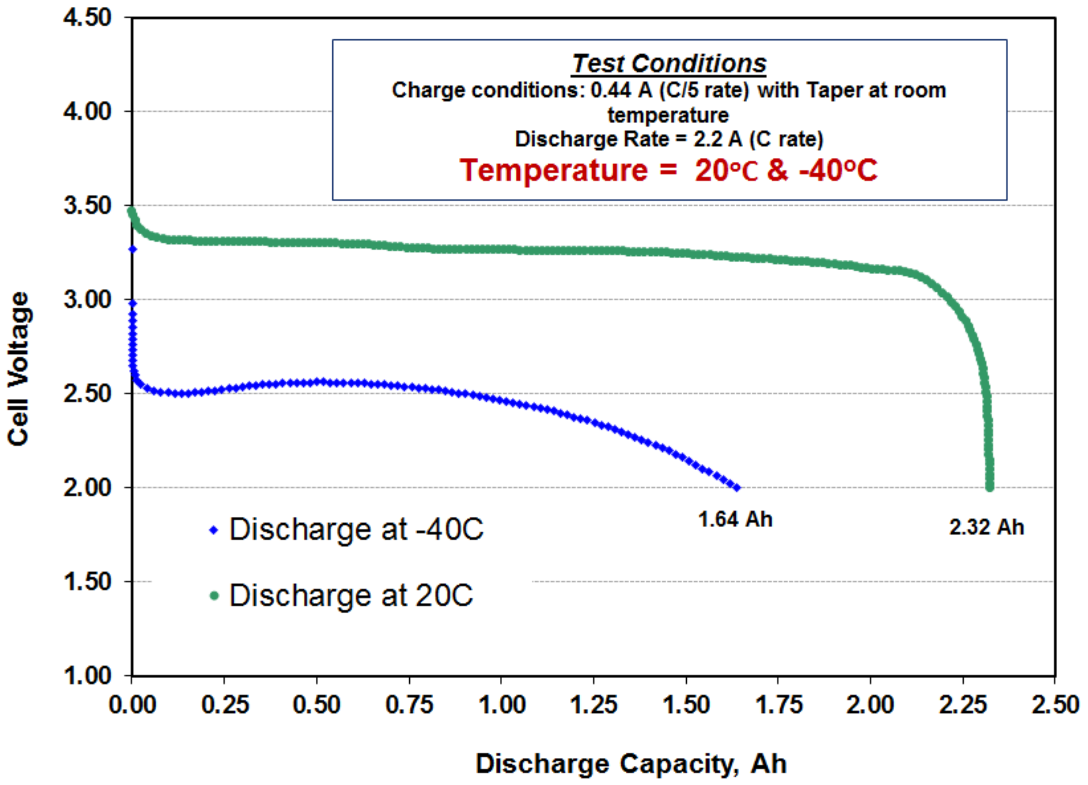
Low Temperature Electrolyte Li-ion Cell

Navitas/A123 Li-Ion Cell ($LiFePO_4$)

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



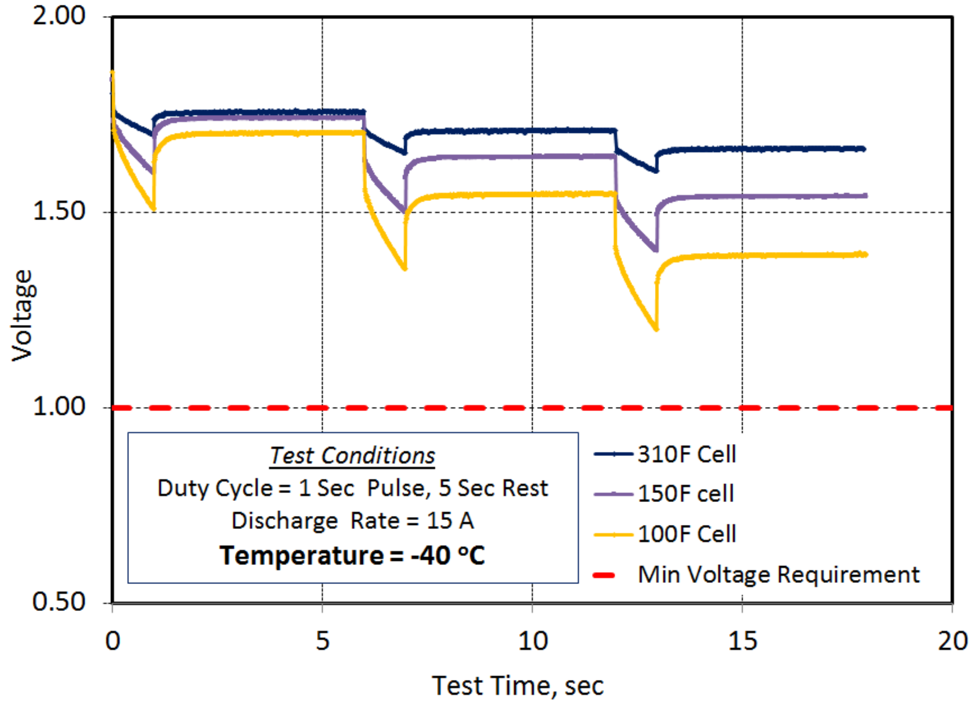
Greater than 2x capacity in 26650-size cell (70 gm).

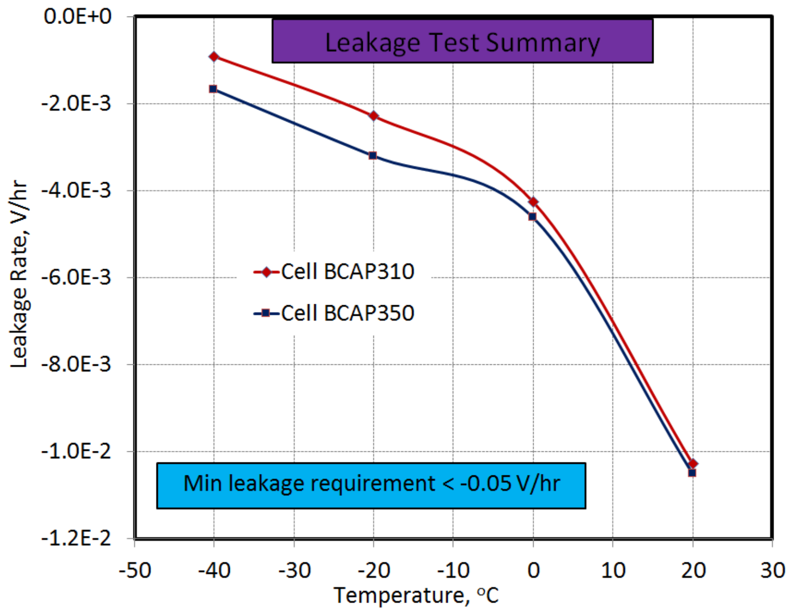
Greater than 70% of maximum capacity retention at -40°C.

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.

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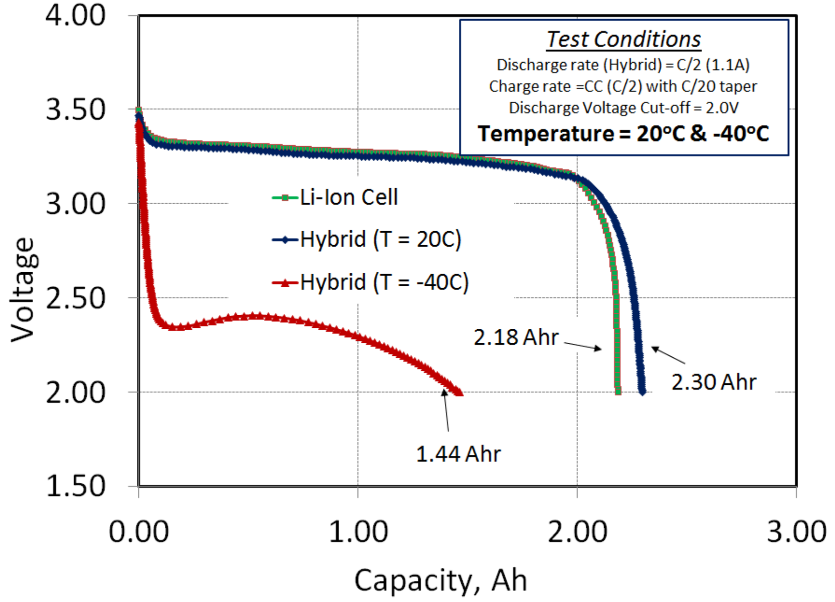
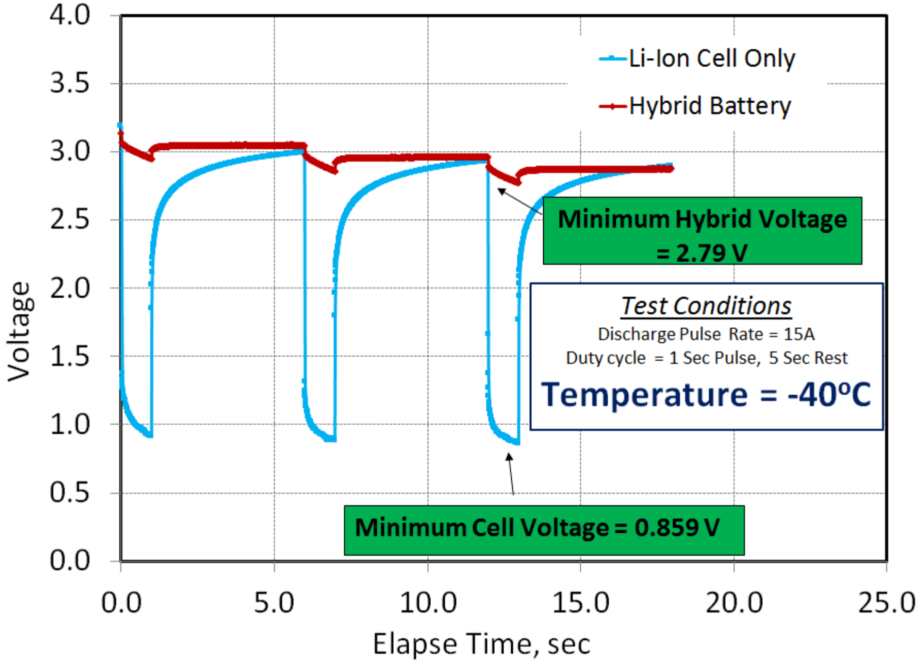
Hybrid Performance





- 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.

In Flight Sequences

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Concept of Operations: Overview

Storage | Launch

↓

Spacecraft Checkout

↓

Payload Checkout: 1 temperature cycle

↓

Primary Experiment

Nominal Temp | Intermediate Temp | Cold Temp

Battery, SuperCap and Hybrid Characterization

↓

Extended Mission

Payload functions as energy storage for CubeSat

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Integration and Test

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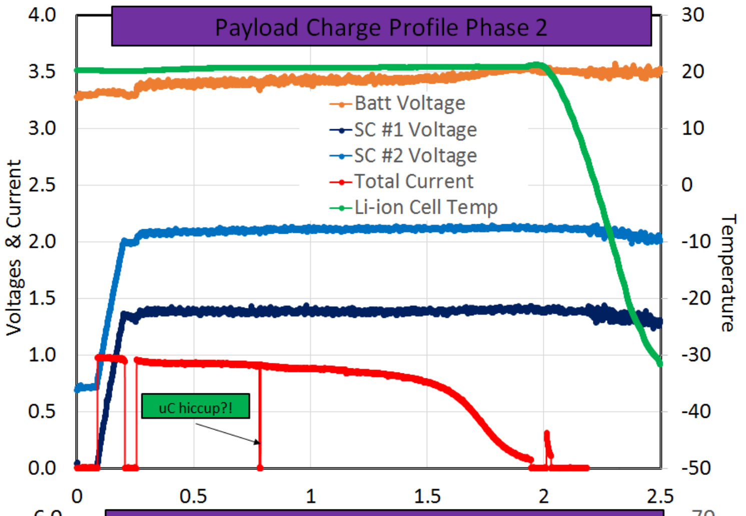
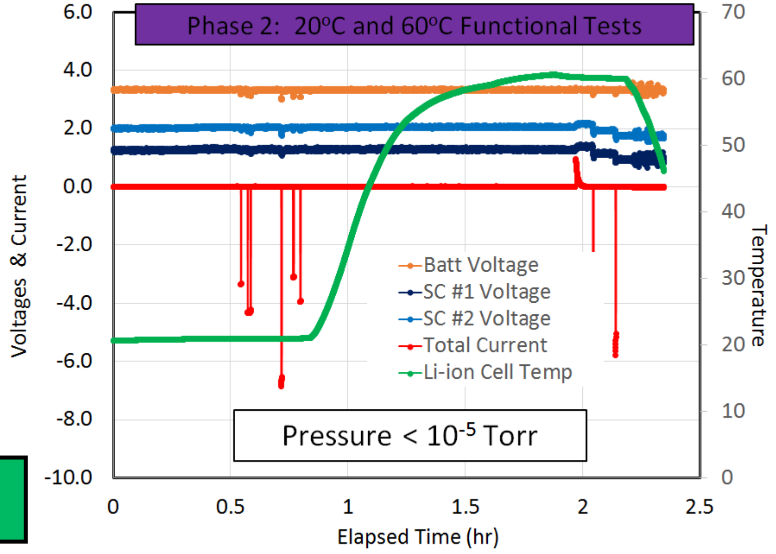
JPL Environmental Testing

Pressure < 10^{-5} torr





- No mass loss, no cell rupture under vacuum!

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Payload Development & Assembly

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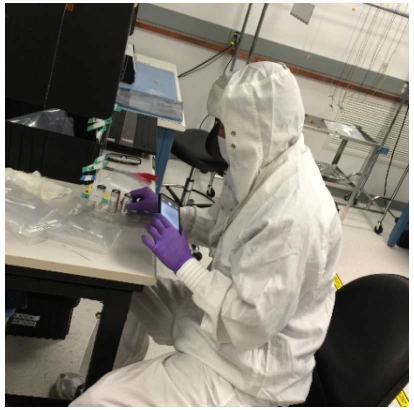
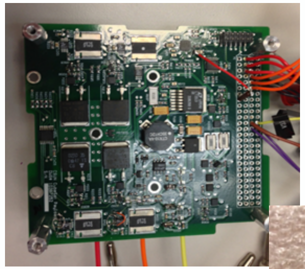
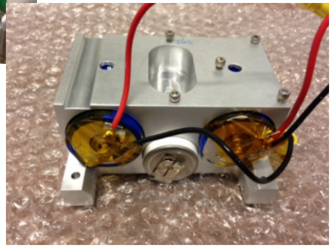


Cell Assembly

Flight Cells

Final Cell Selection





Flight Unit

Final Integration

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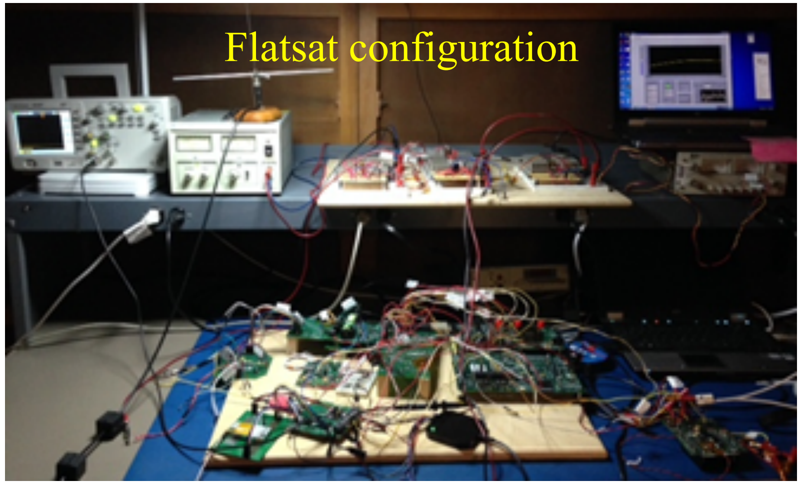
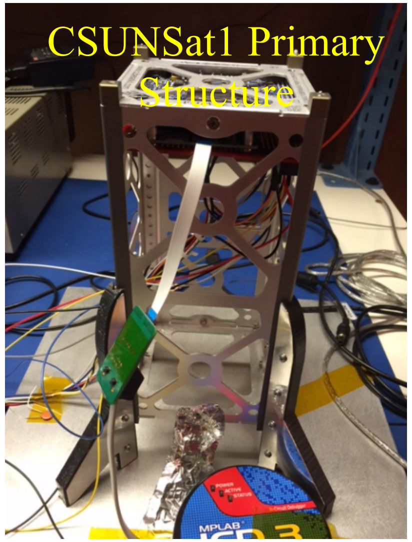
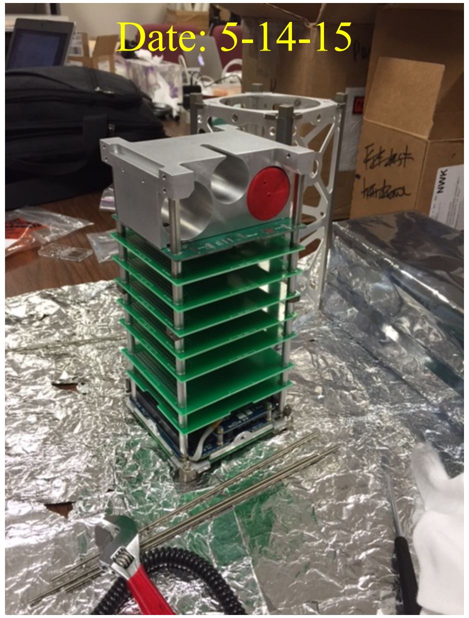
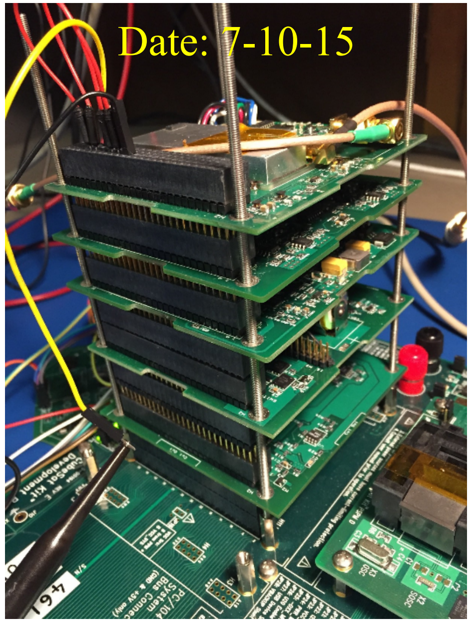
CSUNSat1 Systems Integration







CSUNSat1 Fit Check



CSUNSat1 Stack Assembly

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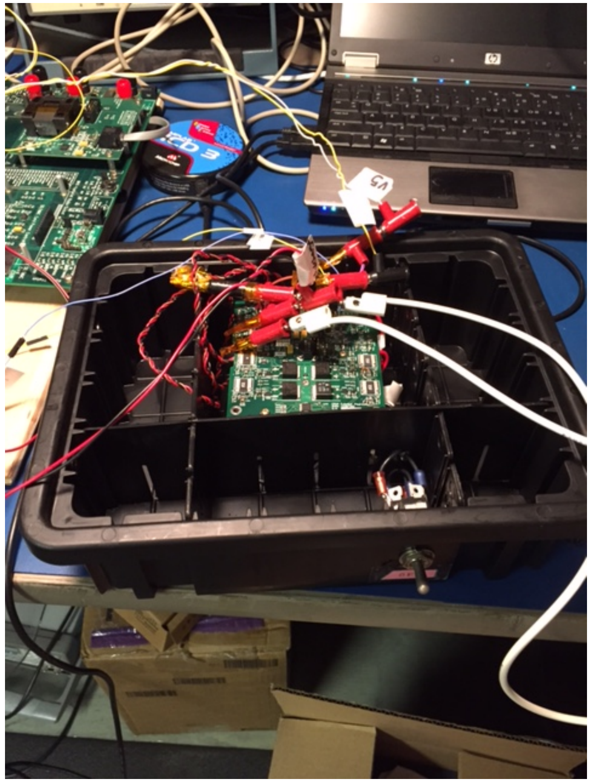
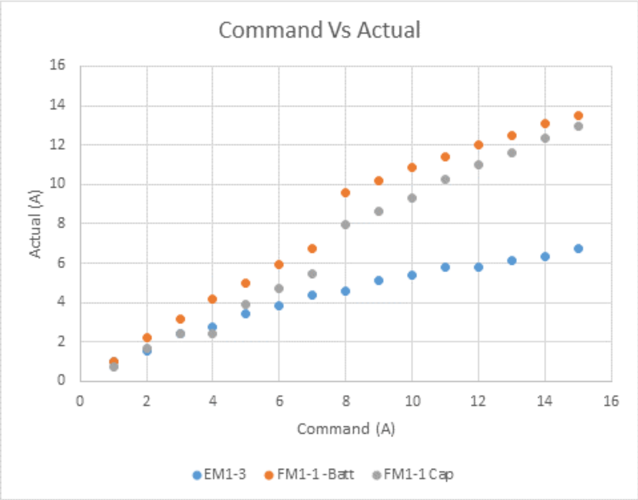
Flight Payload Testing - Successful



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



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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.

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CSUN Acknowledgement

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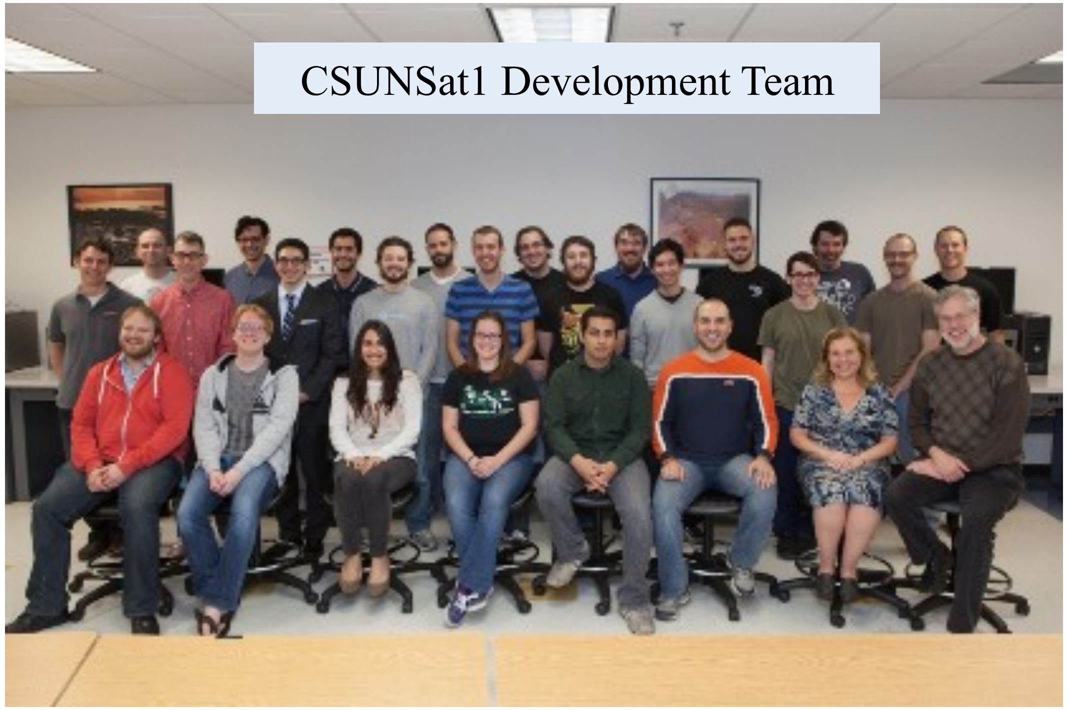
- Dr. Sharlene Katz: Sharlene.katz@csun.edu
- Prof. James Fynn: James.flynn@csun.edu



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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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NASA Acknowledgement

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