



# **NASA Goddard Space Flight Center**

## **SONY Li Ion 18650HC Cell PTC, CID, Operation in a Very Large-Scale Parallel String Configuration**

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NASA Space Battery Workshop

Nov 15 – 17, 2011

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# Background

- The genesis for the test described in this presentation was the result of a concern raised to the Global Precipitation Measurement (GPM) program about the safety of a large scale battery design comprised of SONY 18650HC Li-Ion cells.





# The Investigation

- Various SONY 18650HC cell Positive Temperature Coefficient resistor (PTC) and Current Interrupt Device (CID) operation tests have been performed in the past but nearly all at a limited scale sometimes with just a single cell, string, or perhaps at a pack level.
- The goal of the tests being reported was to observe the operation of the PTC/CID cell features when a cell shorts in a very large-scale parallel string configuration of over 100 strings simulating planned space flight systems and environment to the greatest extent possible. We wanted to verify battery performance in a case where a cell short leaves one string of 7 cells in parallel with a large number of 8 cell strings.





# Test Method

- Two Li-Ion battery test packs were procured from ABSL: PN 014824 SN001, SN002. Each test pack consisted of 8 18650HC cells in series by 12 strings in parallel (8s12p). Accessible leads were provided from 2 cells in each pack to allow external shorting of these cells.
- Tests were run with SN002 to observe the SONY cell Positive Temperature Coefficient (PTC) resistor and Current Interrupt Device (CID) protection features operation.
- The tests consisted of shorting the 2 cells one at a time and documenting the temperature, voltage, and current responses.
- The pack was set up thermally in as flight like configuration as possible mounted on a base plate with mounting brackets and Cho-Therm as the flight unit would be mounted. In addition the pack was blanketed to mitigate any convective effects.
- A 120AH test battery consisting of 8s104p Sony 18650HC cells and a power supply were connected in parallel with low resistance wiring to the block to simulate the large scale cell configuration on the Global Precipitation Measurement (GPM) spacecraft (3 – 8s84p).





# Summary Conclusion

- The results of the tests performed on block SN002 were conclusive, indicating that the internal PTC and CID features operated as designed.
- As observed, the CID activated in multiple cells of the affected strings and removed the strings from the circuit with only moderate thermal response.
- The remainder of the test pack was unaffected by the short circuit event.
- In this test the internal cell safety features activated reliably in response to a simulated fault.
- It is expected that a similar short circuit failure during I&T or on orbit would result in just the loss of the affected string, a very small loss of capacity, and no danger to the GPM spacecraft.
- Since both strings in SN002 operated similarly it was decided not to repeat the tests on the SN001 block.







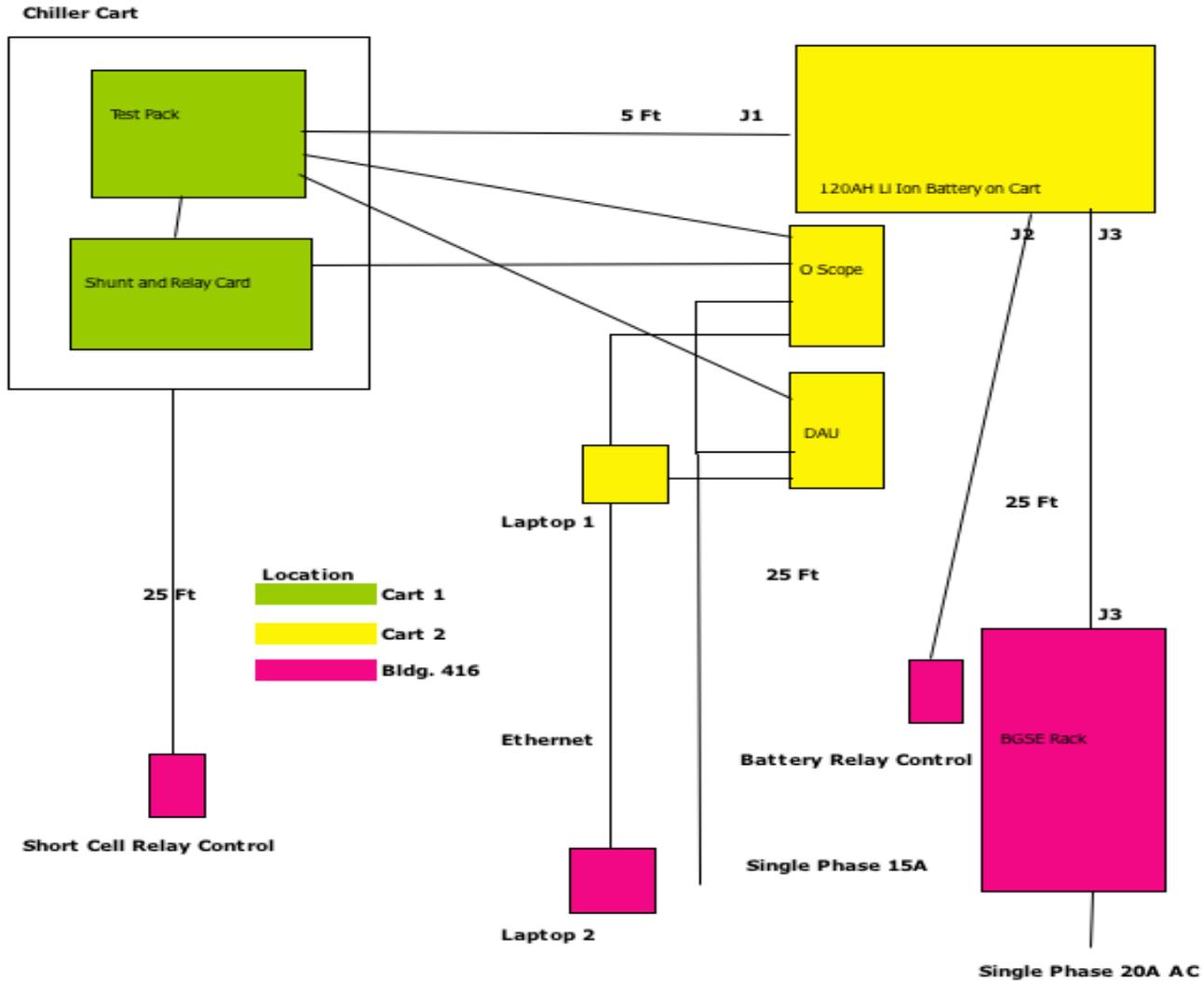
# Telemetry Points

- Telemetry from the test pack included 16 thermocouples, voltage across the top 3 cells of string #6 and the top 4 cells of string #7, current through each shorted cell, current through string #6, current through string #7 and overall pack voltage.



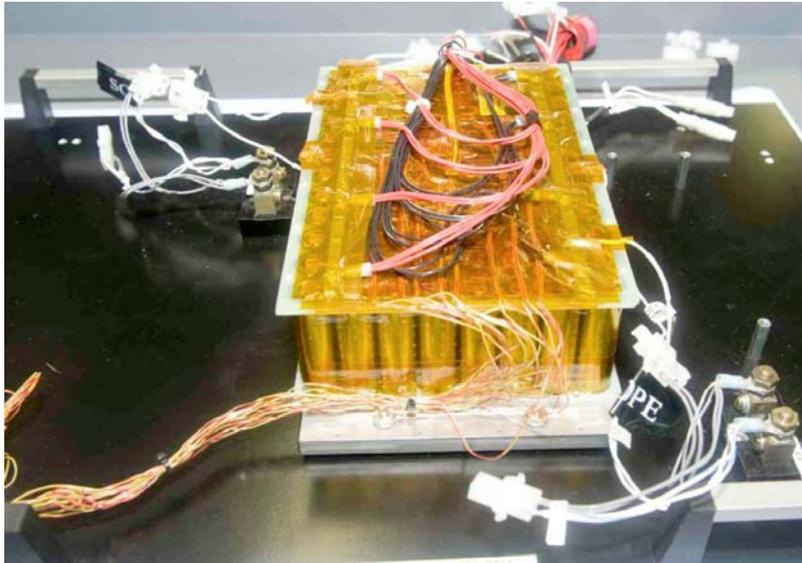


# Test Set Up Block Diagram

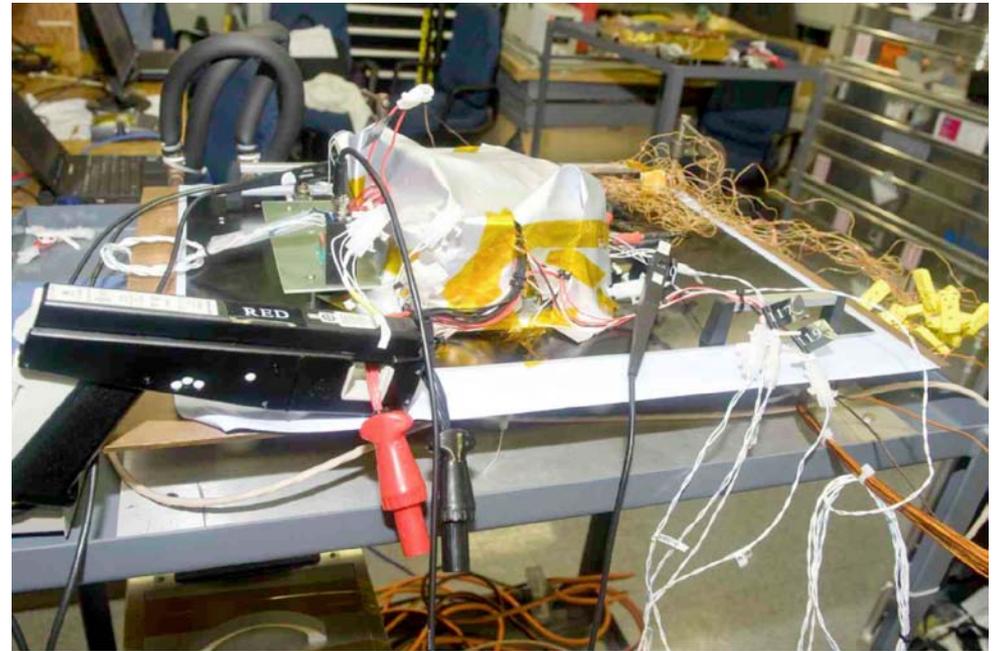




# Pre-Test Photos of Test Pack



Un-blanketed

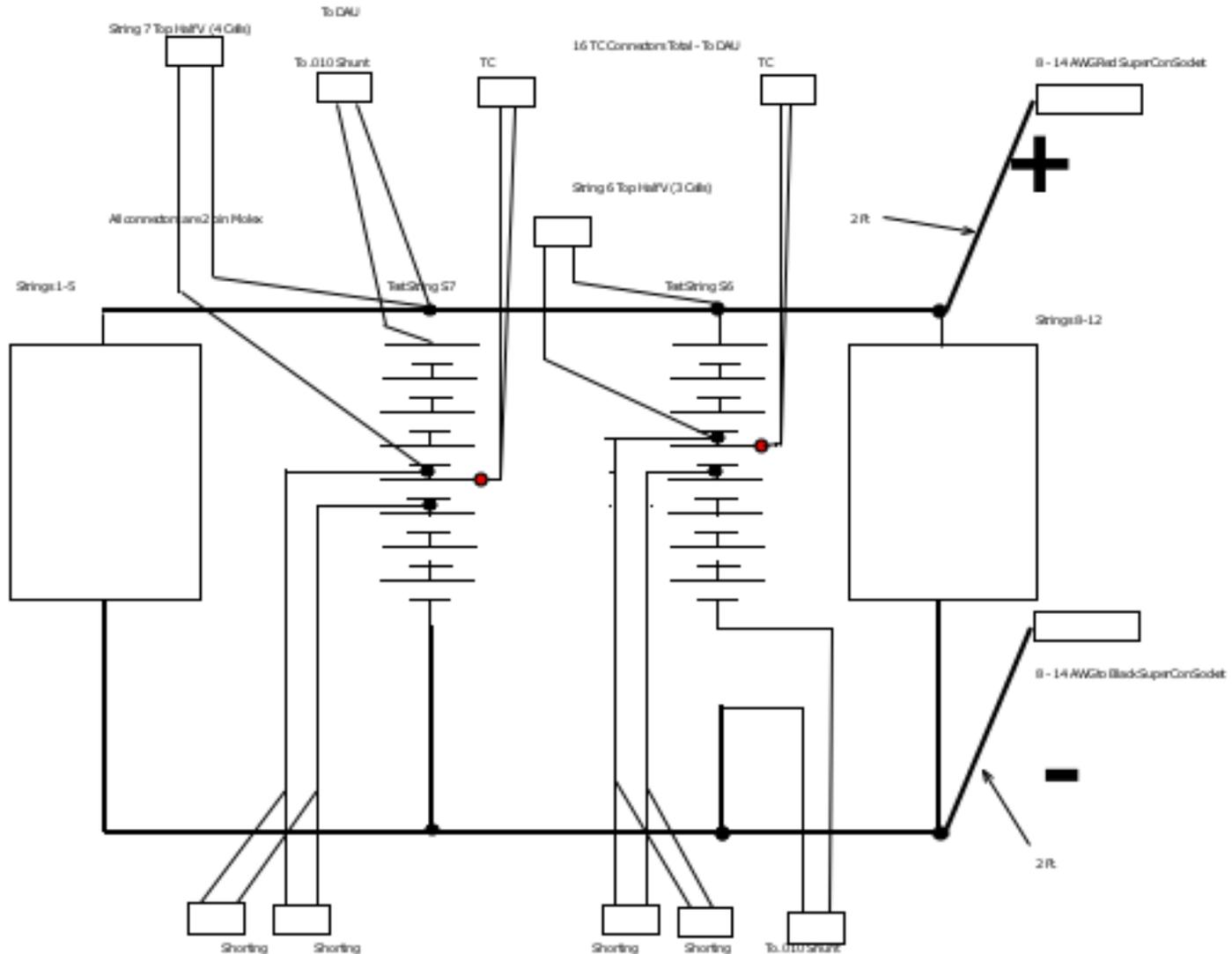


Blanketed and Instrumented





# Pack Connector Wiring





# Test Location – GSFC Test Site

- Creating the shorts and the attending cell over voltage in the test pack would cause heating and possibly a fire.
- Precautions related to these safety concerns resulted in locating the test outdoors and included protective clothing and readily available fire extinguishers.

Test Pack  
“Out Standing  
In its Field”





# Test Flow

- Charge pack to 33.6V
- Charge 120AH test battery to 33.6V
- Close the battery to pack relay
- Close shorting relay across S6C4
- Record data
- Allow pack to stabilize (voltage and thermal)
- Install permanent short across S6C4
- Close shorting relay across S7C5
- Record data
- Allow pack to stabilize
- Install permanent short across S7C5
- Repeat for second pack (if necessary)





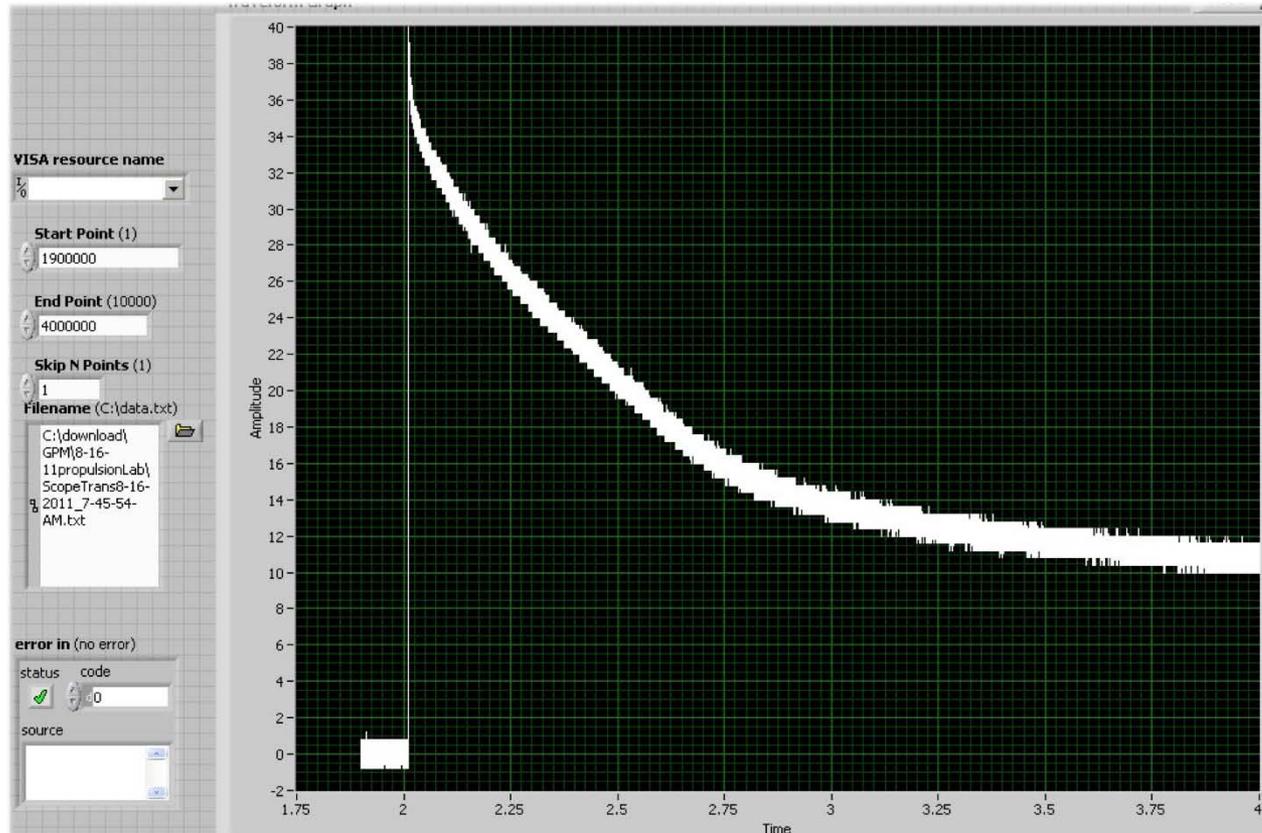
# Test Day

- The test was run early in the morning of August 16, 2011.
- A short was commanded across S6C4 at 0658 EST, however to do an operator error this initial short was removed inadvertently after only a few seconds.
- The expected current pulse through the cell was observed but due to the brevity of the short the pack quickly returned to its stable pre-short state.
- The S6C4 shorting command was reissued at 0745 EST and this time the short maintained.





# S6C4 Shorting Current Results

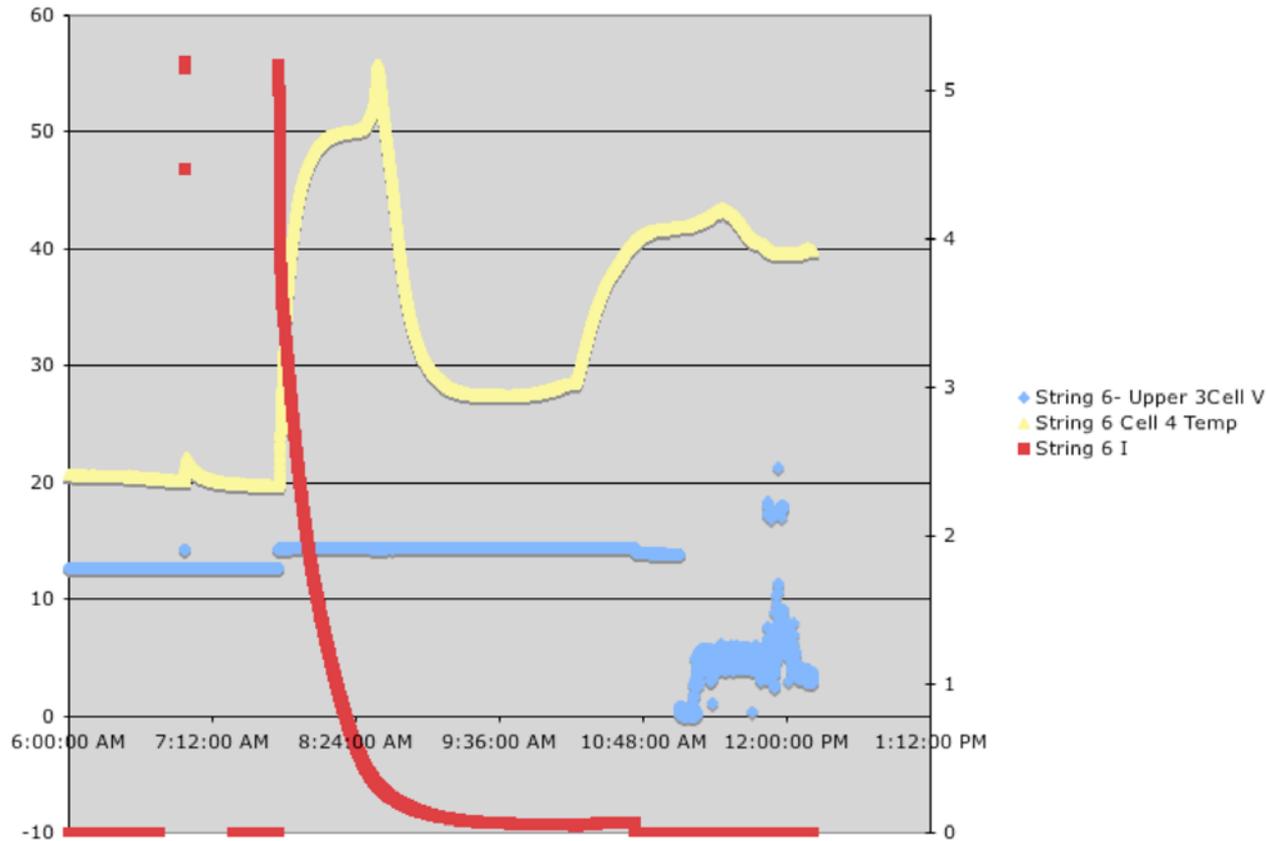


This is a data capture of the transient through S6C4 after the 0745 EST short was commanded. The time scale is 2 sec. The cell internal PTC device actuated quickly to reduce the current from 40 to 10 A.





# String 6 Telemetry

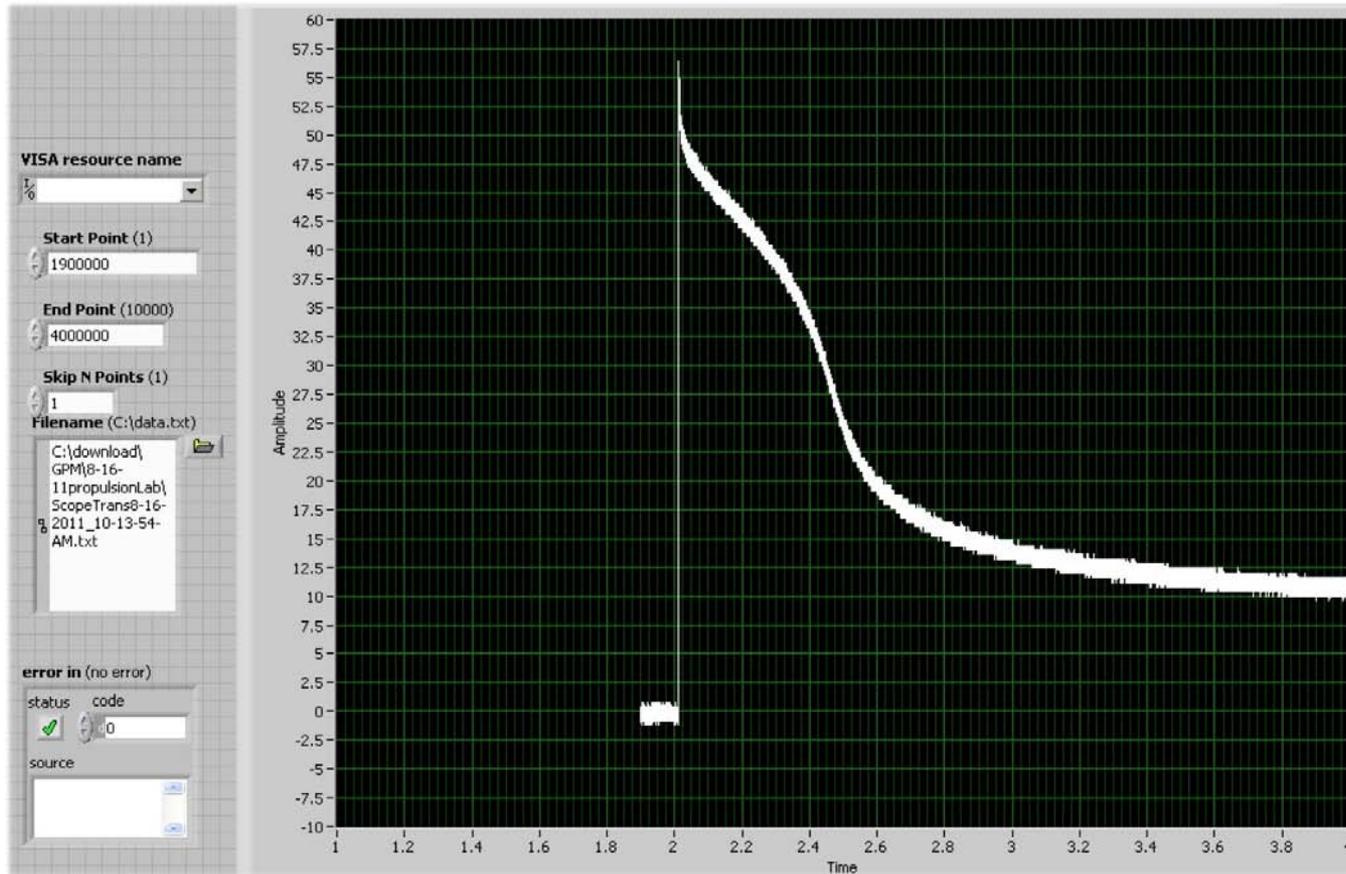


The data shows that the current through the shorted string continued to decrease for about 3 hrs. to about 70 mA and then abruptly went to 0A at 1044 EST. This indicated one or more of the string's Current Interrupt Devices (CIDs) had opened up electrically isolating the string from the rest of the pack. (Note that the temperature rise after 1044 EST above was due to the adjacent S7C5 being shorted at 1013 EST)





# S7C5 Shorting Current Results

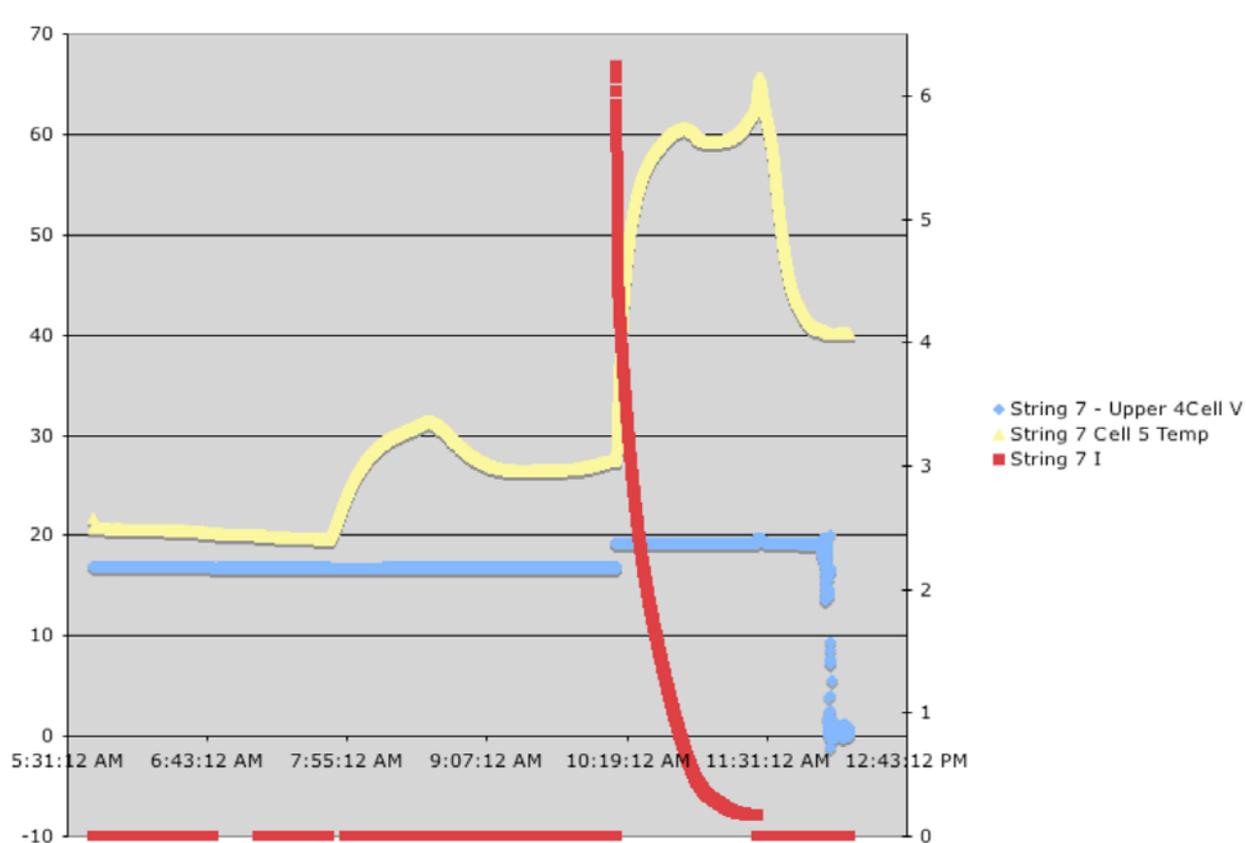


This is a data capture of the transient through S7C5 after the 1013 EST short was commanded. The time scale is 2 sec. The cell internal PTC device actuated quickly to reduce the current from 55 to 10 A.





# String 7 Telemetry

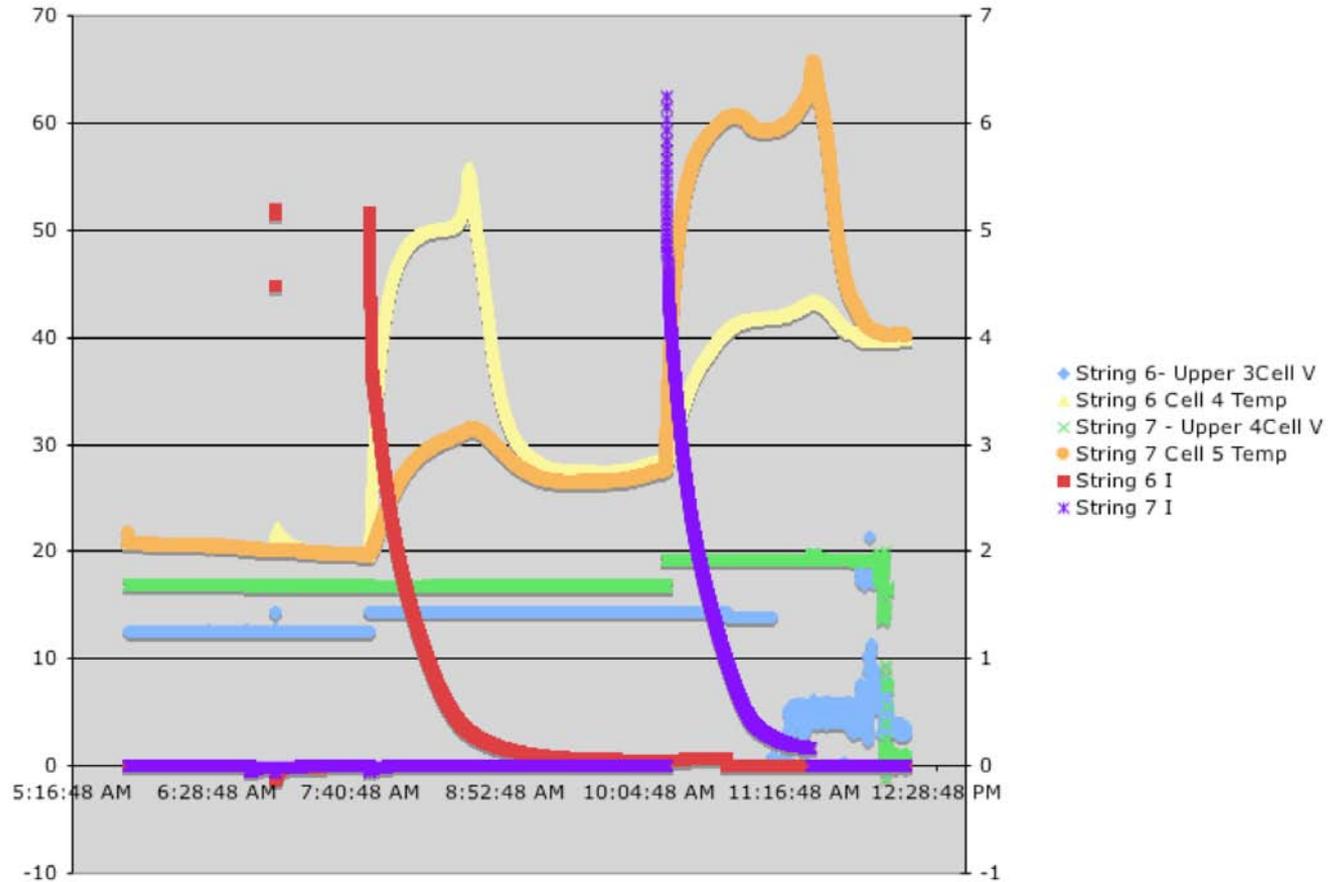


The data shows that the current through the shorted string continued to decrease for about 1.25 hrs. to about 170 mA and then abruptly went to 0A at 1125 EST. This indicated one or more of the strings Current Interrupt Devices (CIDs) had opened up electrically isolating the string from the rest of the pack.





# String 6 and 7 Telemetry



Combined S6, S7 trend data





# Post Test Results

- Post-test measurements indicate
  - String #6
    - Cell #4 still shorted with external shorting plug
    - Other 7 cells indicated an open circuit meaning 7 individual CIDs had activated
  - String #7
    - Cell #5 still shorted with external shorting plug
    - Cell #8 at 4.5V indicating its CID did not activate
    - Other 6 cells indicated an open circuit meaning 6 individual CIDs had activated



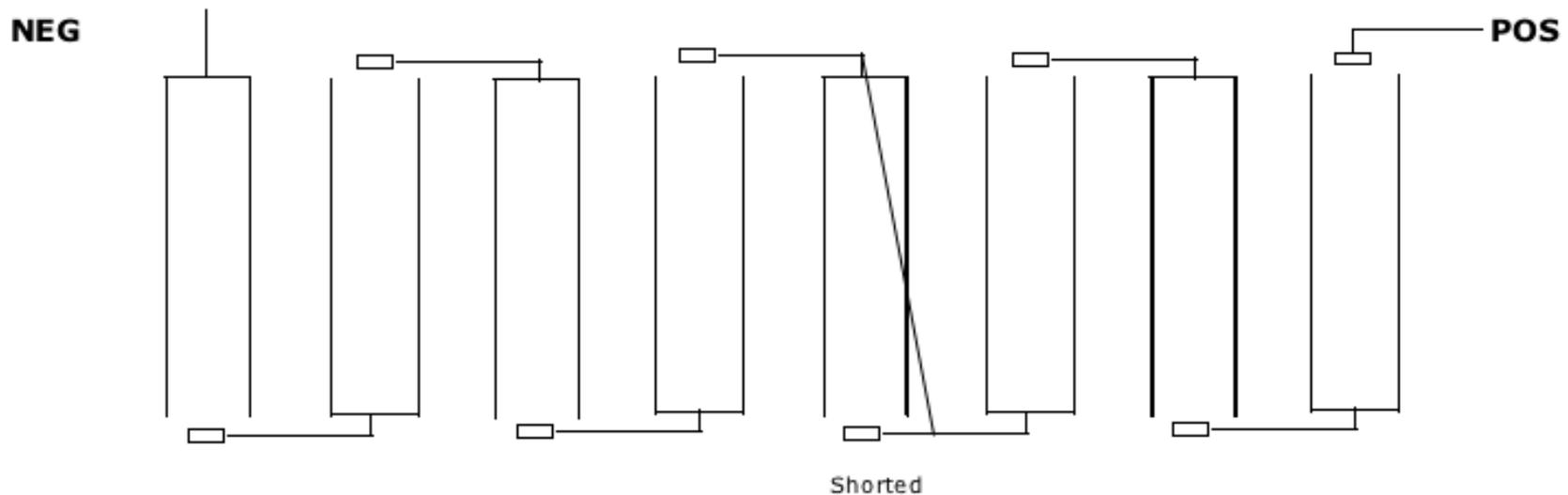


# String 6 Post Test Cell Voltages

## ABSL SN002 Test Pack

### String 6

	Cell 8	Cell 7	Cell 6	Cell 5	Cell 4	Cell 3	Cell 2	Cell 1	
8/17/11	.000V	.000V	.000V	.050V	.000V	.200V	.093V	.400V	
8/23/11	2.7V *	0.031V	2.9V*	0.041V	.000V	.4V*	.2V*	3.0V*	* Decaying voltages
9/7/11	3.3V *	0.020V	2.8V*	0.023V	.000V	.4V*	.3V*	1.6V*	* Decaying voltages



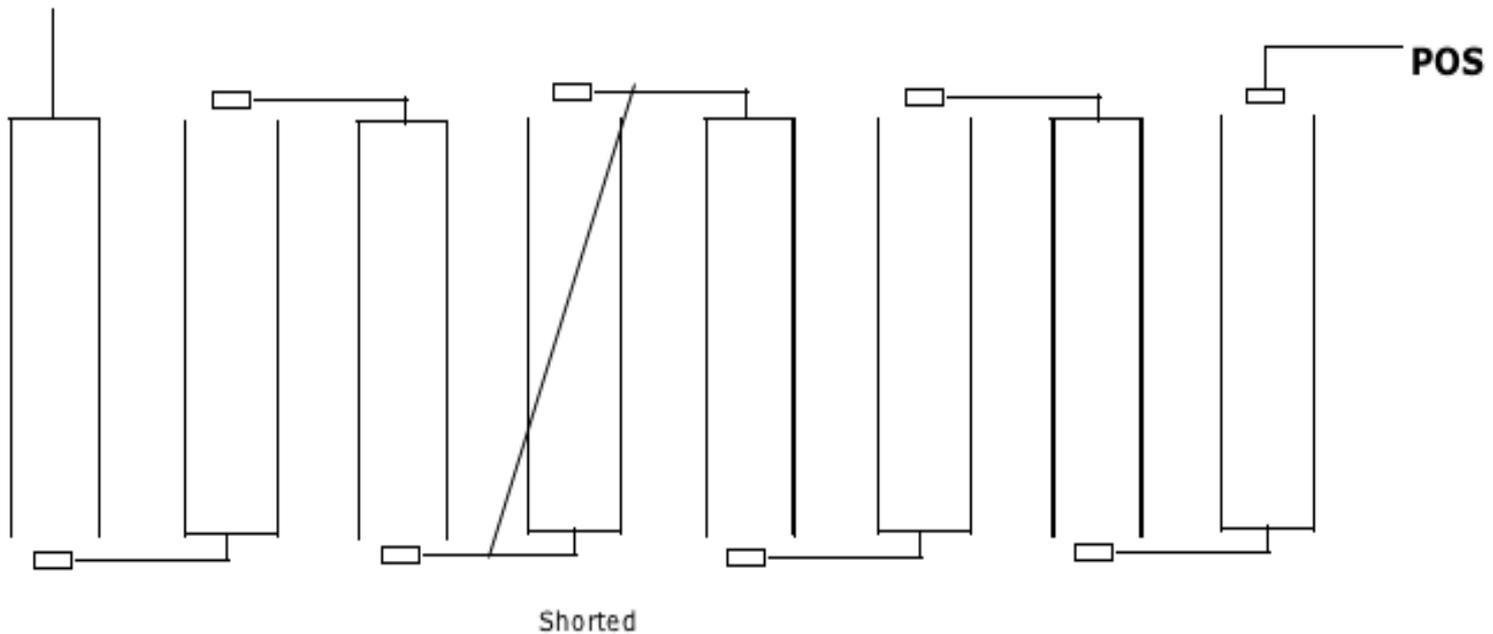


# String 7 Post Test Cell Voltages

## String 7

	Cell 8	Cell 7	Cell 6	Cell 5	Cell 4	Cell 3	Cell 2	Cell 1	
8/17/11	4.578V	.007V	1.4V	.000V	1.5V	1.6V	2.0V	.000V	
8/23/11	4.542V	0.01V	2.8V*	.000V	2.2V*	2.1V*	2.7V*	.006V	* Decaying voltages
9/7/11	4.49V	0.006V	3.2V*	0.000V	3.3V*	2.5V*	2.7V*	.008V*	* Decaying voltages

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# Additional Observations

- The #6 string current tapered to 70 mA and the string finally opened approximately 3 hours after the cell #4 shorting event.
- The #7 string current tapered to 170 mA and the string finally opened approximately 1.25 hours after the cell #5 shorting event.
- The temperature rise of the shorted cells and throughout the pack was moderate with a max peak of 65 C being recorded on the shorted cells, well below the thermal runaway point.
- No smoke, electrolyte leakage, or any other physical pack damage was noted.





# Conclusions

- In this test the 18650HC cells internal PTC/CID features responded as designed. The short across a cell resulted in large instantaneous currents in that cell that tapered within 2 seconds due to the action of that cells internal PTC feature.
- After the shorting event the voltage across the other 7 series cells had to increase from 4.2V/cell to an overcharge of approximately 4.8V/cell at which point multiple CIDs activated and removed the string from the circuit.
- A curious aspect of the results was that nearly all the CIDs in both shorted cell strings activated nearly simultaneously rather than perhaps only one or two activating as expected.
- In this test the battery cell internal safety features provided a reliable response to the simulated fault. There is a high probability a similar event during spacecraft I&T or on orbit would result in only a very small loss of capacity and no danger to the spacecraft.





# Thanks for Making This a Successful Test

- *GSFC Code 563*
  - George Dakermanji
  - Leo Lee
  - Davy Baker
  - Tom Rozanski
  - Dong Sui
- *GSFC Code 552*
  - Ian Banks
- *NEESC*
  - Denney Keys
- *GSFC Safety*
- *GSFC Facilities*
- *GSFC Environmental*
- *GSFC GPM Project for Funding and Support*





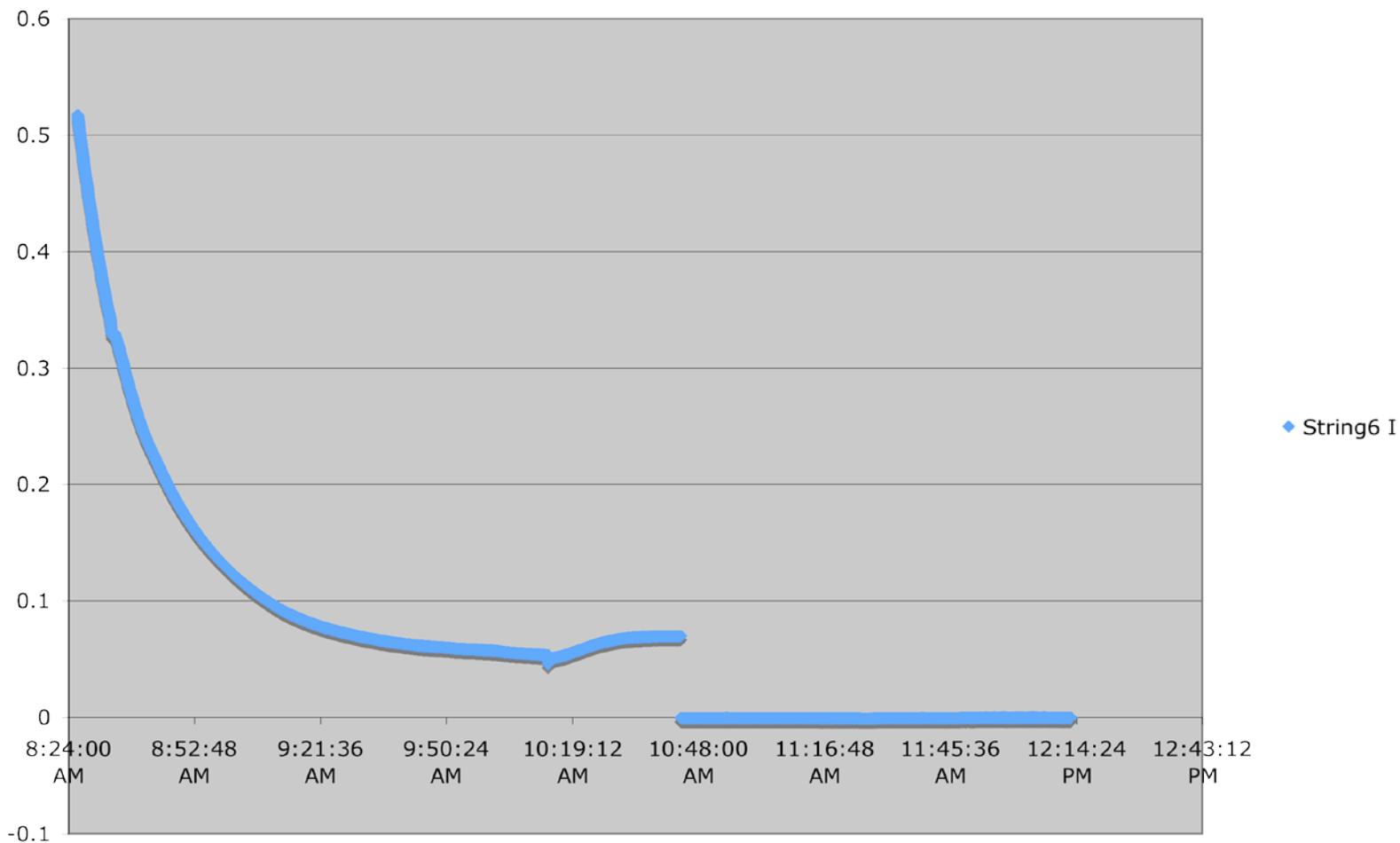
# Back Up Slides





# String 6 Telemetry Detail

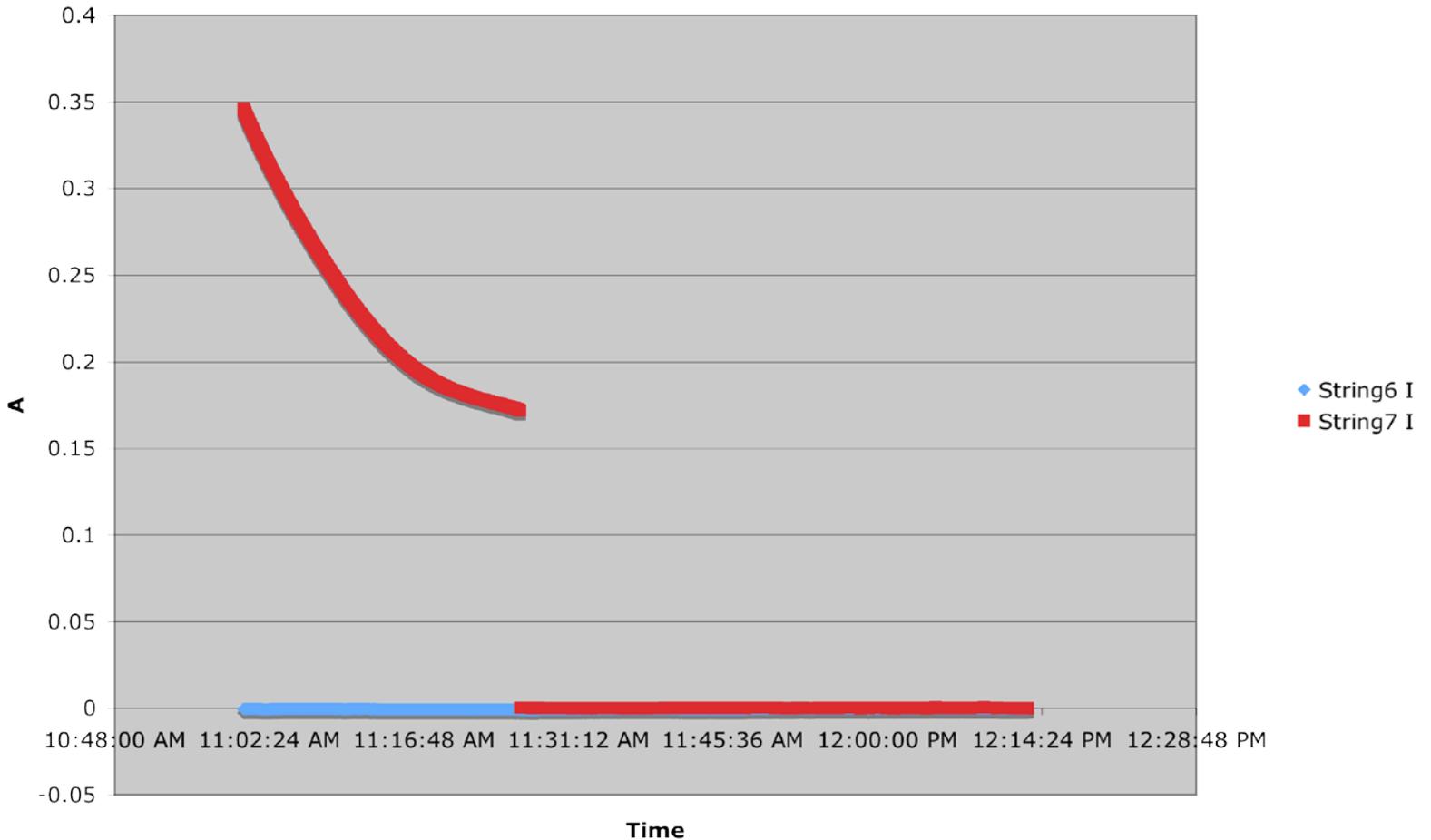
String6 I





# String 7 Telemetry Detail

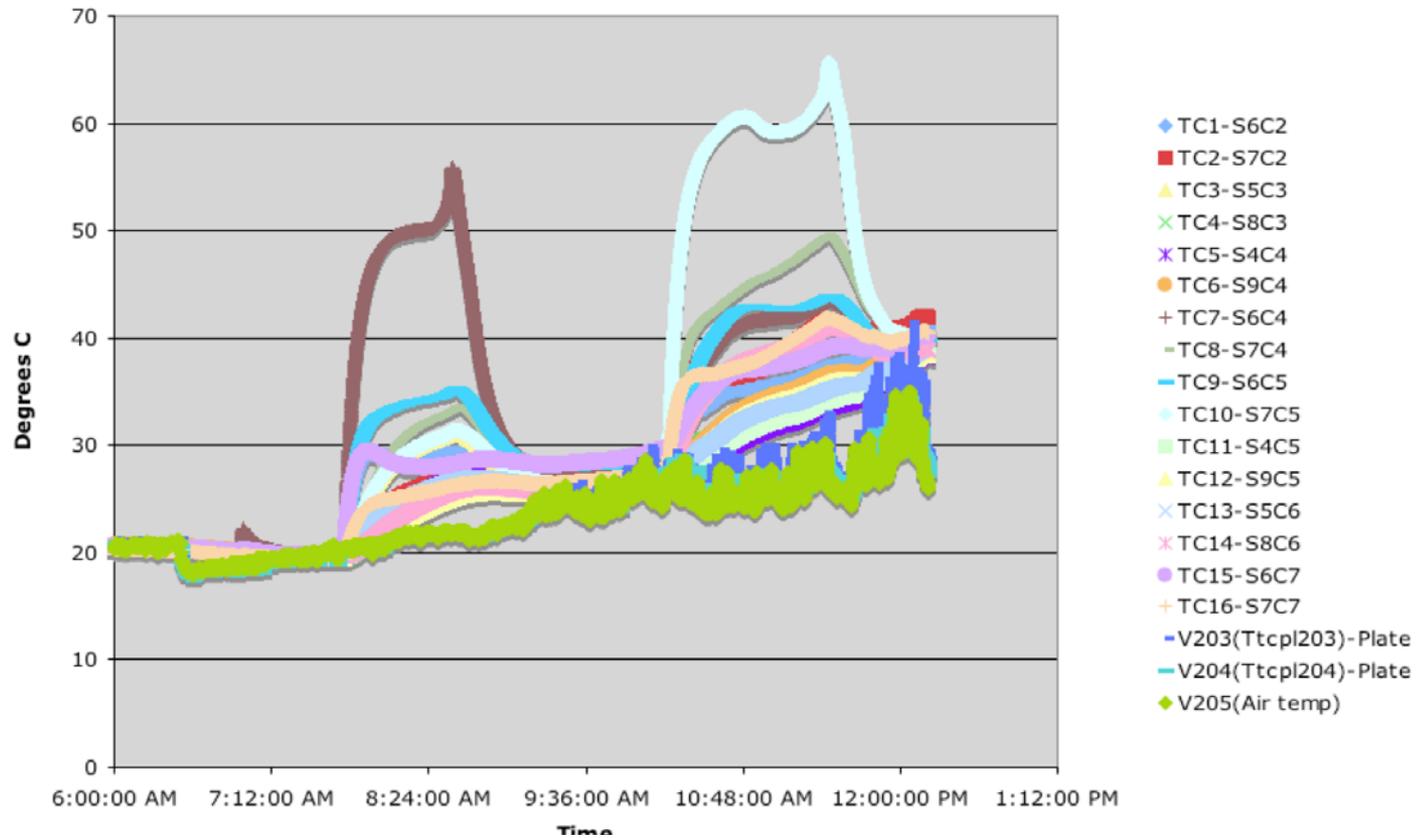
String 7 I Detail





# All Temperature Telemetry

PTC/CID Pack SN002 Test Temps



All Temperatures

