Naval Research Laboratory
Li-Ion 30-AH Battery
ORS Phase 3 (TacSat-IV) Project

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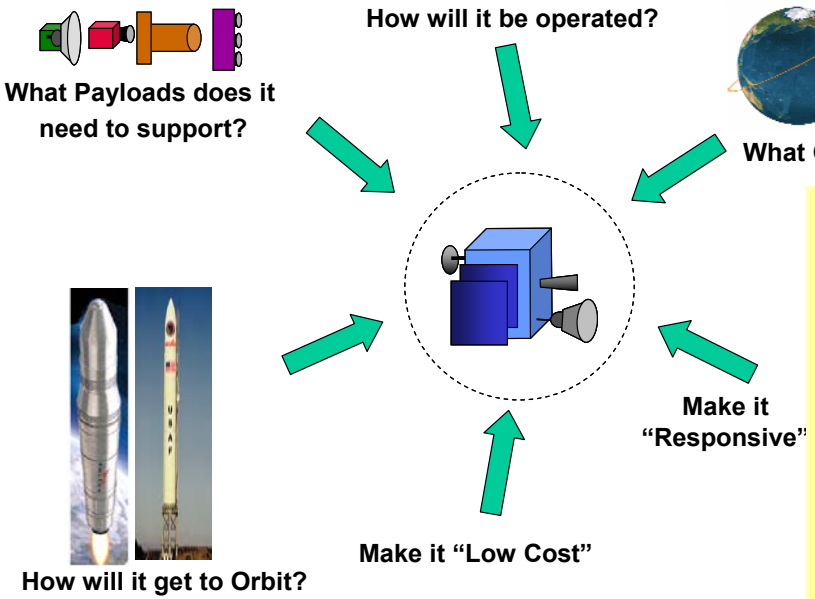
Agenda

- ORS Introduction
- Quallion Battery Cell
- ORS Battery Design
- Pictures of Battery
- Charge/Discharge Data
- Current Status

ORS/ISET* Activities



Charter

Generate a Set of Spacecraft Bus Standards, in Sufficient Detail to Allow a Vehicle Manufacturer to Design, Build, Integrate, Test, and Deliver a Low Cost Spacecraft Bus Satisfying an Enveloping Set of Mission Requirements (Launch Vehicle, Target Orbit, Payload, etc.) in Support of a Tactical Operational Responsive Space Mission

- Government and Industry Team Defined Capabilities
- Documents created to capture capabilities include
  - Payload Developers Guide (For payload developer independent of Bus Fab)
  - General Bus Specification (performance capabilities of the Bus)
  - Software Interface Standards (Ground – Bus and Bus – Payload)

* Operationally Responsive Space/Integrated System Engineering Team

Document Descriptions

Spacecraft Bus Prototype

Payload Developers Guide
- Mechanical, Electrical, Thermal Interface Definition

General Bus Specification
- Performance Characteristics,
- Launch Vehicle Interfaces, etc.

Software Interface Standards
- Space to Ground
- Bus to Payload

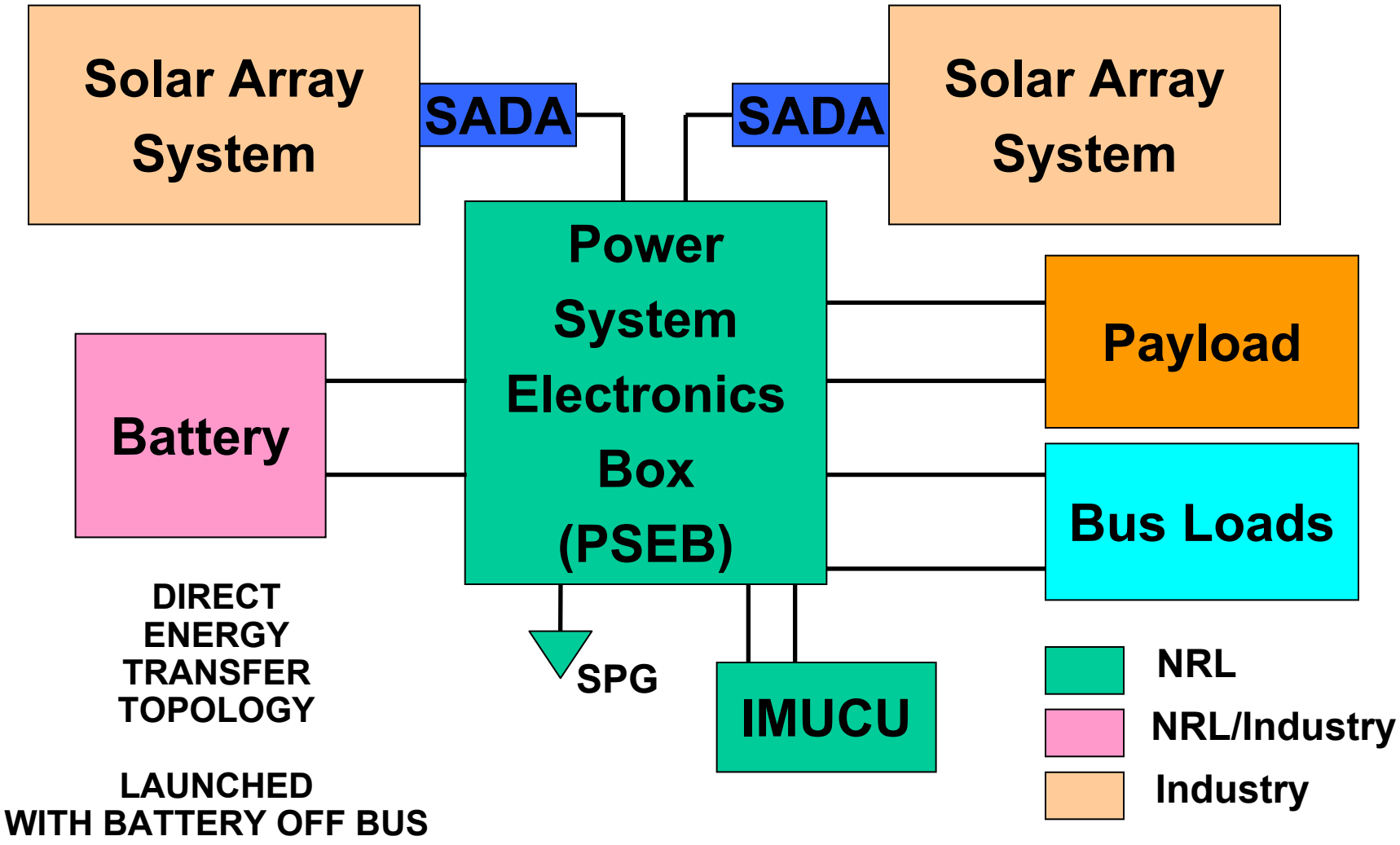
ISET Standards (Performance)

Parameter	ORS Bus Standard*
Total Wet Mass	425 kg
Payload Mass	175 kg
Bus Wet Mass	250 kg
Payload Power (Orbital Average)	200 W (700 W Peak)
Pointing Control (3-sigma)	0.05 deg
Pointing Knowledge (3-sigma)	0.01 deg
Slew Rate (deg/sec)	Up to 2
Orbit Position Knowledge	30 m (1-sigma)
Payload Data Storage	Payload Specific/ 1 Gbyte for Payload Health & Status
Payload Data Transfer Capability [Telemetry D/L]	500kbps to 2Mbps for HEO orbits/ 2Mbps for LEO
Payload Digital Command & Data Interface	RS-422/ HDLC and Spacewire
Switched 28V Power Lines For Payload	3 -> 2 (Critical & Nominal)
Payload Interface Temperature	-30°C to +55°C on the Bus, Isolated from the P/L
Bus Propulsion Capability (DeltaV)	300 -> 175 m/s min.

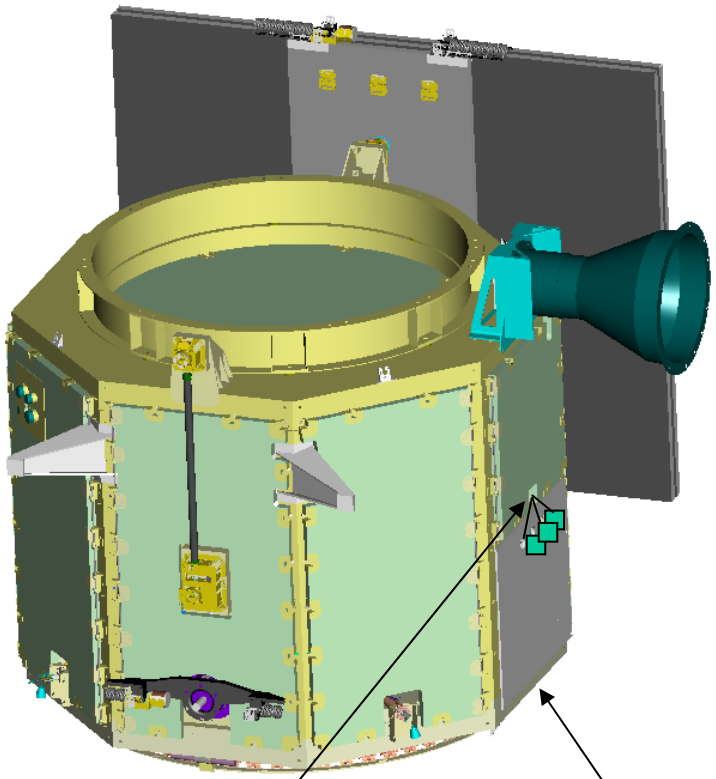
* Services supplied to a Payload

Other Derived Power Rqmts.
- 350 Watt-hours in Eclipse for P/L
- System Powered off at Launch
- Battery Stored Separate from Bus
- Battery Installation < ~ 1 day
- No charging of Battery once integrated with the Launch Vehicle

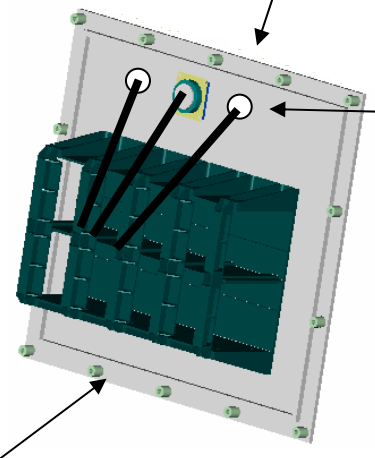
EPS Block Diagram



30 AH LITHIUM ION Battery Required Bus Installation



Last Panel Installed Into Bus
Removable at Any Time



Battery Maintenance Done External to Vehicle (Charge/Discharge/Test) Using Three External Connectors

Vehicle Harness Egress Port

Battery Radiator Plate

Battery Mechanically Installed Fully Charged and Then Connected to Vehicle Harness

Initial Battery Sizing Estimates

- Battery Sized to Maximize Eclipse Energy Usage
  - Limited by Mass of Battery
- Chose Li-Ion Family for DOD and Self Discharge
  - Chose 60% DOD for One Year Operation
  - 14 Day Pad Operations Requirement
- Energy Calculations For 1 Hour Eclipse
  - Bus Loads Are at 250W for One Hour Long Eclipse = 250 WHr
  - Standards Define Payload Operation in Eclipse = 350 Whr
  - Total Needed Energy in Eclipse = 600 Whr
  - Average Voltage During 60% DOD for Lithium-Ion = 29V
  - Ampere Hours Needed to Meet Loads in Eclipse = 20AHrs
  - Battery Size Needed at 60% DOD = 34.5 AHrs
- Battery Capacity Selected = 30.0 AHrs
  - Size Chosen Covers 80/20 Eclipse Cases
  - Achievable Payload Energy in Eclipse (1 Hour) = 290 Whr
  - Achievable Payload Energy in Eclipse (1/2 Hour) = 350 Whr

Battery/Cell Acquisition Approach

- NRL Surveyed the Li-Ion Industry for Low Cost Battery Cells
- NRL Introduced to Quallion through Joe Stockel
  - Quallion Builds State-of-the-Art Li-Ion Battery Cells for DoD, NRO, and NASA
  - Provided Cells at Low Cost in Exchange for Knowledge and Data
- Cooperative Agreement Contract Awarded to Quallion October 2006
  - Coop-Agreement Instead of CRDA (Cooperative Research & Development Agreement), Because $$ Provided to Quallion for Cells
- Quallion Built, Tested, and Delivered 40 Cells to NRL on or Before 15 August 2007 (in Batches So NRL Can Begin Battery Build)
- NRL to Provide Quallion With Design “Know-How” for the Build and Qualification of Battery Assembly Including Drawings, Procedures, Test Plans, etc.
- Quallion Will Be Observing Construction and Testing, and Will Receive On-Orbit Data
- Cells Selected: QL015KA Which Are 15-AHr Rated
- Battery Topology Selected Is 2 in Parallel, 8 Pairs in Series

QL015KA 15 AH Li-Ion Cell Detail

- Manufacturer: Quallion
- Chemistry: LiNiCoAlO
- Nameplate Capacity: 15 Amp-Hours*
- Part Number: QL015KA
- Voltage Range: 0.0 - 4.1 Vdc
- Cell Mass: 475 grams
- Cell Cover Material: SS
- Cell Case Material: SS
- Cell Dimensions: 3.5” x 2.0” x 2.5”
- Energy Density: 121 Whr/kg

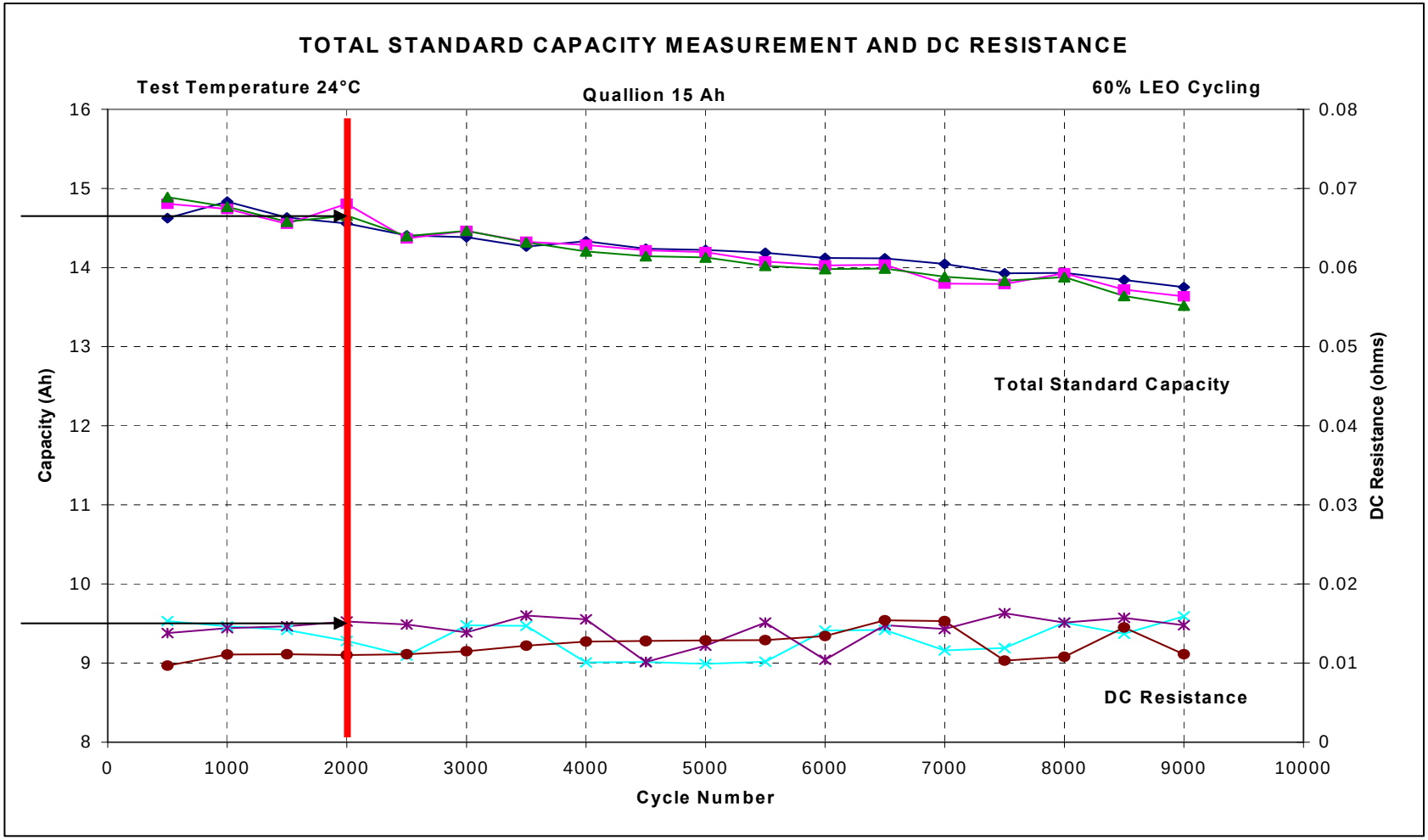
* When Charged to 4.1 Vdc and Discharged to 2.7 Vdc

- Cell Level Tests Performed by Quallion
  - DC Internal Resistance Test Pre- and Post-Testing
  - C/5 Cycling at 0, 25, and 40°C: Cycle Between 3.0 and 4.1 V (With Taper Charge) Three Times; Evaluate Capacity
  - Self Discharge Test; When Cells Are Fully Charged, Let Stand for 72 Hours, Then Evaluate the Drop in Cell Potential
  - C/5 Cycling at 0, 25, and 40°C After Storage at 50% SOC over 90 Days; Evaluate Capacity; Calculate Capacity Loss If Any
  - X-Ray Photographs and Leak Test

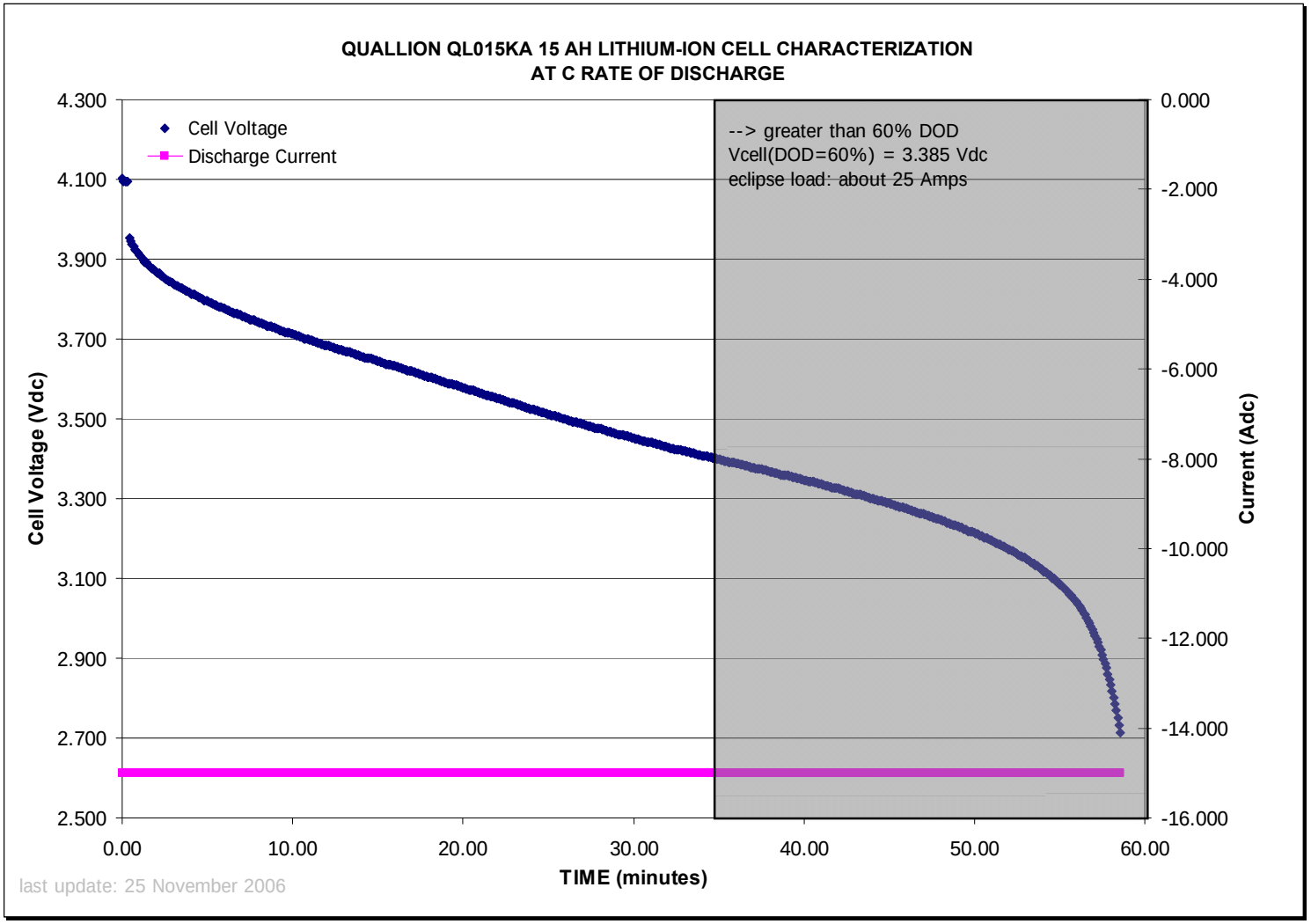
QUALLION QL015KA 15 AH LI-ION CELL
Electrical Performance Data (Life Data)

95+%

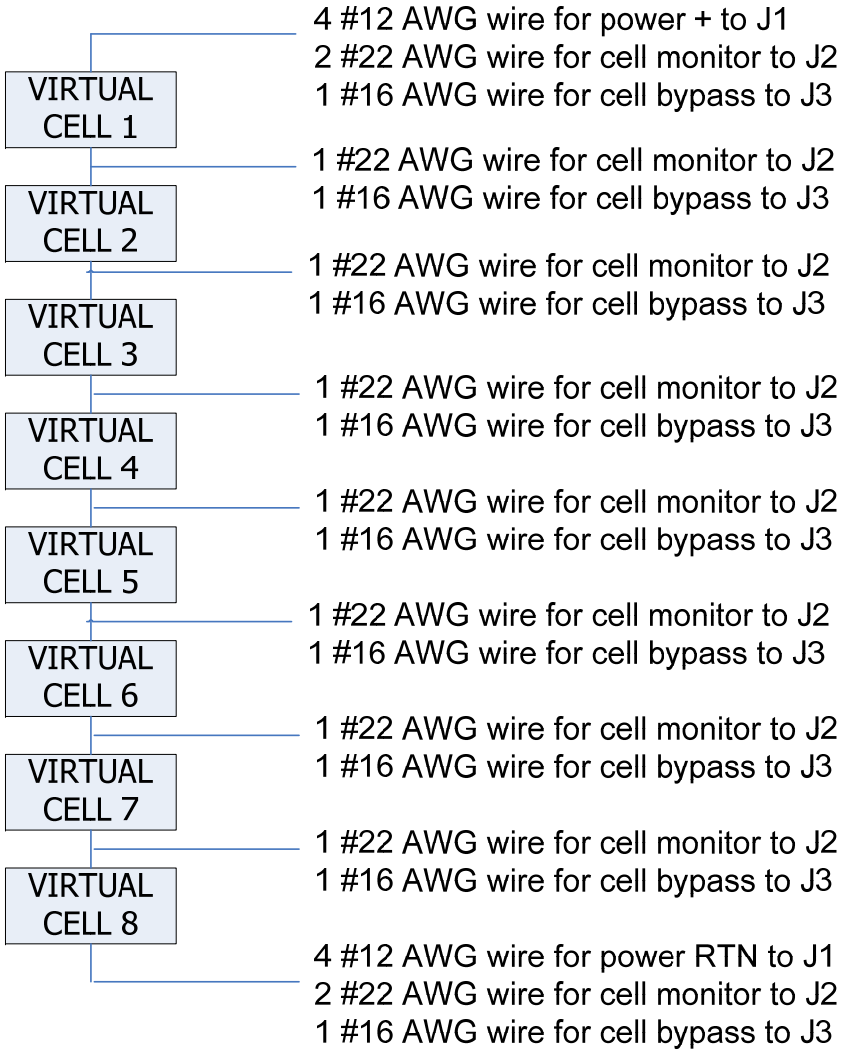
~15mΩ



QUALLION QL015KA 15 AH LI-ION CELL
Electrical Performance Data



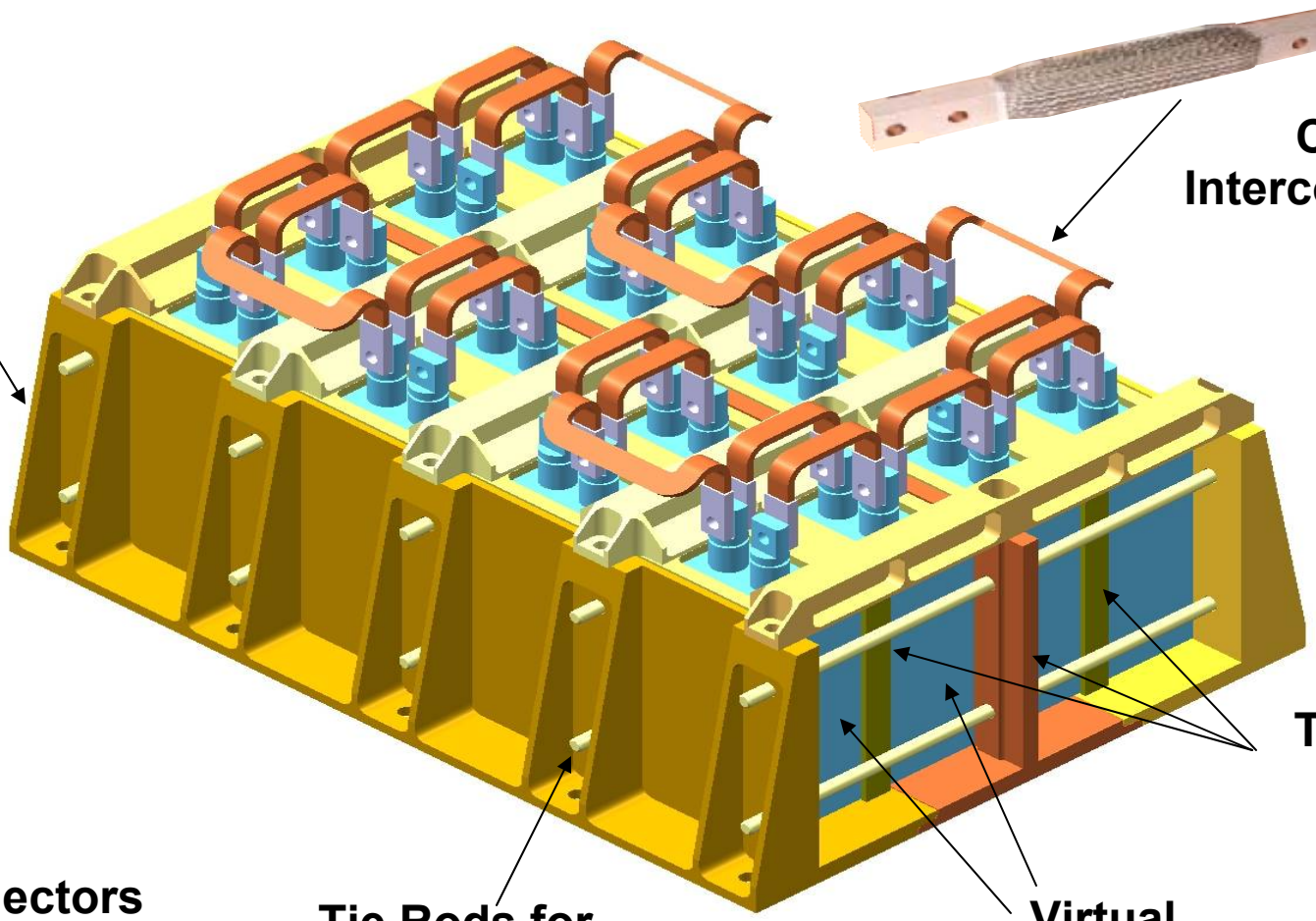
30 AH LITHIUM ION BATTERY
Electrical Block Diagram



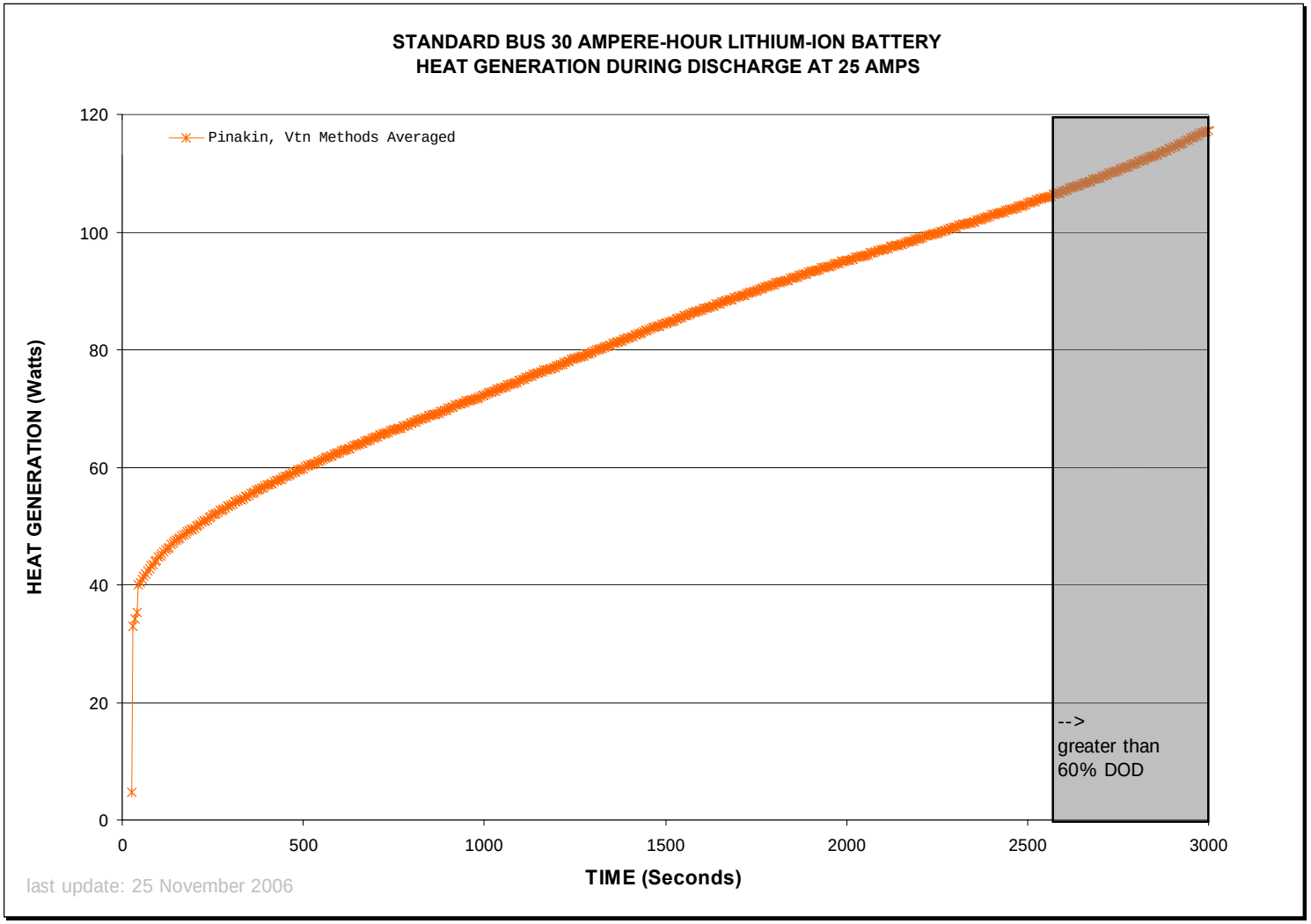
- Wiring Per SB-EP-0010
- Box ID: A015
- Cell to Cell Interconnects Using Custom Flexible Bus Bars Manufactured by Storm Copper
  - 2 Sizes Required: Parallel, Series Connections
  - Copper Braid in Between seamless copper bars that are nickel flashed and gold plated

- 4 Temperature Sensors
  - 2 AD590 sensors for Telemetry
  - 2 LTN11 sensors for Ground Test
- 3 Circular Connectors: D38999 Series IV Wall Mount
  - J1 Power – 4 +, 4 Rtn lines
  - J2 Telemetry (Voltages, Temps)
  - J3 Ground Charge – Cell Balance

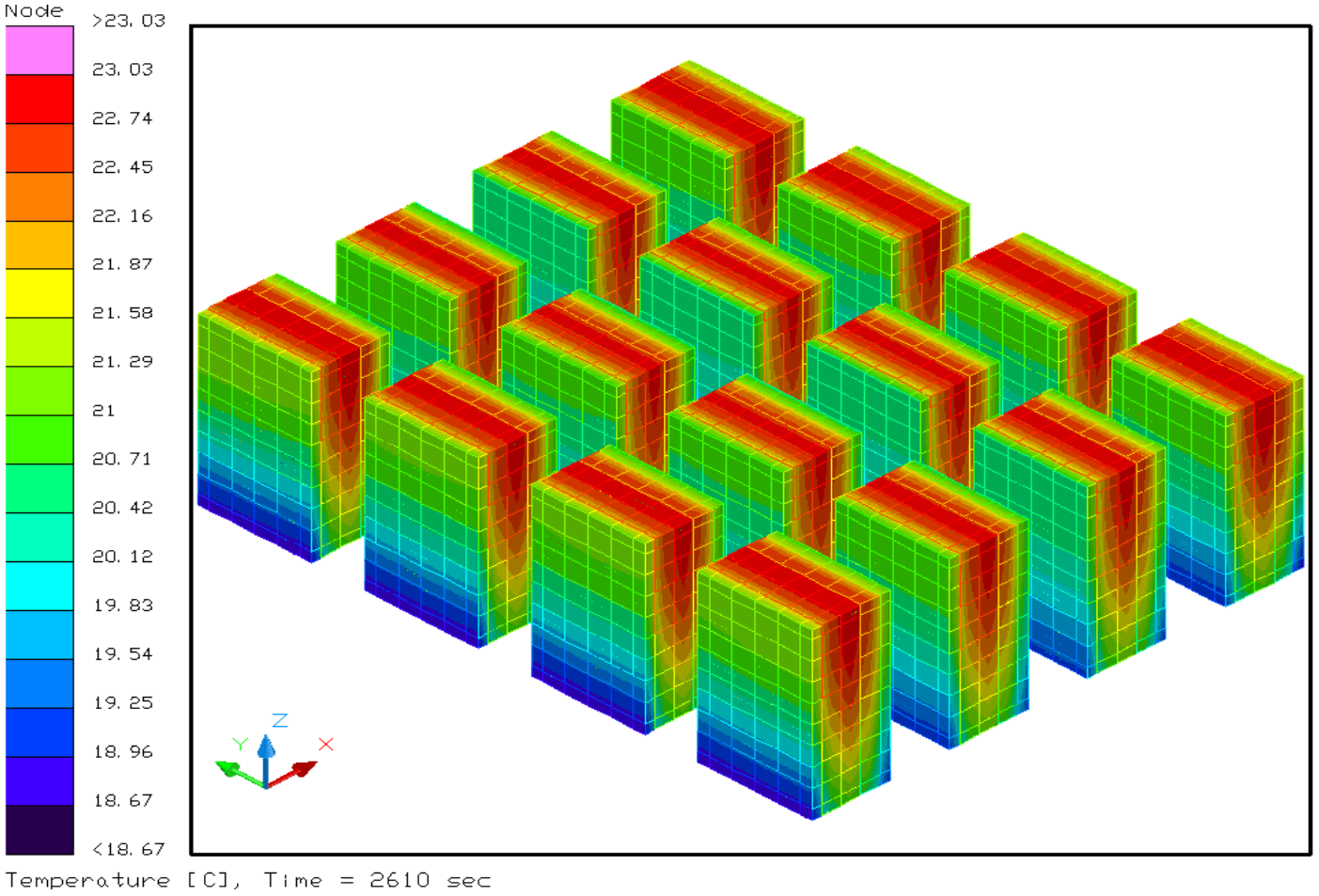
30 AH Lithium Ion Battery Packaging

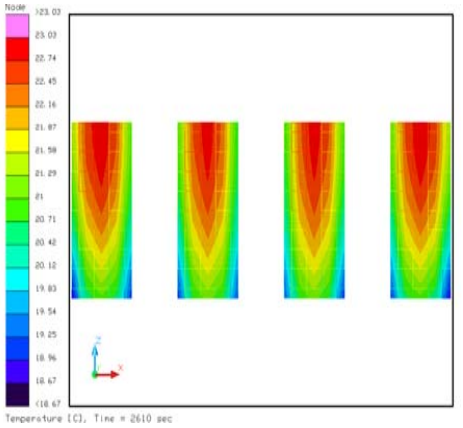


30 AH LITHIUM ION BATTERY
Thermal Analysis - Heat Dissipation



30 AH LITHIUM ION Battery Thermal Analysis



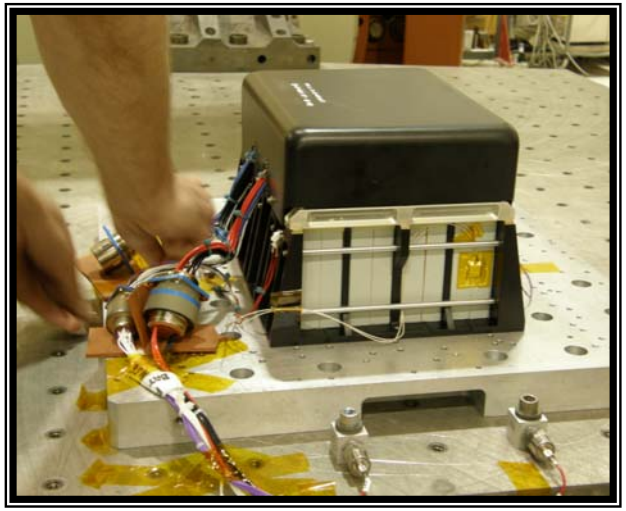


Baseline Deviations:

- 2610 Second Transient Calculation (43.5 Minutes), 10 Second Time Step
- Transient Power Dissipation Curve (Pinakin, Vtn Methods Averaged) Supplied by 8244
- Power Group on 11/30/2006
- No Shims
- Walls 1 and 5 are 0.075 in. Thick
- Walls 2 and 4 are 0.225 in. Thick
- Wall 3 is 0.300 in. Thick

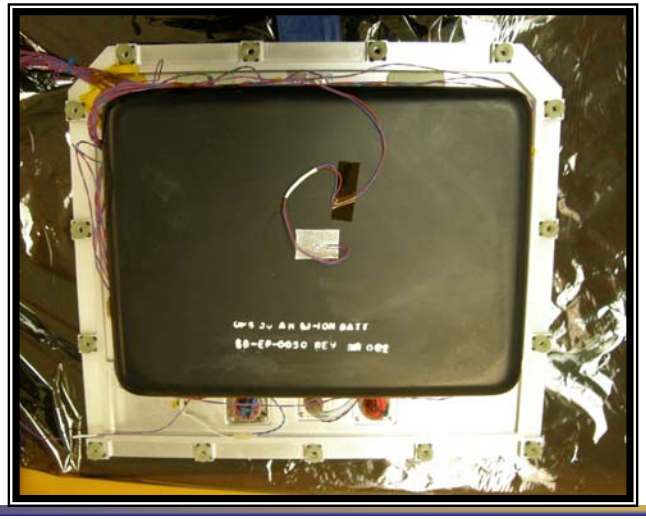
- Maximum Cell Temperature Delta (End of Transient) = 4.36 °C
- Cell Thermal Profiles Are Matched Well From Cell to Cell
- Less Than 3 °C Temperature Delta Within Planes Parallel to the Baseplate From Virtual Cell to Virtual Cell, and Within a Cell

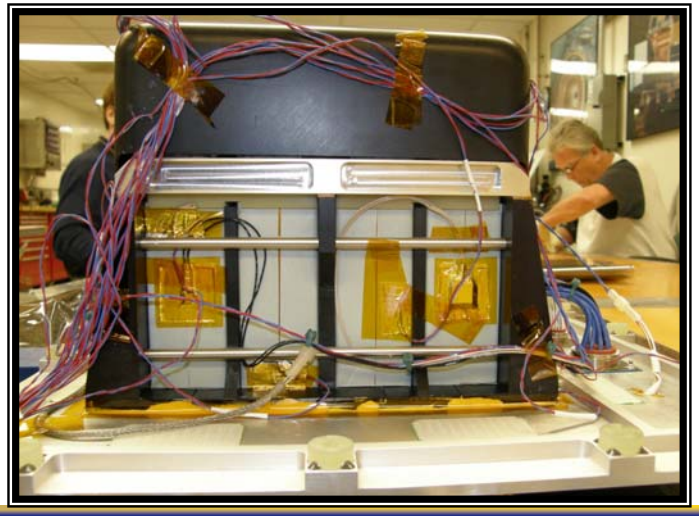
Photos of Battery



Battery Mass
29.6 lbs.

Battery Size
10-31/32” x
8-26/32” x
7-1/16”

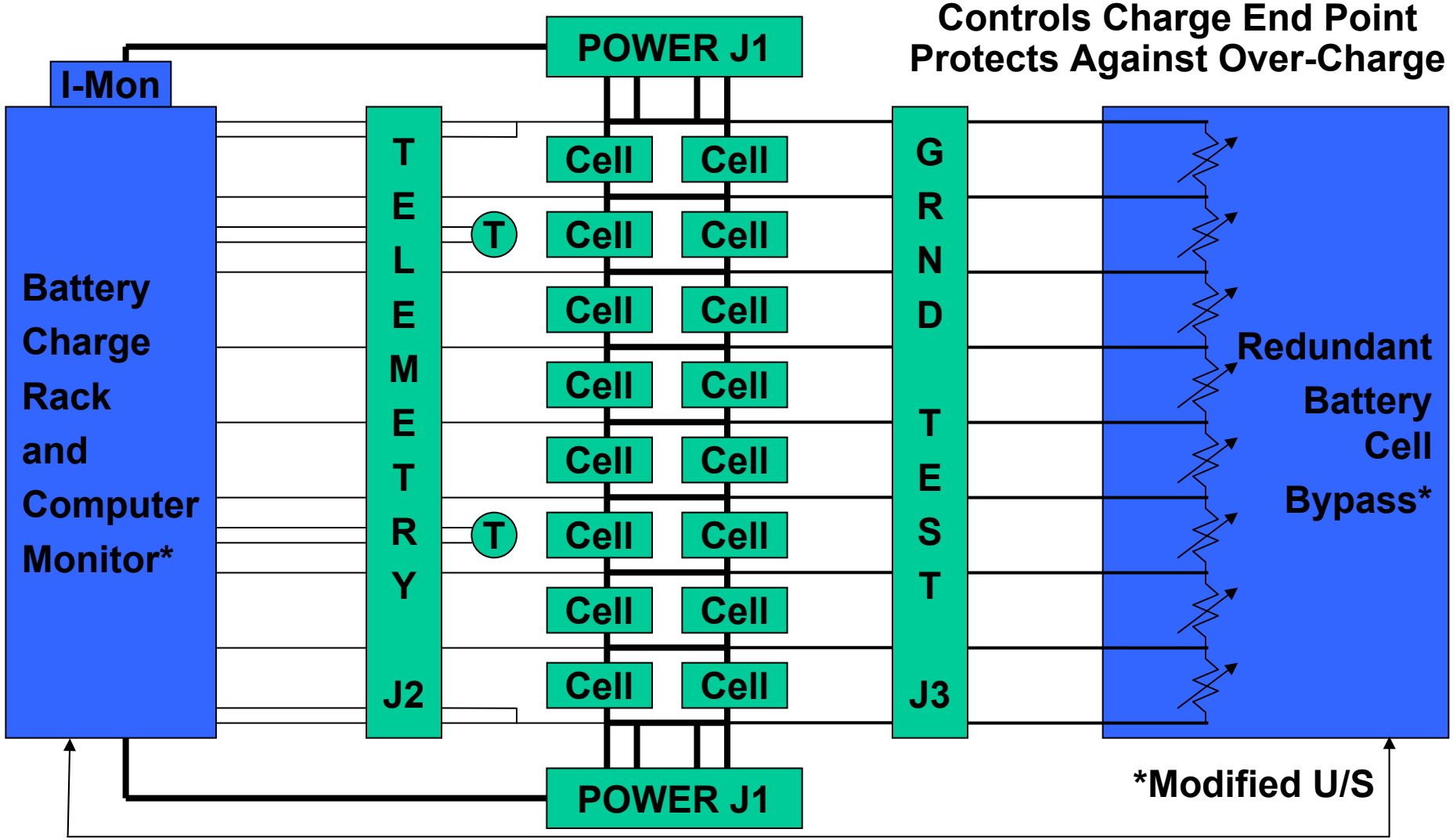




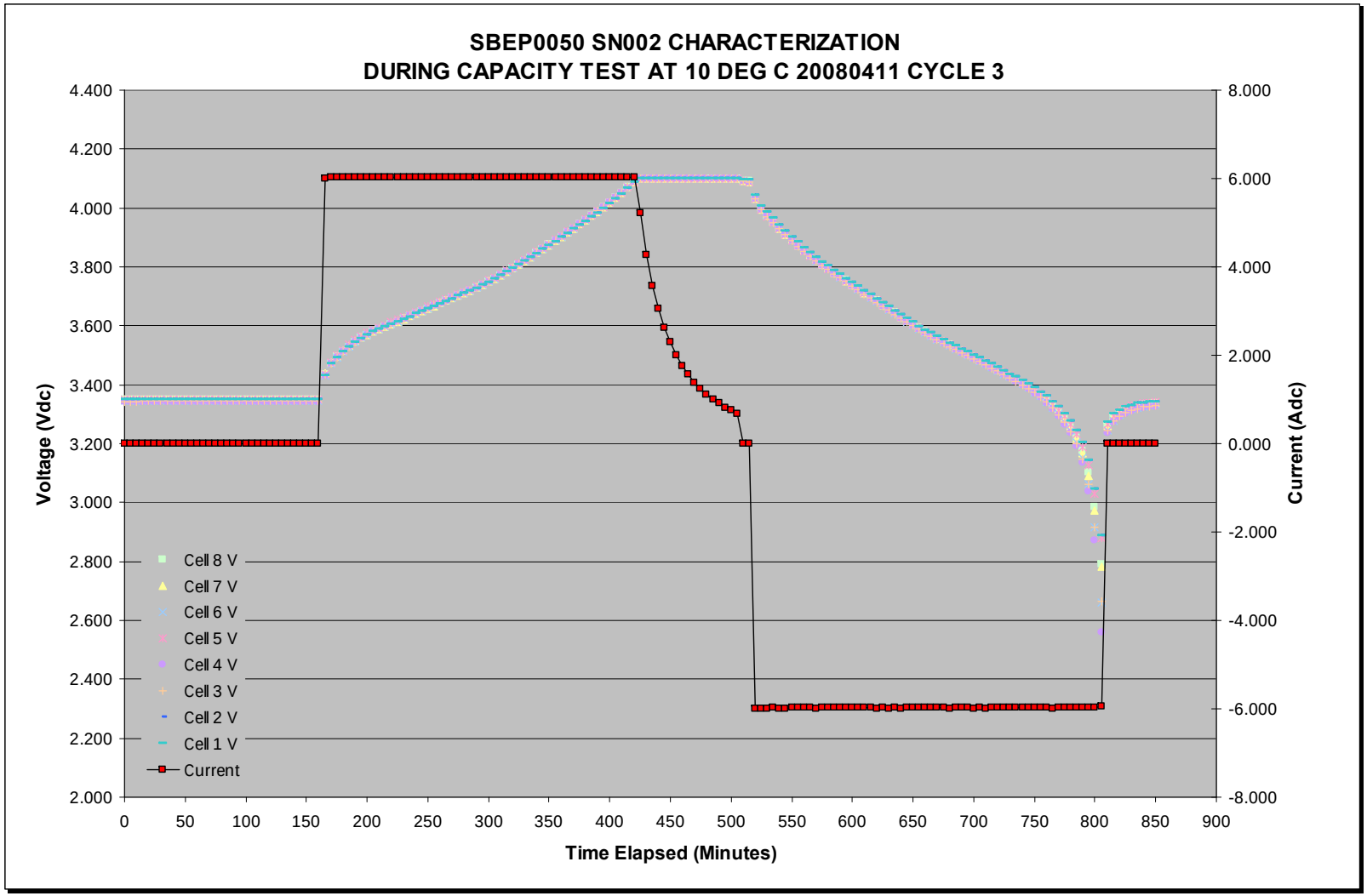
Battery Tests/Charging Operations

- Battery was Tested per NCST-TPL-SB008
- The Tests were Performed between 21 March 2008 and 4 May 2008
- Testing Performed
  - Safe to Mate
  - Insulation Resistance (performed pre- and post- Random Vibration)
  - Capacity Tests (3 cycles at 10°C, 20°C, and 30°C; 2 more cycles at 10°C performed post-Random Vibration and TVAC)
  - Orbital Cycling (2 days → 12 cycles)
  - Random Vibration
  - TVAC (1 day → 6 cycles at 10°C, 20°C, 30°C, then 20°C again)
- All Tests PASSED
- System Level Tests Supported by Battery
  - Vibration
  - EMI
  - Magnetic Dipole Moment
- Charge Control
  - All Charging Done by Battery Charging/Test System
  - Charging Can Be Done in Parallel With Bus Testing If Battery Is Installed

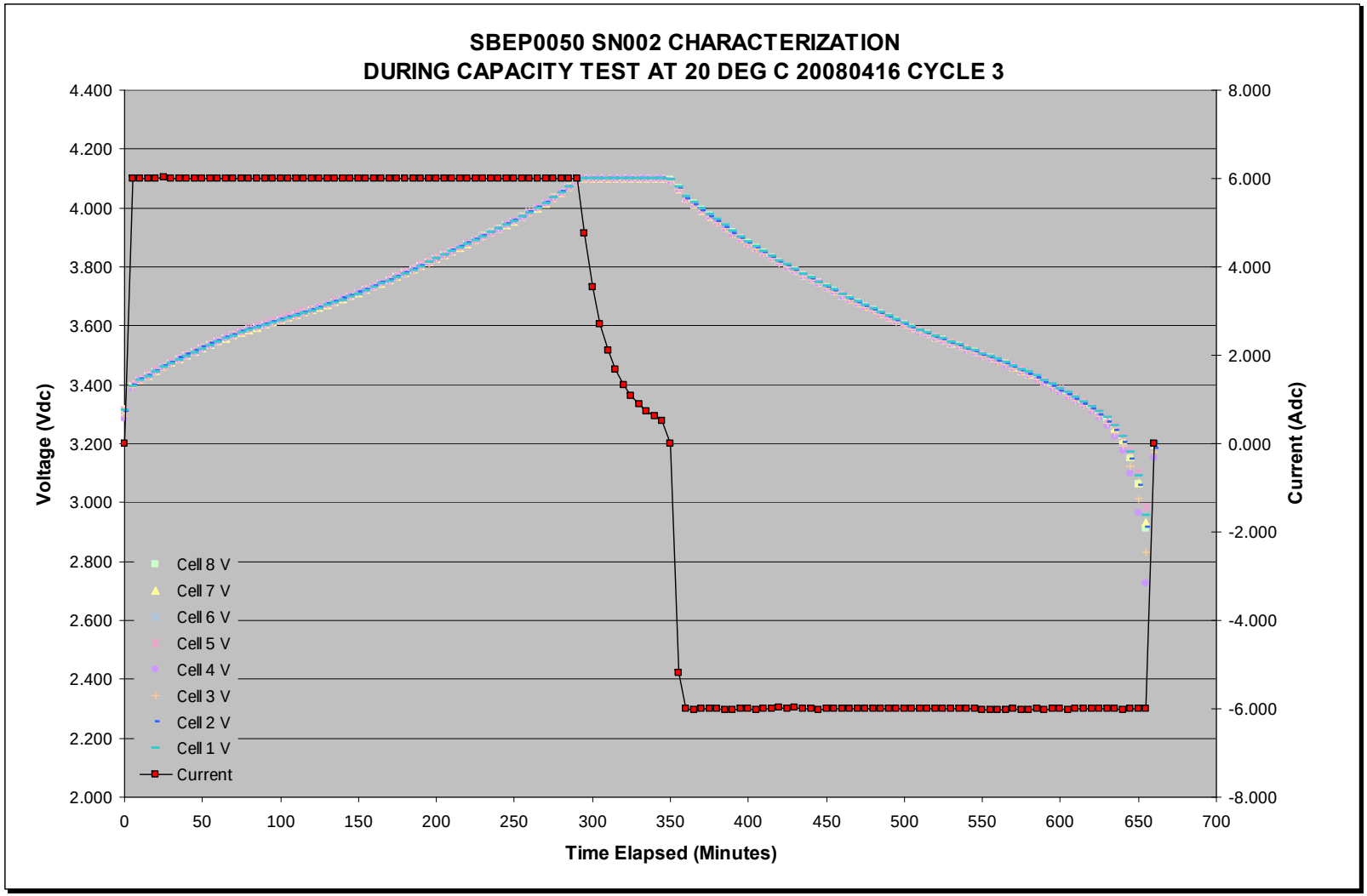
Battery Test/Charge Control Approach



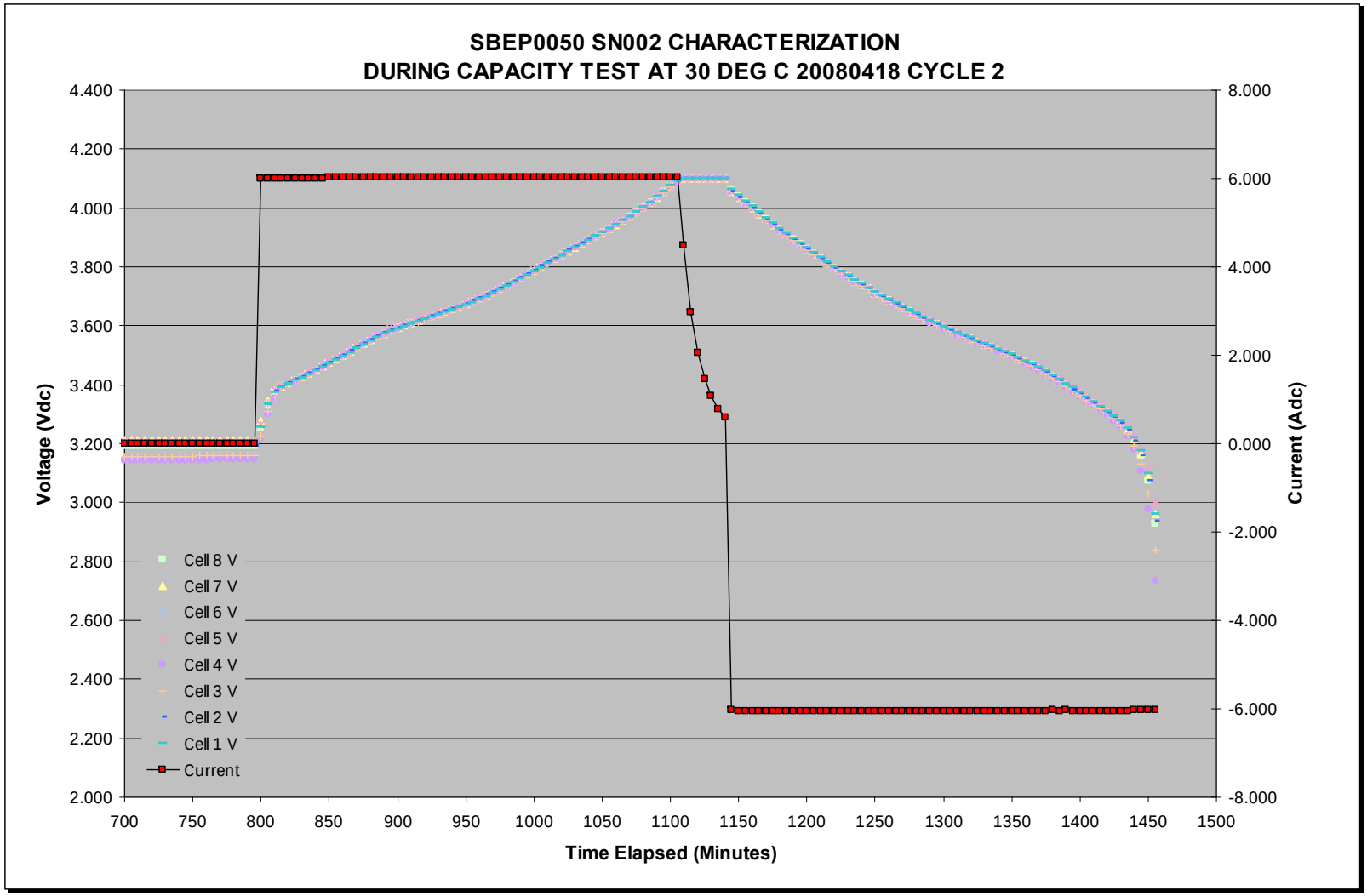
Capacity Test @ 10°C



Capacity Test @ 20°C



Capacity Test @ 30°C



Current & Future Status

- Bus Structure in Storage
- Battery is Monitored Daily with a Monthly Cell Voltage Check
  - Proto-Qualification Testing Completed Early May 2008
  - Cells at ~3.34 Vdc
    - Cell Voltages shall be between 3.25 and 3.40 Vdc. Capacity test cycles to be performed if the cell voltages are outside of this range.
  - Battery at ~26.73 Vdc
    - Battery Voltage shall be between 26.0 and 27.2 Vdc. Capacity test cycles to be performed if the battery voltage is outside of this range.
  - Room Temperature with Humidity Control via Nitrogen Purge when Necessary
- Awaiting Payload Integration
- Current Launch Date: September 2009